Assessing Physical Activity and Sedentary Behaviour Long-Term Post Roux-en-Y Gastric Bypass Surgery

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DEDICATION

To my mother and grandmother, without you this would never have been possible.

ABSTRACT

Over the past 30 years, the prevalence of obesity (BMI $\geq$ 30kg/m^2) in Canada has increased 400 %. Even more concerning, the prevalence of Class III (BMI $\geq$ 40kg/m^2) obesity has increased over 1000 % during the same period. Obesity is associated with type-2-diabetes, cardiovascular disease, depression, and musculoskeletal pain. These co-morbidities collectively cost the Canadian economy $ 4.3 billion per year in healthcare costs and lost productivity at work. Moreover, obesity results in mobility impairments including reduced stride length and slower walking cadence. For individuals living with extreme obesity and a related co-morbidity, bariatric surgery is the preferred treatment option. Bariatric surgery yields dramatic weight loss, resolution of most co-morbidities, reductions in pain, and improvements in physical functioning. Although these alterations are thought to yield more physical activity, to date, no changes in steps per day or sedentary time have been objectively measured from pre- to one-year post-surgery. After surgery, patients fail to meet established physical activity guidelines and begin to show small amounts of weight regain as early as two-years post-surgery.

The first two manuscripts presented in this dissertation focused on evaluating the free-living movement patterns of individuals' long-term post-bariatric surgery (steps, sedentary time, and cadence), and determining if these patterns affect weight regain. It was found that patients do not step enough (6375 $\pm$ 2690 steps/day), are excessively sedentary (9.7 $\pm$ 2.3 hrs/day), and walk at significantly slower speeds on weekends compared to weekdays. As the built environment plays a role in physical activity and sedentary time on a population scale, it became important to assess if these constructs had the same effect on the bariatric population. Therefore, the third and fourth investigations evaluated the effect

of neighbourhood walkability and employment status on physical activity, sedentary time, and weight regain respectively. These investigations proved that the built environment does not affect activity habits or obesity severity in the bariatric population. As substantial weight loss from surgery and aspects of the built environment have failed to promote physical activity and limit sedentary time, it is apparent that self-monitoring in this population is important. Therefore, the final investigation of this dissertation examined the validity of inexpensive, commercially available physical activity monitors against a research-grade accelerometer. This study showed that Fitbit™ activity monitors are effective measurement tools for monitoring daily steps and time spent in light intensity activities. This confirmation allows bariatric surgeons to prescribe these activity monitors with confidence and can help patients self-monitor, meet established physical activity guidelines, and avoid weight regain post-surgery.

This thesis was the first to objectively monitor physical activity and sedentary time long-term post-bariatric surgery. These studies filled important gaps in the literature related to the effects of the built and occupational environments on physical activity, sedentary habits, and weight regain post-surgery. Future studies should evaluate the effectiveness of interventions pre- and post-surgery designed to reduce and break up extended periods of sedentary time, while simultaneously promoting walking through light intensity activities. Interventions should employ the use of inexpensive commercially available activity monitors to improve self-monitoring, which can help individuals to meet established national activity guidelines.

RÉSUMÉ

Au cours des 30 dernières années, la prévalence de l'obésité (IMC $\geq$ 30kg/m^2) au Canada a augmenté de 400%. De plus, la prévalence de l'obésité de classe III (IMC $\geq$ 40kg/m^2) a augmenté de plus de 1000% au cours de la même période. L'obésité est associée au diabète de type 2, aux maladies cardiovasculaires, à la dépression, et aux douleurs musculo-squelettiques. Ces comorbidités ont couté collectivement 4,3 milliards de dollars à l'économie canadienne par année au système de la santé et due à la perte de productivité au travail. De plus, l'obésité entraine des troubles de la mobilité, une réduction de la longueur de l'enjambée, et une cadence de marche plus lente. La chirurgie bariatrique est l'option de traitement préférée pour les personnes vivant avec une obésité extrême. La chirurgie bariatrique entraine une perte de poids spectaculaire, une diminution de la plupart des comorbidités, une réductions de la douleur, et des améliorations du fonctionnement physique. Ces modifications nous font penser que cette population devrait augmenter leur niveau d'activité physique, mais à ce jour, aucun changement mesuré de façon objective avec une identification du nombre de pas par jour ou de temps sédentaire après la chirurgie n'ont été documenté. Après la chirurgie, les patients ne respectent pas les lignes directrices établies sur l'activité physique et commencent à démontrer de petites quantités de récupération de poids dès deux ans après la chirurgie.

Les deux premiers manuscrits présentés dans cette thèse ont porté sur l'évaluation des modes de mouvement de la vie de la chirurgie post-bariatrique à long terme (pas, le temps sédentaire, et la cadence) et déterminent si ces modèles influcent le regain de poids. On a constaté que les patients ne marche pas assez (6375 ± 2690 pas/jour), sont excessivement sédentaires (9.7 ± 2.3 hrs/jour), et se promènent à des vitesses beaucoup

plus lentes le week-end par rapport aux jours de la semaine. Comme l'environnement joue un rôle dans l'activité physique et le temps sédentaire à l'échelle de la population, il est important d'évaluer si l'environnent avait le même effet sur la population bariatrique. Par conséquent, les troisièmes et quatrièmes études ont évalué l'effet de la proximité du quartier et le statut de l'emploi sur l'activité physique, le temps sédentaire et le regain de poids respectivement. Ces recherches ont prouvé que l'environnement n'affecte pas les habitudes d'activité ou la sévérité de l'obésité dans la population bariatrique. Comme la perte de poids après la chirurgie et les aspects de l'environnement n'ont pas favorisé l'activité physique et ont limité le temps sédentaire, il est évident que l'auto-contrôle de cette population est important. Par conséquent, l'étude finale de cette thèse a examiné la validité des moniteurs d'activité physique disponibles sur le marché contre un accéléromètre de recherche. Cette étude a montré que les moniteurs d'activité « Fitbit™ » sont des outils de mesure efficaces pour surveiller le nombre de pas quotidien et le temps consacré à des activités d'intensités légères. Cette confirmation permet aux chirurgiens bariatriques de prescrire ces moniteurs d'activités en toute confiance et peuvent aider les patients à s'auto-surveiller, respecter les lignes directrices établies sur l'activité physique et éviter le regain de poids.

Cette thèse a été la première à surveiller l'activité physique mesurée de manière objective et le temps sédentaire à long-terme après la chirurgie bariatrique. Ces études ont relevé des lacunes importantes dans la littérature liées aux effets de l'environnement lors de leur loisirs et lors de leur travail, les habitudes sédentaires, et le regain de poids après la chirurgie. Les prochaines études devraient évaluer l'efficacité des interventions pré- et post-chirurgicales destinées à réduire et à éliminer les périodes prolongées de temps sédentaires, tout en favorisant simultanément la marche à travers les activités d'intensités légères. Les interventions devraient utiliser des moniteurs d'activité disponibles sur le marché pour améliorer l'auto-contrôle, ce qui peut aider à respecter les lignes directrices nationales établies en matière d'activités.

