Comparison of Tools to Measure Physical Activity and Stationary Behavior in Older Adults Following Total Knee Arthroplasty

by

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Abstract of Thesis

Background: Although the detrimental effects of physical inactivity on health are well-documented, there is inadequate knowledge of physical activity in older adults following total knee arthroplasty (TKA). Information is lacking regarding the effect of physical activity on risk for revision following TKA, the validity of tools to measure physical activity in this population, and the levels of stationary behavior in older adults following TKA.

Objectives: The primary aim of this research program was to evaluate tools that measure physical activity in older adults following TKA to determine which tools are most appropriate for use in this cohort. An introductory objective was to address an identified gap in the literature on factors increasing risk for revision following TKA, including the effect of physical activity on revision risk. The primary objective was to determine the concurrent criterion validity between a reference standard research accelerometer (SWA) and two clinical tools, a) the commercially available personal activity monitor (Fitbit) and b) the self-report measure (CHAMPS). The secondary objective addressed the lack of information on stationary behavior in older adults following TKA by describing levels of stationary behavior and examining whether the step-defined sedentary lifestyle index (SLI) may be an appropriate tool to discriminate stationary behavior.

Methods: A scoping review was completed to identify factors that may increase the risk of revision surgery following TKA. The primary objective was addressed in the first clinical study, a cross-sectional validation study which determined the concurrent criterion validity of a consumer-level activity monitor and a self-report questionnaire as compared to a reference standard research accelerometer when measuring physical activity in 47 older adults following

TKA. The secondary objective was fulfilled in the second clinical study, a cross sectional study measuring stationary time, bouts and breaks, and examining the role of SLI on stationary behavior in 65 older adults following TKA using accelerometry.

Results: Increased risk of revision following TKA was found to be associated with demographic factors (younger age and African American), surgical factors (uncemented components, implant malalignment and increased surgery duration) and the health service factor of low volume hospitals. Moderate to good correlations were observed between the Fitbit and SWA for steps (ICC = 0.79), energy expenditure (ICC = 0.78) and energy expenditure <3 METS (ICC = 0.79). There was poor to moderate correlation (ICC = 0.43) between the CHAMPS questionnaire and the SWA data with the CHAMPS questionnaire reporting lower daily energy expenditures than the SWA. When examining stationary behavior in this population, participants spent 80% (13.17 hours, SD 2.30) of their waking time in stationary time and had an average of 6.06 bouts of stationary time > 30 minutes per day. The SLI had significant effects on both waking stationary time ($p<0.001$) and number of breaks in stationary time ($p<0.001$).

Conclusions:

These findings reinforce the need for further information on levels of activity in older adults following TKA and provide guidance on how best to measure physical activity. The current literature did not suggest that physical activity increases the risk for revision following TKA; however, further research is needed. The Fitbit is an appropriate tool to measure physical activity in older adults following TKA using step counts, energy expenditures and time spent in lower intensity activities. Caution must be used when measuring higher intensity activities. The CHAMPS questionnaire may also be an appropriate tool to use within the limitations of self-report measures as, although poor to moderate, the correlations were higher than those reported

for other self-reported questionnaires in this population. The SLI discriminated between stationary time and breaks from stationary time suggesting clinical utility to measure stationary behavior. Older adults following TKA demonstrated high levels of stationary behavior putting them at risk for adverse health effects and suggesting that the entire spectrum of activity should be measured, not just the traditional measurements of physical activity. Achieving adequate levels of activity is essential to maximize health in older adults following TKA, who are at risk for detrimental health effects due to inactivity.

Preface

This thesis represents original work completed by Lisa Jasper. The two clinical studies in this thesis were part of the larger COACH intervention study led by Dr. Allyson Jones. The COACH study received research ethics approval from the University of Alberta Health Research Ethics Board, Project: Coaching for older adults (with osteoarthritis) for community health (COACH Study), No. Pro00062054, February 4, 2016. The COACH study also received operational approval from Covenant Health Research Centre. For all projects in this thesis, I was responsible for the design, data acquisition, data analysis and manuscript preparation with assistance in all aspects from my supervisory committee.

Chapter four has previously been published as:

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For this chapter and publication, I participated in study design, data collection and analysis, and manuscript preparation, with mentorship from my supervisors. L. Beaupre and C.A. Jones were supervisory authors and oversaw all components. J. Mollins and Sheri Pohar assisted in data collection, extraction and analysis. I also presented these study findings orally at Cochrane Canada 12th Annual Symposium:

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Dedication

To Jim, Jodi, Anne and Margaret

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List of Abbreviations

BMI – body mass index

BMR – basal metabolic rate

CHAMPS – Community Healthy Activities Model Program for Seniors

COACH – Coaching for Older Adults with Osteoarthritis for Community Health

EE – energy expenditure

EULAR - European League Against Rheumatism

HR – hazards ratio

ICC – intraclass correlation coefficient

ICF – International Classification of Functioning, Disability and Health

IPAQ – International Physical Activity Questionnaire

LEAS – Lower Extremity Activity Scale

MCID – minimal clinically important difference

METS – metabolic equivalents

MVPA – moderate to vigorous physical activity

OARSI - Osteoarthritis Research Society International

OR – odds ratio

PASE – Physical Activity Scale for the Elderly

RMR – resting metabolic rate

RR – relative risk

SWA – SenseWear armband

TEE – total energy expenditure

TEF – thermic effect of feeding

TJA – total joint arthroplasty

TKA – total knee arthroplasty

THA – total hip arthroplasty

UCLA - University of California at Los Angeles activity scale

VO_2 – oxygen uptake per kilogram of body weight

Chapter 1 Introduction

1.1 Background

Physical inactivity is a global problem despite the well-documented detrimental effects on health including increasing incidences of coronary heart disease, cancer and type 2 diabetes (1-3). Physical inactivity, in fact, has been described as one of the most pressing healthcare issues in this century with over 30% of the world population considered inactive. This percentage increases to 43% in the Americas (4, 5). The World Health Organization adopted guidelines in 2010 recommending that the global adult population achieve a minimum of either moderate-intensity aerobic physical activity for at least 150 minutes per week or vigorous-intensity aerobic activity for at least 75 minutes per week including bouts of aerobic activity of at least 10 minutes in length (6). Unfortunately, approximately 33% of adults globally and 80% of adolescents do not meet public health guidelines for physical activity (5, 6). In Canada, the numbers are even more concerning as only 16% of adults met the recommended physical activity guidelines between 2007 and 2017 (7). Maintaining healthy levels of physical activity is even more challenging in populations with chronic diseases such as osteoarthritis. A recent meta-analysis reported high quality evidence that only 13% of the 3266 participants with knee osteoarthritis met the recommended guidelines for physical activity (8).

The prevalence of osteoarthritis in Canada is approximately 12% of the general population with between 60% and 70% of those over 65 years demonstrating radiographic changes of osteoarthritis (9). These numbers are expected to increase given the aging population and increasing incidence of obesity (10, 11). With the high prevalence of this chronic condition in older adults, physical inactivity is a significant issue in patients with osteoarthritis both on an individual level affecting health and quality of life, and at a population level affecting overall health of populations and corresponding cost and allocation of health resources (4).

To further compound the problem, physical activity is a recommended management strategy for knee osteoarthritis. Osteoarthritis of the knee is often associated not only with physical inactivity but also with pain and loss of function and independence in older adults (12, 13). With increasing pain and loss of function, inactivity is often further increased setting up a vicious cycle of increasing pain and inactivity and decreasing function. It is most commonly the symptoms of pain that cause the older adult to seek surgical treatment for the knee (12-14). Total knee arthroplasty (TKA) is an elective surgical option resulting in substantial pain relief and functional improvement. However, it is not clear that the levels of physical activity increase after the surgery as expected. There is a small emerging body of literature measuring physical activity levels following TKA; however, several studies report small or no increases in physical activity levels after the procedures (15-17). Given the significant adverse health effects that occur with physical inactivity, it is important that older adults return to healthy levels of physical activity following TKA.

Using reliable and valid tools to measure physical activity in older adults following TKA is necessary as a first step to address physical inactivity and the associated health risks. Step counts, energy expenditure (EE) and time spent in specific activity intensities are outcome measures that are commonly used to quantify levels of physical activity (18). However, no consensus exists as to a reliable, valid and practical measure of physical activity that can be used in real-world situations in older adults following TKA. Physical activity has been measured using varying approaches from self-report measures to simple pedometers to personal activity monitors to research grade accelerometers. The addition of the rapidly expanding field of personal activity trackers and smartphone applications has also recently increased the options available. Different measurement tools vary in the constructs measured, the domains of activity included, and the appropriate populations for administration of the tools. Many have associated measurement biases. The measurement of physical activity in daily lives provides a functional component that may avoid potential biases, or inaccurate measurement of physical activity in clinical and community-based cohorts (19).

A number of accelerometers are currently used for research purposes including a research accelerometer, the SenseWear Armband (SWA), which has been shown to be a valid and reliable tool to measure physical activity in older adults following TKA (20, 21). SWAs are expensive and require complex data analysis limiting the feasibility for large studies (20, 22). The newer generation of accelerometers in personal activity trackers, such as the Fitbit, are promising as they are less expensive with easier access to data with widespread consumer use (23). There is, however, limited evidence on the reliability and validity of these newer devices, and no information thus far in older adults following TKA. Assessing the criterion validity of the personal activity monitor (Fitbit) against the proven reference standard (SWA) will provide important evidence as to whether the personal activity monitor is appropriate to use to measure physical activity in this population.

A number of self-report questionnaires that measure physical activity exist. However, the psychometric properties, associated recall bias and practicality of the self-report questionnaires, particularly in older adults following TKA, are not fully understood (24). The Community Healthy Activities Model Program for Seniors physical activity questionnaire (CHAMPS) is a self-report questionnaire that has been used to measure EE in older adults and in patients following TKA. Knowledge of the criterion validity of the CHAMPS questionnaire as compared to the known reference standard (SWA) will also guide the choice of measurement tools for use in the population of older adults following TKA.

Given the importance of returning to adequate levels of physical activity to achieve health benefits, measurement of physical activity levels in older adults following TKA is essential so that physical activity can be evaluated during the recovery process of TKA (24). Identifying valid tools for measurement of physical activity in these older adults is an important step towards obtaining accurate measurements of physical activity and developing interventions to promote physical activity in this population which is at risk of inactivity and the resulting health risks.

1.2 Dissertation Objectives

The primary aim of this research program was to evaluate tools that measure physical activity in older adults following TKA to determine which tools are most appropriate for use. There were a number of steps that were identified to accomplish this aim. First, a thorough understanding of total knee arthroplasty was necessary. A gap in the literature was identified regarding the factors affecting the need for revision following TKA, and if physical activity was indeed a factor that needed to be considered in the rehabilitation process. A scoping review was therefore undertaken to supply this important background information. Second, a thorough understanding of the literature and evidence regarding tools measuring physical activity following TKA was necessary with the focus on validity and clinical relevance. A comprehensive literature review was completed resulting in three primary conclusions. First, the SWA was the research grade accelerometer that has best demonstrated validity in this population (20, 21). Second, the Fitbit personal activity tracker is the most popular personal activity tracker in use globally and has potential for widespread use (25). Third, the CHAMPS questionnaire has some evidence on validity in older adults following TKA and has been recommended as a clinically useful self-report measure (18, 21, 26). Comparing the Fitbit personal activity tracker and the CHAMPS self-report questionnaire to the SWA research grade accelerometer therefore composed the primary study in this doctoral work. Finally, as we progressed through this primary study, a number of studies were published calling for further information on levels of activity in this population (16, 17, 27). Not only was there inconclusive data on whether older adults returned to adequate levels of physical activity for health benefits following TKA, it became increasingly clear that it was not sufficient to only examine the traditional measures of physical activity but that the broader spectrum of activity including sedentary and stationary behaviors should also be considered (28, 29). Although there was increasing evidence that sedentary and stationary behaviors have a significant role in activity and health, there was limited information on sedentary and stationary behaviors in older adults following TKA (27, 30). Similar to the measurement of physical activity in this population, there was inconclusive evidence as to whether levels of sedentary and stationary behaviors improved post TKA, and little information on how best to measure sedentary and stationary behaviors (27). Using a threshold of 5000 steps per day as a step-defined sedentary lifestyle index (SLI) has been suggested to be an appropriate tool for researchers, clinicians and the general public; however, this tool has not been evaluated in older adults following TKA (31). Further, there was inconsistency in the measurement and definitions of sedentary behavior in the literature that was available (27). In 2017, the Sedentary Behavior Research Network (SBRN) terminology consensus project expanded the recommendations for consistent definitions to include not only sedentary behavior but also concepts such as stationary behavior which did not include a postural component (32). As much of the data obtained from accelerometry did not include a measured postural component, it was determined that stationary behavior may be a more accurate term to describe the waking behaviors without ambulation (27). A final objective of this work was to provide a comprehensive description of stationary behavior in older adults following TKA and to determine if the SLI is appropriate for use post TKA.

Specifically, the primary aim of this research program was to evaluate tools that measure physical activity in older adults following TKA to determine which tools are most appropriate for use.

1. The introductory objective was to conduct a scoping review to identify and assess demographic, surgical/health services and physical activity factors that may increase the risk for revision surgery following TKA.

2. The primary objective was to determine the concurrent criterion validity between the personal activity tracker (Fitbit) and the self-report measure (CHAMPS) with the reference standard (SWA). This objective was fulfilled in the first clinical study, a cross-sectional study in older adults six months following TKA.

3. The secondary objective was to describe levels of stationary behavior in older adults following TKA and examine whether the SLI may be an appropriate tool post TKA. This objective was accomplished in the second clinical study, a cross sectional study which described stationary behavior at three months post TKA and examined the effects of SLI on stationary behavior.

1.3 Structure of the Dissertation

The structure of the dissertation follows this research aim and these three objectives. A comprehensive literature review on physical activity in older adults following TKA and its measurement is provided in chapter 2. An overview of the common methods for the clinical studies follow in chapter 3 and referenced appendices. Chapter 4 contains the scoping review examining factors increasing rates of revision following TKA which addresses the introductory objective. Chapter 5 addresses the primary objective of the dissertation and details the primary clinical study, a study examining the validity of the personal activity tracker (Fitbit) and self-report measure (CHAMPS) as compared to the reference standard (SWA). Chapter 6 addresses the secondary objective and discusses the second clinical study providing a comprehensive description of stationary behavior in older adults three months following TKA as well as examining the clinical utility of the SLI in older adults post TKA. Chapter 7, the final chapter, summarizes the contributions and clinical implications of this research program and provides recommendations for future research.

Chapter 2 Literature Review

2.1 Physical Activity

Physical inactivity is a global public health concern with significant adverse effects to both individuals and populations (1, 2). It is the fourth leading cause of global mortality and has been determined to increase the risk of cardiovascular disease, stroke, hypertension, colon cancer, breast cancer, diabetes mellitus and osteoporosis (33-35). Prevalence is more than twice as high in high-income countries as compared to low-income countries with levels continuing to increase in high-income countries (36). Physical activity has been defined as any bodily movement that is produced by skeletal muscles and results in energy expenditure, and physical inactivity defined as an insufficient level of physical activity to meet present physical activity recommendations (32, 37). Despite the fact that the important health benefits of regular physical activity have long been undisputed, 31% of the global population is not meeting the minimum recommended level of physical activity (1, 5, 38). Canadian statistics are even more concerning with only one in five adults meeting the minimum guidelines (7, 39). Further, if physical activity were to increase by 10% or 25%, more than 533000 or 1.3 million deaths respectively, globally could be prevented yearly (34). In Canada, Bounajm et al. predict that if 10% of physically inactive Canadians increased their physical activity, the gross domestic product would increase by a cumulative $7.5 billion by 2040, and health care spending on hypertension, diabetes, heart disease, and cancer would be reduced by a cumulative $2.6 billion between 2015 and 2040 (40). The pandemic of physical inactivity has been described as one of the most pressing healthcare issues in this century (2).

2.1.1 Guidelines for Physical Activity

In recognition of this growing epidemic, in 2010 the World Health Organization adopted physical activity guidelines for the adult population. These guidelines, titled *Global Recommendations on Physical Activity for Health,* recommend a minimum of either moderate intensity aerobic physical activity for at least 150 minutes per week or vigorous intensity aerobic activity for at least 75 minutes per week including bouts of aerobic activity at least 10 minutes in length (6). The guidelines for older adults also recommend those adults with limited mobility should perform balance exercises on three or more days per week (6). When older adults are unable to do the recommended amounts of physical activity due to health conditions, the guidelines suggest they should do as much physical activity as they are able. These World Health Organization guidelines were consistent with the Physical Activity Guidelines for Americans developed in 2008 (41) and the Canadian Physical Activity Guidelines for adults and older adults developed in 2011 (42, 43). In 2018, the Physical Activity Guidelines for Americans were updated, eliminating the recommendation for moderate to vigorous activity to occur in bouts of 10 minutes or greater and emphasizing the importance of moving more and sitting less throughout the day (44). These guidelines provide useful benchmarks for activity levels in both clinical and research settings.

2.1.2 Frameworks

Physical activity is a complex behavior which is influenced by many intra-individual (person) and extra-individual (environment) factors (45). Recognizing the effects of these factors as well as understanding related yet distinct concepts such as sedentary behavior, exercise and fitness are necessary for a thorough discussion of physical activity.

A framework presented by Gabriel et al. in 2012 recognizes physical activity as a complex and multidimensional behavior and depicts many of the factors influencing physical activity in older adults following TKA, demonstrating their interrelationships (46). The framework depicts the behavior of human movement as either active (physical activity) or sedentary. Both active and sedentary behaviors are affected by upstream factors such as physiological, psychological, social and environmental correlates, and both constructs have effects on physiological attributes of health (46). The framework describes outcomes including EE and physical fitness and highlights important distinctions between physical activity and sedentary behavior. Physical activity is described as health enhancing whereas sedentary behavior is described as health compromising (although it may be suggested that too much physical activity or too little sedentary behavior may also be health compromising in extremes). Physical activity is also described in terms of the four domains of leisure, occupation, household/domestic/self-care activities, and transport (46). This framework has important clinical utility as it can help organize and show the interrelationships of the various factors affecting individual and population physical activity.

The framework is helpful to demonstrate context to this research program measuring physical activity in a population of older adults following TKA. For example, when measuring physical activity through the measurement of EE, we must consider whether we are capturing physical activity throughout the domains of leisure, occupation, household/domestic/self-care and transport. Although the measurement tools examined in these studies do not differentiate between these domains, they do capture physical activity in all of these domains due to the 24-hour nature of the measurement. Physiological, psychological and environmental correlates that will influence physical activity such as pain, motivation and accessibility of environment must also be considered. As detailed later in this thesis, the sample population in these clinical studies have all undergone TKA which will introduce physiological, psychosocial and environmental correlates that may influence physical activity. As the primary aim of this research program addresses physical activity, this framework helps to distinguish physical activity from sedentary behavior and physical fitness.

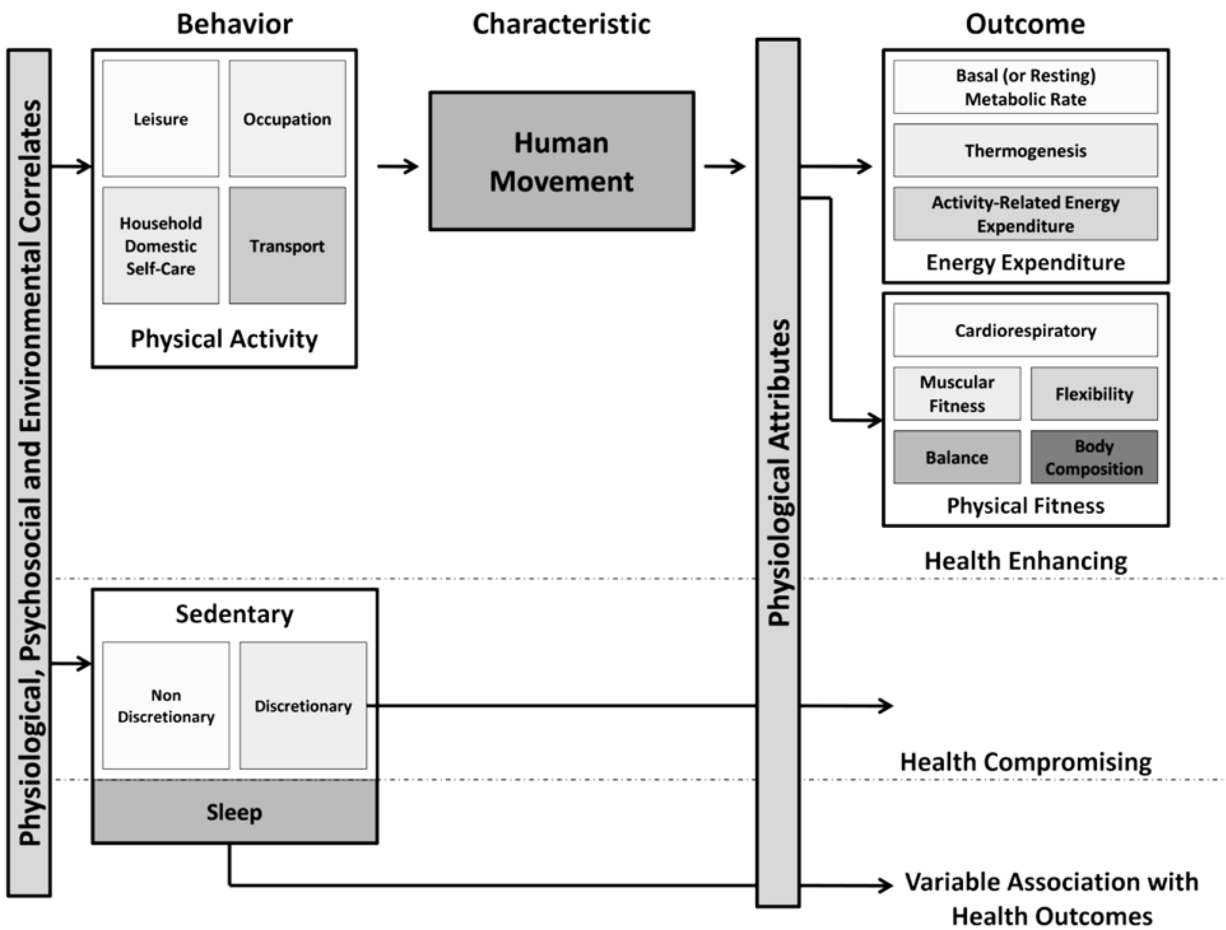

Figure 1 Framework for Physical Activity (46)

(Reprinted with permission: Gabriel KP, Morrow JR, Woolsey AL. Framework for physical activity as a complex and multidimensional behavior. Journal of Physical Activity & Health. 2012;9:S11-S18.)

The International Classification of Functioning, Disability and Health (ICF) disability framework provides a second relevant conceptual framework in which to situate discussion and research regarding physical activity in relation to a chronic condition such as osteoarthritis (47). While the Gabriel model illustrates physical activity in the framework of other movement concepts, the ICF expands upon the broader environmental context and the effects of these components.

The ICF framework has two main components. The first component is **Functioning and Disability,** which includes body functions and structures, activities and participation. **Body functions** include the physiological and psychological functions of the body, and **body structures** include the anatomical part of the body (47). The presence or impairment of body structures and functions can have significant effects on physical activity. For example, an older adult with knee osteoarthritis may have resulting impairments of decreased strength and ROM. **Activities** are defined as execution of any tasks by the individual with participation including the individual's involvement in life activities (47, 48). Continuing the example of the older adult with knee osteoarthritis, the decreased strength and knee ROM may limit the older adult's ability to walk longer distances or climb stairs thus restricting their activities. This restriction in activity may influence their participation in activities such as walking for mail or to a seniors' centre. Alternately, **participation** may influence activities and physical activity such as an individual being motivated to attend the local seniors' center, which results in increased walking and physical activity.

The second component of the ICF framework is **Contextual Factors** and includes both environmental and personal factors (47, 48). **Environmental factors** include the physical, social and attitudinal environment in which individual's live and function. **Personal factors** include the features of the individual that are not part of a health condition or state and include features such as gender, race, age, fitness, lifestyle, habits, past and current experience, coping styles and social background. In our example, both personal factors such as age and hobbies and environmental factors such as weather and presence or absence of sidewalks would also influence physical activity, activities and participation. Finally, body structures and functions, activities and participation would also influence contextual factors such as where the individual lives, assisted equipment available etc.

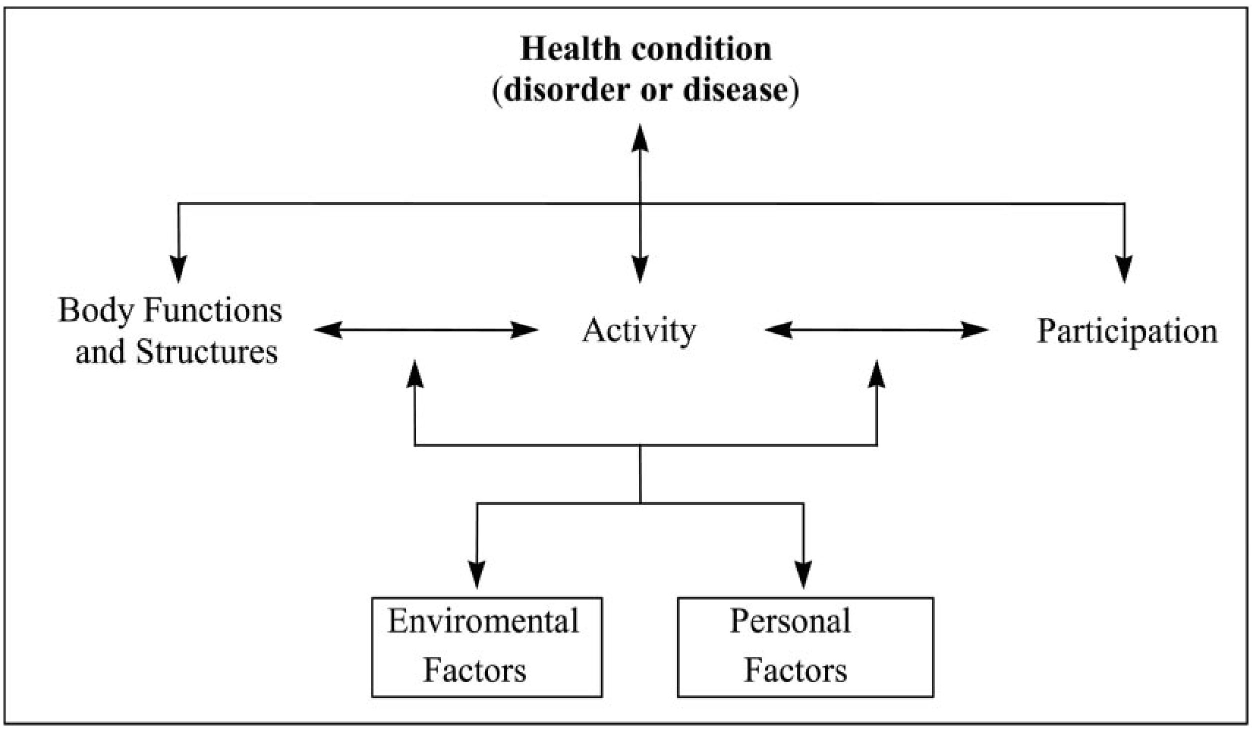

Figure 2 International Classification of Functioning, Disability and Health Framework (47)

(Reprinted with permission: Stucki G. International Classification of Functioning, Disability, and Health (ICF): a promising framework and classification for rehabilitation medicine. Am J Phys Med Rehabil. 2005;84(10):733-40.)

2.1.3 Physical Activity and Osteoarthritis

Musculoskeletal disorders are the second-leading cause of years lived with disability globally, with osteoarthritis of the knee particularly prevalent (4). Felson et al. predicted that osteoarthritis is expected to afflict 40 million Americans by the year 2020 (10). In 2014, the age-adjusted prevalence of arthritis in 43706 community-dwelling adults in the United States aged 20 or older was 24.7% with the prevalence of osteoarthritis increasing from 6.6% to 14.3% from 1999 to 2014 (49). In Canada, an estimated 7.5 million Canadian adults will have arthritis by 2036 – one in five Canadians (11). Radiographic appearances have historically been the key factor for the diagnosis of osteoarthritis, but there is an increasing recognition of the significant effects of the physical limitations of the disease, such as pain and limited mobility, on the capacity to participate in everyday social, work and recreational activities (13, 50, 51). Consequently, people with osteoarthritis are often less active than the population without this condition because of pain, joint deformity, loss of joint range and muscle weakness (52).

There are Canadian Physical Activity Guidelines for special populations such as multiple sclerosis, spinal cord injury, Parkinson's disease and most recently Alzheimer's but not specifically for osteoarthritis at this time (42, 53). Wallis et al. completed a meta-analysis evaluating the proportion of individuals with hip and knee osteoarthritis that met current physical activity guidelines finding high quality evidence that 13% of those with knee osteoarthritis completed ≥ 150 minutes of moderate to vigorous physical activity (MVPA) in bouts of ≥ 10 minutes and moderate quality evidence that 19% completed ≥ 10000 steps per day (8). Further, Kaptein and Badley compared a group of adults (n = 4426262) with arthritis to those with other chronic diseases and reported that participants with arthritis did less physical activity in their leisure time than those with back problems, other physical chronic conditions such as diabetes, heart disease, hypertension and cancer and no physical chronic conditions (12). Recently, Daugaard et al. used accelerometry to measure physical activity in 54 participants with knee osteoarthritis reporting significantly fewer daily short walking bouts < 10 seconds than healthy participants but no significant differences in number of daily steps (54).

Obesity

Obesity is a recognized risk factor in developing osteoarthritis (55-57), requiring knee replacement surgery (58), and is associated with lower levels of physical activity (59). Increasing rate of obesity worldwide have a direct impact on physical activity and osteoarthritis (56-58). The World Health Organization defines obesity as a body mass index of ≥ 30 kg/m^2 which may impair a person's health, overweight as ≥ 25 kg/m^{2,} and estimates that obesity has more than doubled from 1980 to 2014 (60). In 2014, 39% or more than 1.9 billion adults worldwide were overweight with 13% or 600 million of these individuals classified as obese (60). In Canada, 40% of men and 27.5% of women were classified as overweight with 20.2% of Canadians classified as obese (61).

Several studies have concluded that higher BMI increases the risk of osteoarthritis of the knee (55-57). In the Framingham study of 1420 participants, Felson et al. found that higher BMI was associated a higher risk of knee osteoarthritis and that this relationship was stronger for women (RR 2.07 95% CI 1.67 to 2.55) than for men (RR 1.51 95% CI 1.14 to 1.98) (55). Similarly, both Grotle et al. and Mork et al. found that a high BMI was significantly associated with knee osteoarthritis in women (OR 2.81 95% CI 1.32 to 5.96; RR 4.37 95% CI 3.01 to 6.33) and men (RR 2.78 95% CI 1.59 to 4.84) (56, 57). In a prospective cohort study of 105 189 participants, overweight and obese participants were at > 40% and 10%, respectively, increased risk of knee replacement surgery as compared to patients with a normal weight (58). The proportion of individuals undergoing total joint arthroplasty (TJA) who were obese increased from 31% in 1990 to 52.1% in 2005, which is concerning as the rates of obesity have also increased since 2005 (62).

Lower levels of physical activity have been found in overweight and obese individuals as compared to individuals with lower BMI (59, 63). The American National Health and Nutrition Examination Survey reported that 1016 adults with normal weight demonstrated an average of 7190 steps/day, 1195 adults who were in the overweight category demonstrated an average of 6879 steps /day and 1242 adults in the obese category demonstrated an average of 5784 steps/day (63).

In response to the escalating rates of obesity, both research and clinical guidelines for the management of osteoarthritis are increasingly containing recommendations on weight loss. The Canadian Arthritis Foundation has developed 14 quality indicators that should be present in quality health care for osteoarthritis and three of these 14 quality indicators are on the topic of weight loss (9). The European League against Rheumatism (EULAR) recommendations for the non-pharmacological management of hip and knee include a detailed recommendation on weight loss citing grade 1a evidence for knee (64). The Osteoarthritis Research Society International (OARSI) recommendations also include a guideline advising weight loss if patients are overweight (65). The recently published Canadian Adult Obesity Clinical Practice Guideline contains a number of recommendations on increasing physical activity including aerobic activity and resistance exercises (66).

2.1.4 Total Knee Arthroplasty

Total joint arthroplasty is often an elective surgical treatment for individuals with osteoarthritis experiencing severe pain, functional limitations and achieving little success with conservative treatment. The effectiveness of TJA in relieving pain and improving function has been well-documented (67-70). The incidence of TKA in particular is increasing exponentially largely due to the aging population, increase in obesity and the general success of the procedure (71, 72). Using historical procedure rates and population projections, Kurtz et al. estimate that the number of TKAs in the United States will grow by 673% by 2030 to 3.48 million procedures annually as compared to 402,100 TKAs in 2003 (71). Further, they estimate that revisions of TKA will grow by 601% between 2005 and 2030. In 2017–2018, there were over 70000 knee arthroplasties performed in Canada, representing a 5-year increase of 22.9% (73).

There is a consistent body of literature demonstrating the success of TKA in relieving pain, improving function and health-related quality of life (70, 74). Pain is the most common indicator for TKA for knee osteoarthritis, and TKA is consistently successful in decreasing pain for patients with advanced-stage osteoarthritis (14, 70, 74). A review of health-related quality of life following TJA found clinically relevant changes for pain after TJA with large effect sizes (range 1.5 to 2.4) both short and long term (74). Pain levels significantly decrease after the initial post-surgical pain following TKA. Success of TKA in improving function for patients with advanced-stage arthritis has also been well established (16, 70, 74, 75). Similar to findings regarding pain, significant and clinically relevant improvements in function were also found following TJA with large effect sizes (range 0.8 to 2.4) both short and long term (74). Improved function was demonstrated in activities such as improved gait, distances walked and joint ROM resulting in benefits in activities of daily living, heavy housework and moderate sports activities (75).

Total Knee Arthroplasty and Physical Activity

As there is limited and somewhat conflicting evidence on physical activity levels in individuals following TKA, it is not clear whether TKA is as successful in delivering the expected corresponding increase in physical activity levels. Prior to TKA, individuals are typically not physically active due to issues related to pain, which in turn can cause a loss in functional mobility and physical activity (51). After surgery and rehabilitation, it is plausible that individuals should be able to engage in a more physically active lifestyle, since they are no longer limited in terms of knee pain, function and mobility (76, 77). The limited literature examining physical activity levels after TKA reports this does not always appear to be the case (16, 17).

Current literature based on small clinical samples suggests that although activity may increase after TKA, the gains are small and inconsistent (16, 17). Patients typically leave the hospital less active than prior to surgery due to the short hospital length of stay and acute stage of recovery after TKA (78). The number of daily gait cycles have been shown to significantly increase over the next 4 months with maximal gains reported by one-year post TKA (78). However, there appears to be variation in these gains post TKA. A systematic review by Arnold et al. examined studies that used uniaxial, biaxial, and triaxial accelerometers to measure changes in physical activity after total hip arthroplasty (THA) and TKA in 373 adults with osteoarthritis (79). A number of outcome variables were included in the review such as activity counts, duration of physical activity, step counts, and distances. Based on 238 adults (5 studies) after TKA, mixed results were seen with physical activity at six months after surgery (standardized mean differences ranging from -0.36 to 0.63); however, physical activity increased at 1 year after TKA (standardized mean differences ranging from 0.10 to 0.85). In spite of the relative increase, physical activity remained lower than healthy controls at 1 year after TKA (standardized mean differences ranging from -1.46 to -1.80) (79). Several subsequent reviews had similar inconclusive findings. Hammett et al. examined changes in physical activity pre and post TKA relative to quality of life, pain and physical function outcomes and reported no significant increase in physical activity at six months and small to moderate significant effects at twelve months (16). Mills et al. reported no change in duration of physical activity six months following TKA and a small increase in frequency of physical activity at twelve months following TKA (15). A critical review by Paxton et al. reported similar findings with physical activity levels following TKA equal to or below pre-surgical levels and often less than age-matched healthy controls (28).

Several studies using self-report measures found that participants perceived themselves as more active than before the surgery (28). The authors suggest that decreased pain following TKA in conjunction with increased function may contribute to the participants' beliefs that they have increased levels of physical activity (28). Kahn et al. used data from the Osteoarthritis Initiative, including both accelerometry and self-report data, and found no significant difference in physical activity between 60 patients who had already received a TKA (range 65-1444 days post TKA) and 73 patients who eventually received a TKA (80). However, the WOMAC, KOOS Quality of Life, KOOS Knee Pain and KOOS function were significantly improved in the post TKA cohort (80).

Additionally, the literature suggests that many individuals are not active enough after TKA to maintain health and fitness nor meet generally accepted activity guidelines (80-82). Using a self-report questionnaire to measure physical activity (Short Questionnaire to Assess Health-Enhancing Physical Activity), 49% of 830 participants did not meet the health recommendations of moderate intensity physical activity for at least 30 min on 5 days/week following TKA (82). When physical activity levels were measured objectively by accelerometry, the findings were even more concerning – only 2% of the 52 participants who underwent TKA or THA and had available data at six months met the guidelines (81). Similarly, Kahn et al. reported only 5% or less of 60 patients post TKA met physical activity guidelines (80).

A small body of emerging literature identified characteristics of individuals following TKA who achieved higher physical activity levels. Males (OR 1.48, 95% CI 1.34 to 1.68) and participants with higher education (OR 1.99 95% CI 1.15 to 3.50) had higher odds of meeting these physical activity recommendations (83). Several studies have found that activity level after treatment was influenced by physical activity levels before surgery (78, 84, 85). That is, participants who were more active prior to surgery were more likely to increase their activity levels after surgery. A recent study examining 1986 women following TKA found that women with lower physical activity levels before TKA were more likely to have limited mobility at age 85 than women with higher physical activity pre TKA (OR 1.68, 95% CI 1.15-2.45) (86). Issa et al. reported that older age, tobacco use, history of cancer, cardiovascular disease, lymphatic disease and renal disease also had a negative impact on levels of physical activity following TKA (87). Finally, higher BMI was found to be associated with lower changes in physical activity following TKA, which is especially concerning give the rising rates of obesity (84, 85).

In spite of surgeons often advising patients to avoid intense or high impact activities following TKA, few studies examined the effect of physical activity on the risk of revision arthroplasty (88, 89). A small matched case control study of 26 pairs concluded that physical activity did not appear to be a risk factor for revision arthroplasty and that physical activity should continue to be encouraged post TKA (88). A number of studies have found younger age increases the risk for revision arthroplasty (HR 0.62, 95% CI 0.57 to 0.67 with each increasing 10 year increments, and HR 0.43, 95% CI 0.27 to 0.67 for > 55 years of age) (90, 91). As younger adults are potentially more active than older adults, it has been suggested that it may be the increased loading of the prosthesis that contribute to the increased risk for revision and not just the duration of the implant increasing the revision risk (89). Further research is necessary to understand the relationship between physical activity and revision risk (88, 89).

2.1.5 Physical Activity Measurement

Overview

There is strong consensus on the importance of physical activity; however, there is little agreement on the best approach for the measurement of physical activity (24, 92, 93). To measure the complex behavior of physical activity, a measurement tool would ideally obtain information on all four dimensions of physical activity – frequency, intensity, duration and type as illustrated in the Gabriel framework (46). Different measurement tools measure these dimensions to different degrees (18, 46, 94, 95). There is not one ideal measurement tool and the choice of tool must also be a balance between reliability, validity and practicality (93, 94).

Reliability refers to the consistency with which an instrument or rater measures the intended variable (96). An instrument is reliable when it obtains the same value or measurement when it is repeated subsequent times (95). Factors affecting reliability include the sample and the sample variability, the number of items or observers, instrumentation and the time between testing (95). Increasing the sample size, variability in participants, familiarity of the tester or person being tested, number of items on a written tool, number of observers, number of repeated assessment times, and precision of the measurement tool all generally increase reliability (95).

Validity is the degree to which the instrument or rater truthfully measures what it is intended to measure and includes concepts such as content validity, criterion validity and construct validity (95, 96). Content or face validity is a less stringent form of validation evidence assessing the degree to which the measurement tool appears to be logical in measuring the content domain being measured (96). Criterion-related validity refers to the assessment of how a measurement tool compares in performance to a criterion measure that has been shown to accurately measure the variable in question. It may, however, be impractical or expensive for widespread use (95, 96). This study assessed criterion validity as it compares the measurements of EE from the personal activity tracker (Fitbit) and self-report questionnaire (CHAMPS) to the previously validated measurement tool (SWA) which has been shown to be accurate in measuring EE in older adults following TKA (20). The SWA is a reference standard in this research as there is a not a feasible gold standard that may be used as a criterion measure (96). Concurrent validity and predictive validity are two types of criterion validity that differentiate between measures taken at the same time (concurrently) or at different time frames (predictive) (95). In this study, the measurements were taken at the same periods so concurrent validity was evaluated. Construct validity is another type of validity that evaluates the theoretical construct being measured and is based on a series of studies or rational evidence of validity (95, 96).

Issues influencing **practicality** include factors such as cost, time to administer, patient burden, equipment necessary, and outcomes provided (94). Even a reliable and valid measurement tool will not be appropriate for use if it is too cumbersome for the participant, too costly for widespread use, require specialized equipment or exhibit other factors decreasing practicality.

To determine the best practical, reliable and valid way to measure physical activity, it is helpful to consider these characteristics in the context of the common outcome measurements used in the measurement of physical activity. The measurement of number of **step counts** in a specified time period**, energy expenditures**, and **time spent** in various activity intensities are three common outcome measures quantifying physical activity and can be measured by various measurement tools (94).

Step Counts. The use of step counts as an outcome measure has been popular long before the advent of accelerometers through the use of **pedometers**. Over the past two decades, pedometers have frequently been used to quantify physical activity through the measurement of step counts based on the vertical motion of the person's body. While the initial pedometers relied on the use of a mechanical gear, subsequent generations are electronic (97). Pedometers are a low cost, reliable option to measure step counts and are relatively easy to use. Number of step counts is an easy to understand outcome measure for the general population and can raise awareness of levels of physical activity both on an individual and population basis (98). Public health guidelines recommending 10000 steps per day for the average population and 7000 - 8000 steps for older adults and special populations for health benefits have garnered media and public attention (98, 99).

The number of step counts have been used in the development of pedometer-determined indices of physical activity. Tudor-Locke et al. proposed classifying < 5000 steps/day as a 'sedentary lifestyle index', 5000 - 7499 steps/day as low active, 7500 – 9999 steps/day as somewhat active, > 10000 steps/day as active and > 12500 steps/day as highly active (98). The authors suggest that 7000 to 10000 steps/day in healthy older adults would be roughly equivalent to 30 minutes of daily MVPA accumulated in addition to habitual daily activities. This estimation is based on healthy older adults taking an average 2000 to 9000 steps/day so it is recognized that these targets would need to be adjusted accordingly for special populations reporting averages of 1200 to 8800 steps/day (99). A recent review provided further evidence for the health benefits of higher step counts reporting an inverse relationship between daily step counts and all-cause mortality, cardiovascular events and type 2 diabetes (35). Number of step counts in a specified time period therefore is a feasible measure of physical activity; however, it is limited in the data provided as estimates of EE or intensity of exercise are not possible (100, 101).

Energy Expenditure. Physical activity can be defined in terms of movement producing **EE** (37). EE is the amount of energy used for physical functioning of the body, and is often measured in the units of kilocalories (94). Total Energy Expenditure (TEE) is composed of the Resting Metabolic Rate (RMR), the Thermic Effect of Feeding (TEF) and the Activity Energy Expenditure (AEE), i.e. TEE = RMR + TEF + AEE (102). RMR refers to the EE at rest by a fasted individual in a thermo-neutral environment, and TEF is the EE related to feeding. AEE refers to the EE through all active movements including exercise and non-exercise activities and is the most variable component of TEE (102). When discussing and measuring EE, it is typically TEE that is being quantified unless specified otherwise and that convention was continued throughout this paper.

There are several different methods to estimate EE. Administering **doubly labeled water** to calculate oxygen uptake ($V0_2$), and therefore EE, is often considered the gold standard when measuring total EE (94). Participants consume doubly-labelled water which then travels throughout the body and is eventually eliminated throughout the participant's urine. The isotope dose and excretion rate can then be used to calculate metabolic CO_2 and therefore VO_2 and EE.

Although safe and precise, this method is not often practical due to the equipment needed, time for testing and the necessity of obtaining frequent urine samples from the participants.

A second method, **indirect calorimetry**, also uses VO_2 to measure EE by measuring the consumption of oxygen and the production of carbon dioxide to calculate the amount of energy produced in a certain period. This method requires the participants to wear a mask and have the necessary equipment to measure expired air which is also costly and cumbersome. This equipment also limits the activity of the participant, and therefore influences the AEE portion of TEE. Neither the doubly-labeled water or indirect calorimetry techniques are practical for measuring large samples but may be feasible for validation studies with small samples (94).

The use of **accelerometers** is a third method for estimating EE and measures movement in one, two or three planes with a lower level of patient burden than using doubly-labelled water or indirect calorimetry (94). Accelerometers also allow the measurement of frequency, intensity and time of exercise with some providing information on type of exercise as well. Accelerometer use is common in research settings as they have been shown to measure physical activity EE accurately, be suitable for many populations, minimize recall bias and have a relatively low response burden (93). Triaxial accelerometers, which measure acceleration in three directions, have been shown to have higher validity than single and biaxial accelerometers (103). Many of the newer accelerometers allow for the input of individual data (i.e. gender, age, height and weight) to increase the accuracy of the calculations, most specifically the RMR portion of TEE. Disadvantages include the high cost of these monitors and the complexity of the data analysis (18, 93).

It is common to categorize measurement of EE by levels of intensity of the physical activity. Physical activity intensity can be discussed relative to resting values of EE by using

metabolic equivalents (METS) (94). METS are a physiologic measure of the ratio of EE of the individual compared to that level at rest. By convention, 1 MET is the EE or oxygen consumption at rest for an average individual and is defined as 1 kcal/kg*hour or 3.5 mL of O_2/kg*min (94). The intensities of other activities are then described as multiples of 1 MET (104). The Ainsworth Compendium was developed in 1993, and subsequently updated in 2000 and 2011, to provide a standardized resource of MET values for common physical activities that could be used as a basis for population health and epidemiological research (104). The MET values range from 0.9 METs for sleeping to 23 METs for running at a speed of 14.0 mph (104). More recently, the use of the METs values has expanded to include the calculation of measurement of physical activity in individuals and is also used in some self-report measures (104). There is, however, a growing body of research suggesting that standardized METs values are not appropriate for all individuals. Resting metabolic rates vary for age, height, weight and sex so these factors need to be considered when determining the intensity of activity (104-106). Metabolic costs of physical activities tend to increase with age, and for many purposes standardized METS values are now adjusted according to age (26). These variances should be considered when measuring and prescribing physical activity for older adults (105).

Categorization of physical activity intensity can vary depending on the use and population but the following **generally accepted categories** are common: 1 to 1.5 METS very light intensity, 1.5 to 2.99 light intensity, 3 to 5.99 moderate intensity, and $\geq$ 6 vigorous intensity (6). Categorizing physical activity intensity can assist in research, discussion and promotion of physical activity.

Many clinical guidelines now specify not only the duration of recommended physical activity but also the intensity recommended. For example, the World Health Organization

Global Recommendations on Physical Activity for Health recommend a minimum of either moderate intensity aerobic physical activity for at least 150 minutes per week or vigorous intensity aerobic activity for 75 minutes (6). Similarly, the Canadian Physical Activity Guidelines recommend 150 minutes of moderate to vigorous intensity aerobic physical activity per week (42). These two guidelines, as well as others, also recommend physical activity at these intensities occur in **bouts of 10 minutes or greater** (6, 42). However, there is no consensus in the literature on the need for physical activity to occur in sustained bouts of time (107). In 2009, Murphy et al. reviewed sixteen studies to compare the effects of similar amounts of exercise undertaken in either one continuous timeframe or two or more accumulated bouts on several health outcomes (107). Most studies did not find a difference on cardiovascular outcomes following activity in either continuous or accumulated bout formats (107). A recent review examined whether physical activity occurring in < 10 minute durations also have health-related benefits or whether bouts of physical activity ≥ 10 minutes are necessary (108). Based on the included 13 cross-sectional and prospective cohort studies examining bouts < 10 minutes, the review concluded that physical activity of any bout duration, not just ≥ 10 minutes, demonstrated improved health outcomes including all-cause mortality (108).

While the 2008 Physical Activity Guidelines for Americans included the recommendation of moderate to vigorous activity occurring in bouts of ≥ 10 minutes, the second edition published in 2018 reflects these findings, and no longer includes that requirement (44). There is an increasing trend in literature and recommendations to encourage activity throughout the entire day rather than focus only on bouts of moderate to vigorous activity (109, 110). Further research is necessary to determine if bouts of accumulated exercise are effective for a variety of health outcomes as well as whether shorter bouts (< 10 minutes) also have positive effects on health (108, 111).

Challenges in Measurement with Accelerometry

A number of measurement challenges affect the accuracy of measurement of physical activity using accelerometry (112, 113). These challenges include variations in wear, human factors, and data analysis decisions.

Wear Time. Wear time can significantly affect measurements of physical activity and sedentary behavior (19, 114). A review of studies using accelerometry for physical activity measurement found between 27% and 74% of participants averaged between 13 and 15 hours per day of wear time, demonstrating that some awake time was not monitored (19). Additionally, discrepancies of 28-30% in time spent in sedentary behavior were found when a 10 hour/day accelerometer wear time was compared to a 14 hour/day accelerometer wear time (115). Potential differences in wear time must be considered when using study data.