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BMI: Body Mass Index

MVPA: Moderate to Vigorous Physical Activity

CV: Coefficient of Variation

Kg: Kilogram

MET: Metabolic Equivalent

RYGB: Roux-en-Y gastric bypass

LRYGB: Laparoscopic Roux-en-Y gastric bypass

LSG: Laparoscopic Sleeve Gastrectomy

AGB: Adjustable Gastric Band

M: Mean

SD: Standard Deviation

LAGB: Laparoscopic Adjustable Gastric Band

GPS: Global positioning system

Hz: Hertz

CPM: Counts Per Minute

G: Grams

CM: Centimeter

CO_2: Carbon dioxide

SES: Socio-Economic Status

HDL: High-Density Lipoprotein

LDL: Low-Density Lipoprotein

ASMBS: American Society for Metabolic and Bariatric Surgery

F: French

ATP: Adenosine tri-phosphate

DXA: Dual-Energy X-Ray Absorptiometry

MRI: Magnetic Resonance Imaging

CT: Computed Tomography

PCr: Phosphocreatine

NSAID: Non-Steroidal Anti-Inflammatory Drug

C-PAP: Continuous Positive Airway Pressure

EBW: Excess Body Weight

CC: Cubic Centimeter

PREFACE

This dissertation presents work carried out in order to determine the physical activity and sedentary habits of individuals long-term post-bariatric surgery. Pre-surgery, patients demonstrate limited mobility, low levels of physical activity [1], and sedentary time that is meaningfully higher than the national average [2,3]. In the short-term post-surgery, patients report higher levels of physical activity and reductions in sedentary time [4]. Unfortunately, even though there is substantial weight loss and improvements in physical functioning [5], objective monitoring shows no changes in physical activity or sedentary time three, six, and 12 months following surgery [4]. If these habits are not altered the risk of weight regain post-surgery is dramatically increased. A recent review has shown that, on average, small amounts of weight regain start to occur as early as two years post-surgery [6]. As regular daily physical activity is a cornerstone of weight loss maintenance, it is important to investigate the effects of the built environment on these outcomes in the bariatric population. Pre-surgically, bariatric patients report lower levels of employment [7], primarily due to extended sick leave from obesity related co-morbidities. As such, it is important to not only investigate the effect of employment status on physical activity, sedentary time, and weight regain, but also neighborhood walkability as many patients may still be spending the majority of their week day time at, or near their homes. The knowledge gained from these analyses may give rise to more informed methods of intervening in this population pre- or in the short-term post-surgery to improve daily activity, as well as reduce overall and promote breaks in sedentary time in order to avoid the weight regain seen in the long-term post-surgery.

Dissertation Organization and Overview

The format of this dissertation follows McGill University's guidelines for manuscript style according to the Office of Graduate and Postdoctoral Studies. The dissertation is partitioned into five main chapters preceded by a short introduction that offers a brief overview of the rationale and objectives for this doctoral work. Chapter 1 summarizes the scientific literature on obesity and associated health outcomes, weight loss techniques, bariatric surgery results in the short-, medium-, and long-term, assessment of physical activity and sedentary time, and the effects of employment status and neighborhood walkability on these factors.

Chapter 2 consists of two manuscripts: Manuscript 1, entitled Physical Activity and Sedentary Behavior in Bariatric Patients Long-Term Post-Surgery, published in the Obesity Surgery journal; and Manuscript 2, entitled Walking Cadence Among Bariatric Patients Long-Term Post Roux-en-Y Gastric Bypass. The results of these investigations determined the physical activity and sedentary behaviour (Manuscript 1); and the cadence patterns, (Manuscript 2) of individuals long-term post-RYGB.

Chapter 3 consists of two manuscripts: Manuscript 3, entitled Effects of Neighborhood Walkability on Physical Activity and Sedentary Behavior Long-Term Post-Bariatric Surgery, published in the Obesity Surgery journal, and Manuscript 4, entitled Effect of Employment Status on Physical Activity and Sedentary Behavior Long-Term Post-Bariatric Surgery, under revisions at the Obesity Surgery journal. The results of these investigations determined how physical activity and sedentary behaviour were affected by neighborhood walkability (Manuscript 3); and employment status, (Manuscript 4) in individuals long-term post-RYGB.

The results from the first four manuscripts presented in this dissertation indicated that long-term post-surgery, patients are not stepping enough, sitting too much, and regaining weight that was initially lost post-surgery. These studies also indicated that neighborhood walkability and employment status do not influence these measures as they typically do in the national population. It became clear that behavioural interventions would be necessary to improve physical activity and reduce sedentary time in this population. Research has shown that self-monitoring can be helpful in meeting daily recommended levels of activity [8]. However, the most popular and affordable personal activity monitor, Fitbit, had yet to be validated for use in the free-living environment. Therefore, in Chapter 4, consisting of Manuscript 5, entitled Validity and reliability of Fitbit activity monitors compared to ActiGraph™ GT3X+ with female adults in a free-living environment, published in the Journal of Science and Medicine in Sport, the validity of these devices was investigated.

Chapter 5 provides a summary and conclusions of the dissertation in which the results are discussed in relation to clinical implications, the role of kinesiologists in pre- and post-bariatric care, as well as future research directions. The limitations and strengths of this doctoral project are also discussed in this chapter.

Contribution of Co-Authors

For all five manuscripts (Chapter 2 to 4), the candidate conceptualized the research questions, was involved in the data collection process, performed all statistical analyses, and wrote the manuscripts with feedback provided by Dr. Ross Andersen (supervisor). The candidate proposed all original ideas and was responsible for the quality of the research and reporting. All materials presented in the dissertation have not been published elsewhere except where specific references indicate. Dr. Andersen oversaw all aspects of the research project and provided expertise and input into the development of the research protocol and publications. His laboratory provided the necessary equipment to conduct the research. Tamara E Carver, Tyler GR Reid, Kathleen M Andersen, Katerina Jirasek, Charlotte D Haugan, and Mare-Aude Picard-Turcot provided technical support for data collection and helped with the writing of the publications for Manuscripts 1 – 4. Jessica A Insogna, Nicole A Bewski, Cristina Sciortino, and Andrea M Comptour provided technical support for data collection and helped with the writing of the publication of Manuscript 5. All patients were recruited from the Bariatric Surgery Department of the MUHC and Drs. Court and Christou were instrumental in this collaboration. They provided feedback on the preparation of the manuscripts as well.

Statement of Originality

This doctoral work contributes to the research literature and knowledge base in several ways. To date, no other study has objectively monitored the physical activity and sedentary behaviour of patients long-term post-surgery. This information provides surgeons with much needed information concerning the activity patterns of their patients. Secondly, no studies have evaluated the effects of neighborhood walkability or employment status on physical activity, sedentary time, or weight regain in this population. This information is vital to urban planners who design neighborhoods to be more walkable and employers who are seeking information on how to improve the working environment of their workers who are living with obesity. Finally, this doctoral work provided the first known study to validate the Fitbit activity monitor against a research grade activity monitor (ActiGraph™) on steps, sedentary time, and time spent in light, moderate, and vigorous intensities of activity in free-living conditions. This information is crucial for physicians who can now prescribe personal activity monitors to patients in order to help them self-monitor and avoid weight regain long-term post-surgery. All data presented in this dissertation were collected at the Department of Kinesiology, McGill University, Montréal, Québec.