Absolute vs. Relative Intensity. The intensity of physical exercise can be expressed as absolute intensity (expressed as the METS level, a multiple of the resting EE) or relative intensity (expressed as a rate relative to an individual's fitness level and their maximum level of work). Absolute intensity is more commonly used in the measurement of physical activity but there are limitations that need to be considered (113). Two individuals participating in a similar activity may be working at different intensity levels depending on their individual demographic and medical characteristics. For example, an activity may require an older adult to work at a moderate intensity as compared to a lighter level of intensity in younger adults (113). Similarly, a moderate activity intensity defined as 3 to 6 METS may in fact include activities that are categorized as 3 METS but are actually at a light intensity for a healthy young active person. The interpretation of work expended may vary and yield inaccurate measurement of time spent in moderate intensities (113). Relative intensity may be useful for individual measurement or exercise prescription but is less useful for broad application (113).

Human Factors. Although accelerometers are generally considered objective measurement tools, they are still subject to human-related factors. Chosen behaviors such as intentional non-wearing, a change in habitual behaviors due to social desirability or other external factors, and shaking or tampering with the device can also influence results (19, 113). As with all measurements, the Hawthorne effect may influence data on habitual behaviors as the participants are aware that their physical activity is being monitored and therefore may change their behavior. Data on the influence of the Hawthorne effect on accelerometry remains limited (19).

Gait Speed. As adults age, walking speeds tend to decrease and walking aides may be more frequently used (116). A review of validity and reliability of activity trackers in older adults found greater percentage errors or increased data acquisition difficulties in a number of studies with reduced walking speeds or lower activity levels (116). These findings were consistent with subsequent validity studies examining various gait speeds (117, 118). The use of walking aides also decreased the accuracy of measurement of steps for a number of activity monitors (119).

Location of Wear. Accelerometers are worn on several places on the body which can affect the accuracy of physical activity measurement (113). Historically, the most common location of wear was over the hip; however, accelerometers are now also worn on the thigh, arm and wrist both in clinical and research applications (113). The wrist is now emerging as the most common location of wear. Because the wrist is more accessible, higher rates of compliance are reported for this location than with other body locations. Common research accelerometers include the ActiGraph which may be worn at the waist or wrist, GENEActiv worn on the wrist, Actical at the waist, Actiheart on the chest and ActivPal on the thigh. The thigh placement of the ActivPal has the increased functionality of being able to assess body position. In general, hip placement has demonstrated higher accuracy in measuring physical activity as compared to the wrist, but to date, there is not sufficient evidence to make conclusive recommendations (113). There is increasing evidence regarding the validity of specific accelerometers in specific populations but further research is required (113).

Cut-off points/thresholds. The use of cut-off points is the most common method to define the intensity level of physical activity in accelerometry (19). Cut-off points are often developed by analyzing the relationship between the counts and objectively measured EE. In spite of this widespread use, many experts do not recommend their use and suggest other methods such as pattern recognition that may provide better estimates of activity and especially physical activity in the moderate to vigorous range (19). Potential issues with the use of cut-off points include non-representativeness of the calibration study sample or activities undertaken, differences in accelerometer models and inconsistent choice of cut-off values between studies. Additionally, the choice of cut-off points is not always known due to proprietary algorithms and, even for those known, there is often inconsistency (19, 120). For example, the ActiGraph is a commonly used accelerometer and cut-off points are not consistent between studies and can influence study results and conclusions (19, 29).

Data Sampling and Processing. Other considerations of data acquisition include data sampling and processing which affect accelerometer outputs. It is beyond the scope of this paper to discuss the technical details as this literature review focuses on the clinical application of accelerometers. Users of accelerometry, however, must be cognizant of the variations in sampling rates, filters and epoch lengths that may influence data (113). Sampling rates typically range from 30-100 Hertz but can vary between accelerometers. The data are normally condensed to smaller windows or epoch lengths which can also vary between accelerometers. Because some accelerometers, such as the ActiGraph, use low-pass frequency filters to decrease the effect of extraneous noise, this may decrease accuracy of higher intensity physical activities. Machine learning is being increasingly used to transform accelerometer data to clinically useful physical activity outcomes with complex analysis (113). There are a number of reviews that discuss these issues but there is currently no consensus on recommendations for many of these considerations (19, 113).

Measurement of Physical Activity in Older Adults Following TKA

Accelerometers – SenseWear Armbands

A number of different accelerometers are commercially available for use to measure physical activity (18, 19, 103). Much of the literature evaluating reliability and validity of these devices has been undertaken on research grade accelerometers such as the ActiGraph, RT3-Research Tracker and the SWA (103, 121, 122). Several reviews conclude that accelerometers, in general, demonstrate good reliability and validity although population specific evaluation must be undertaken (18, 19, 122).

The SWA is one of the most common research grade accelerometers and has been determined to be valid research tool for measurement of EE with lower patient burden than multiple accelerometers (94, 126). The SWA is a lightweight armband that is worn on the upper arm next to the skin and contains four physiological sensors – skin temperature, galvanic skin reaction, heat flux and accelerometry in three axes. These sensors allow the calculation of EE, METS, step counts, physical activity duration, sleep time and lying down time (123). SWAs provide information about frequency, intensity and duration of the physical activity. Raw data are generally available for analysis which is preferred to the use of proprietary algorithms for accuracy of interpretation; however, this does increase the complexity of data analysis (124). Disadvantages of the SWAs include the high cost for the device and software and the requirement of the patient to wear the armband at all times.

Criterion validity of SWAs was examined in a study by Colbert et al. when SWAs were shown to be correlated with doubly labeled water measured physical activity EE in free-living older adults ($r=0.479$, $p<0.01$) (125). Mackey et al. reported similar results as they did not find a difference in mean ± SD in TEE when comparing the results from doubly labeled water (2 040 ± 472 kcal/day) and from SWAs (2 012 ± 497 kcal/day) (126). They reported an ICC value of 0.904 (95% CI 0.770 to 0.962) and that no bias was found in the Bland Altman plots (126). When compared to the ActiGraph GT3X accelerometer in the evaluation of sedentary and light-intensity physical activities, the SWA had higher accuracy in identifying light activities (specificity 0.61-0.71) than the ActiGraph (specificity 0.27-0.47) which is especially relevant in the population of older adults (127). In TKA cohorts, Almeida et al examined the validity of physical activity measures and concluded that the SenseWear Pro3 Armband demonstrated better criterion validity than the comparison accelerometer (ICCs 0.48 to 0.81). They recommend the SWA as an appropriate tool to measure physical activity in older adults following TKA (20). Most recently, Almeida et al. also found SWAs to have excellent test-retest reliability when comparing physical activity measurements from two different weeks in older adults following TKA (21).

The SWA therefore has been shown to be an appropriate tool to measure physical activity in older adults following TKA; however, the practical widespread application of the SWA is limited due to the cost, complex data analysis and relatively high patient burden (18, 93).

Accelerometers - Fitbits

In spite of the wealth of data available from accelerometers, widespread use of accelerometry outside of the research setting has typically been limited, in part, because of the high cost of the devices (128). Due to recent technological advances, the cost of this technology has decreased and consumer markets have seen a proliferation of personal activity monitors. Accelerometry and wearable technology is predicted to be a major trend in technology in the upcoming years (23, 128-130). Personal activity trackers, which include the new generation of accelerometers, are increasing steadily in popularity and can often relay data to mobile devices or computers for longer term tracking and storage (130). The Fitbit has emerged consistently as one of the forerunners of the industry holding the largest market share in activity trackers from 2013 to 2015 (130, 131). Fitbit has recently reported 25 million active users and sales of 15 million devices (131).

Advantages of this new generation of accelerometers include the common characteristics of being small, portable, relatively inexpensive and easy to use. Data are displayed in a useable, easy to understand format and may include information on step counts, EE, stairs climbed, distances traveled, levels of activity, heart rate and sleep. These devices may provide immediate feedback through interactive displays and corresponding mobile and internet-based applications. Many provide real time data connectivity expanding the potential for use as monitors, interventions and research methods. Devices may provide the opportunity to share information and interact with other users facilitating a social network and peer support (128, 132, 133). Fitbits are also becoming increasingly common to measure physical activity in research. One recent review reports a total of 171 clinical trials registered between 2011 and 2017 using the Fitbit as an outcome measure (132, 133). In spite of the extensive potential of these products, the field is still at its infancy in terms of assessing the reliability and validity of these products in various populations (130).

Interdevice Reliability of Fitbits. There is an increasing body of evidence reporting good reliability between Fitbit devices in step counts, distances measured and EE. In a systematic review by Evenson et al., five studies evaluated interdevice reliability in these measures with four studies evaluating walking on a treadmill (134-137) and one in free-living (130, 138). All studies consistently reported high measures of reliability with ICCs ranging from 0.76 to 1.0 for step count, 0.90 to 0.99 for distance and 0.74 to 0.97 for EE (139). Although the interdevice reliability of the Fitbit is reasonable, no studies reported intradevice reliability of the Fitbit (139).

Fitbit Step Count Measurement. A recent systematic review found a total of 27 studies that evaluated step count measurements as compared to a reference criterion of direct observation or counting of steps in controlled settings (133). The majority of these studies (n=21) involved healthy adults, and six studies involved adults with limited mobility or chronic disease. Overall, 46% of the studies were within a ±3% measurement error with the Fitbit having a tendency to underestimate steps. Measurement error varied according to gait speed with increased measurement error for slow and very slow ambulation speeds. The review reported 13 studies in free-living environments finding that 55% of Fitbit devices were within the less stringent $\pm$ 10% measurement error when the Fitbits were worn on the torso or wrist with the Fitbits demonstrating a tendency to overestimate steps (133).

The Fitbit tended to underestimate step counts by 25% in two of three comparisons in adults with mobility limitations (133). In contrast, one comparison reported that the Fitbit tended to overestimate steps by more than 35%. Results from the free-living studies suggested that wearing the Fitbit on the torso may overestimate steps in older adults without mobility limitation and underestimate steps in older adults with limited mobility when compared to wearing the Fitbit on the ankle (133).

Fitbit EE Measurement. There were consistent findings that measurement of EE in controlled studies were less likely to produce accurate results than the measurement of step counts (133). The Fitbits tended to overestimate EE during activity and underestimate activity at rest. Again, accuracy seemed to vary according to gait speed although no trend was noted for the measurement error in slow and very slow ambulation speeds. In free-living environments with healthy adults, the Fitbit tended to underestimate EE with the mean measurement error ranging from 7.4 to 15.3% (133).

Fitbit Time Spent Measurement. The review found eight studies evaluating validity in time spent in different activity intensities in free-living settings (133). The results were consistent suggesting that the Fitbit devices may underestimate time spent in sedentary intensities (mean measurement error -11.1%) and overestimate time spent in the higher intensities (mean measurement error ranging from 43.5 to 84.9%). Measurement errors tended to increase as activity intensities increased (133).

Monitor Placement. The original Fitbit model, the Classic, was introduced in 2009 and was a clip-on device which could be worn on the torso (133). This model was followed by other clip-on models including the Ultra, Zip and One models. The next models were worn on the wrist and include the Force, Flex, Charge, Alta and Inspire (133). Results were mixed as to the most accurate placement of the activity monitors with investigators suggesting increased accuracy with torso placement for steps during normal or self-paced walking, with wrist placement for jogging and ankle placements during slow or very slow walking in adults without mobility limitations (133). Similarly, a recent study in older adults with knee osteoarthritis reported that accelerometer placement, i.e. hip vs. wrist in this study, also influenced physical activity data (22).

Fitbit Validity in Older Adults. Although there is a rapidly expanding body of research examining the validity of Fitbits, studies have been generally undertaken in young to middle aged healthy adults. Findings are not generalizable to older adults. Straiton et al. recently conducted a systematic review examining the validity and reliability of consumer-grade activity trackers, including several models of Fitbits, in older adults (116). Seven studies were included examining the measurement of steps and/or activity duration in 290 older, community-dwelling adults with a mean age of 70.2±4.8 years (116). Five studies involved free-living environments and two studies controlled environments. In free-living environments, the authors found step counts were highly correlated with reference standards for most consumer-grade accelerometers (ICCs for the Fitbit One 0.94, Fitbit Zip 0.94, Fitbit Charge HR 0.86 and Misfit Shine 0.96). The Fitbit One (ankle) percentage error was < 10% at gait speeds of 0.4-0.9 m/s and Fitbit One (waist) was < 10% for only the 2 fastest gait speeds of 0.8 and 0.9 m/s in controlled environments. Another study found the Fitbits underestimated step counts by 2.6% for the Fitbit

One worn at the hip (ICC=0.80) and 26.9% Fitbit Flex worn at the wrist (ICC=0.15) in adults with nonimpaired gait and by 1.7% Fitbit One worn at the hip (ICC=0.96) and 16.3% Fitbit Flex worn at the wrist (ICC=0.25) in adults with impaired gait (140, 141). The consumer-grade devices accurately captured daily activity duration; however, with a lower correlation than step counts (r=0.74). Similar to Feehan et al., the Straiton review found that slower gait speeds reduced the levels of agreement (116, 133).

Two more recent articles also examined the accuracy of Fitbits in older adults in controlled environments (142, 143). Consistent with previous findings, Burton et al. reported high correlation between step counts and direct observation for the Fitbit Flex and ChargeHR in a two-minute-walk-test (ICC 0.86, 95% CI 0.76 to 0.93) although both monitors tended to underestimate steps (142). Hergenroeder et al. reported a range of accuracy when comparing step counts from seven activity monitors to direct observation in older adults with varying walking abilities (Accusplit AX2710 93.68%±14.95, Fitbit Zip at waist 75.25%±35.56, Omron pedometer 71.71%±38.01, Yamax EX-510 pedometer 71.01%±35.0, Fitbit Zip worn at shirt collar or pocket 69.8%±40.35, Garmin Vivofit 56.95%±46.54, Digiwalker 52.83%±37.73, and Fitbit Charge 39.12%±40.3) (143). Using a benchmark of ± 3% for accuracy, none of the activity monitors were ≥ 97% accurate in measuring step counts for those who used assistive devices and only the Accusplit was ≥ 97% for those not using an assistive device. Accuracy again decreased with decreasing gait speed with none of the activity monitors demonstrating accuracy ± 3% at speeds <0.8 m/s, only the Accusplit at 0.8-10.0 m/s and the Fitbit Zip, Accusplit, Omron and Yamax at >1.0 m/s (143).

Fitbit Use in Older Adults. Several studies examined the experience of use of Fitbits in older adults. McMahon et al. assessed 95 community-dwelling older adults using a Fitbit One examining acceptance, ease-of-use and usefulness (144). The study found 91% of participants agreed or strongly agreed that the Fitbit One was easy to use, useful and acceptable. No significant difference was found with gender or educational attainment (144). Tocci et al. reported similar findings in twelve older men wearing six different physical activity monitors including the Fitbit Flex. The participants reported that they enjoyed using the devices, and found them easy to wear, comfortable and an informative measure of physical activity (145). Mercer et al. conducted a study with a sample of 32 older adults living with chronic illness where five physical activity trackers were assessed including the Fitbit Zip (146). Although prior to enrolling few of the participants were even aware of activity trackers, following the study 73% planned to purchase one, with the Fitbit being the most popular choice (50%) (146). Participants in the study by Hergenroeder at el. reported the most important features of activity monitors were accuracy of the activity monitor, ease of application and ease to read (143). All of these findings suggest that older adults may benefit from the use of the Fitbit devices.

Fitbit Validity in Adults with Chronic Conditions. Studies evaluating the accuracy of Fitbits are being undertaken in other populations such as individuals following stroke and traumatic brain injury, COPD, cardiac conditions, cancer and transfemoral amputations with varying results reported (147-151).

In older adults with knee osteoarthritis, Collins et al. compared steps and time spent in sedentary, light, and moderate-to-vigorous activity with the Fitbit and ActiGraph. The authors reported that the Fitbit overestimated steps by 39% and sedentary time by 37% but underestimated MVPA by 5 minutes (22). Although a number of studies reported the use of Fitbits in interventions to increase physical activity in individuals following TKA, to our knowledge there are no studies reporting the validity of Fitbits in adults with total joint arthroplasties (152, 153).

Self-report Measures

Self-report measures are another option to measure physical activity. Formats can range from a single item rating using a Likert scale to lengthy documents querying about frequency, intensity, type and duration of physical activity (154).

Compared to many objective measures, self-report measures are inexpensive and easy to administer, making them feasible for epidemiologic studies (18, 94, 154). There is, however, a growing body of literature describing poor validity of self-report measures when compared to direct measures of physical activity such as indirect calorimetry or accelerometry (18) . In a review including 57 articles, Skender at al. found weak to moderate correlations between accelerometry and self-report questionnaires, which was in agreement with findings of two previous reviews (158). Factors such as recall/interviewer bias, participants' cognitive status, cultural specificity of the questionnaire, consistent administration and reliability must be considered when self-report measures are used (93). Social desirability is a bias that may cause participants to over report MVPA and under report light physical activity (157). Many of the self-report methods currently used in interventions have not undergone rigorous psychometric testing and lack appropriate research into criterion and construct validity (122). The logistical advantages and validity must be carefully considered when deciding on the use of self-report measures. Recommendations suggest the use of a combination of accelerometry and self-report measures to obtain the most accurate information (122, 158).

When looking specifically at the measurement of EE with self-report measures, there is a wide variability in the ability of these measures to calculate EE (18, 94). In a review of measurement tools used to measure physical activity in older adults, 50% of the self-report measures evaluated were able to calculate EE with the CHAMPS questionnaire used most frequently (122). The authors concluded that valid and reliable measures of physical activity such as the CHAMPS Physical Activity Questionnaire for Older Adults should be used in conjunction with accelerometry for accurate measurement of physical activity in older adults (122).

Self-report Measures in Older Adults Following TKA. In spite of a lack of information on the validity of self-report measures, many measures are currently in use in clinical practice in older adults following TKA (24, 154, 156). Measurement of physical activity in older adults can have the additional challenge of changes in the metabolic costs of activities due to aging or disability (18). Older adults tend to spend a higher percentage of their day in low intensity activity and a lower percentage in high intensity activity (159). As recall for the type and time spent in high-intensity activities has been shown to be more accurate than for low intensity activities, activity intensity may also influence the reliability and validity of self-report tools (26). These potential variations in activity intensities and recall may further complicate measurement of physical activity in populations with chronic conditions such as osteoarthritis of the hip and knee (76, 160). Physical activity measurement must be discussed in relation to the population being measured.

Several self-report measures have been evaluated specifically for individuals following TKA with inconsistent results and no clear recommendations for use. Bolszak et al. evaluated the validity and reproducibility of the physical activity scale for the elderly (PASE) questionnaire using accelerometry as a comparison and found reliability was acceptable for men (ICC=0.77) but not women (ICC=0.58) (161). The construct validity score and agreement were also low for both genders with the authors concluding that the use of the PASE was not recommended for individuals following TKA.

Naal et al. compared the construct validity, test-retest reliability, feasibility and floor and ceiling effects of the UCLA, the Tegner score and the Activity Rating Scale (162). The authors concluded that the UCLA was the most appropriate scale for assessment of physical activity in patients following TJA with the best reliability, highest completion rate and lack of floor effects (162). The UCLA however is limited in the information provided as the questionnaire consists of a one item Likert scale (163).

The Lower Extremity Functional Scale is a 20-item functional scale designed for patients with lower extremity orthopedic conditions (164). Crizer et al. found only a weakly positive correlation when comparing the LEFS with step count in patients following TKA (Spearman rank coefficient 0.29 at weeks 1 and 6 post TKA) (165).

The CHAMPS questionnaire showed promising results when compared to the SWA and ActiGraph accelerometers (21). The CHAMPS questionnaire and the SWAs both had excellent test retest reliability (ICC = 0.86 to 0.92 and 0.93 to 0.95 respectively). The authors suggested that the lower physical activity values found in the second measurement period by the CHAMPS questionnaire may be a result of increased physical activity due to increased awareness of the monitoring in the first measurement period, and that this effect may have decreased by the second measurement period (21). The CHAMPS questionnaire also has the practical advantage of allowing the calculation of EE (26). Daily AEE is calculated by the questionnaire, and TEE can then be calculated by summing the AEE and the BMR of each participant (166).

CHAMPS Questionnaire. The CHAMPS questionnaire was, therefore, chosen as the primary self-report measure in this study due to the support in the literature for its use in the population of older adults and following TKA as well as its increased clinical utility allowing calculation of EE (21, 26, 166, 167). The 40-item self-report measure of physical activity asks participants to recall the type and duration of activity over a typical week within the past four weeks (see Appendix F). Specific activities are listed to help stimulate recognition. The questions are structured so the respondents report the number of times per week they undertook the activity and then the approximate duration in hours of participation over the entire week. Frequency per week and estimated EE in physical activity per week are then derived (26). The estimated EE can then be categorized into average daily EEs in all categories of physical activity intensity as well as average daily EEs in moderate and greater intensity categories. TEE is calculated by summing the AEE from the CHAMPS questionnaire with the BMR calculated by the Harris Benedict equation (166, 168).

Research in adults and older adults (but not following TKA) was also promising. CHAMPS discriminates well across groups of older adults with varying activity levels ($p<0.001$) and demonstrated six-month stability (ICCs 0.56 to 0.70) (26, 157). Stahl et al. found the CHAMPS questionnaire was significantly correlated with Fitbit estimates of total EE per day ($r=0.61$, $p<0.5$) suggesting acceptable criterion validity (166). Giles et al. examined the CHAMPS questionnaire completed by mail rather than in person completion finding observed measurement coefficients comparable to those reported in previous studies thus expanding potential clinical use (169).

2.2 Sedentary and Stationary Behavior

Sedentary behavior is a relatively new concept that is becoming recognized both in research and in the popular press (170-172). There is growing consensus that sedentary behavior is a distinct entity from physical activity posing its own health concerns and as such should be considered in discussions of activity and health (170). Although this dissertation focuses on the measurement of physical activity, it is being increasingly recognized that due to its significant effects on health, sedentary behavior is also an important concept to measure. Recent findings suggest that individuals with high levels of sedentary behavior are at a higher risk of morbidity and mortality even if they engage in moderate to vigorous physical activity than those with lower levels of sedentary behavior (173, 174). The risks due to excessive sedentary behavior and inadequate MVPA are two separate risk factors for the development of chronic disease (114, 170, 171). A 2015 systematic review and meta-analysis found that sedentary time was significantly associated with the following health outcomes independent of levels in physical activity – all-cause mortality (HR 1.240 95% CI 1.090 to 1.410), cardiovascular disease mortality (HR 1.179 95% CI 1.106 to 1.257), cardiovascular disease incidence (HR 1.143, 95% CI 1.002 to 1.729), cancer mortality (HR 1.173, 95% Ci 1.108 to 1.242), cancer incidence (HR 1.130 (95% CI 1.053 to 1.213) and type 2 diabetes incidence (HR 1.910, 95% CI 1.642 to 2.222) (170). A recent update reported strong evidence that high amounts of sedentary behavior are associated with higher risk for all-cause and cardiovascular disease mortality and incident cardiovascular disease and type 2 diabetes (30). The authors also reported moderate evidence for associations with incident endometrial, colon and lung cancer and limited evidence on associations with cancer mortality and weight status. There was strong evidence that there were increased risks for the adverse effects due to sedentary behavior in people who are less physically active (30). This is cause for concern as population-based studies have demonstrated that more than one-half of the average person's waking day is spent in sedentary behavior (30). Older adults are one of the most sedentary groups spending approximately 65-80% of their time in sedentary behavior (175). Similarly, a sample of 1168 adults with knee osteoarthritis spent two-thirds of the day in sedentary behavior (176).

2.2.1 Total Knee Arthroplasty and Sedentary and Stationary Behavior

Sparce evidence is inconclusive regarding improvement in sedentary behavior after TKA. A recent systematic review on sedentary behavior in patients before and after TKA reported two studies showing a reduction in sedentary behavior, one study reporting an increase in sedentary behavior and seven studies showing no change in sedentary behavior following TKA (27). Two studies have examined physical activity and sedentary behavior following the review (29, 177). When comparing activity at six weeks post TKA to their pre-operative levels, participants spent less time standing ($p<.001$) and more time sitting ($p<0.001$) six weeks following their surgery (177). At six months after TKA, no significant changes were found in the time spent standing (=0.78) or sitting ($p=0.29$) when compared to the pre-operative levels (177). In the second study, no significant differences were found in total sedentary time ($p=0.62$) nor number of long sedentary bouts per day ($p=0.37$) pre and 1-year post TKA (29). Given these inconclusive findings, further research into sedentary behavior following TKA has been recommended (27, 29, 177).