Publication List

1. **Ryan ER Reid**, Tamara E Carver, Tyler GR Reid, Marie-Aude Picard-Turcotte, Kathleen M Andersen, Nicolas V Christou, Ross E Andersen. (2016). Effects of Neighborhood Walkability on Physical Activity and Sedentary Behavior Long-Term Post-Bariatric Surgery. *Obesity Surgery*. 27(6): 1589-1594.

2. **Ryan ER Reid**, Jessica A Insogna, Tamara E Carver, Andrea M Comptour, Nicole A Bewski, Cristina Sciortino, Ross E Andersen. (2016). Validity and reliability of Fitbit activity monitors compared to ActiGraph GT3X+ with female adults in a free-living environment. *Journal of Science and Medicine in Sport*. 20(6): 578-582

3. **Ryan ER Reid**, Ekaterina Oparina, Hugues Plourde, Ross E Andersen. (2016). Energy Intake and Food Habits between Weight Maintainers and Regainers, Five Years after Roux-en-Y Gastric Bypass. *Canadian Journal of Dietetic Practice and Research.* 77: 195-198.

4. Olivier Babineau, Tamara E Carver, **Ryan ER Reid**, Nicolas V Christou, Ross E Andersen. (2015). Objectively Monitored Physical Activity and Sitting Time in Bariatric Patients Pre- and Post-Surgery. *Journal of Obesity and Bariatrics.* 2(2): 1-5.

5. **Ryan ER Reid** and Ross E Andersen. (2015). Affordable Activity Monitors Can Improve Post-Surgical Care in Bariatric Surgery Patients. *Anaplastology*. 4(1): 1-3.

6. **Ryan ER Reid,** Tamara E Carver, Kathleen M Andersen, Olivier Court, Ross E Andersen. (2015). Physical Activity and Sedentary Behavior in Bariatric Patients Long-Term Post-Surgery. *Obesity Surgery*. 25(6): 1073-7.

Introduction

From 1981 to 2015, the prevalence of Canadians living with obesity (defined as a BMI > 30 kg/m^2) has more than doubled (13 to 28.1 % respectively) [9]. More concerning is the increasing prevalence of Class III obesity (defined as a BMI > 40 kg/m^2) that has increased by over 1000 % from baseline in the past 25 years (1990 to 2015) [10-12]. Severe obesity is associated with a greater risk of morbidity and mortality from chronic health conditions such as type-2-diabetes [13], cardiovascular disease [14], and hypertension while also associated with physical disability [15], and poorer quality of life [16]. The ever-increasing obesity epidemic has led to a search for more effective methods of immediate weight loss as well as successful long-term weight loss maintenance. Diet, exercise, behavioural, and pharmacological therapies have been largely ineffective at treating severe obesity in the long-term. As a result, individuals living with severe obesity are increasingly looking to weight loss surgery as their optimal treatment option.

Bariatric (weight loss) surgery reduces the size of an individual's stomach and in some instances will also bypass a portion of the small intestine resulting in the reduction of calories absorbed into the body [17]. Globally, the total number of bariatric procedures in 2011 was 340,768 performed by 6,705 bariatric surgeons [18]. More specifically, in Canada, the number of bariatric surgeries performed annually has increased over 90 % since 2004 [19]. This surgery not only results in weight loss but also improvements in obesity-related comorbidities and mortality [20]. The peak of this weight loss typically occurs between 12 to 18 months and levels off by two years post-surgery. Unfortunately, some patients experience weight regain and the return of co-morbidities long-term post-surgery (five years or more post-surgery) [6].

Rationale

Over the past decade, the assessment of physical activity and sedentary behaviour has improved with new equipment and advances in technology making it easier and less expensive to perform these analyses. Still, the bariatric literature continues to focus on physical activity either before or in the short-term following surgery, rarely investigating further. Even though there is dramatic weight loss immediately after surgery, physical activity and sedentary time remain relatively unchanged [21]. Bariatric experts note that regular physical activity is essential for long-term weight loss maintenance [22]; however this extended follow-up remains non-existent in the literature. In addition, research consistently shows weight regain beginning as early as two years post-surgery [6], still with no appreciable increases in physical activity or reductions in sedentary time. Therefore, it is crucial that the physical activity and sedentary habits of individuals long-term post-surgery be investigated and to determine how these habits are impacting their weight regain.

Research has shown that for individuals living with obesity, integrated lifestyle activity is more effective for weight loss maintenance compared to a structured aerobic exercise regime [23]. There are numerous lifestyle factors that affect the daily physical activity levels of normal weight individuals, including but not limited to neighborhood walkability, employment status, and job-type. Since bariatric patients report different barriers to physical activity compared to the normal weight population [24], show a history of low activity levels [1], and high sedentary time [2], it seems necessary to determine how these commonly encountered factors affect the daily physical activity and sedentary habits of this unique population.

Problem Statements

One goal of bariatric surgery is to reduce weight in order to improve physical function and in theory, improve patients' ability to be more active. With dramatically rising numbers of bariatric surgeries being performed each year, it is increasingly important that we understand these changes in activity and sedentary time. In order to detect longitudinal changes, it is critical to be able to objectively assess these habits. This doctoral work will provide a better understanding of how bariatric surgery interacts with physical activity and sedentary time in the long-term and may also inform policy changes for pre-surgical care. This series of proposed investigations will address gaps in the literature:

1) Physical activity and sedentary time both independently affect weight gain, risk of morbidity, and mortality [25]. National recommendations for physical activity and sedentary time exist to provide a clear goal for individuals to meet and promote optimal health [26]. Individuals who undergo bariatric surgery are at risk of weight regain if their habits remain unchanged post-surgery [6]. Currently there are no studies in the literature assessing the weight regain, physical activity, sedentary habits, or their association with each other long-term post-surgery. It is important to understand how steps, cadence, sedentary time, and adherence to national recommendations impact weight regain long-term post-surgery in order to better understand how to intervene pre-surgically and avoid weight regain completely.
2) Integrated lifestyle physical activity and sedentary time can be influenced by a multitude of factors. Two factors that affect most individuals living in North America are the neighborhood in which they reside in and their occupation. Neighborhood walkability is a construct which encourages changes in the built

environment to allow domiciles to be located within a convenient walking distance, allowing more tasks to be completed on foot (e.g. retail, education, transport, etc.) yielding an increase in overall physical activity mostly from active transport and not structured exercise [27]. The normal weight population emphasizes a lack of time as a major barrier to physical activity and therefore it is logical that by improving neighborhood walkability, which decreases the time required to perform tasks through active transport, will yield improvements in physical activity [28]. As individuals who have undergone bariatric surgery report pain during movement as a major barrier to physical activity [24] it is important to determine if neighborhood walkability is affecting their habits in the same way as the normal weight population. For the typical North American middle aged population, time spent engaged in occupational activities represents approximately one-third to half of an individual's waking time [29]. Therefore, occupation status plays a major role in daily physical activity and sedentary habits. As extreme obesity is associated with extended medical leave and unemployment, it is important to determine how occupation is affecting their daily lifestyle activity and sedentary habits, and how these trends may be affecting their weight regain long-term post-surgery.