2.2.2 Challenges in Measurement in Sedentary and Stationary Behavior

Many of the issues described above in the discussion of challenges of measurement of physical activity are also relevant to the measurement of sedentary behavior. Wear time, bias associated with social desirability, body location of device worn, cut-off points/thresholds and data sampling/processing can all affect the measurement of sedentary behavior as well as physical activity. There are also challenges unique to the measurement of sedentary behavior. While the Gabriel model provides a useful framework to discuss factors affecting physical activity and does identify sedentary behavior as a concept independent of physical activity, the framework does not reflect more recent generally accepted definitions of sedentary and stationary behavior (46, 178). Traditionally, inconsistencies have been found in literature regarding the definition and measurement of sedentary behavior (32). Many different outcomes have been used to describe sedentary behavior including sitting time, screen time, sit to stand transitions, time spent in lower intensity activities and time spent in specific postures (170). In response to these challenges, the 2017 SBRN terminology consensus project revised the definition of **sedentary behavior** to "any waking behavior characterized by an EE ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture" and expanded the recommendations to include concepts such as stationary time, screen time, patterns, bouts, and interruptions (32). **Stationary behavior** was defined as "any waking behavior done while lying, reclining, sitting, standing, with no ambulation, irrespective of energy expenditure". A key concept to this definition is that a behavior cannot be designated as sedentary unless an indication of posture is included along with an estimate of energy expenditure in the assessment. This postural measurement may include methods such as self-reported sitting or objective postural measurements as determined by an inclinometer. Following this definition, stationary behavior may be a more accurate description of what is measured with most accelerometers (i.e., no ambulation) (32, 179). The SBRN suggests that researchers can now use the term "stationary time" for data collected from an accelerometer that does not have the capability to determine posture (32). It should also be recognized that many of the studies providing the evidence on the health effects of 'sedentary behavior' did not follow these specified definitions so were based on what would now be defined as stationary behavior (170, 180). As newer accelerometers with the capabilities to measure the postural component of sedentary behavior become more available, research using accelerometers with this capability would be beneficial in this patient population (181).

There is emerging evidence suggesting that patterns of sedentary behavior also affect health outcomes with longer bouts of sedentary time corresponding to higher rates of all-cause mortality (182). To encourage consistency in research and discussion, the Sedentary Behavior Research Network (SBRN) has recommended standardized definitions for these concepts (32). **Sedentary time** is defined as the time spent for any duration or in any context in sedentary behaviors. A **sedentary bout** is a period of uninterrupted sedentary time. **Sedentary breaks** are defined as the non-sedentary bouts in between sedentary bouts (32). **Stationary time** includes the time spent for any duration, in any context, and at any intensity in stationary behaviors. A **stationary bout** is correspondingly defined as a period of uninterrupted stationary time, with a **stationary break** defined as a period of uninterrupted stationary time (32). Although there is increasing research on the effects of sedentary and stationary bouts on health, there is not yet consensus on the length of time a sedentary or stationary bout needs to be to cause these adverse health effects (182). Consistent use of definitions for these concepts will assist in accurate measurement, data collection, interventions and policies to help maximize health (32).

The step-defined sedentary lifestyle index of 5000 steps/day (SLI) has also been suggested as a clinically relevant tool for sedentary behaviors (31). Taking < 5000 steps/day has been associated with negative indicators of body composition, increased cardiovascular risk and risk for falls (31, 183). Given that step counting is a common and easily understood method of measurement, further research into its association with stationary behavior would be helpful to determine the clinical utility of the SLI.

2.2.3 Measurement of Sedentary and Stationary Behavior in Older Adults Following TKA

Accurate information on levels of sedentary and stationary behaviors post-surgically are necessary to inform recommendations, interventions and guidelines aimed at mitigating the negative effects of sedentary and stationary behavior in older adults post TKA (27). In order to obtain accurate information, there must be clarity and consistency in the definitions of stationary and sedentary behaviors as well as evidence on the most appropriate tools for measurement (24, 32). There is not currently clear evidence on levels of sedentary and stationary behaviors post TKA nor information on the best tools to measure sedentary or stationary behaviors.

Chapter 3 Methods

The methods for each study are described in the corresponding articles detailed in chapters four thru six. Additional detail is found in the appendices, specifically:

- Coaching for Older Adults with Osteoarthritis for Community Health (COACH) Study Overview (Appendix A)
- Recruitment and Study Processes (Appendix B)
- Outcome Measures (Appendix C)
- Data Analysis (Appendix D)
- Sample Size and Power (Appendix E)
- CHAMPS Physical Activity Questionnaire (Appendix F)
- CHAMPS Codebook for EE calculation (Appendix G)
- COACH SWA Patient Instruction (Appendix H)
- COACH Fitbit Patient Instruction (Appendix I)

Chapter 4 Risk Factors for Revision of Total Knee Arthroplasty: A Scoping Review

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Abstract

Background: In spite of the increasing incidence of total knee arthroplasties (TKA), evidence is limited regarding risk factors for revision. The objective of this scoping review was to identify and assess demographic, surgical and health services factors that may increase the risk for revision surgery following TKA.

Methods: A scoping review was undertaken following an electronic search in MEDLINE (1990 to December 2013), CINAHL (to December 2013), EMBASE (1990 to December 2013) and Web of Science (1990 to December 2013).

Results: Of the 4460 articles screened, 42 were included of which 26 articles were based on registry data. Increased risk of revision was associated with demographic factors (younger age; African American), surgical factors related to the primary TKA (uncemented components, implant malalignment, increased surgery duration), and health services (low volume hospitals).

Conclusions: Identifying emerging trends in characteristics of those requiring revision following TKA can help identify those at risk and allocate appropriate resources. Further primary clinical articles on risk factors for revision of TKA are necessary to ensure maximal function and lifespan following TKAs.

Keywords: total knee arthroplasty, revision, prognosis, TKA, TKR

INTRODUCTION

The effectiveness of total knee arthroplasty (TKA) in relieving pain and improving function has been well documented [1,2]. TKA is considered a cost effective and efficacious treatment for patients with end stage knee osteoarthritis who experience severe pain, activity limitations and for whom conservative treatment is unsuccessful [3-5]. With more than 700 000 primary TKAs performed annually in the USA, estimates of TKA are projected to increase to 673% by 2030 in the USA. The large demand for TKA is primarily related to the aging population, the obesity epidemic and technical advancement of the surgical procedure [6-8]. The longevity of implants is typically greater than 10 years with 32,700 revisions performed annually in the USA. Significant demand for primary TKA will correspond to a growing demand for revisions of TKA which are projected to increase by 601% from 2005 to 2030 [6].

Revisions for TKA pose unique challenges as revision surgery is a more complex surgery than a primary TKA with increased complication and mortality rates [9-11]. Identifying emerging trends in characteristics of those requiring revision following TKA can help identify those at risk and allocate appropriate resources. Several articles have identified risk factors for revision surgery of TKA yet, to our knowledge, the synthesis of these findings have not been documented. A more comprehensive understanding of the potential risk factors for revision of TKA will provide important knowledge for surgeons and patients. The objective of this scoping review was to identify and assess demographic, surgical and health services factors that lead to increased risk of revision surgery following TKA.

METHODS

A scoping review of the literature was undertaken to identify and assess relevant evidence given the limited existing evidence on revisions of TKA. Inclusion criteria consisted of studies that comprised a) adult patients who received primary TKA and received a subsequent revision, b) comparative groups or risk-adjusted analyses, and c) at least 20 or more revision cases. Cohort and case control articles were included while descriptive studies and randomized controlled trials comparing specific interventions were excluded. Articles which included hemiarthroplasty, primary TKA used to stabilize a fracture or management of bone pathology or malignancy, simultaneous bilateral TKAs, and patellofemoral arthroplasty were excluded. Revisions for all reasons were included except revisions occurring in the first three months due to sepsis. Ethics was not obtained for this study as the study was a retrospective scoping review that did not involve any individual data or identifying information. In discussion with our Health Research Ethics Board at the University of Alberta, we do not require ethics for review.

Data Sources and Search Strategies

A search strategy was developed and implemented by a health sciences librarian for 4 databases: Medline (1990-Dec 2013; includes in-process & other non-indexed citations), EMBASE (1990-Dec 2013), CINAHL (1990-Dec 2013), and Web of Science (1990-Nov 2012). Date (1990-2013) and language (English) restrictions were applied to the searches. The decision to restrict the search to English articles was based on findings from systematic research evidence that reported no empirical evidence of bias was seen if papers written in languages other than English (LOE) were excluded [12]. The search included an extensive list of subject headings and keyword terms for 3 concepts: 1) hip or knee arthroplasty, 2) revision surgery, and 3) prognosis (see Supplemental File 1). Total hip arthroplasty articles were included in the search because we did not want to inadvertently exclude articles that reported both total hip and total knee arthroplasties. Case articles or case reports were removed along with conference abstracts. This initial search yielded many non-relevant papers so an additional search string was added to increase the relevancy of the results (by including certain terms in either the title or marked as the most important subject headings). A "relevancy forcing search set" was performed to ensure that all relevant papers were captured. All duplicate citations were removed.

Study Selection

To ensure consistency with screening of title and abstract, 20 citations were independently reviewed by both reviewers (LJ & SP) using a standardized form based on broad criteria including population intervention, comparison, outcome and study design. The remaining citations were then independently screened for relevance.

If a citation was selected by either reviewer, the full-text article was obtained for further review. Full-text articles were further screened for selection using a standard study selection form, based upon the predetermined inclusion criteria. The study selection form was initially piloted on a sample of 20 articles to ensure that the selection criteria were applied consistently across reviewers. Relevant full-text articles were then reviewed by one of the two reviewers using standardized inclusion and exclusion criteria. Disagreement of article inclusion was resolved through consensus between reviewers or through third party adjudication if the reviewers did not arrive at consensus. Full-text papers were included only if consensus was achieved by reviewers. For those articles selected for full review, data were extracted by one reviewer (LJ) and verified by a second reviewer (LB or AJ). The first 20 full text articles reviewed by both reviewers had excellent agreement (Kappa value 0.96, $p<0.0001$). All selected articles were included in data synthesis regardless of methodological quality. Inconclusive findings and gaps in the literature were identified. A narrative description of the included articles was completed and potential patterns identified in terms of targeted behaviors, study outcomes, and intervention effectiveness.

Quality Assessment

The Oxford Level of Evidence was used to evaluate the quality of selected full-text articles [13], and has been recommended to determine a hierarchy of the best evidence [14]. SIGN guidelines were also used to assess study quality through completion of their cohort checklist including items such as subject selection, assessment, confounding and statistical analysis [15].

RESULTS

Of the 4460 articles identified through the search strategies, 266 articles remained after the abstracts were screened for eligibility. After full text review, 42 articles met the inclusion criteria for the review (see Figure 1). Twenty-six (62%) articles were based on registry or insurance databases of which 12 were based on Nordic registries and 11 from American insurance databases.

All articles were prognostic retrospective articles with level III quality except for one which was a level II prognostic prospective study [13,16]. Using the SIGN guidelines, 31 articles were regarded of *acceptable* quality and 11 articles were deemed *poor* quality often due to incomplete reporting of multivariate analyses [15].

Of the 34 (81%) articles that reported mean follow-up from the primary TKA, six articles reported 10 year survival rates and two articles reported 20 year survival rates (see Table 1). While survival rates of the primary TKA were consistently high at 10 years ranging from 89.5-98.6% [17,18], 20 year survival rates were expectedly lower at 78-99% [19,20].

Demographic Risk Factors

Sex: While all articles reported sex, the association of sex and TKA revision was only examined in 10 articles (see Table 2). Inconsistent findings were reported in that males had a higher risk of revision surgery than females in 5 articles (see Table 2), females had a higher risk of revision (HR 1.513, 95% CI 1.116 to 2.051) in one article, based on American registry data, [21] and four articles, from different countries, did not find a significant association between sex and TKA revision [16,18,22-24].

Age: Among the 15 articles that examined age as a risk factor, 13 articles reported that revision rates decreased with older age (see Table 3).

Race: Race was examined in 3 American articles, of which 2 were based on the same registry [25,26]. African American patients had a higher risk for revision than Caucasian patients (HR 1.73, 95% CI 1.33 to 2.25, $p<0.001$; HR 1.82, 95% CI 1.33 to 2.48, $p<0.001$; HR 1.39, 95% CI 1.08 to 1.80, $p=0.01$) and represented 5.5 and 8.4% of the patient population reported in these registries. [25-27].

Medical Risk Factors

Primary Diagnosis: Although the majority of patients undergoing TKA were diagnosed with osteoarthritis, 4 articles specifically examined diagnosis and its potential association with TKA revision with mixed results [19,21,22,28]. Two large registry articles reported differing results with inflammatory arthritis having a greater and lesser risk for revisions than patients with osteoarthritis (HR 1.6, 95% CI 1.06 to 2.38 and HR 0.5, 95% CI 0.3 to 0.7, $p<0.001$) [19,28]. A clinical study of 4743 patients found that osteoarthritis or post-traumatic arthritis had a greater risk of revision than RA (HR 1.51, 95% CI 1.116 to 2.051) [21]. Further, in a clinical sample of

14352 patients, Kreder et al. reported no significant association between the diagnosis of osteoarthritis and risk for revision [22].

Comorbidities: Eleven articles specifically looked at the effect of comorbidities examining both total number of conditions and specific conditions. Jamsen et al. found that risks increased if there were one or more of the comorbidities identified (HR 1.23, 95% CI 1.16 to 1.30) [29]. Alternately, Kreder et al. did not find a significant association between the presence of comorbidities and revision following TKA [22].

When looking at comorbidities associated with osteoarthritis, cardiac disease and diabetes were at high risk of revision. Two American TKA registries reported increased risk of revision for patients with a higher BMI (BMI 30-35 kg vs <30kg HR 1.48, 95% CI 1.00 to 2.19 and BMI ≥35 kg/m2 vs. <30 kg/m2 HR 0.78, 95% CI 0.63 to 0.96, p=0.020) [26,30]. However, 3 other articles did not find a significant relationship between BMI and risk for TKA revision [18,23,31].

The presence of cardiac conditions at time of the primary TKA increased the risk of revision including hypertension with early revision (0 – 5 years) (HR 1.14, 95% CI 1.01 to 1.29), coronary disease (HR 1.27 95% CI 1.07 to 1.50) and cardiovascular disease (HR 1.29, 95% CI 1.14 to 1.45) [29,32].

Three articles reported an increased risk of revision for the patients with diabetes. Jamsen et al. and Namba both found an association with diabetes and revision (HR 1.27, 95% CI 1.08 to 1.50 and HR 1.21, 95% CI 1.04 to 1.41, p=0.014) although Jamsen et al. was examining early revisions [26,29]. Similarly, King et al. also found the 46 to 55 years and 66 years and over diabetic cohorts had increased risk of revision as compared to the non-diabetic cohort (HR 2.9 95% CI 1.5 to 5.8, p=0.004 and HR 1.5, p=0.0037 respectively) although there was not a significant difference in the 56 to 65 years cohort [33].

Joint Implant Factors

Fixation: Two articles consisting of 9337 patients from the US found cemented primary TKAs had a protective effect on receiving revision as compared to cementless/hybrid TKAs [19,34]. Hybrid fixation, in which the proximal component was cementless and the distal component was cemented, also demonstrated a higher risk than cemented TKAs in both US and Norwegian studies [34,35].

Cruciate retaining implants: Cruciate ligament status was reported in several articles with inconsistent findings (see Table 4) [16]. Two large American registry studies reported that posterior stabilized implants had increased risk of revision when compared to posterior cruciate-retaining implants (HR 2.6, 95% CI 2.1 to 3.5, $p<0.0001$ and HR=2.0 95% CI 1.67 to 2.5, $p<0.001$) [19,36]. Conversely, an American registry study of 1047 patients found ligament status was not significant [16]. Further, Stiehl et al. found both posterior cruciate retaining arthroplasties and bicruciate retaining arthroplasties had increased risk of revision compared to rotating platform (HR 1.552 95% CI 1.157 to 2.081 and HR 2.188, 95% CI 1.454 to 3.294) [21].
Patellar resurfacing: The 6 articles that specifically examined patellar resurfacing had inconsistent findings. Three articles found that the risk of revision increased when the patella was resurfaced (patella not resurfaced HR 1.4, 95% CI 1.2 to 1.7, patella resurfaced HR 0.84, 95% CI: 0.071-1.0, $p=0.052$, and patellar resurfaced HR 1.814, 95% CI 1.320 to 2.558 respectively) [21,35,37]. Alternately, two articles found that the unresurfaced patellae had higher risks of revision than resurfaced patellae (HR 2.09, 95% CI 1.07 to 4.06, $p=0.03$, HR 1.4, 95% CI 1.2 to 1.7) [25,35]. Two studies did not find an association between patellar resurfacing and revision significant [23,38]. One study reported that metal-backed patella were more likely to be revised than all polyethylene patellar components (HR 2.4, 95% CI 1.9 to 3.1, $p<0.0001$) [19]

Alignment: Malalignment was reported to be a large risk factor for revisions (HR >2.7) in three studies with both varus and valgus malalignment having a greater risk of revision [20,39,40]. Two US studies reported an increased risk of revision with varus tibial malalignment (<90º) (HR 10.6, 95% CI 5.4 to 20.6, p<0.0001; OR 3.0, p=0.04 respectively) [20,39]. Valgus femoral malalignment also showed an increased risk with ≥8º of valgus (HR 5.1, 95% CI 2.8 to 9.5, p<0.0001) [40].

Bone quality: As bone stock is a key determinant of the type of implant used and possible peri-prosthetic fracture, bone quality is an important surgical consideration. Only one study examined bisphosphonate use and reported a protective effect for risk for revision (HR 0.40, 95% CI 0.15 to 1.07, p=0.068) [41] recommending its use for those patients with the diagnosis of osteoarthritis.

Health Services

Of the 3 articles that reported hospital volume in Canada, US and Norway, low volume hospitals had an increased risk for revision of primary TKAs [22,42,43]. The definition of low volume, however, varied from less than 25 to less than 50 procedures annually. Further, Harrysson et al. found that the risk of revision decreased when comparing the year of surgery to the previous year (HR 0.92, 95% CI 0.89 to 0.96, p<0.0001) over a 10 year time period [44].

Length of surgery was also found to have a significant association with revision risk in TKA primary surgery >240 minutes (OR 1.34, 95% CI 1.07 to 1.67, p= 0.012) as compared to <240 minutes, 150 to 180 minutes (OR 1.31, 95% CI 1.09 to 1.57, p= 0.004) as compared to 120 to 150 minutes and <90 minutes (OR 1.47, 95% CI 1.10-1.95, p=0.008) as compared to 120 to 150 minutes [45].

DISCUSSION

We identified 42 articles that reported risk factors for TKA revision using risk-adjusted analyses. Demographic, medical and implant factors were identified as risk factors for revision of TKA ranging from short-term (<5 years) to long-term follow-up (20+ years). Risk factors were derived largely from registry data, which inherently restricts the type of risk factors examined.

Primary TKA has been consistently identified as a successful surgery with high survival rates even at 10 and 20 years post-surgery. Others have reported rates of 1.26 revisions per 100 observed component years for TKA as compared to 1.29 revisions per 100 observed component years for total hip replacements and 3.29 revisions per 100 component years for total ankle replacements [46]. Given the success of the surgery, it has been suggested the focus of research should perhaps shift to patient selection for these procedures to optimize outcomes and health resources [47].

The trend of increasing revision rates will likely increase [47,48]. This information was especially relevant given that the 45-64 year old cohort is one of the fastest growing demographics [49,50]. Further, this age cohort demonstrated an increased use of TKA and will require a longer life expectancy for the TKA, an important consideration when planning for future allocation of resources [47,50]. The increased risk for revision in the younger population must be further examined to determine if it is indeed age that is the risk factor or if age is a proxy for higher activity levels or increased expectations in this younger patient population.

Comorbidities such as diabetes, cardiovascular disease, hypertension, cancer and lung disease were found to increase the risk for revision. These findings are particularly meaningful given the increasing prevalence of multi-morbidity and the challenge of surgical management of patients with other chronic diseases [51,52]. Further investigation of management programs of secondary chronic diseases such as hypertension and diabetes in patients with primary TKA is warranted.

Often heterogeneity was found among the reported results for other risk factors for TKA revision. For example, mixed results were reported regarding sex, primary diagnosis, BMI, patellar resurfacing and implant components suggesting a need for further investigation. Some consensus existed, however, regarding cemented prostheses which had a lower risk of revision than uncemented or hybrid in spite of an initial goal of uncemented fixation to decrease complications associated with aseptic loosening [19,34,35]. Increased surgery length and low hospital volumes were also found to negatively affect revision rates, important information to consider in health resource allocation and planning.

In spite of a wide body of literature published on various surgical factors, many articles were of low quality and few included risk-adjusted analysis. The majority of included articles (41/42) were retrospective prognostic articles limiting the quality of the articles to an Oxford level III. Because the majority of data (26/42) was taken from registry data, the data were often limited to basic demographic information such as age, gender and BMI and did not evaluate pain and functional measures. An inherent limitation of these large, population-based registries is that demographic, surgical and health services data over decades have typically been evaluated and do not provide patient-reported outcomes or patient-reported experience measures which are central to clinical outcomes of TKA. Finally, findings were derived from two geographical populations, 12 in the USA and 11 in the Nordic countries. External validity to other populations is uncertain because of different healthcare systems and potentially different prostheses.

In spite of an extensive search strategy and a strong systematic approach to undertaking this systematic review, identifying risk factors for revision was challenging because of low revision rates in the first 10 years following surgery. Most articles had follow-up periods of <10 years which reflected high survival rates of TKA. Due to these high survival rates, it can be a lengthy and costly process to undertake studies for the appropriate duration to acquire accurate information on revisions. Another consideration is that many early revisions occurring within 10 years are often related to surgical techniques and few articles made the distinction between early and later revisions. Finally, as TKAs are most often performed on an older population, the development of other chronic conditions and mortality poses a challenge to long-term follow-up.

CONCLUSIONS

Current literature suggests an increased risk for revision following TKA is associated with younger age, greater number of comorbidities, African American race, uncemented components, increased surgery duration, and lower volume hospitals. This scoping review allowed us to identify areas where consistent results were found but also highlight areas with heterogeneous results or insufficient data where further research is required. These findings also demonstrate the need for large scale and high quality investigations examining factors that increase the risk for revision following TKA including patient-reported outcomes and patient-reported experience measures. Given the increasing numbers of TKA procedures and revisions, information on risk factors for revisions following TKAs is necessary for appropriate interventions to be delivered in a timely manner and for the development of effective health care policy.

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Author contributions

All authors were involved in conception and design, analysis and interpretation of the data, drafting and revisions of the article and had final approval of the article.

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There are no conflicts of interest.

Availability of data and materials

The dataset supporting the conclusions of this article is included within the article and its additional files.