3) Research has consistently shown that daily self-monitoring of weight and physical activity will lead to improved health and better long-term weight maintenance. However, it can be difficult to accurately perceive one's personal physical activity level or sedentary time [30]. This is especially true for individuals who have undergone bariatric surgery and who have never been consistently active throughout their lives. Pedometers are an inexpensive method of assessing steps

per day. However, these devices have limited reliability and are incapable of monitoring different intensities of physical activity or sedentary time. Another drawback of pedometers is that they are incapable of storing activity data, making it difficult for the novice exerciser to keep track of their activity over time. Recently there has been an emergence of inexpensive commercially available activity monitors which claim to be able to monitor steps, sedentary time, as well as time spent in light, moderate, and vigorous intensity activities likewise to research-grade accelerometers which were used to develop current national physical activity guidelines. It is crucial to determine if these commercially available monitors are indeed as accurate as research monitors and whether or not they can be prescribed to bariatric patients as a means of accurately monitoring and logging their daily activity over time.

General Aim and Research Framework

The overall purpose of this doctoral work was to explore the physical activity and sedentary behaviour of individuals long-term post-bariatric surgery. This dissertation consists of five investigations that addressed components related to the overall purpose. The first two investigations objectively determined the physical activity, cadence, and sedentary time of this population. This information allows researchers and clinicians to understand how these variables change cross-sectionally from pre- to short-term, and now, crucially, long-term post-surgery (Specific Aims 1 and 2). The third and fourth investigations explored how environmental factors such as neighborhood walkability (Specific Aim 3) and occupation (Specific Aim 4) affected the physical activity, sedentary time, and weight regain in this population. These investigations provided researchers with information concerning how a post-bariatric population reacts to their living environment and how that response differs from the non-bariatric population. This information can be used to better tailor changes in their living and working environments to better suit the population-specific needs and barriers to physical activity. The fifth investigation demonstrated the validity of an inexpensive activity monitor compared to a research-grade accelerometer (Specific Aim 5). Findings from this investigation proved that these monitors can provide similar activity monitoring compared to research devices. Doctors treating individuals considering bariatric surgery can safely recommend these monitors as a means of quantifying and tracking their patients' activity levels which should promote better weight loss maintenance post-surgery. The data for these investigations were collected from bariatric patients of the McGill University Health Centre in Montreal, Quebec, Canada. The specific aims and hypotheses for each investigation are addressed below.

Primary Aims and Hypothesis

Primary Aim of Study # 1:

To objectively measure the sedentary behaviours and physical activity of individuals long-term post-Roux-en-Y Gastric Bypass (RYGB) surgery and to determine if they are meeting national physical activity guidelines that would promote favorable long-term weight loss maintenance.

Hypothesis of Study # 1:

Individuals long-term post-RYGB will not be meeting national physical activity guidelines.

Primary Aim of Study # 2:

To objectively examine the cadence of individuals long-term (≥ five years) post-RYGB, and determine how time in different cadence bands will relate to body composition, weight re-gain, and sedentary time.

Hypothesis of Study # 2:

Participants who spend more time in higher cadence bands will have a lower body fat percentage, have regained less weight, and be less sedentary.

Primary Aim of Study # 3:

To investigate the effects of neighborhood walkability on weight regain, physical activity, and sedentary behaviour in a group of individuals long-term (≥ five years) post-RYGB.

Hypothesis of Study # 3:

Participants living in more walkable neighbourhoods will be more active, less sedentary, and have regained less weight than those living in less walkable neighbourhoods.

Primary Aim of Study # 4:

To explore the influence of employment status on the daytime sedentary and physical activity habits of individuals long-term (≥ five years) post-RYGB.

Hypothesis of Study # 4:

Participants who are employed will be less sedentary and more active compared to those who are unemployed.

Primary Aim of Study # 5:

To compare the accuracy of the Fitbit™ Flex and Fitbit™ One activity monitors in measuring sedentary time, step-count, and time spent in different intensities of activity against the previously validated ActiGraph™ GT3X+ tri-axial accelerometer.

Hypothesis of Study # 5:

There will be differences between the ActiGraph™ and Fitbit™ activity monitors in the measurement of time spent in all intensities of activities and all Fitbit devices will provide similar monitoring.

Methodology:

This section will describe the quantitative approaches used commonly across the five investigations that make up this doctoral thesis. In the following paragraphs, we will describe the research design, recruitment process, inclusion and exclusion criteria, as well as the procedures and tools used to accomplish our goals.

Research Design

In order to characterize the physical activity and sedentary behaviours of individuals long-term post-bariatric surgery, we enlisted the help of Montreal-based bariatric surgeons (Dr. Nicolas V Christou and Dr. Olivier Court) who put our research team in contact with patients who they had operated on between 1996 and 2011.

Recruitment Procedure, Inclusion, and Exclusion Criteria

Working on behalf of their surgeon, patients were contacted by telephone and were asked to complete a long-term post-bariatric surgery follow-up questionnaire. Those who were interested in taking part in our additional study then visited our laboratory located at the McGill University downtown campus. To participate in this study, all participants had to have undergone RYGB surgery at the McGill University Healthcare Centre (MUHC), between 1996 and 2011. As our main measure of interest was physical activity, only ambulatory patients (able to walk on their own without the need of a cane or other walking aid) were eligible to participate in this study. Also, women who were pregnant or breastfeeding were excluded due to the potentially harmful effects of radiation produced by the body composition assessment technique described below. The protocol was reviewed and approved by the Medical Institutional Review Board of McGill University and all participants provided informed consent.

Eligible candidates reported to the McGill University Health and Fitness Promotion Laboratory where the nature, purpose, and risks of the investigation were described to participants and written informed consent was obtained prior to the start of assessment. Next, anthropometric measures were taken, and participants were outfitted with the ActivPAL™ activity monitor. Participants were not financially compensated for their part in this study, but were provided with free parking, as well as detailed reports of their physical activity, sedentary behaviour, and body composition.