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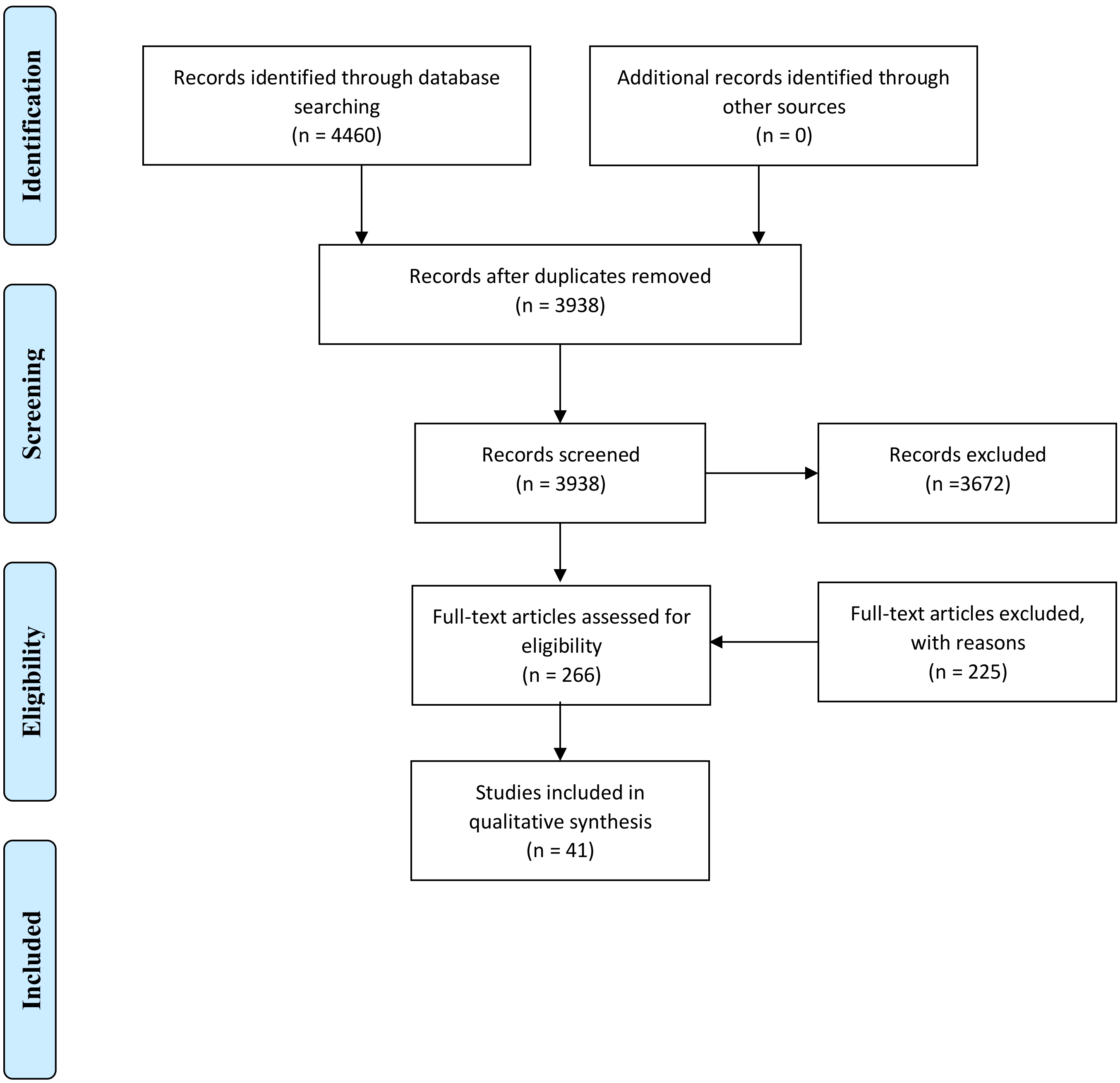

Figure 1 PRISMA Flow Diagram

Table 1. Survival Rates at 10 and 20 Years*

Author(s), Year	Duration of Follow-up (yrs)	Index Procedure (n)	Revision (n)	Survival rate (%, CI)
Badawy M. et al., 2013[42]	10	26,698	1169	Low hospital volume†: 92.5%, 95% CI 91.5 to 93.4 High hospital volume: 95.5%, 95% CI 94.1 to 97.0
Gothesen, Ø. et al., 2013[17]	10	17,782	NR	89.5% to 95.3%, CI- NR
Himanen, A. et al., 2007[23]	10	751	37	Prosthetic moulded component: 94.4%, 95% CI 90.4 to 96.7 Prosthetic modular component: 93.6%, 95% CI 89.7 to 96.0
Jämsen, E. et al., 2013[29]	10	53,007	1919	94.5%, 95% CI 94.1 to 94.8
Rand, J. et al., 2003[19]	10	11,606	NR	91%, 95% CI 90% to 91%
Vessely, M. et al., 2006[18]	10	1000	45	98.6%, 95% CI 97.8 to 99.4
Fang, D. et al., 2009[20]	20	6070	51	99%, CI - NR
Rand, J. et al., 2003[19]	20	11,606	NR	78%, 95% CI 74% to 81%

* See Supplemental Table 1 for further detail. Not reported in publication, NR.

†Low hospital volume is 1-24 TKA performed per year; High hospital volume is ≥150 TKA performed per year

Table 2 Sex and Adjusted Risk of Revision*

Author(s)/Year	Control	Hazard Ratio (CI)
Blum, M. et al., 2013[27]	Female	0.81, 95%CI 0.71 - 0.92, p<0.01
Fehring, T. et al., 2004[57]	Male	2.771, 99% CI 1.662 - 4.620, p<0.0001
Harrysson, O. et al., 2004[44]	Male	1.64, 95%CI 1.23 - 2.18, p=0.0007
Rand, J. et al., 2003[19]	Male	1.6, 95% CI 1.4 - 2.0, p<0.0001
Schrama, J. et al., 2010[28]	Female	0.67, 95% C I 0.47 - 0.88
Stiehl, J. et al., 2006[21]	Female	1.513, 95% CI 1.116 - 2.051

*See Supplemental Table 1 for further detail.

Table 3 Age and Adjusted Risk of Revision*

Author(s)/Year	Age	Hazard Ratio (95%CI) unless otherwise stated
Bini, S. et al., 2013[30]	>55 yrs	0.43, 95% CI 0.27 to 0.67, p<0.001
Blum, M. et al., 2013[27]	18-64 yrs vs. 65+ yrs	2.30, 95% CI 1.96 to 2.69, p<0.0001
Bordini, B. et al., 2009[31]	Age at surgery (per year)	1.05, 95% CI 1.03 to 1.06, p=0.0001
Fehring, T. et al., 2004[57]	Age at surgery (per year)	0.953, 99% CI 0.932 to 0.975, p<0.0001
Gioe, T. et al., 2004[59]	Age <70 yrs	0.46, 95% CI.0.33 to 0.64, p<0.001
Harrysson, O. et al., 2004[44]	Older patients (≥ 60 yrs) Revision Attributable to Any Reason Revision Attributable to Loosening of Components	 0.49, 95% CI 0.38 to 0.62, p<0.0001 0.41, 95% CI 0.27 to 0.62, p<0.0001
Julin, J. et al., 2010[35]	Age ≤ 55 yrs: Revision for reasons other than infection Revision for any reason	 2.9, 95% CI 2.3 to 3.6

		2.4, 95% CI 2.0 to 3.0 Age 56-65 yrs
	Age 56-65 yrs: Revision for reasons other than infection Revision for any reason:	 1.7 95% CI 1.4 to 2.0 1.5, 95% CI 1.3 to 1.7
Kreder, H. et al., 2003[22]	Younger age per 10 yrs: At 1 year after revision At 3 years after revision	 OR 0.77, 95% CI 0.67 to 0.89 OR 0.70, 95% CI 0.66 to 0.81
Lygre, S. et al., 2011[37]	Age >70 yrs vs. <60 yrs	0.4, 95% CI 0.3-0.4, 0<0.001
Namba, R. et al., 2013[26]	Age (increasing 10 yr increments)	0.62, 95% CI 0.57 to 0.67, p<0.001
Namba, R. et al., 2012[25]	Age (increasing 10 yr increments)	0.64, 95% CI 0.58 to 0.70, p<0.001
Rand, J. et al., 2003[19]	Age 56-70 yrs vs. ≤55yrs Age >70 yrs vs. ≤55yrs	0.7, 95% CI 0.5 to 0.9, p<0.01 0.5, 95% CI 0.3 to 0.6, p<0.0001

Stiehl, J. et al., 2006[21]	Younger patients (for every yr increase)	0.979, 95% CI 0.968 to 0.989

*See Supplemental Table 1 for further detail.

Table 4. Implant Type/Technique and Adjusted Risk of Revision*

Author(s)/Year	Implant Type/Technique	Reference	Hazard Ratio (95%CI) unless otherwise stated
Abdel, M. et al., 2011[36]	Cruciate Status: Posterior cruciate-retaining	posterior cruciate-stabilizing	0.5, 95% CI 0.4 - 0.6, p<0.001
Rand, J. et al., 2003[19]	Cruciate Status: Posterior Stabilized Constrained condylar	posterior cruciate-retaining posterior cruciate-retaining	2.6, 95% CI 2.1 - 3.5, p<0.0001 2.1, 95% CI 0.9 - 4.9, p=0.08
Stiehl J. et al., 2006[21]	Cruciate Status PCRs BCRs	rotating platform	1.552, 95% CI 1.157 - 2.081 2.188, 95% CI 1.454 - 3.294
Gøthesen, O. et al., 2013[17]	Implant Type: Duracon LCS Classic HR LCS Complete AGC Universal	Profix	2.6, 95% CI 1.9 - 3.4, p<0.001 1.3, 95% CI 1.0 - 1.6, p=0.017 1.5, 95% CI 1.1 - 1.9, p=0.002 1.6, 95% CI 1.3 - 2.0, p<0.001
Lygre, S. et al., 2010[37]	Implant Type: NR Tricon NR Genesis 1 NR Duracon NR Profix NR e.motion NR AGC anatomic PR AGC universal PR NexGen	NR AGC Universal	Relative Risk = 1.67, 95% CI 1.24-2.24, p=0.001, 1.43, 95% CI 1.14-1.79, p=0.002, 1.45, 95% CI 1.05-1.99, p=002. 0.66, 95% CI 0.52-0.82, p<0.001, 0.09, 95% CI 0.02-0.37, p=0.001, 0.66, 95% CI 0.45-0.99, p=0.04, 0.48, 95% CI 0.27-0.83, p=0.009, 0.40, 95% CI 0.22-0.74, p=0.004.
Namba R. et al., 2013[26]	Implant Type: Rotate LCS	Fixed PS	2.07, 95% CI 1.53 - 2.80, p<0.001

	High flexion	Yes versus No	1.76, 95% CI 1.29 - 2.41, p<0.001
Namba R. et al., 2012[25]	Implant Type: LCS	 Fixed	2.01, 95% CI 1.41 - 2.86, p<0.001
Inacio M. et al., 2013[62]	Bearing or inserts: CoCr-HXLPE OZ-CPE	 CoCr-CPE C0Cr-CPE	 NS 1.2, 95% CI 0.9 - 1.5, p>0.05 NS 1.4, 95% CI 0.3 - 5.9, p>0.05

Abbrev: relative risk, RR; not significant, NS; bicruciate preservation, BCR; posterior cruciate retention, PCR; patella resurfaced (PR); patella non resurfaced (NR); low contact stress, LCS; oxidized zirconium, OZ; cobalt chromium, CoCR; conventional polyethylene, CPE; highly crosslinked polyethylene, HXLPE;

*See Supplemental Table 1 for further detail.

Chapter 5 Validity of Tools to Measure Physical Activity in Older Adults Following Total Knee Arthroplasty*

*Formatted for submission to *Journal of Aging and Physical Activity* as accepted pending minor revisions. There may be minor editorial differences between this version and the final published version.

Abstract

Few validated tools exist for measuring physical activity following total knee arthroplasty (TKA) despite the importance of returning to sufficient levels of physical activity post-TKA to achieve health benefits. This study examined validity of two clinical measures - the Fitbit, a commercially available personal activity monitor, and the CHAMPS, a self-report questionnaire - as compared to a reference standard accelerometer, the SenseWear^{TM} Armband (SWA). At six months post-TKA, 47 participants wore the Fitbit and SWA for five days and then completed the CHAMPS. Moderate to good correlation was observed between the Fitbit and SWA for steps (ICC=.79), EE (ICC=.78) and EE <3 METS (ICC=.79). Poor to moderate correlation was observed between the CHAMPS and SWA (ICC=.43) with the questionnaire reporting lower daily EEs than the SWA. Results showed the Fitbit may be a reasonable measurement tool to measure steps and EEs in older adults following TKA.

Key Words: Accelerometer, steps, energy expenditure, self-report

Physical inactivity is a global problem despite the well documented detrimental effects on health (Kohl et al., 2012). Physical inactivity is even more prevalent in populations with mobility challenges such as osteoarthritis, with only 13% to 48% of adults with knee osteoarthritis achieving recommended physical activity guidelines (Wallis, Webster, Levinger, & Taylor, 2013). Although total knee arthroplasty (TKA) is often a successful intervention resulting in pain relief and improved health-related quality of life, clarity is lacking as to whether physical activity levels also increase adequately post-TKA to achieve health benefits (Almeida, Khoja, & Piva, 2018; Jones & Pohar, 2012).

Limited research exists regarding the validity of measurement tools used to measure physical activity in older adults post-TKA (Mills, Falchi, Duckett, & Naylor, 2018). Triaxial accelerometers are typically the reference standard for measuring physical activity in free-living environments (Feehan et al., 2018). Research-grade triaxial accelerometers, such as the SenseWear^{TM} Armband (SWA), appear to have reasonable validity in measuring physical activity in this patient population (Almeida, Wert, Brower, & Piva, 2015; Almeida, Irrgang, Fitzgerald, Jakicic, & Piva, 2016). However, these accelerometers are not practical for clinical and epidemiologic studies due to the expense of the tool, the complex data collection and analyses requirements (Almeida, Wert, Brower, & Piva, 2015; Almeida, Irrgang, Fitzgerald, Jakicic, & Piva, 2016; Collins, Yang, Trentadue, Gong, & Losina, 2019).

With the expanding availability and functionality of personal activity monitors, there is increasing use of devices from brands such as Fitbit, Garmin, Misfit, Apple and Polar to monitor physical activity. With the advantages of being user-friendly and relatively inexpensive, the commercially available Fitbits are now the most widely used personal activity monitors globally (Henriksen et al., 2018). They are also increasingly used for research purposes to measure physical activity, including in older adults following TKA, (Feehan et al., 2018; Losina et al., 2018; Twiggs et al., 2017; Crizer et al., 2017) but their validity in this population has not previously been evaluated. Although several studies of healthy adults suggested acceptable validity in the use of Fitbits, a recent systematic review suggests Fitbits overestimate steps in free-living activities, overestimate time spent in higher-intensity activities, and are inaccurate in the measurement of EE when compared to other reference criteria (Feehan et al., 2018). Collins et al. (2019) found similar findings in adults with knee osteoarthritis reporting that Fitbits tended to overestimate steps by 116% and overestimate the amount of time spent in moderate-to-vigorous activity (MVPA) when compared to the ActiGraph GT3X+. Fitbits also tended to underestimate sedentary time by 66% (Collins et al., 2019). Thus, further research is necessary to determine the validity of Fitbits in specific patient populations including older adults following TKA.

Self-report measures are another common method of measuring physical activity, offering an inexpensive, and easy to administer, alternative to accelerometry (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012; Kowalski, Rhodes, Naylor, Tuokko, & MacDonald, 2012). Despite widespread use, several reviews have shown self-report measures have limited validity when compared to data obtained from accelerometry in free-living environments (Helmerhorst et al., 2012; Kowalski et al., 2012). Similarly, in older adults following TKA, several self-report measures reported poor correlations with accelerometry and other self-report measures (Bolszak, Casartelli, Impellizzeri, & Maffiuletti, 2014; Naal, Impellizzeri, & Leunig, 2009). The Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire is a common measure used in older adults and allows the calculation of EEs (Kowalski et al., 2012). It discriminated well across groups of older adults with varying activity levels ($p<.001$) and demonstrated excellent test-retest reliability (intraclass correlation coefficient [ICC] = .86 to .92) in older adults following TKA (Stewart et al., 2001; Almeida et al., 2016). However, validity for the CHAMPS questionnaire to report physical activity has also not yet been established in older adults following TKA.

Given the importance of restoring physical activity following TKA to sufficient levels for health benefits, physical activity needs to be considered an integral component of recovery in older adults following TKA (Almeida et al., 2018). Valid and reliable measures of physical activity need to be ascertained in this patient population at risk for adverse health outcomes due to inactivity (Kurtz, Ong, Lau, Mowat, & Halpern, 2007). Therefore, the overall aim of this study was to examine the concurrent validity of two clinical tools, a commercially available personal activity monitor and a self-report questionnaire, to measure physical activity in older adults following TKA. The primary objective was to determine the concurrent criterion validity between the personal activity monitor (Fitbit) and the research-grade accelerometer (SWA) in the measurement of steps, EE, and time spent in various activity intensities in patients post-TKA. The secondary objective was to determine the concurrent criterion validity between the self-report questionnaire (CHAMPS) and the SWA in the measurement of EE.

Methods

Participants

Recruitment occurred at a high volume surgical intake clinic as part of a primary longitudinal study that evaluated a physical activity intervention. Patients were eligible for inclusion if they 1) received a primary elective bicondylar or tri-condylar TKA within the last six weeks to three months, 2) were 60 years of age or older, and 3) spoke English. Patients were excluded if they had 1) pre-existing comorbidities that significantly limited physical activity, 2) were wheelchair dependent, or 3) received bilateral or unicondylar TKA. Using the Power Analysis & Sample Size (PASS) software program, a target of minimum of 30 participants was set to achieve 80% power with two measurement tools for an intraclass correlation coefficient (ICC) (2,1) estimated at .6 (NCSS Statistical Software, 2017). Ethical approval was obtained from the university ethics board. All participants provided written informed consent.

Measures

Accelerometers. The SWA (Body Media, Pittsburgh, PA) was chosen as the reference standard for this study. It is a lightweight armband worn on the upper arm and contains four physiological sensors measuring skin temperature, galvanic skin reaction, heat flux and accelerometry in three axes. These sensors allow the calculation of EE, the metabolic equivalent of task units (METS), step counts, physical activity duration, sleep time and lying down time (Almeida, Wasko, Jeong, Moore, & Piva, 2011). The SWA software uses a proprietary algorithm requiring information including each participant's sex, age, height, and weight to calculate the corresponding data.

Criterion validity of the SWA has been examined in healthy older adults comparing total energy expenditure (TEE) values obtained from doubly labeled water. The ICC was .904 (95% CI .770 to .962), no differences were observed for TEE (means ± SD 2,040 ± 472 vs. 2,012 ± 497 kcal/day), and no bias was detected in the Bland Altman plots (Mackey et al., 2011). The SWA had higher specificity in identifying light activities (specificity = .61 to .71) than the ActiGraph GT3X accelerometer (specificity = .27 to .47) which is especially relevant in the population of older adults who were likely less active than younger populations (Feehan, Goldsmith, Leung, & Li, 2016). In a sample population of older adults following TKA, Almeida et al. concluded that the SenseWear Pro3 Armband demonstrated better criterion validity than the comparison accelerometer, the ActiGraph GT1M, (ICCs 0.48 to .81) and had excellent test-retest reliability when comparing physical activity measurements from two different weeks in older adults following TKA (Almeida et al., 2016; Almeida et al., 2015).

The personal activity monitor, the Fitbit Alta, is a slim lightweight wristband that uses triaxial accelerometry to calculate step counts, EE, METS, distance traveled, sleep and time spent in different activity intensities (Fitbit Inc., 2018). Similar to the SWAs, the algorithm for calculation of EE by the Fitbit is proprietary and not available; however, demographic information including right or left-handed, sex, age, height and weight was required upon set up of the Fitbit to improve the accuracy of the calculations (Fitbit Help, 2016). Although aggregate data are available to the Fitbit user, for purposes of this validity study, we obtained minute by minute data for step counts, EEs and corresponding METS levels through a database application (Small Steps Labs, 2016).

Outcomes. For both accelerometers, minute-by-minute data were used to calculate a number of variables to describe physical activity including steps, EEs, and time spent in specific activity intensities. Mean daily steps were calculated by taking the mean of the daily totals for the number of steps for each minute in the included days. The mean daily steps were then categorized based on activity intensity (light: METS levels of < 3 METS; moderate to vigorous: METS levels ≥ 3 METS) for each minute (Rosenberger et al., 2019; U.S.Department of Health and Human Services, 2018).

Mean daily EEs were also calculated by taking the mean of the total daily EEs, in kilocalories, for each minute for the included days. Similar to steps, mean daily expenditures were then estimated by activity intensity (light: METS levels of < 3 METS; moderate to vigorous: METS levels ≥ 3 METS).

Mean daily EEs spent in moderate to vigorous physical activity in bouts of ≥ 10 minutes were also calculated. Specifically, activity intensity was required to be at ≥ 3 METS for ≥ 10 consecutive minutes with a maximum of two minutes falling below 3 METS to be included in the bouts calculation (Ramadi, Stickland, Rodgers, & Haennel, 2015; Colley et al., 2011). Mean daily time spent in each category of activity intensity was also estimated (< 3 METS, ≥ 3 METS, 3 to 6 METS, > 6 METS).

Self-Reported Physical Activity. The CHAMPS questionnaire includes 40 items asking about the type and frequency of physical activity in a typical week over the past four weeks.

It provides estimates of EE per week in physical activity and EE per week in activities of moderate or greater intensity (METS ≥ 3) (Stewart et al., 2001). The estimated EE values are obtained by multiplying the estimated duration of each recorded activity by the corresponding MET value and then summing these values across all relevant activities (Stewart et al., 2001). The MET values assigned to each recorded activity were based on those suggested by Ainsworth et al. (2011) with adjustments made to increase the accuracy for the population of older adults (Stewart et al., 2001). Similar to previous studies, and to minimize respondent burden, we did not include the questions that did not relate to physical activity and are not included in the standard calculations (Hekler et al., 2012). As the CHAMPS calculates EE from activity alone, the EE derived from it was summed with the basal metabolic rate for each participant using the Harris Benedict equation to derive the total EE (Harris & Benedict, 1918; Karlsson et al., 2017).

Procedures

At six months post-TKA, participants were asked to wear the SWA and Fitbit for five consecutive days at all times except for water activities. At the conclusion of this period, each participant was contacted by the research assistant to complete the CHAMPS questionnaire. Data were collected from October 2016 to December 2018.

Data Analysis

Data were only included in the analysis if the participant wore the SWA and Fitbit > 95% of the day and night for at least four consecutive days and completed the CHAMPS questionnaire (BodyMedia, 2017; Almeida, Wasko, Jeong, Moore, & Piva, 2011). Descriptive statistics were calculated for the characteristics of the participants and to quantify the measures of physical activity. To examine criterion validity, five statistical analyses were undertaken: ICC, Pearson correlation, Bland Altman plot, equivalence test using the two one-sided test (TOST) procedure, and equivalence plots.

ICCs (ICC 2,1) were used to determine the level of agreement between each of the comparisons. ICCs were chosen as the index provides a measurement of agreement as well as covariance. ICC values of .90 – 1.00 were considered excellent, .75 – .89 good, .50 – .74 moderate, and below .50 poor (Koo & Li, 2016). As recommended by Koo and Li (2016), if the 95% confidence intervals for the ICC values overlapped the ranges of two categories (e.g., moderate and good), then the stated level of agreement reflected that overlap (e.g., moderate to good).

Pearson correlation coefficients (r) indicated linear correlation between the measurement tools and allowed for comparison with previously published studies. In addition, Bland Altman plots were employed to provide visual representations of the differences between the measurement techniques against the means of the differences to help identify systematic bias in the comparisons (Bland & Altman, 1986).

Rather than the typical hypothesis testing, equivalence testing with the TOST procedure was used for statistical examination of whether the measurement tools were significantly equivalent to each other (Hauck & Anderson, 1984; Lakens, 2017). Additionally, although not as statistically robust as the TOST method, equivalence plots were used to allow comparison to other results (e.g., Lee et al., 2014; Redenius, Kim, & Byun, 2019; Floegel, Florez-Pregonero, Hekler, & Buman, 2016; Brooke et al., 2016). An equivalence zone of ±10%, while arbitrary, is consistent with other activity monitor validation studies (Lee, Kim, & Welk, 2014). Specifically, it can be concluded with 95% confidence that the estimate (Fitbit or CHAMPS questionnaire) was considered to be equivalent to the criterion standard (SWA) if the 90% confidence interval for the mean of the estimated physical activity outcome fell into the equivalence zone of ±10% of the mean of the criterion measured physical activity outcome (Lee, Kim, & Welk, 2014). Data were analyzed with SAS (Version 9.4, SAS Institute, Cary, NC) and IBM SPSS Statistics (Version 26, IBM Corporation, New Orchard Road Armonk, New York). The R-project for Statistical Computing (Version 3.6.2) was used for equivalence test analysis.

Results

Following the completion of at least four days of wear for both the SWA and Fitbit, as well as the completion of the CHAMPS questionnaire, 47 participants were included in the analysis. Data for METS levels from the Fitbits for five participants were not available; this may be due to infrequent syncing of the Fitbit devices (Fitbit, 2019). These participants were included in all analyses except for those requiring intensity categories, which were based on the corresponding METS levels.

The majority of the participants were female (n=31, 66%) and had a mean age of 69.3 years (SD 6.4) (see Table 1). Most lived in small towns (n=25, 53%) with the rest distributed between rural (n=12, 26%) and urban (n=10, 21%) settings. Participants had a mean of 4 comorbidities with high blood pressure (n=23, 49%), digestive problems (n=16, 34%) and thyroid disease (n=14, 30%) being the most commonly reported conditions. Fifteen (32%) reported a history of smoking with one current smoker.

As measured by the SWA, the majority (89%; 21.45 hours) of the participants' daily times was spent in sedentary or light activity intensities, 9.4% in moderate intensity, and 1% in vigorous intensity (see Table 2).

The mean number of daily steps were 6194 (SD 3417.7) with the majority of steps (4276, 69%) occurring at a sedentary or light activity intensity level, i.e. < 3 METS (see Table 2). The mean daily EE was 2412.8 (SD 302.710) kilocalories with the majority (2065.35, 86%), similarly, in < 3 METS.

SWA and Fitbit

Correlations between the Fitbit and SWA ranged between poor to good with steps and expenditures demonstrating higher correlations than time spent in specific activity intensities.

Steps: The ICC between Fitbit and SWA data was moderate to good, with ICC = .79 (95% CI .64 to .87) for measuring steps (see Table 2). That is, the ICC value fell in the moderate range with the confidence interval spanning the moderate (.50 to .75) and good (.75 to .90) ranges. When the data were stratified into mean daily steps < 3 and ≥ 3 METS, the correlation between devices decreased, particularly for the lower METS level. The values for mean daily steps ≥ 3 METS were ICC = .63 (95% CI .41 to .78), with the Fitbit reporting more steps. Correlation decreased to ICC = .31 (95% CI .005 to .56) for mean daily steps < 3 METS, with the Fitbit reporting fewer steps than the SWA. The two accelerometers were not found to be equivalent using either the TOST procedure (p=1.00) (see Table 2) or the equivalence plots.

Energy Expenditure: Correlation for the mean daily energy expenditure for the Fitbit and SWA was also moderate to good, ICC = .78 (95% CI .64 to .87). The Fitbit and SWA also showed moderate to good correlation, ICC = .79 (95% CI .63 to .88), for mean daily energy expenditure < 3 METS, but only poor to moderate correlation for mean daily EE ≥ 3 METS, ICC = .60 (95% CI .36 to .76). The Fitbit tended to underestimate mean daily EE < 3 METS and overestimate mean daily EE ≥ 3 METS relative to the SWA. Neither of the equivalence tests, using the TOST procedure or equivalence plots, indicated that the two measurement tools were equivalent in the measurement of EEs (see Table 2). Variability tended to increase as the EE values increased.

Energy Expenditure in Bouts of MVPA: When reporting bouts of ≥ 10 minutes of moderate to vigorous physical activity, i.e. ≥ 3 METS, the Fitbit and SWA showed poor to moderate correlation, ICC = .36 (95% CI .070 to .60). Neither of the equivalence tests suggested that the two measurement tools were equivalent (see Table 3). On the Bland Altman graph, there again appeared to be increased variability in the measurements as the EEs increased.

Time Spent in Varying Activity Intensities: Correlations between the Fitbit and SWA for time spent in the various activity intensities were poor to moderate (see Table 2). The Fitbit recorded more time spent in < 3 METS and less time spent in the higher intensities than the SWA. Although the equivalence test using the TOST procedure did not result in the measurement tools being equivalent in any activity intensity, the equivalence plot for time spent in 3 – 6 METS demonstrated that the two measurement tools were equivalent in this measurement (see Table 3). The Bland Altman plots were congruent with these findings in that variability increased for times in the higher activity intensities.

SWA and CHAMPS

Energy Expenditure: The CHAMPS questionnaire reported a mean daily EE of 2285.33 kilocalories (SD 673.64) as compared to 2412.79 kilocalories (SD 518.62) measured with the SWA (see Table 3). For mean daily EEs ≥ 3 METS, CHAMPS reported 1890.22 kilocalories

(SD 356.19) with the SWA measuring 354.12 kilocalories (SD 403.10). When comparing data from the SWA to that from the CHAMPS, poor to moderate agreement was found for daily EEs with ICC = .43 (95% CI .17 to .64). Using the TOST equivalence test, the two measurement tools were not equivalent (p=.64). The ICC value was even lower in mean daily EEs ≥ 3 METS, .18 (95% CI -.11 to .44), with the CHAMPS reporting higher EEs than the SWA. Similarly, the p-value for the TOST equivalence test for mean daily EEs ≥ 3 METS was not significant (p=1.00), indicating the measurement tools were not statistically equivalent (see Table 3). Using the equivalence plots, while the mean daily EE approached equivalence, the values for mean daily EEs ≥ 3 METS did not. There was a slight tendency for increased variation as EEs increased when examining the Bland Altman plots for both mean daily EEs and mean daily expenditures ≥ 3 METS.

Discussion

This study examined the validity of the Fitbit and the CHAMPS for assessing physical activity in older adults following TKA. The findings suggest that the Fitbit may be an appropriate tool to measure physical activity in older adults following TKA as there was moderate to good correlation with the SWA in the measurement of steps, EE in general, and EE < 3 METS. However, none of the comparisons were found to be equivalent using more robust statistical analyses suggesting that the research-grade accelerometers are still more appropriate when high accuracy is required. Although the CHAMPS questionnaire demonstrated poor to moderate correlation as compared to the SWA when measuring EEs, the correlation was higher than reported for other self-report outcome measures in older adults following TKA (Bolszak, Casartelli, Impellizzeri, & Maffiuletti, 2014; Naal, Impellizzeri, & Leunig, 2009). Thus, the CHAMPS may be the most appropriate tool within the limitations of self-report measures for this patient group (Bolszak et al., 2014; Crizer et al., 2017). Ultimately, the purpose and context will be important factors when choosing the most appropriate measurement tools for physical activity.

Measuring daily step count is an easily accessible method of monitoring physical activity, and good evidence exists for an inverse dose-response relationship of daily steps with all-cause mortality, cardiovascular events, and type 2 diabetes (Kraus et al., 2019). A recent systematic review by Feehan et al. (2018) reported that steps tend to be the most valid metric provided by Fitbits to measure physical activity in the general adult population. Our study findings were consistent with these results showing the highest correlations for step count as compared to our other outcomes. Similarly, we found that, relative to research grade accelerometers, the Fitbit tended to overestimate steps in the TKA patient population as was reported in both the general population (Feehan et al., 2018) and in older adults with knee osteoarthritis (Collins et al., 2019).

Our study expands on previous findings by examining correlations of step count at activity intensities < 3 METS and ≥ 3 METS. Lower correlations were reported in steps at a METS level of < 3 METS with the Fitbit reporting fewer steps than the SWA. This distinction is important as TKA patients spend the majority of their time being sedentary or engaging in light activities (Harvey, Chastin, & Skelton, 2015).

Moderate to good correlation was also found between the Fitbit and SWA for the measurement of EE. This finding is in contrast to a review of Fitbit accuracy in the general adult population, mostly measured in controlled environments, which reported that Fitbit devices did not often provide accurate measures of EE (Feehan et al., 2018). A study in older adults in free-living conditions compared seven consumer-level activity monitors to research grade accelerometers and had similar findings as the current study (Ferguson, Rowlands, Olds, & Maher, 2015). They reported that all of the monitors correlated moderately to strongly for total daily EE (r=.74 to .81) with two Fitbit models performing strongly (r=.81 and .76; ICC=.57 and .55).

Accurate measurement of time spent in various activity intensities is essential to determine if older adults post-TKA are meeting physical activity guidelines. Many guidelines, including the recommendations for older adults in the Physical Activity Guidelines for Americans, recommend at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity or equivalent combination of aerobic exercise weekly (Stamatakis et al., 2019). Although a systematic review reported the Fitbit tends to overestimate time spent in moderate to vigorous intensities (Feehan et al., 2018), in our study, Fitbits often underestimated time spent in these higher activity intensities. In subsequent studies in older adults with knee osteoarthritis, the Fitbit also tended to underestimate time spent in moderate to vigorous activity (Silva, Yang, Collins, & Losina, 2019; Collins et al., 2019). We included comparison of bouts of moderate to vigorous activity, which have been included in physical activity guidelines (Tremblay et al., 2011; World Health Organization, 2010). We found a lower correlation when comparing EEs occurring in bouts of 10 minutes or greater in MVPA suggesting the Fitbit is not an appropriate choice to measure this outcome.

Self-report measures have typically shown poor validity when compared to accelerometry (Helmerhorst et al., 2012). Despite poor correlations with accelerometry, self-report measures are used to report physical activity in large population studies where accelerometry may not be feasible. The Physical Activity Scale for the Elderly (PASE) demonstrated low construct validity and agreement when compared to accelerometry in older adults following TKA (Bolszak et al., 2014). When compared with the Tegner score and the Activity Rating Scale, the single item University of California at Los Angeles activity (UCLA) scale, showed the strongest correlations with other measures (r=-.55 to .23) for patients following TJA (Naal et al., 2009; Zahiri, Schmalzried, Szuszczewicz, & Amstutz, 1998); however, correlations were still low. Thus, the CHAMPS questionnaire, which showed a correlation of .43 for daily mean EEs relative to the SWA appears to be an appropriate choice in this population, when a self-report measure is selected over accelerometry.

In our rigorous evaluation of validity, we used several statistical tests to compare measurement tools. This approach allowed comparisons with previous studies where heterogeneous statistical approaches were used (Feehan et al., 2018; Evenson et al., 2015), but also demonstrated findings varied by the analyses used. For example, despite finding moderate correlations using ICC and Pearson correlation coefficients, no measurements were deemed equivalent when using more statistically rigorous equivalence tests (i.e., TOST method). Thus, users should consider intent of measurement when selecting tools. Less accuracy may be needed when tools are used to encourage physical activity (where any increase has health benefits) while more accuracy is needed when inaccurate measurement may have undesired consequences.

To our knowledge, this study is the first to examine the validity of the Fitbit for use with older adults following TKA undertaken in a free-living environment over a 24-hour period. We evaluated several physical activity outcomes, including steps, EEs, and time spent in various activity intensities. The sample size was as large, if not larger than comparable studies and power was adequate (Tully, McBride, Heron, & Hunter, 2014; Collins et al., 2019).

However, there are limitation of note. A systematic review suggested that measurement errors for steps were dependent on the reference criterion/measurement tool used, placement of the device on the body, and participant age and mobility (Feehan et al., 2018). These potential sources for errors reinforce the importance of the current study, which provides population-specific validity using these measurement tools for several physical activity outcomes. In addition, both the SWA and Fitbit use proprietary algorithms to calculate the METS values based on participants' sex, age and BMI, but this limitation applies to all studies using these devices. Finally, our evaluation occurred at six months post-TKA. Although physical activity and function levels are plateauing six months post-TKA, care must be taken when generalizing these findings to other time points pre and post-TKA (Almeida et al., 2018).

In summary, this study filled an important information gap on the accuracy of clinical tools to measure physical activity in patients post-TKA. Our results suggest that the Fitbit is appropriate to measure step counts, EEs, and time spent in specific activity intensities in these older adults. Although the CHAMPS had lower correlation with the SWA than the Fitbit, the CHAMPS may also be an appropriate self-report tool to measure physical activity.

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The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Table 1

Characteristics of Participants

Characteristics	n= 47
Age in Years, mean (SD)	69.3 (6.6)
Female, n (%)	31 (66%)
BMI in kg/m^2, mean (SD)	31.59 (3.82)
Other Joint Involvement, n (%)	13 (28%)
Employed Outside of Home, n (%)	
Yes	22 (47%)
Full-time	16 (34%)
Part-time	6 (13%)
Retired	25 (53%)
Occupation's Physical Intensity, n (%)	
Heavy labour	4 (9%)
Moderate labour	9 (19%)
Light labour	2 (4%)
Sedentary	7 (15%)
Locality of Residence, n (%)	
Rural	12 (26%)
Small town	25 (53%)
Urban	10 (21%)
Highest Education Achieved, n (%)	
Elementary or Junior high school	3 (6%)
High school	16 (34%)
University/College/Vocational	28 (59%)

BMI, Body Mass Index

Table 2

Physical Activity Outcomes and Comparisons for SWAs and Fitbits

	Mean (SD)		Median (IQR)		ICC (95% CI)	r	Equivalence Testing Using TOST procedure (p-value)
	SWA	Fitbit	SWA	Fitbit			
Steps	6193.6 (3417.8)	8198.4 (3971.3)	5619.4 (4776.6)	8022.2 (5772.1)	.79 (0.64 to 0.87)	.79	1.00
Steps < 3 METS	4276.2 (1929.5)	2209.1 (2110.6)	3994.4 (2170.2)	1777.9 (861.9)	.31 (.01 to .56)	.31	1.00
Steps ≥ 3 METS	2224.0 (2400.9)	6035.1 (3736.2)	1084.6 (2517.2)	6074.7 (4877.2)	.63 (.41 to .78)	.70	1.00
EE (kcals)	2412.79 (518.62)	2154.73 (444.45)	2244.95 (673.64)	2067.80 (690.65)	.78 (.64 to .87)	.79	1.00
EE < 3 METS (kcals)	2065.35 (302.71)	1508.56 (256.10)	2045.99 (332.39)	1536.30 (378.40)	.79 (.63 to .88)	.80	1.00
EE ≥ 3 METS (kcals)	354.12 (403.61)	557.63 (320.90)	179.69 (395.09)	531.78 (439.32)	.60 (.36 to .76)	.61	1.00
EE in bouts of MVPA (kcals)	223.23 (318.50)	199.44 (186.97)	102.76 (267.23)	191.23 (241.94)	.36 (.07 to 0.60)	.42	.22
Time Spent < 3 METS (hours)	21.45 (1.36)	22.59 (1.20)	23.02 (1.32)	21.42 (1.85)	.52 (.26 to .71)	.53	1.00
Time Spent 3 to 6 METS (hours)	2.26 (1.34)	1.02 (1.09)	0.608 (1.30)	2.08 (0.79)	.56 (.31 to .73)	.57	1.00
Time Spent ≥ 6 METS (hours)	0.30 (0.29)	0.04 (0.16)	0.00 (0.012)	0.24 (0.37)	.42 (.14 to .64)	.50	1.00

CI, Confidence interval
EE, Energy expenditure
ICC, Intraclass correlation coefficient
IQR, Interquartile range
METS, Metabolic equivalent of task units
MVPA, moderate to vigorous activity
SD, standard deviations
TOST, two one-sided tests

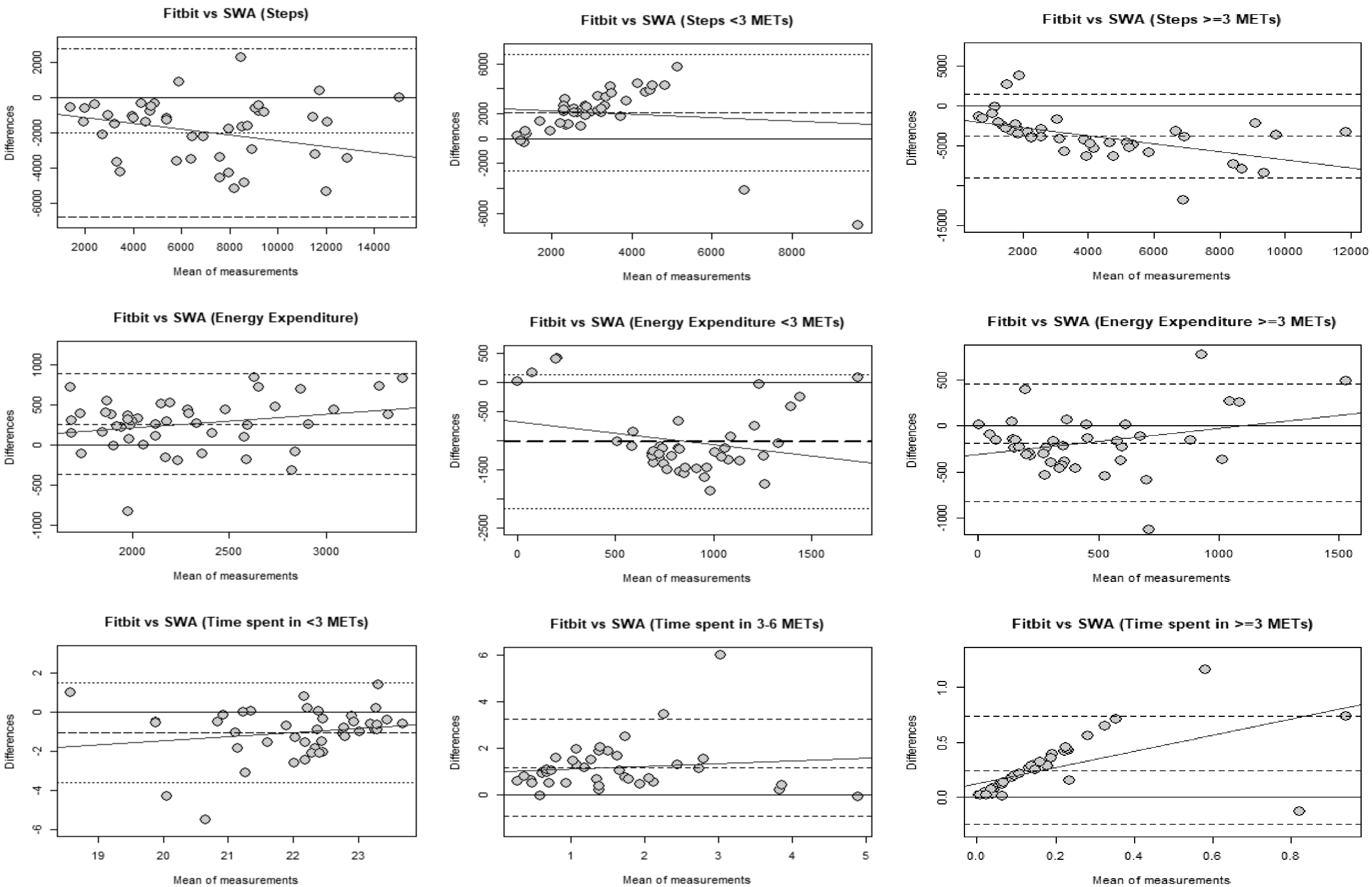
Table 3

Physical Activity Outcomes and Comparisons for SWAs and CHAMPS

	Mean (SD)		Median (IQR)		ICC (95% CI)	r	Equivalence Testing Using TOST procedure (p-value)
	SWA	CHAMPS	SWA	CHAMPS			
EE (kcals)	2412.79 (518.62)	2285.33 (421.77)	2244.95 (673.64)	2248.84 (530.87)	.43 (.17 to .64)	.40	.64
EE ≥ 3 METS (kcals)	354.12 (403.61)	1890.11 (356.19)	179.69 (395.09)	1839.91 (422.29)	.18 (-.11 to 0.44)	.18	1.00

CI, Confidence interval
EE, Energy expenditure
ICC, Intraclass correlation coefficient
IQR, Interquartile range
METS, Metabolic equivalent of task units
SD, standard deviations
TOST, two one-sided test

Supplementary File *Bland Altman Plots for Physical Activity Outcomes for Fitbit vs. SWA*



Chapter 6 Stationary Behavior in Older Adults Following Total Knee Arthroplasty*

*Formatted for submission to peer-reviewed journal

Abstract

Objectives

To measure stationary behavior in a cohort of older adults following total knee arthroplasty (TKA) and determine the clinical utility of the step-defined sedentary lifestyle index (SLI) as a measure of stationary behavior following TKA.

Design

Stationary behaviors, including stationary time, stationary bouts, breaks from stationary time, and the proportion of participants meeting the SLI, were measured in older adults three months post-TKA using accelerometry. A two-way analysis of variance test ($\alpha = 0.05$) was conducted to determine the effects of SLI (<5000 or ≥5000 daily steps) and possible interactions with sex on stationary behavior.

Results

Participants (n=65) spent 80% (13.17 hours, SD 2.30) of their waking time in stationary time and had an average of 6.06 bouts of stationary time >30 minutes per day. Forty (61.5%) of the participants fell below the SLI of 5000 steps/day. SLI had significant effects on both waking stationary time ($p<0.001$) and number of breaks in stationary time ($p<0.001$) with participants taking <5000 daily steps having longer stationary times and fewer breaks in stationary time. Sex had a significant effect on the number of breaks in stationary time ($p = 0.04$) with males (n=23, 35%) reporting more breaks than females (n=42, 65%), (mean difference 13.36, 95% CI -2.67 to 18.69). No interactions were found between SLI and sex.

Conclusions

Both women and men had high levels of stationary behavior three months after TKA. The SLI discriminated waking stationary time and breaks in stationary time so may have clinical utility in measurement of stationary behavior.

Keywords: sedentary behavior, stationary time, TKA, bouts, accelerometry, sedentary lifestyle index

Introduction

Sedentary behavior is a risk factor for morbidity and mortality independent of physical inactivity including all-cause mortality, cardiovascular disease incidence and mortality, cancer incidence and mortality, and type 2 diabetes incidence [1-3]. Emerging evidence also suggests that patterns of sedentary behavior influence risks for adverse health effects [4]. Higher rates of sedentary time in combination with longer duration of uninterrupted bouts of sedentary time has been shown to increase the risk of all-cause mortality in comparison to sedentary time accumulated in shorter bouts [4]. It is not yet known how often breaks in sedentary time should be encouraged or the duration of breaks required to mitigate the health risks of sedentary behavior. To obtain a comprehensive understanding of sedentary behavior, it is necessary to not only measure the time spent in sedentary behavior but also obtain information on the patterns of behavior such as bouts of sedentary time and breaks in sedentary time [5, 6].

The negative effects of sedentary behavior on health are especially pertinent to people with functional and ambulatory impairments. Knee osteoarthritis is one such condition, as adults with knee osteoarthritis demonstrate limited physical activity and high levels of sedentary behavior [8, 10, 29]. Although total knee arthroplasty (TKA) is often an effective surgical option resulting in improved pain and health-related quality of life [9, 11], little information exists on whether levels of sedentary behavior also improve postoperatively[10]. An early systematic review on sedentary behavior concluded that insufficient evidence existed to determine if sedentary behavior improved following TKA [10].

While there has been a rapid increase in research in sedentary behavior and consistent evidence on the detrimental effects on health, inconsistency exists in the measurement and definitions of sedentary behavior [6]. For example, the review on sedentary behavior following

TKA included various outcomes such as sit to stand transitions and time spent in sitting/lying/reclining [10]. Others have also included sitting time, screen time, television watching time, sedentary time (as measured with an accelerometer), and sedentary activities when evaluating sedentary behavior [1]. Although the Sedentary Behavior Research Network (SBRN) published a widely accepted letter in 2012 defining sedentary behavior (i.e., “any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting or reclining posture”) and inactive (i.e. “those who are performing insufficient amounts of MVPA”), there was varied uptake of the definitions and further standardization was necessary [6, 12]. In 2017, the SBRN terminology consensus project revised the definition of sedentary behavior to “any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture” and expanded the definitions to include concepts such as stationary behavior, screen time, patterns, bouts, and interruptions [6]. Stationary behavior was defined as “any waking behavior done while lying, reclining, sitting, standing, with no ambulation, irrespective of energy expenditure”. Thus, unless an indication of posture is included in the assessment (e.g., self-reported sitting, posture as determined by an inclinometer), a behavior cannot be designated as sedentary. Instead, stationary behavior may be a more accurate description of what is measured with most accelerometers (i.e., no ambulation). Furthermore, much of the evidence for the health effects of ‘sedentary behavior’ were based on what would now be defined as stationary behavior [1, 13].

The step-defined sedentary lifestyle index (SLI) has been proposed as a clinically relevant measure of sedentary behavior [14]. Taking < 5000 steps per day has been associated with sedentary behavior, higher BMI, increased cardiometabolic risk and increased risk of falls when compared to those taking ≥ 5000 steps per day [14, 15]. Although adults in a National Health and

Nutrition Examination Survey taking < 5000 steps per day engaged in higher levels of stationary behavior, it is not yet known if older adults following TKA follow a similar trend [14]. As males tend to have a higher step count than females [14], there may be sex differences with SLI and stationary behavior. Given the widespread use of step count as a surrogate measure of physical activity, it would be helpful to know how the SLI relates to stationary behavior and the effect, if any, of sex.

Due to the importance of gaining mobility after TKA to maximize health following these surgeries, information on stationary behavior in this cohort is needed [16]. The first objective of this study was to measure stationary behavior, including stationary time, stationary bouts, and breaks from stationary time, using accelerometry in a cohort of older adults three months following TKA. The second objective was to determine the utility of the SLI as a measure of stationary behavior by examining how SLI and sex affect stationary behavior in older adults following TKA and if any interaction is present.

Methods

Participants

As part of a primary study that examined a physical activity intervention in older patients who received TKA, we examined stationary behavior three months post-operatively. Inclusion criteria consisted of patients who 1) received a primary elective bicondylar or tri-condylar TKA within the last three months, 2) were 60 years of age or older, and 3) spoke English. Patients were excluded if they 1) had comorbidities that significantly limited ability to increase physical activity (e.g. cardiopulmonary involvement that precluded regular physical activity), 2) were wheelchair dependent, or 3) received bilateral or unicondylar TKA. Ethical approval was obtained from the university ethics board (No. Pro00062054).

Measures

Stationary behavior. The SenseWear MiniPro Armband™ (SWA) (Body Media, Pittsburgh, PA) was used to estimate stationary behavior. The SWA is a tri-axial accelerometer armband that is worn on the upper arm. It contains physiological sensors measuring skin temperature, galvanic skin reaction, heat flux and accelerometry in three planes [17-19]. The SWA has been shown to be a valid tool to estimate physical activity in free-living older adults (ICC 0.90, 95% CI 0.77 to 0.96) and in older adults following TKA (ICCs 0.48 to 0.81) [17, 19-21]. The SWA also has high accuracy in identifying stationary activities (sensitivity > 0.89) [22]. The participants wore the SWA for four consecutive days (five nights) which has been recommended as sufficient to capture consistent data [18]. Continuous minute-by-minute data from the SWAs, including energy expenditures, METS levels, step counts and date stamps, were downloaded using the SWA software SenseWear Professional 8 [23].

Stationary behavior was described as time and percentage of day spent in stationary time, bouts of stationary time, and breaks from stationary time [24, 25]. The mean number of daily steps was calculated by averaging the number of steps taken daily for the included days. The proportion of participants achieving the 5000 step threshold of the SLI was determined [14].