Assessment of Anthropometric Measures and Body Composition

Height was measured to the nearest one cm using a Seca™ 216 wall-mounted stadiometer and weight was assessed to the nearest tenth kilogram using a Seca™ 635 platform bariatric scale (Seca, Birmingham, UK). Body mass index was calculated as the participant's weight in kilograms divided by their height in meters squared (kg/m^2). Body composition was obtained using a Dual energy X-ray Absorptiometry (DXA) scanner (Figure 1) equipped with a large scanning area (198 cm × 66 cm) capable of accommodating participants weighing up to 200 kg (Lunar iDXA; GE Healthcare™). A single technician was responsible for testing and calibration of the iDXA using a GE Lunar calibration phantom prior to each scan. DXA provides both total body and regional measures of fat tissue mass, lean tissue mass, fat percentage, as well as visceral adiposity. A complete description of the DXA scanning process has been previously described [31]. All assessments were performed in lightweight indoor clothing without footwear. Pre-surgery weight and nadir (lowest) post-surgical weight were both reported by the surgeon through detailed notes kept for each pre- and post-surgical follow-up visit. Weight change was calculated as percent weight regain: [(current weight– nadir weight) / (pre-surgery weight – nadir weight)] * 100.

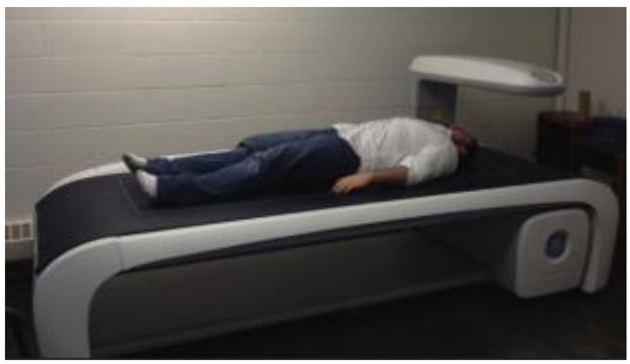


Figure 1. Lunar iDXA™ (Dual Energy X-Ray Absorptiometry (DXA), GE Healthcare™, USA)

Physical Activity and Sedentary Behaviour Monitoring

Objective assessments of physical activity and sedentary behaviour were obtained using the ActivPAL™ tri-axial accelerometer (Figure 2) (PAL Technologies Ltd., Glasgow, UK). The ActivPAL™ is a small (53 mm x 35 mm x 7 mm, weighing only 15 g) wearable accelerometer programmed to classify an individual's free living-activity into: sitting/lying time, standing time, stepping time, measure the number of transitions from seated to standing as well as the number of steps taken.

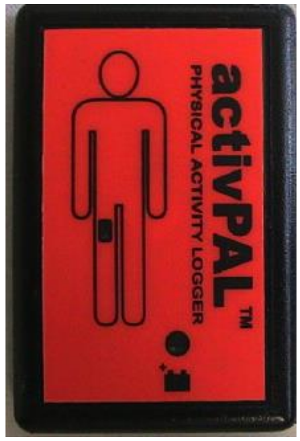


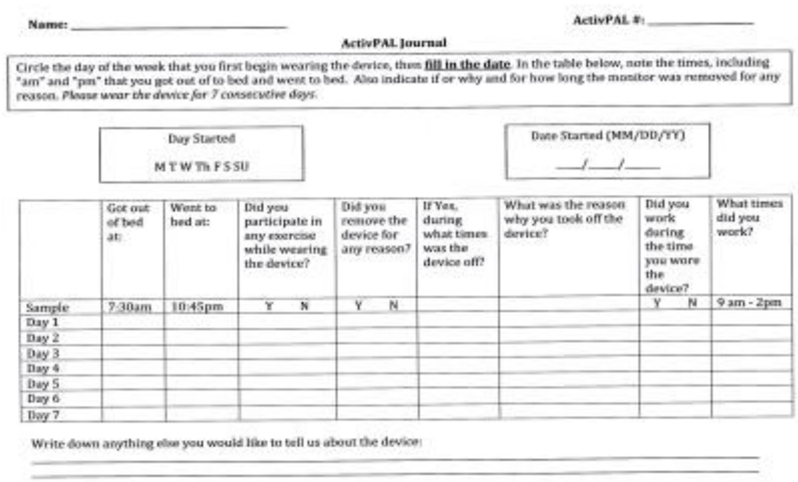
Figure 2. Physical activity monitor ActivPAL™

This device detects limb position using an accelerometer that samples at 10 Hz over a specified period or epoch (i.e. 15 seconds). This activity monitor has been validated and is reliable to evaluate physical activity and sedentary behaviours [32]. On-board monitor battery charging, initialization, and data transfer are facilitated through a USB cable connected to a computer.

During the laboratory visit, the ActivPAL™ was placed inside a latex sleeve and then affixed on the participant's mid-thigh using a Tegaderm™ adhesive patch making the unit water and sweat resistant (Figure 3). This type of attachment method allowed participants to wear the device 24 hours per day. They were asked to remove the unit only upon bathing or any other prolonged underwater activity, but not for showering as the device is sufficiently water resistant for this task. The unit was set to begin recording at midnight the day following placement in the laboratory.

Figure 3. ActivPAL^{TM} affixed to participant's leg in Tegaderm^{TM} adhesive

Participants were also given a wear time journal (Figure 4) to be used for the duration of the wear period in order to help differentiate between day sedentary time and sleeping time and whether or not the participant removed the device for any reason. Moreover, the wear-time journal asked if and during what hours the participant worked during their wear-period.



Name: ______________________ ActivPAL #: ____________

ActivPAL Journal

Circle the day of the week that you first begin wearing the device, then **fill in the date**. In the table below, note the times, including "am" and "pm" that you got out of to bed and went to bed. Also indicate if or why and for how long the monitor was removed for any reason. *Please wear the device for 7 consecutive days.*

Day Started

M T W Th F S SU

Date Started (MM/DD/YY)

___/___/___

	Got out of bed at:	Went to bed at:	Did you participate in any exercise while wearing the device?	Did you remove the device for any reason?	If Yes, during what times was the device off?	What was the reason why you took off the device?	Did you work during the time you wore the device?	What times did you work?
Sample	7:30am	10:45pm	Y N	Y N			Y N	9 am - 2pm
Day 1								
Day 2								
Day 3								
Day 4								
Day 5								
Day 6								
Day 7								

Write down anything else you would like to tell us about the device:

Figure 4. Wear-time journal

Following the seven-consecutive day wear-period, the unit was returned via a prepaid envelope or picked up at the participant's residence by courier and delivered to the McGill University Health and Fitness Promotion Laboratory. The accelerometer data was extracted using ActivPAL™'s proprietary software, version 17.18.1, and saved in 15 second epochs for each participant's seven day wear period. A valid day was considered to be at least 20 hours of wear time (including sleep), and a valid wear period was four to six days including at least one weekend day [33]. The ActivPAL™ data and self-reported wear time journal information were entered into a MATLAB™ computer program that used this information to effectively isolate the day wear-time from the 24 hour per day accelerometer recordings. This step is necessary given that the ActivPAL™ software is not capable of distinguishing between day time sedentary behaviors and sleeping time which are both automatically classified as sedentary time by their software. Data was further separated by week day and weekend day in order to better understand participant behaviour.

Statistical Considerations & Power Analysis

For further information regarding statistical analysis and power calculations, please see the methodology section of each of the corresponding five following manuscripts. Each manuscript has specific aims, statistical tests, and target variables which will influence their power analysis.

1.0 CHAPTER 1: LITERATURE REVIEW

1.1 OBESITY

1.1.1 Prevalence, Comorbidities, and Health Outcomes

Obesity is the presence of excess body fat resulting in an elevated risk of developing several other medical conditions which increase morbidity and mortality. There are metabolic consequences such as the development of type-2-diabetes [34], cancer [35], dyslipidemia, and high cholesterol leading to cardiovascular disease. There are physical consequences such as severe osteoarthritis which leads to great pain during movement [36]. Also, there are psychological consequences such as the presence and severity of depression and anxiety. Together these health consequences not only reduce lifespan but also dramatically reduce quality of life.

Although obesity has a clear and robust relationship with the aforementioned co-morbidities, it is important to consider that obesity can be classified in a multitude of ways. The most commonly employed form of obesity measurement is the body mass index (BMI). This is a simple and inexpensive method of assessing disease risk associated with weight. Body mass index is calculated by dividing an individual's body weight (kilograms) by their squared height (meters). Based on the number obtained from this equation, an individual can either be categorized as normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), class I obese (30 to 34.9 kg/m^2), class II obese (35 to 39.9 kg/m^2), and class III obese ($\geq$ 40 kg/m^2). Body mass index is widely used to assess an individual's risk of developing co-morbidities associated with obesity [11]. The greater the category of obesity, the greater the risk of developing an obesity related co-morbidity. Analysis of Canadian Community Health Survey data reveals associations between excess weight and high blood pressure, diabetes, and heart disease. In 2004, fewer than 10 % of men and women whose BMI was in the normal range reported having high blood pressure. The figure rose to just over 15 % among those who were overweight, and to more than 20 % among those who were classified as obese [37]. Even when age, marital status, education, household income, smoking status, and leisure-time physical activity were taken into account, excess weight was strongly associated with reporting high blood pressure. Just 2.1% of men whose BMI was in the normal range reported having diabetes; 3.7 % among overweight men, and increased to 11% among those who were classified as obese [37]. This pattern was similar for women, and even when the effects of the other factors were taken into consideration, men and women who were classified as obese had significantly higher odds of reporting diabetes. The prevalence of heart disease increased with BMI among men. While 2.8 % of men with a normal BMI reported having heart disease, 6.0 % overweight, and almost 8 % among those who were classified as obese reported living with heart disease [37].

Other commonly used anthropometric measures of obesity are waist circumference and the waist to hip ratio. This technique is widely used since it is inexpensive, requiring just a measuring tape, and is simple to conduct with little training required. Another benefit is that results are easy to interpret, for men, ≥ 94 cm waist circumference or a waist to hip ratio of 1.02 signifies that the individual is at an increased risk of developing co-morbidities and for women ≥ 80 cm, and ≥ .88 respectively [38]. Although BMI, waist circumference, and waist to hip ratio are generally effective in determining one's risk of obesity-related co-morbidities, this may not be the case for all individuals. Body mass index does not truly measure body composition, therefore, an individual with high levels of lean mass (but also a low body fat percentage), such as an athlete, may be erroneously classified [39,40]. To address this ambiguity, disease risk can be more accurately assessed using total body fat percentage. Although body fat percentage is the preferable method employed in assessing disease risk, it is rarely used in population studies as this methodology can be complex and expensive. For example, hydrostatic weighing is not widely used in clinical settings as it requires total submersion under water while it indirectly obtains body fat percentage through body density [41]. Air-displacement-plethysmography, dual X-ray absorptiometry (DXA), magnetic resonance imaging (MRI), and computed tomography (CT) all estimate body fat percentage; however, these methods are not commonly used because of their high costs and requirement of trained technicians [42,43]. As each assessment technique measures adiposity slightly differently, it is important to consider which type of assessment is used when comparing important research, as well as for patient diagnosis in a clinical setting.

It is projected that by the year 2030, almost 60 % of the global adult population will be overweight or obese, about double the estimated prevalence of 2005 [44]. Moreover, in Canada, only 34.2 % of the population is classified as normal weight, down from 37.6 % in 2011[12], and 48 % in 2004 [10]. In Canada specifically, high costs to the health care system and insurance claims due to obesity costs the Canadian economy 4.3 Billion CAD per year. In essence obesity is inflicting a strong economic burden on Canada [45]. Likewise, the increase in obesity worldwide will have an important impact on the global incidence of cardiovascular disease, type-2-diabetes, cancer, osteoarthritis, work disability, and sleep apnea [46]. Disability due to obesity-related cardiovascular diseases will increase particularly in industrialized countries, as patients survive cardiovascular diseases in these countries more often than in non-industrialized countries. Moreover, disability due to obesity-related type-2-diabetes will increase particularly in industrializing countries, as insulin supply is usually insufficient in these countries. As a result, an increase in disabling nephropathy, arteriosclerosis, neuropathy, and retinopathy is expected [46].

The extent of the obesity problem has shifted the focus from the clinical treatment of obesity towards obesity prevention strategies that address the socio-cultural, economic, environmental, and lifestyle-related causes of population weight gain. Compared with treatment, these strategies are likely to be more realistic and cost-effective, even within low-income countries [47].

1.1.2 Traditional Weight Loss Options

Although prevention is considered the optimal method of improving the health consequences associated with obesity, once already living with obesity, it must be treated to improve health and prevent further negative health results. One technique that seems to be coupled with all other weight control strategies is behaviour modification.

1.1.2.1 Behaviour Modification

There are several behavioural strategies to improve weight management [48]. All behaviour modification strategies focus on understanding and modifying the behaviours that lead to increased food consumption and decreased physical activity. By this theory, the individual in question is able to then analyze their behaviour and make lifestyle changes to initiate, continue, and maintain weight loss. Some commonly used behavioural strategies include self-monitoring, goal setting, stimulus control, cognitive restructuring, problem solving, relapse prevention, stress management, contingency management, social support, and ongoing contact [48]. A randomized control trial performed by Foster et al. (2010)

identified the robustness of weight loss with low-fat/low-carbohydrate diet when combined with behavioural treatment [49]. In this multicenter trial, over 300 participants with a mean BMI of 36.1 kg/m^2 were provided calorie and nutrient controlled diets and behavioural therapy. Weight loss at one year was 11 %, and 7 % at two years. Remarkably, low fat and low-carbohydrate diets did not significantly affect results. In fact, both types of diets when combined with structured behavioural therapy, achieved clinically significant and identical data at one and two years as above [49]. This study demonstrates the significant role that behavioural modification plays in successful long-term weight loss.