Specifically, the mean daily time spent (in hours) and the mean percentage of daily time spent in stationary activity were reported from the SWA. Stationary time was operationalized as time spent in ≤ 1.5 METS which is consistent with previous literature and reported METS values for no ambulation, i.e. lying, reclining, sitting and standing still [24, 25]. A bout of stationary time was defined as an uninterrupted period of stationary time. The mean number of stationary bouts lasting ≥ 30 minutes was calculated.

A break in stationary time was defined as an interruption that was ≥ 1 minute with an energy expenditure > 1.5 METS [26]. The number, mean length in minutes, mean and total energy expenditures in kilocalories, and average METS intensities of the breaks in stationary time were recorded.

Procedures

Upon securing consent, participants were asked to wear a SWA for 5 consecutive days at three months post TKA. Sociodemographic (age, sex, employment status, education) and medical comorbidities were recorded. Height and weight were measured and body mass index (BMI) in kilograms/metres^2 was estimated.

Data Analysis

Data were only included in the analysis if the participants wore the SWA > 95% of the day and night for at least 4 days [18]. Summary statistics for stationary behavior outcomes were determined for all participants.

To determine the effect of SLI and possible interaction with sex on stationary behavior, two-tailed two-way analysis of variance (ANOVA) tests ($\alpha = 0.05$) were conducted for waking stationary time, number of bouts ≥ 30 minutes in stationary time, number of breaks, average length of break and means METS level of breaks in stationary time. SAS (Version 9.4, SAS Institute, Cary, NC) and SPSS Statistics (Version 26, IBM Corporation, New Orchard Road Armonk, New York) were used for data analysis.

Results

Of the 68 participants recruited, data from three were excluded because of insufficient SWA wearing time (< four complete days). The remaining cohort wore the SWA 98.7% of the time during the 24 hours period (mean 23.45 hours/day, SD 0.13) with a mean waking time of 16.92 hours (SD 1.59). The mean age of participants was 70.2 (SD 6.5) years, and 65% (n=42) were female (see Table I). The most commonly reported comorbidities were high blood pressure (n=37, 57%), digestive problems (n=24, 38%) and thyroid disease (n=17, 26%). In terms of other musculoskeletal involvement, 26% (n= 17) had undergone previous joint replacements, and 23% (n=15) reported severe back pain.

(insert Table I)

Waking Stationary Time, SLI and Bouts ≥ 30 minutes

During waking time, the mean stationary time per day was 13.17 hours (SD 2.3) or 80% of the waking day. Only 25 (38.5%) participants averaged > 5000 steps/day. The average number of steps/day was 4093.5 (SD 2547.6) for all participants, 2421.18 (SD 1142.5) for the older adults < 5000 steps/day and 6769.3 (SD 1751.3) for those achieving ≥ 5000 steps/day. Participants averaged 6.06 (SD 2.46) bouts of stationary time lasting ≥ 30 minutes per day.

Breaks from Stationary Activity

On average, participants took 27.75 (SD 12.3) breaks from stationary behavior per day with an average intensity of each break being 1.86 METS (SD 0.2) and each break averaging 6.6 minutes (SD 2.8). Over a day, the average total length of breaks in stationary behavior was 3.28 hours (SD 2.2).

Stationary Behavior by Sex and Step-Derived SLI

Those participants who took < 5000 daily steps had significantly more waking stationary time (mean 13.98 hours, SD 2.33) than those who took ≥ 5000 steps (mean 11.88 hours, SD 1.57) (mean difference 2.09, 95% CI 1.13 to 3.06, $p < 0.001$). The participants below the SLI also took significantly fewer breaks in stationary time (mean 22.62, SD 11.73) than those who took ≥ 5000 steps (mean 35.98, SD 7.97) (mean difference 13.36, 95% CI -8.48 to 18.25, $p<0.001$). Males had more breaks (mean 33.47, SD 10.32) than females (mean 24.62, SD 12.23) (mean difference 8.85, 95% CI -2.86 to 14.59, $p=0.04$). No significant interactions were found between SLI and sex for any of the stationary behavior measures when assessed by two-way ANOVA (see Table II).

(insert Table II)

Discussion

This study found worrisome levels of stationary behavior in older adults following TKA at three months post-operatively. The participants recorded a high percentage of waking time spent in stationary behaviors, and the majority of participants were below the step-derived sedentary lifestyle index of 5000 steps. Frequent long bouts of stationary time were recorded, and when breaks from stationary time were taken, the average intensity of these breaks was only slightly higher than resting levels. All of these findings increase the participants' risk for adverse health effects due to stationary behavior [1].

The step-derived SLI appears to discriminate stationary behavior in older adults following TKA which supports the clinical utility of this tool. When the sample was stratified by the SLI, the older adults below the 5000 daily steps demonstrated more stationary time and fewer breaks in stationary time than those achieving 5000 steps or greater. Although no generally accepted minimal clinically important differences (MCID) for reductions in stationary time or increasing frequency of breaks exist, evidence suggests that a reduction of 30-60 minutes of sedentary time per day is associated with improvements in cardiometabolic markers, health related quality of life and improved mortality [27, 28]. The difference in stationary time between the two groups stratified by the SLI appears, therefore, to be clinically relevant. There has been some prior evidence suggesting males tend to take more daily steps than females [14]; yet our findings suggest that sex did not affect the relationship between SLI and stationary behavior. As step counting is a common and easily accessible form of measuring activity [29], these findings shed insight on a potential clinically relevant tool for measuring stationary behavior.

This study was novel in that it provided a comprehensive description of stationary behavior in older adults following TKA including not only the typical metric of sedentary time but also descriptions of bouts of stationary time ≥ 30 minutes, breaks from stationary time, and the proportions of participants meeting the SLI. One of the key findings of this study was that 80% (13.17 hours) of the participants' waking time was spent in stationary behavior. These high levels of stationary time put these older adults at risk for negative health effects and reinforce the need for further research and interventions to help change behaviors and decrease these risks [1]. A systematic review of objectively measured and subjectively reported sedentary behavior (which did not discriminate between stationary and sedentary time measures) in older adults reported 65-80% of older adults' days spent in sedentary behavior [30]. Older Canadians (65 years and older) spend approximately 10 hours of their waking time in stationary behavior [31]. Thus, our participants who were three months after surgery were more stationary throughout the day than national norms for their age [31].

Longer stationary bout duration, in addition to greater total stationary time, has been found to be associated with a higher risk for all-cause mortality [4]. Although there are not yet clear guidelines specifying after what period of stationary time a break should be taken, uninterrupted stationary behavior in bouts of 30 minutes or greater is associated with a greater risk for all-cause mortality than bouts of less than 30 minutes [4]. This study found that that the participants averaged 6.06 (SD 2.46) bouts of stationary time ≥ 30 minutes each day suggesting this population is at risk for adverse health effects.

In spite of increasing evidence on the detrimental health effects of sedentary and stationary behaviors, there are no clear recommended guidelines for older adults following TKA. The updated American Physical Activity guidelines recommend moving more and sitting less throughout the day but state no specific targets or recommended limits – nor are there definitions regarding sedentary or stationary behavior. Although recommendations for sedentary behavior have been added to the guidelines for Canadian children, the current Canadian Physical Activity Guidelines for Older Adults do not contain recommendations for sedentary or stationary behaviors [32]. The 2019 American College of Rheumatology/Arthritis Foundation Guideline for the Management of Osteoarthritis of the Hand, Hip, and Knee recommend exercise but do not specifically mention physical activity or stationary or sedentary behavior [33]. From these study results, we now know that older adults post TKA spend the majority of their time in stationary behavior with only a small increase in activity intensity even when they do take breaks from stationary behavior. What is not yet known is whether activity recommendations should focus on decreasing overall stationary time, increasing light or MVPA, increasing frequency or intensity of breaks from stationary behavior – or what combination of these factors should be considered. In this population of older adults following TKA, it may be more feasible to set goals of decreasing stationary time or decreasing length of stationary bouts rather than focusing on achieving the recommended weekly 150 minutes of moderate to vigorous physical activity [10]. There also needs to be clarity on the use of the terms sedentary and stationary behaviors in these guidelines. This gap in knowledge is consistent with a recent review on sedentary behavior and health that emphasizes the importance of integrating sedentary behavior and physical activity guidelines and calls for further research into the role of bouts and breaks in sedentary behavior in relation to health outcomes [5].

Relative to the SLI, 39% of participants achieved 5000 steps per day suggesting increased risk for cardiometabolic disorders [14] and falls [15]. In contrast, 61% to 95% of adults over the age of 65 years achieved more than 5000 steps in a Swedish population-based cohort study. However, we measured stationary behavior at three months post-operatively so it is possible that some of the participants would have eventually exceeded the 5000-step threshold.

Discrepancies exist in the literature as to whether males exhibit higher levels of sedentary or stationary behaviors [37, 38]. In this study, the number of breaks in stationary time was the only measure where sex had a significant effect, with males taking breaks more frequently than females. The clinical relevance of this difference, 35.96 (7.96 SD) vs. 22.62 (SD 11.73) is not yet known as further research is required to determine relevant MCIDs for these stationary behavior metrics. Information on the effect of sex on stationary behavior is important as stationary behaviors have been shown to have more of a negative impact on health for females than males and are associated with worsening frailty for females [37].

This study measured stationary behavior at three months post TKA, a clinically relevant time point when significant gains have been made in terms of decreasing pain, and increasing function and quality of life [9]. At this time, active therapy typically ceases and patients are discharged from rehabilitation [39]. Information on stationary behavior at the three month time point was lacking prior to this study and is necessary to make informed decisions to maximize health in this population [10, 36, 40, 41].

This study is the first to provide a comprehensive description of stationary behavior in patients three months after TKA, including not only the metrics of stationary time, but also information on bouts of stationary time, breaks from stationary time, proportion of participants meeting the SLI and relevant characteristics of study participants. Additionally, there are data for the entire 24-hour period in the included days and the percentage wear times were very high. This is a key point as wear time can significantly affect measurements of stationary behavior [42, 43]. However, this study is not without limitations that should be acknowledged. First, the SWA was selected as a measure of stationary behavior because it had been validated for older adults following TKA [20, 21], yet caution needs to be taken when comparisons are made with data from other measurement devices. Second, participants with substantial mobility limitations were not included in this sample so generalizability may be limited.

Conclusions

These findings will influence guidelines and recommendations regarding stationary behavior as well as informing design and evaluation of appropriate interventions to maximize health for older adults following TKA. As step counting is a common and easily accessible form of measuring activity [29], these findings shed insight on a potential clinically relevant tool for measuring stationary behavior.

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Author Contributions

Conception and design of study and obtaining of funding: Jones CA, Beaupre L.

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Interpretation of data, drafting and revising article, final approval: All authors

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Competing Interest Statement

The authors have no declared conflicts of interest.

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Characteristic	Total n= 65	< 5000 steps/day n=40	≥ 5000 steps/day n=25
Age in years, mean (SD)	70.2 (6.49) Range 62 to 94	71.7 (6.74)	67.9 (5.41)
Female, n (%)	42 (65%)	30 (71.4%)	12 (28.6%)
BMI in kg/m^2, mean (SD)	31.51 (4.65)	31.30 (4.53)	31.88 (4.92)
Other Joint Involvement, n (%)	24 (37%)	20 (83.3%)	4 (16.7%)
Employed Outside of Home, n (%)			
Yes	28 (43%)	12 (42.9%)	16 (57.1%)
Full time	19 (29%)	7 (36.8%)	12 (63.2%)
Part-time	9 (14%)	5 (55.6%)	4 (44.4%)
Retired	36 (55%)	27 (75.0%)	9 (25.0%)
Occupation's Physical Intensity, n (%)			
Heavy labour	5 (7.7%)	0 (0.0%)	5 (100.0%)
Moderate labour	11 (17%)	4 (36.4%)	7 (63.6%)
Light labour	5 (7.7%)	4 (80.0%)	1 (20.0%)
Sedentary	7 (11%)	4 (57.1%)	3 (42.9%)
Highest Education Achieved, n (%)			
Elementary	1 (1.5%)	1 (100.0%)	0 (0.0%)
Junior high	5 (7.5%)	2 (40.0%)	3 (60.0%)
High school	21 (32%)	16 (76.2%)	5 (23.9%)
University/college/technical	38 (59%)	21 (55.3%)	17 (44.7%)

BMI, Body Mass Index

Table I Characteristics of Participants

Variable and Source	MS	F	p-value	Partial ETA^2
Waking stationary time (hours)				
SLI	2.72	17.595	**< 0.00**	0.22
Sex	75.49	0.63	0.43	0.01
SLI x Sex	4.93	1.15	0.29	0.02
Number of bouts of ≥ 30 minutes in stationary time				
SLI	0.00	0.00	0.99	0.00
Sex	0.00	0.00	0.99	0.00
SLI x Sex	1.26	0.17	0.68	0.00
Number of breaks in stationary time				
SLI	458.70	20.33	**<0.00**	0.25
Sex	2118.31	4.40	**0.04**	0.07
SLI x Sex	117.57	1.13	0.29	0.02
Average length of breaks in stationary time (minutes)				
SLI	2.74	0.19	0.67	0.00
Sex	1.48	0.35	0.56	0.00
SLI x Sex	3.45	0.44	0.51	0.00
Mean METS level of breaks in stationary time				
SLI	0.04	3.16	0.08	0.05
Sex	0.12	0.93	0.34	0.02
SLI x Sex	0.09	2.38	0.13	0.04

SLI, sedentary lifestyle index
MS, mean square

Table II Two-Way Analysis of Variance for Stationary Behavior Measures

Chapter 7 Conclusions

7.1 Summary of Contributions

The primary aim of this doctoral research work was to evaluate tools that measure physical activity to determine which tools are most appropriate for use in older adults following TKA. At the onset of this research program a gap in the literature regarding the role of physical activity on the risk for revision following TKA was identified. A scoping review examining the factors increasing risk for revision was completed to address this. Through further review of the literature and clinical experience, it became clear that patients and researchers were starting to use emerging technologies such as personal activity trackers like the Fitbit in older adult populations. There were, however, little data on the validity and appropriateness regarding use of these devices. As this research program progressed, it also became clear that an additional gap in the literature existed on lower levels of activity including stationary behavior. Therefore, the aim of this research program was to address these identified gaps. The specific objectives were to a) identify what factors increase the risk of revision following TKA, b) determine if the Fitbit or CHAMPS questionnaire were appropriate to measure physical activity following TKA and c) describe stationary behavior and determine if the SLI would be appropriate to measure stationary behavior post TKA.

The findings from these interrelated objectives reinforced the importance of the use of valid tools to measure activity levels following TKA, and of older adults achieving sufficient levels of physical activity, sedentary and stationary behaviors post TKA. The scoping review revealed that the little research available did not suggest physical activity increased the risk for revision but further research is necessary in this area. Despite the importance of older adults returning to sufficient levels of physical activity following TKA, little information existed on the validity of tools to measure physical activity post TKA. The findings from the primary validity study provide guidance on the choice of measurement tool suggesting that the Fitbit may be an appropriate tool to measure physical activity in older adults following TKA when compared to the previously validated SWA in situations where high precision is not necessary. In situations where self-report measures are more appropriate to use than accelerometry and lower precision is acceptable, the CHAMPS questionnaire may be an appropriate choice. The SLI may assist in discriminating stationary behavior through the commonly used and easily accessible method of step counting. Finally, the high levels of stationary behavior measured three months post TKA reinforce the importance for accurate measurement and subsequent interventions to increase activity levels in this group of older adults who are at risk for detrimental health effects due to inactivity.

7.2 Clinical Implications

As a component of rehabilitation, older adults need to increase their levels of physical activity and decrease their sedentary and stationary behavior following TKA to avoid detrimental health effects (27, 17). Results from this research program will help older adults achieve these goals through a number of ways. The findings suggest that the Fitbit is an appropriate tool to use when measuring steps, EEs and time in lower intensity activities in older adults following TKA when high precision is not necessary. Researchers and clinicians should consider the intent when selecting measurement tools to determine the level of precision required. In clinical situations with the goal of improving physical activity, less accuracy may be acceptable as any increase in physical activity may have health benefits. Alternatively, the more precise research grade accelerometers, such as the SWA, may be more appropriate in situations where in inaccurate measurement may have negative consequences (133).

Secondly, in clinical situations when accelerometry is not feasible or the use of self-report measures is preferred, the CHAMPS questionnaire is an appropriate choice to measure physical activity in older adults following TKA. As the CHAMPS questionnaire is one of the most commonly used self-report measures of physical activity in older adults, this information will have widespread implications for use (18). Again, users of this self-report measure must consider the intent and goal of use. We now know that correlation is poor to moderate for the CHAMPS questionnaire as compared with accelerometry; however, the correlation is higher than those reported in the literature for other self-report outcome measures evaluated in this specific population. If accuracy is necessary, a self-report measure may not be the best choice. Our findings suggest that the CHAMPS questionnaire should not be used to calculate EEs in specific activity intensities, i.e. ≥ 3 METS, as the correlation with the SWA was much lower with the CHAMPS tending to overestimate EE at this higher activity intensity.

This research program also highlighted measurement issues that both health care providers and older adults following TKA must be aware of when using accelerometry. Examples of measurement issues that may directly affect the validity of measurements include the ongoing development of new models of activity trackers, the variation in locations where activity trackers are worn, the types of activities being measured and variation in data analytic approaches.

Although the primary aim of the program was to provide information on tools measuring physical activity, it became clear that the entire spectrum of activity must be considered when measuring activity to maximize health, particularly in older adults with mobility issues. As high levels of stationary behavior have been independently associated with adverse health effects, clinicians and patients must be made aware of the current high levels of stationary behavior following TKA. Older adults need to understand that TKA provides an opportunity to decrease stationary time, but only if they change their behaviors. Thus, postoperative interventions designed to help achieve adequate levels of physical activity and reduce stationary behavior may be necessary. The SLI may be a clinically relevant tool to help identify and decrease stationary behaviors as step counting is a common and easily understood methods of quantifying activity (31).

Finally, the scoping review findings also have immediate clinical application for both older adults following TKA and their health care providers. Older adults undergoing TKA can be reassured that the survival rates of a TKA are very high. While many of the factors identified as increasing risk for revision are non-modifiable, this information should inform clinical practice including follow-up monitoring practices, care plans and clinical practice guidelines. This information will also help patients and healthcare providers develop realistic expectations. Both health care providers and older adults can use the information on modifiable risk factors both prior to the surgery as well as after the procedure to try to minimize risk. Additionally, the health services data can inform health policy and health services utilization such as location of service delivery and care plans including triage, pre-operative care, acute care and rehabilitation.

7.3 Future Research

Reviews of the measurement of physical activity in older adults following TKA, and in older adults in general, are consistent in their recommendations that further research is necessary regarding the validity of measurement tools in specific populations (15-18). While this program of research answers several clinically important questions, further research into the measurement of physical activity in older adults following TKA is needed, as well as the expansion of the scope of measurement to include sedentary and stationary behaviors.

1. With the evolving availability and advancing technology of personal activity trackers, it will be an ongoing challenge for research to remain current with the commercially available personal activity trackers. For example, a systematic review discussing the accuracy of Fitbits lists eight consecutive commercially available models between 2009 and 2013 (133). Further research is necessary to determine if the conclusions regarding validity remain applicable to the newer Fitbit models (111).

2. Although these research findings address gaps in the literature regarding measurement of physical activity in older adults following TKA, further research is necessary to evaluate the effects of characteristics of this population such as lower gait speeds and the potential use of mobility aides (184, 185). As discussed in the Gabriel framework, physiological, psychosocial and environmental factors that influence physical activity must also be considered (46).

3. Typically, validation studies compare discrete models of measurement tools (18, 111). It has been proposed that changing to a more collaborative approach of measurement and validity testing and away from multiple independent calibration studies would be beneficial (112). An example of this approach is the Axivity accelerometer which provides access to the raw acceleration data and an open application programming interface (113, 186). A consensus approach and collaboration could accelerate progress by standardizing core activities to be included in protocols, naming conventions for variables in calibration studies, choice of machine learning approaches and signal features to include in algorithm development (112). Researchers must also investigate these advances in specific populations such as older adults following TKA to ensure generalizability of their findings.

4. Determining the most appropriate method for the assessment of agreement is an ongoing issue in biomedical research (187). Ongoing research and discussion as to the most appropriate statistical analyses for validity studies in physical activity monitors and the clinically acceptable ranges of error is essential to ensure that appropriate conclusions are being drawn. As recommended, this validity study used a number of statistical analyses to draw conclusions, and it is recommended that further research also consider this issue (187).

5. The overall goal of research into physical activity measurement tools is to improve the health of the users. Thus, researchers, clinicians and older adults must collaborate to investigate the roles of activity trackers in intervention studies and behavior change.

6. The scoping review identified areas where the literature was consistent in identifying factors that affect risk of revision following TKA. It also helped identify areas where inconsistent or insufficient data were available and further research was needed, including factors such as BMI, sex, primary diagnosis and a number of surgical factors (189). In the context of this research program, it was interesting to find little research on the effect of physical activity on the risk of revision following TKA. Many people following TKA are apprehensive to engage in vigorous activities or have been advised to avoid intense or high impact activities (88). Given the well-documented risks on health of physical inactivity, further research is necessary to ensure that recommendations regarding physical activity following TKA are appropriate and promoting healthy levels of physical activity.

7. There is preliminary evidence on the effects on health of bouts and breaks in stationary behavior in other populations, but further research, in both the general

population and in specific populations, is needed. It is not yet known what recommendations should be regarding stationary behavior. Further information is necessary to answer questions such as how long can you sit before you should take a break, how long does the break need to be, at what activity intensity does the break need to be, should the goal be to replace stationary behavior with light activities or is MVPA necessary.

9. Although there are Canadian Physical Activity Guidelines for special populations such as multiple sclerosis, spinal cord injury, Parkinson's disease and Alzheimer's, there are none specifically for older adults with osteoarthritis at this time nor those for following joint arthroplasty (42, 190). These findings will help guide further research and recommendations on physical activity, as well as stationary behavior.

7.4 Conclusion

Given the negative health consequences of physical inactivity, accurate measurement of physical activity following TKA is essential to ensure older adults achieve sufficient levels of activity to maximize health. Information on the validity of clinical tools measuring physical activity is necessary for health care providers and older adults to make informed decisions on how best to monitor activity levels after TKA. The Fitbit has shown to be an appropriate tool to measure physical activity in older adults following TKA when high precision is not necessary. The CHAMPS questionnaire provides an alternate measure for clinical situations when self-report format is preferred and high precision is not required. This information on clinically relevant measurement tools is necessary to develop and evaluate interventions to maximize activity and health in older adults following TKA.

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Appendix A COACH Study Overview

The clinical studies detailed in this thesis took place within the context of a longitudinal Coaching for Older Adults with Osteoarthritis for Community Health (COACH) study. The COACH study was a feasibility study examining whether a physiotherapist led coaching and monitoring intervention would increase levels of physical activity in older adults following TKA. Sixty-eight patients were recruited from the Camrose Hip and Knee Clinic and received a weekly coaching intervention over the telephone by a physiotherapist for three months beginning three months after surgery. The coaching intervention was an individualized intervention involving information sharing, personalized goals and action items. Participants were given a Fitbit activity monitor to wear and upload the data from the Fitbit on a weekly basis which the physiotherapists were able to access to assist in the coaching intervention. The primary aims of the COACH study were to examine the effectiveness of this coaching intervention and to determine the feasibility of its implementation in older adults post TKA.

The COACH study included patients 1) having received a primary elective TKA at the Camrose Hip and Knee Clinic within the last six weeks to three months, 2) 60 years of age or older, 3) English speaking, 4) having access to a computer or mobile device with Internet access to upload physical activity data, and 5) willing to participate in the weekly coaching interventions with the physiotherapist. Patients were excluded if they had 1) comorbidities that affect physical activity (e.g. cardiac involvement) or 2) have cognitive impairments that would affect physical activity or the measurement of physical activity.

Participants were recruited from the Alberta Hip and Knee Clinic in Camrose, Alberta. Participants were given Fitbits with instructions to start wearing it when the coaching intervention began three months post TKA. Participants were evaluated at three months after surgery and then six and nine months after surgery.

Ethical Considerations

Ethical approval was obtained from the University of Alberta and Alberta Health Services (Pro00062054).

Appendix B Recruitment and Study Processes

Participants were recruited from the Alberta Hip and Knee Clinic in Camrose, Alberta in conjunction with the COACH study as described above. Data collection for the validation study occurred six months post TKA and for the stationary behavior descriptive study at three months post TKA.

The two clinical studies included participants 1) having received a primary elective TKA at the Camrose Hip and Knee Clinic within the last six weeks to three months, 2) 60 years of age or older, 3) English speaking, and 4) having access to a computer or mobile device with Internet access to upload physical activity data. Patients were excluded if they had 1) previous joint revisions, 2) comorbidities that affect physical activity (e.g. significant cardiac involvement) or 3) have cognitive impairments that would affect physical activity or the measurement of physical activity.