1.1.2.1.1 Physical Activity

The relationship among energy intake, energy expenditure, and energy storage is complex, but put simply, in order to maintain a healthy body weight and composition, the energy that an individual consumes from food and beverages must equate to the amount of energy that they expend through their resting metabolic rate, thermic effect of feeding, and physical activity throughout the day [50]. If intake of energy exceeds expenditure, excess nutrients must be stored within the body for use at a later time [51]. Excess glucose will be stored as either muscle or liver glycogen or circulating glucose, fat will be stored within adipose tissue either within the muscle, subcutaneously, or viscerally (most dangerous for health, associated with the most co-morbidities and mortality as compared to other storage sites) [50]. During negative caloric balance through food restriction (dieting), causing a negative energy balance. In the presence of a negative energy balance, without exercise stimulus, the body will breakdown either stored protein, glycogen, or adipose tissue to provide itself with the energy necessary to complete the daily requirements of life. With diet alone, 25 % of weight lost will come from metabolically important fat-free mass [50].

Appropriate physical activity is beneficial for optimizing health in addition to long-term weight control. Several large studies have demonstrated that overweight individuals who participate in at least 30 minutes of moderate intensity physical activity three to five days per week or who have moderate to high cardio-respiratory fitness, also have decreased all-cause mortality compared to their sedentary and unfit counterparts [51]. Moreover, active individuals living with obesity will have lower morbidity and mortality than normal-weight sedentary individuals [51].

1.1.2.1.2 Diet and Physical Activity

Interventions including dietary restriction combined with exercise seem to be the optimal approach to weight loss and improved body composition [52]. A meta-analysis by Miller et al. which included over 700 published research studies throughout a 25-year period demonstrated that a combination of diet and exercise combined provides optimal results for weight loss, fat loss, percentage body fat reductions, BMI lost, and sustained weight loss over time [52]. Moreover, it is important to consider the differences between planned aerobic activity compared to lifestyle activity for long-term weight management. Research has demonstrated that in the short term, a structure of diet and planned aerobic exercise and diet with lifestyle physical activity can provide similar initial weight loss results [23]. However, because lifestyle physical activity focuses on changing behaviour and incorporating physical activity into regular activities of daily living, individuals who engaged in lifestyle activity were able to better maintain weight loss over time compared to the structured aerobic exercise group [23]. Therefore, although physiologically, structured vigorous aerobic exercise will expend more energy for less total amount of time input per day, individuals who do not enjoy or are not able to exercise will be less likely maintain higher levels of activity.

1.1.2.2 Pharmacotherapy

Beyond the most traditional methods of diet and physical activity, some medications can also facilitate weight loss in individuals living with obesity. There are certain BMI criteria that must be met in order to prescribe pharmacotherapy to individuals living with obesity. Candidates for pharmacotherapy must be living with a BMI greater than 30 kg/m^2 (class I obese) or at least 27 kg/m^2 with obesity-related co-morbidities. These types of medications are often required long-term, as many patients regain weight when they are discontinued. In addition, patient compliance with these daily medications is of concern, especially considering cost, potential lack of insurance coverage, and possible side effects. Sibutramine which allows for early satiety, leading to overall decreases in the oral intake of food is also associated with common side effects including dry mouth, constipation, and insomnia [53]. Another frequently used pharmacotherapy for weight loss is Orlistat which inhibits the user's body from absorbing fat [54]. Orlistat has demonstrated eight to 10 % of initial body weight lost in year one, with common side effects of gastrointestinal complaints being experienced [55-57] Finally, phentermine, a medication that induces anorexia, provides a weight loss of approximately 13 % of initial body weight at one year. Common side effects include dry mouth, insomnia, constipation, hypertension, and tachycardia [58]. The main difficulty with all pharmacotherapy is that it is ineffective at maintaining weight loss in the long-term. Although some pharmaceutical methods produce modest short-term results, long-term usage may increase the risk for other conditions such as high blood pressure. Moreover, without the addition of physical activity to help maintain weight loss, cardiovascular and substrate utilization systems will not undergo any of the favorable alterations associated with sustained regular bouts of moderate to vigorous physical activity (MVPA).

1.1.3 Surgical Weight Loss Options

Although physical activity and dietary changes are integral components of weight loss and long-term healthy bodyweight maintenance, for individuals living with extreme obesity, one or more obesity related co-morbidities, and who have been unable to lose weight through traditional means, bariatric surgery represents a more effective method of achieving optimal weight loss results. Bariatric surgery is sometimes referred to as metabolic surgery as it serves a dual purpose. The goal of all types of bariatric surgery is to reduce body weight, allowing individuals to adopt a more active lifestyle, while simultaneously treating or eliminating the effects of the metabolic syndrome [59]. Classically, bariatric procedures have been categorized as restrictive (blocking the transit of food), mal-absorptive (preventing the absorption of food), and combined. However, this traditional view should be broadened, and the importance of satiety, change of taste, neural and hormonal mediation, and the effects of aversion need to be included [60].

1.1.3.1 Adjustable Gastric Band

The adjustable gastric band (AGB) is a reversible procedure. The mortality associated with the AGB is 0.05 to 0.5 %, the lowest of all weight loss procedures. The band creates a 10 to 20 cc partitioned section of the stomach just distal to the gastroesophageal junction. This band constricts the gastric wall in order to create a mechanical constriction limiting the passage of food. The band is filled with saline solution that enables progressive tightening of the artificial stoma which ultimately leads to the restriction of food transit and further weight loss. Adjustable gastric bands use a malleable silicone locking ring connected to a subcutaneous infusion port by a few feet of very thin tubing. The port is placed on the anterior abdominal wall and attached to the anterior rectus fascia. The port is accessed similar to any medical "infuse-a-port", with a Huber needle. Under sterile conditions, the saline solution contained within the band may be added or removed as necessary. As weight loss occurs, more saline solution can be pumped into the band, further restricting food transit and maintaining weight loss over time.

In large studies, weight loss after AGB has been approximately 45 % at one year, and approximately 50 % at two years [61-63]. One study reported eight-year data, with mean excess weight loss of 59.3 %. Given the consistent loss of 50 % excess weight and plateau after that, gastric banding should be avoided in patients with a BMI > 50 kg/m^2 as they may not achieve desirable results with this limited weight loss. Individuals who have undergone the AGB procedure acknowledge clinical improvement in obesity-related co-morbidities including: diabetes control, blood pressure, and musculoskeletal complaints [62]. Commonly encountered complications of ABG include slippage and erosion of the band. In a recent meta-analysis examining band slippage and erosion after laparoscopic gastric banding, the mean rates of erosion were 1.03 % and slippage was 4.93 % [64].

1.1.3.2 Sleeve Gastrectomy

The laproscopic sleeve gastrectomy (LSG) is a longitudinal partial gastrectomy which tubularizes the stomach along the lesser curve. A 50 – 32 F bougie is inserted trans-orally and placed in the distal body of the stomach. The French or size of the bougie (sizing cylinder) is determined by the surgeon and patient as it directly impacts weight loss post-surgery. The stomach is divided 6 – 10 cm proximal to the pylorus using serial firings of a stapler. The bougie guides this transection of the stomach and enables the creation of a linear and uniform gastric tube or what can be considered the new food pouch. Some surgeons elect to over-sew the staple line while others may use glue or seam guards while stapling. Air insufflation or methylene blue tests may also be undertaken to verify the integrity of the staple line. The remains of the stomach no longer attached to the digestive system can now be removed through the abdominal wall or trans-orally in some cases [17].