Appendix C Outcome Measures

Primary Outcome Measures

1. EE – For this research program, EE is defined as the amount of energy used for physical functioning of the body and was measured in the units of kilocalories (94). Values for average daily EEs were collected by the research accelerometer (SWA), personal activity tracker (Fitbit) and self-report measure (CHAMPS) and are continuous variables with the units of kilocalories (collected over daily 24-hour periods). Daily average EEs were further stratified into categories of physical activity intensity based on METS levels (SWA and Fitbit: light < 3 METS; moderate 3 to 6 METS and vigorous > 6 METS; CHAMPS questionnaire moderate to vigorous ≥ 3 METS).
2. Time spent in these categories of physical activity intensity categories were also calculated e.g. average daily minutes spent in moderate category (3 to 6 METS).
3. Step counts – Step counts refer to the stepping movement of a leg during walking with one count occurring each time there is vertical acceleration over a certain threshold (97). Values for step counts were collected by the research accelerometer (SWA) and personal activity tracker (Fitbit) and were given as average counts per day (24-hour period).

Outcome Measure Data Collection and Management

1. SenseWear Armbands

The participants were each given a demonstration by the research assistant on the use of the SWA (Armband model MF-SW and Display model DD 100) on the day of initial enrollment of the study and received education as per previously published studies on the use of the SWA (see Appendix H for Participant Instruction Sheet) (191). Similar to the procedure used in the

COACH study, the SWA was then mailed to each participant at both three and six months post TKA for data collection specific to this study. The participants wore the armband for four consecutive days (five nights) except during water activities. After the four days, the participants returned the SWA in the provided postage paid envelope. Contact information for the research assistant was supplied in case of any concerns or equipment difficulties. The research assistant was able to contact the research team with any ongoing or unusual concerns.

Upon the return of the SWAs, the data was downloaded using the SWA software SenseWear Professional 8 (120). The software downloads the raw data including minute-by-minute data for EEs, METS, step counts and date stamps to a data file and then clears the data from the armband. Participant data including date of birth, height, weight, gender, smoker/non-smoker and handedness was then entered to improve the accuracy of the EE calculations. The algorithm through which the software calculates EE is proprietary so is not available; however, the manual does state these variables are required to improve the accuracy of the EE calculation (120). The data was then exported to an Excel spreadsheet stored in a research database.

2. Fitbits

The participants were each given a Fitbit to use upon enrollment in the COACH study and were provided with education regarding its set-up, ongoing use and downloading of information (see Appendix H for Participant Instruction Sheet). The participants began to wear the Fitbit after the first data collection period for the SWA at three months and then continued to wear the Fitbit for the same five consecutive days as the SWA at the six month period to allow for comparison of the data collected. Contact information for the research assistant was supplied in case of any concerns or equipment difficulties. As with the SWAs, the research assistant was able to contact the research team with any ongoing or unusual concerns.

In addition to the participants sharing their physical activity data obtained from the Fitbit with the COACH study physiotherapy coaches, a database program (Fitabase, Small Steps Labs) was used to retrieve more detailed physical activity information from each participant. This data included precise daily step counts, daily EEs and activity intensity levels for each minute including time stamps from all the Fitbit devices allowing the data to be centralized and stored on the research database. Similar to the SWA, the algorithm for calculation of EE by the Fitbit is proprietary and not available; however, demographic information including gender, age, height and weight was also required upon set up of the Fitbit to improve the accuracy of the calculations (193). Values for average daily EE, average daily EE in each physical activity intensity category, average daily step counts and time spent in each physical activity intensity category were used for data analysis. If the data set was not complete for both the Fitbit and SWA for the same 5 days of wear with 10 hours per day of wear, the data from that participant was excluded from the data analysis (191). Due to the cross-sectional design of the study, data imputation was not used.

Fitbit Alta. The Fitbit Alta was the personal activity tracker chosen for this study. This model was chosen from the available Fitbit personal activity tracker models as it has the required functions of tracking EE and steps using a triaxial accelerometer while remaining in the mid-range of costs retailing for approximately $135 Canadian (132). Its thin size and comfort band has received favorable reviews from consumers (194). The Fitbit Alta is not waterproof but there were no waterproof Fitbit devices available at the onset of this study.

3. Self-report Measure (CHAMPS)

The CHAMPS questionnaire was administered over the telephone by the research assistant within three days of the completion of the data collection period when the participants were wearing the SWA and Fitbit for 5 days.

The CHAMPS questionnaire was designed to give two measures of EE - estimated EE per week in physical activity and estimated EE per week in activities of moderate or greater intensity (METS $\geq$3) (26). The estimated EE values are obtained by multiplying the estimated duration of each recorded activity by the MET value and then adding these values across all relevant activities (see Appendix G for codebook) (26). The MET value assigned to each recorded activity was based on the values reported by Ainsworth et al. with adjustments by the authors of the questionnaire to increase the accuracy for the population of older adults (104). Adjustments were made to account for the way that the activities would potentially be performed by older adults, to account for the published values may exceed the aerobic capacity of older adults in endurance-type activities and that older adults may be working at a lower intensity in strength-based activities due to lower levels of muscle strength (26).

The data from the CHAMPS questionnaire was entered in a spreadsheet in the research database that allowed for calculation of AEE per week and therefore average daily AEE (see appendix G for codebook) (26). Data based on water activities was subtracted from the EE calculation as the Fitbit and SWA are not able to be worn during water activities. Additionally, the data was further categorized to allow calculations for daily EE undertaken in moderate or greater intensity activities (METS $\geq$3) (26).

The AEE derived from the CHAMPS questionnaire was then summed with the BMR calculated from the Harris Benedict equation to derive the TEE. These values are then appropriate to compare to the TEE values from the SWA (195). The Harris Benedict equation uses data for age, sex, height and weight to calculate the BMR:

For men $h = 66.4730 + 13.7516w + 5.0033s - 6.7550a$

For women $h = 655.0955 + 9.5634w + 1.8496\,s - 4.6756a$

Where h= total heat production per 24 hours i.e. BMR, w = weight in kg, s = stature in centimeters and a = age in years (168).

Data from incomplete CHAMPS questionnaires that do not have the full set of data required to make the calculation of average daily EE were not included in the analysis (see appendix B). Data imputation was not used based on cross sectional design of the study. The CHAMPS questionnaire was completed through a telephone survey to minimize missing data.

Appendix D Data Analysis

1. Intraclass correlation coefficients (ICC)

ICCs were used to calculate the level of agreement between EEs, time spent and step counts obtained by each of the measurement tools specific to each objective. ICCs were chosen as the index provides a measurement of agreement not just covariance. The index is based on analysis of variance (ANOVA) calculations and is therefore able to separate out variance components including those due to error or true differences in the data (96). The ICC calculations are also based on generalizability theory which takes into account that there may be various facets that contribute to measurement error separate from random error. This theory is demonstrated by the following equation:

$$ICC = \frac{S_T^2}{S_T^2 + S_F^2 + S_E^2}$$

where S_T^2 is the variance in true values and S_E^2 is the variance in error components and S_F^2 is the variance in the facets of interest (96).

There are three models of the ICC which differ on how the raters, or in this case measurement tools, are chosen and subjects are assigned. It was appropriate to use the most common model, model 2, in the context of this study as each subject was assessed by the same raters/tools. Both subjects and raters/tools are considered to be theoretically randomly chosen as they are expected to represent a wider population with the results generalizable to a larger population as well (96, 196). Each model must be further be distinguished as to whether the data values are single or mean ratings. The data values in this study are single ratings so the model ICC(2,1) was used. ICC(2,1) is based on a repeated measures ANOVA with the F statistic calculated by dividing the Between Subjects Mean Square variance by the Error Mean Square (residual) variance. This F statistic should be statistically significant i.e. there should be differences between the subjects in this situation. The ICC is then calculated with a 95% confidence interval using the following formula:

$$ICC(2,1) = \frac{BMS - EMS}{BMS + (k-1) + k(RMS - EMS)/n}$$

where k = number of raters (or tools), n = number of subjects, BMS = Between Subjects Mean Square, RMS = Between Raters Mean Square and EMS = Error Mean Square or residual (96). Although there are various categories in use, there are a number of guidelines suggesting ICC values of 0.90 – 1.00 be considered excellent, 0.75 – 0.89 good, 0.50 – 0.74 moderate, and below 0.50 poor (197). The 95% confidence intervals were also reported for each ICC to provide further information on the precision of the value. The ICC values and their confidence intervals were both the used to make these determinations so we could be confident that the ICC values would fall in the determined range 95% of the time (197, 198).

2. Pearson Correlation Coefficients (r)

As the most commonly reported measure of correlation is the Pearson correlation coefficient (r), this measure was included in this thesis to allow comparison with previously published studies (96). This measure provides an indication of covariance between the measurement tools. With a strong, positive relationship, you would expect high mean values from both measurement tools. Conversely, in strong, negative relationships, you would expect high mean values from one measurement tool and low mean values from the other measurement tool. In weak relationships, there is little consistency in the pattern between the two measurement tools (96).

3. Bland Altman Plots

Statistical analysis using Bland Altman plots was developed in 1986 in response to the need to compare a new measurement technique with an established one to see if the level of agreement is adequate for the new technique to replace the old (199). Bland Altman plots were used in this thesis to provide a visual representation of the difference between the two measurement techniques against the averages of the differences between the two techniques to help identify systematic bias. There are four common patterns of measurement error that may be identified by visual inspection of Bland Altman plots (113). The first pattern occurs when there is high accuracy of both group and individual level data across the spectrum of physical activity. A second pattern is low individual accuracy across the spectrum of the physical activity outcomes. A third pattern is constant systematic error of the tools, i.e. the tool consistently under or overestimates the physical activity values compared to the other tool. The fourth pattern occurs with systematic error related to the value of the physical activity outcome; i.e. systematic error may change as the physical activity outcomes increase in value (113). Limits of agreement were set at the mean difference ± 1.96 times the standard deviation of the mean, i.e. the 2.5th and 95.5th centiles of differences to include 95% of the data (199).

4. Equivalence Testing

Equivalence testing using the two one-sided test (TOST) procedure is a third statistical analysis that was used to calculate the level of agreement between EEs, time spent and step counts obtained by each of the measurement tools. This test provided additional information as this analysis allowed the statistical examination of whether these measurement tools were significantly equivalent to each other rather than the typical hypothesis testing of testing for a significant difference (200). The TOST procedure is used to statistically reject the presence of effects large enough to be determined significant or worthwhile (201).

5. Alternate Method of Equivalence Testing

Based on previous literature and statistical precedence, an alternate method of equivalence testing was also used specifying an error zone of 10% (202). Using a 95% equivalence test the estimate, the Fitbit or CHAMPS questionnaire, was considered to be equivalent to the reference standard, the SWA, if the 90% confidence interval for the mean of the estimated EE falls into the equivalence zone of ± 10% of the mean of the criterion measured EE (202).

Appendix E Sample Size and Power

A sample size of 55 was chosen for the validity study based on sample size and power calculations and previous literature (128, 203). The PASS sample size software was used to estimate the appropriate sample size with 80% power and 2 measurement tools for an ICC(2,1), as demonstrated below in the PASS software output report (204). Even with the conservative estimate of an observed ICC of 0.5, 53 subjects would be an adequate sample size for 80% power. Using the less conservative estimate of 0.6 as an estimate of ICC, the required sample size decreases to 27 subjects. A sample size of 55 would also compensate for the possibility of incomplete datasets. This sample size was similar to those in other validation studies of physical activity monitors (203).

PASS Software Report for Sample Size Calculation:

Intraclass Correlation Analysis

Numeric Results

Power	N Number of Subjects	K Observations Per Subject	ρ0 Intraclass Correlation 0	ρ1 Intraclass Correlation 1	Alpha	Beta
0.80152	53	2	0.20000	0.50000	0.05000	0.19848
0.90123	73	2	0.20000	0.50000	0.05000	0.09877
0.80011	27	2	0.20000	0.60000	0.05000	0.19989
0.90029	37	2	0.20000	0.60000	0.05000	0.09971
0.81734	16	2	0.20000	0.70000	0.05000	0.18266
0.90340	21	2	0.20000	0.70000	0.05000	0.09660
0.80232	9	2	0.20000	0.80000	0.05000	0.19768
0.92081	13	2	0.20000	0.80000	0.05000	0.07919

References

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Report Definitions

Power is the probability of rejecting a false null hypothesis. It should be close to one.
N is the number of subjects.
K is the number of observations per subject in the sample.
ρ0 is intraclass correlation assuming the null hypothesis.
ρ1 is intraclass correlation assuming the alternative hypothesis.

Alpha is the probability of rejecting a true null hypothesis. It should be small.
Beta is the probability of accepting a false null hypothesis. It should be small.

Summary Statements
A sample size of 53 subjects with 2 observations per subject achieves 80% power to detect an intraclass correlation of 0.50000 under the alternative hypothesis when the intraclass correlation under the null hypothesis is 0.20000 using an F-test with a significance level of 0.05000.

Appendix F. CHAMPS Physical Activity Questionnaire (26)

(Reprinted with permission: Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS physical activity questionnaire for older adults: outcomes for interventions. Med Sci Sports Exerc. 2001;33(7):1126-41.)

CHAMPS Activities Questionnaire for Older Adults

CHAMPS: Community Healthy Activities Model Program for Seniors, Institute for Health & Aging, University of California San Francisco and Stanford Center for Research in Disease Prevention, Stanford University

This questionnaire is about activities that you may have done in the past 4 weeks. The questions on the following pages are similar to the example shown below.

INSTRUCTIONS

If you DID the activity in the past 4 weeks:

Step #1 Check the YES box.

Step #2 Think about how many TIMES a week you usually did it, and write your response in the space provided.

Step #3 Circle how many TOTAL HOURS in a typical week you did the activity.

Here is an example of how Mrs. Jones would answer question #1: Mrs. Jones usually visits her friends Maria and Olga twice a week. She usually spends one hour on Monday with Maria and two hours on Wednesday with Olga. Therefore, the total hours a week that she visits with friends is 3 hours a week.

In a typical week during the past 4 weeks, did you…							
1. Visit with friends or family (other than those you live with)? ☒ **YES** How many TIMES a week? 2 ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

If you DID NOT do the activity:

- **Check the NO box and move to the next question**

In a typical week during the past 4 weeks, did you …							
1. Visit with friends or family (other than those you live with)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
2. Go to the senior center? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
3. Do volunteer work? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
4. Attend church or take part in church activities? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
5. Attend other club or group meetings? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
6. Use a computer? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
7. Dance (such as square, folk, line, ballroom) (do <u>not</u> count aerobic dance here)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
8. Do woodworking, needlework, drawing, or other arts or crafts? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
9. Play golf, carrying or pulling your equipment (count <u>walking time</u> only)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
10. Play golf, riding a cart (count <u>walking time</u> only)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
11. Attend a concert, movie, lecture, or sport event? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
12. Play cards, bingo, or board games with other people? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
13. Shoot pool or billiards? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
14. Play singles tennis (do not count doubles)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
15. Play doubles tennis (do not count singles)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
16. Skate (ice, roller, in-line)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
17. Play a musical instrument? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
18. Read? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
19. Do heavy work around the house (such as washing windows, cleaning gutters)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
26. Walk <u>fast or briskly</u> for exercise (do <u>not</u> count walking leisurely or uphill)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
27. Walk <u>to do errands</u> (such as to/from a store or to take children to school <u>(count walk time only)</u>? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
28. Walk <u>leisurely</u> for exercise or pleasure? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
29. Ride a bicycle or stationary cycle? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
30. Do other aerobic machines such as rowing, or step machines (do <u>not</u> count treadmill or stationary cycle)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
31. Do water exercises (do <u>not</u> count other swimming)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
32. Swim moderately or fast? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
33. Swim gently? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
34. Do stretching or flexibility exercises (do <u>not</u> count yoga or Tai-chi)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
35. Do yoga or Tai-chi? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
36. Do aerobics or aerobic dancing? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
37. Do moderate to heavy strength training (such as hand-held weights of <u>more than 5 lbs</u>., weight machines, or push-ups)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
38. Do light strength training (such as hand-held weights of 5 lbs. or less or elastic bands)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
39. Do general conditioning exercises, such as light calisthenics or chair exercises (do not count strength training)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
40. Play basketball, soccer, or racquetball (do not count time on sidelines)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
41. Do other types of physical activity not previously mentioned (please specify)? ____________________ ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

Thank You

Appendix G CHAMPS codebook for EE calculation (26)

(Reprinted with permission: Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS physical activity questionnaire for older adults: outcomes for interventions. Med Sci Sports Exerc. 2001;33(7):1126-41.)

TABLE A1. Codebook for CHAMPS physical activity measures.

Variable Label	Item Nos.	Coding Algorithms
Caloric expenditure/week in all exercise-related activities[a]	7, 9, 10, 14–16, 19–35, 37–40	For each activity 1. Create new duration variables for each activity recoded as follows: 1=0.5, 2=1.75, 3=3.75, 4=5.75, 5=7.75, 6=9.75; if duration variable is not answered, score = 0. Duration is hours/week. 2. For each recoded duration variable, create new weighted duration variable for each activity by multiplying duration variable (no. 1) by corresponding MET value (see Table 2). 3. For each weighted duration variable, create caloric expenditure per week variable for each activity by multiplying weighted duration variable (no. 2) by 3.5 and by 60 (to convert METs/minute to METs/hour) and by (weight in kg/200). 4. Sum caloric expenditure per week variables across activities to create caloric expenditure/week.
Caloric expenditure/week in moderate-intensity exercise-related activities	7, 9, 14–16, 19, 21, 23–26, 29–33, 37, 38, 40	Same as above, subset of activities with MET values ≥3.0.
Frequency/week of all exercise-related activities	7, 9, 10, 14–16, 19–35, 37–40	SUM frequency scores/week for each of the activities (allow those with missing data on frequency to be included in the sum).
Frequency/week of moderate-intensity exercise-related activities	7, 9, 14–16, 19, 21, 23–26, 29–33, 37, 38, 40	SUM frequency scores/week for each of the activities (allow those with missing data on frequency to be included in the sum).

[a] Based on American College of Sports Medicine formula: kcal/min = METs *3.5* (body weight in kg/200). Our formula converts this into kcal/week. *ACSM's Guidelines for Exercise Testing and Prescription*, 5th Ed. Baltimore: Williams & Wilkins, 1995.

Appendix H COACH SWA Patient Instruction

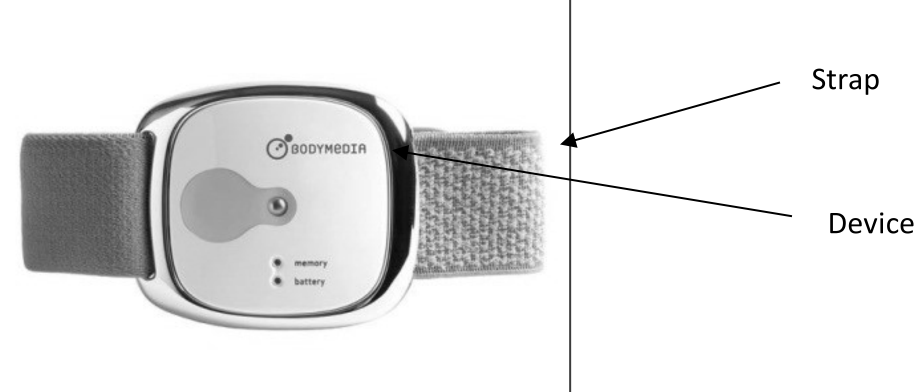
Armband Step-by-Step Instruction

1) We will mail you a package with the armband and you should receive it about 8 weeks after your surgery.

2) When you receive the armband in the mail, please **call xxx** at xxx and leave a message letting her know that you have received the armband and have started to wear it. (You can start wearing the armband immediately – you do not have to wait until you have phoned xxx).

3) Take the armband out of envelope and make sure that it contains the **strap and the device** as shown in Figure 1. Keep the smaller postage paid self-addressed envelope to return the armband after you have worn it for 6 nights (see #8 below).

Figure 1



4) You do not need to do anything else. The device is charged and ready to be worn.

5) Strap the armband so the device is on the back of **your upper left** arm if you are right-handed as shown in Figure 2. If you are left-handed, wear the armband on the right upper arm. It will be worn underneath your clothes.

Figure 2

6) The sensors on the back of the device should always be in contact with your skin. If your arm ever feels uncomfortable or tingly, readjust the strap but **make sure the armband remains in contact with your skin**.

7) Counting the day you put it on, wear the armband for **6 continuous nights and days**. Wear it **all the time** during the day and night (i.e., at work, during exercise, while sleeping).

8) The <u>only</u> times you will remove the armband is when you **shower, bathe or go swimming.** Put it back on after you are dried off. The armband is not waterproof.

9) It is important if you feel any itching, rash or any abnormal skin conditions under the armband, please remove the armband immediately and contact **xxx** at xxx.

10) At the end of the 6th night remove the armband. Place it in the smaller, pre-paid self-addressed envelope you have received as shown in Figure 3. Make sure the armband strap is completely flat.

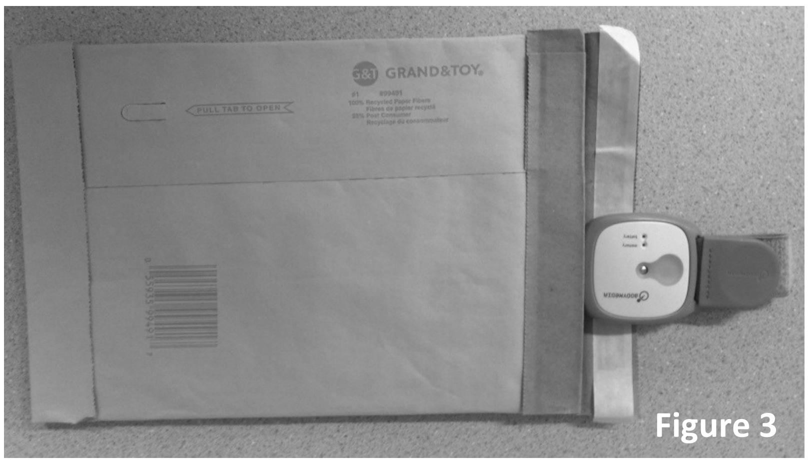


Figure 3

---

11) **Important!**

Fill out the date you put the armband on your body here: X…………………………………….
And the date of last day you have worn it here:

X…………………………………….

Tear off this part of the paper and place it in the envelope. Seal the envelope and **drop the envelope in the mail box.** The postage is **already paid for** and is on the return envelope. Please do not take the envelope to the post office counter as they may ask you to pay more for the postage.

If you have any **questions** please call:

Xxxx
xxxx

Thank you for participating in this study.

Appendix I COACH Fitbit Patient Instruction

Your new Fitbit Alta is going to help track your activity level. Please wear it snuggly, but comfortably around your wrist.

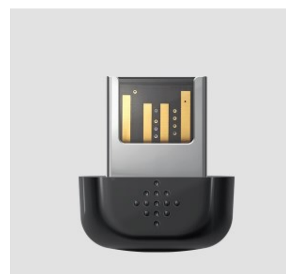
We have already set up your account online.

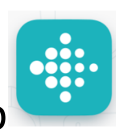
Your username is ______________________

Your password is ______________________. Please do not change your password until after the study is complete.

Your Fitbit data can be download to your Fitbit account in two ways.

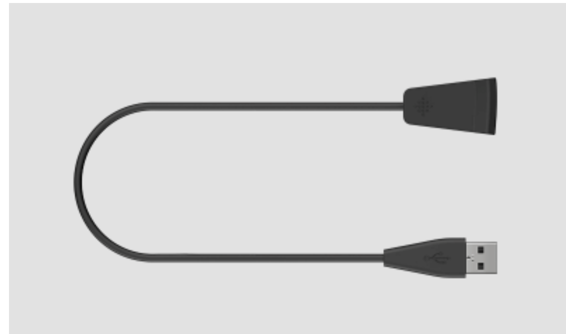
1. This Toggle can be inserted into your home computer to allow the Fitbit to download your data onto your Fitbit profile. Just visit Fitbit.com and login to your account and your data will transfer.



2. Through an App  you can download onto your phone. Once downloaded and your Bluetooth is turned on, you can click on the app and you will see in the upper left-hand corner, two arrows circling (you may have to swipe down to start it). When the download is completed the circles will be replaced by a battery symbol.

   We would ask that you download your data at least once a week.

To charge your Fitbit please insert the charging wire into the back of your Fitbit and the other end into your computer. If you have the proper adapter (from your phone) you can charge by using your adapter and a wall plug. Your Fitbit will need to be charged once every few days. It will also notify you when the batter is getting low. Full charge time takes 1-2 hours.



Your Fitbit is sweat, rain and splash proof. Please take your Fitbit off if you are doing dishes, swimming, bathing or showering.

If you experience itching or a rash please take the Fitbit off and contact us.

Thank you for participating in this study. We hope you enjoy your Fitbit.