In a recent systematic review of LSG, 637 patients with a mean baseline BMI of 47.4 kg/m^2 had a mean percentage of excess weight loss of 47.3 % at 13 months. Resolution of diabetes was reported in 66.2 % for patients, and it improved in an additional 26.9 %, resulting in decreased requirements for diabetic and anti-hypertensive medications [65,66]. The LSG procedure does have higher rates of early post-surgical complications reported in the literature compared to AGB. Long-term outcomes are still pending regarding the success of LSG as a stand-alone weight loss surgery [17].

1.1.3.3 Gastric Bypass

Roux-en-Y gastric bypass (RYGB) is characterized as both a restrictive and mal-absorptive procedure which is defined by its small, 15 – 30 cc gastric pouch and 75 – 150 cm roux limb. The stomach is divided by sequential firing of staplers to create a small pouch and formally separate it from the excluded gastric remnant [17]. The roux-en-Y arrangement of the small intestine facilitates drainage of the newly created gastric pouch and makes up the mal-absorptive portion of the procedure. Different from the LSG, the excluded section of the stomach remains in place to secrete essential digestive hormones and factors: gastric acid, pepsin, and intrinsic factor. When these products are secreted and food bypasses the duodenum, the natural neural-hormonal pathways affecting hunger, satiety, and insulin sensitivity are modified. This feedback yields early satiety, decreased hunger, and ultimately has an early impact on insulin resistance and the resolution of diabetes [17]. Advantages of laparoscopic RYGB over open intervention include decreased hospital length of stay, incidence of wound infection, incisional hernia, and per-operative blood transfusions [67].

The fundamental steps of the operation include a retraction of the greater omentum upwards towards the head in order to identify the Ligament of Treitz. Secondly, a 15 – 100 cm biliopancreatic limb is created. The intestine is divided at this point and the distal component is marked to prevent performing a Roux-en-O (attachment of the proximal end of the jejunum to the gastric pouch) and facilitate later mobilization for the gastro-jejunal anastomosis [17]. After dividing the bowel, the biliopancreatic limb is anastomosed approximately 75 – 150 cm distal to the gastro-jejunostomy. This biliopancreatic limb serves to transport gastric, hepatic, and pancreatic secretions in the usual fashion. At the distal anastomosis, the common channel is where the biliopancreatic limb digestive enzymes are mixed with food that has traversed the gastric pouch and roux limb [17].

Either before or after completion of the jejunjejunostomy, the gastric pouch is made. This is only initiated after the orogastric tube, esophageal stethoscope, and temperature probe have been removed from the stomach. Several staplers are then fired in sequence based on gastric thickness to create a 15 – 30 cc pouch. Landmarks such as the second gastric vein, and measuring of approximately six cm from the gastroesophageal junction, facilitate pouch creation. Stapler lines may be over-sewn, clipped, glued or left untouched depending on surgeon preference [17]. Once the gastric pouch has been created, the previously tagged roux limb is brought cephalad to begin the gasto-jejunal anastomosis.

Finally, to create the gastro-jejunal anastomis, a one to two cm stoma of the roux limb to the gastric pouch is performed [17]. Once this anastomosis is completed the surgeon will perform a provocative air insufflation test with an endoscope or infuse dilute methylene blue through an oral gastric tube to rule out a leak at the gastro-jejunal anastamosis. For surgeons with experience, the RYGB may take anywhere from 90 minutes to 4 hours. Often total length of hospitalization is three days with post-operative recovery on the surgical ward. Outcomes after gastric bypass demonstrate that it has the best outcomes to risk ratio [17].

Results of the surgery are excellent initial weight loss that continues until at least two years following surgery. In a series of 500 patients, the average weight loss exceeded 60 % of excess body weight (EBW) at six months and 77 % at one-year post-surgery. By two years, large studies demonstrate a range of 69 to 83% EBW lost [62,67,68]. In addition to weight loss, these studies also note that 95 % of obesity-related pre-operative co-morbidities are controlled at one year, and 95 % of patients report a significant improvement in quality of life [62,68].

With positive outcomes such as these as well as in response to the growing prevalence of obesity, bariatric procedures have been increasing rapidly. Globally, the total number of bariatric procedures in 2011 was 340,768 and the total number of metabolic/bariatric surgeons was 6,705. The most commonly performed procedures were RYGB (46.6 %); LSG (27.8 %); and AGB (17.8 %). The global trends from 2003 to 2008 to 2011 showed a decrease in RYGB: 65.1 to 49.0 to 46.6 % respectively; an increase, followed by a steep decline, in AGB: 24.4 to 42.3 to 17.8 % respectively; and a marked increase in LSG: 0.0 to 5.3 to 27.89 % respectively [69]. Of interest is that the incidence of bariatric surgery has plateaued at approximately 113,000 cases per year. Open gastric bypass now constitutes only 3 % of all cases but does offer some incentive as it costs 4,800 USD less than laparoscopic procedures. Laparoscopic gastric banding is performed in 37 % of all bariatric surgery cases. Also, complication rates have fallen from 10.5 % in 1993 to 7.6 % of all cases in 2006. Despite its simplicity, laparoscopic gastric banding costs the same as gastric bypass making both equally viable options for individuals living with extreme obesity [70].

1.1.3.4 Surgical Outcomes for Weight Loss

Following surgery, outcomes are commonly expressed as BMI or lost EBW. Weight loss following surgery can be helpful in reducing pain from non-metabolic co-morbidities such as osteoarthritis. Therefore, it is important to understand how much weight is typically lost between each of the surgeries listed above. Laparoscopic RYGB weight loss at one year is 60–75 %, with minimal patient morbidity and mortality. Adjustable gastric banding and LSG both offer approximately 50 % EBW loss at one year [17]. If weight loss failure or regain occurs post-AGB or LSG, the patient can be treated by surgical conversion to LRYGB [17].

De Aquino et al. followed a group of 114 patients undergoing LRYGB for 30- and 180-days post-surgery. Their results indicated that bariatric surgery proved to be effective in reducing total body mass and body fat at every time interval [71]. A study by Carvey et al. has shown that bariatric surgery appears to have been highly successful over a 12-month follow-up period, with 50.9 kg weight loss, 38.3 kg (75.2 %) fat mass loss, and 12.6 kg (24.8 %) lean body mass loss for their study population [72]. Thus demonstrating a good proportion of fat to lean mass loss which is encouraging for the functional capacity of individuals who have undergone the surgery [72]. Moreover, O'Brien et al. have shown that at five years after LRYGB, there is typically a loss of 30–35 kg representing 50–60 % of EBW. This weight loss is associated with major improvements or complete resolution of many serious co-morbidities, quality of life, and mortality. Moreover, randomized controlled trials have shown AGB to achieve better weight loss, health, and quality of life than traditional lifestyle therapies (diet and physical activity) for individuals living with obesity [60].

1.1.3.4.1 Possible Complications

Post-operative complications are rare; however, when they do occur they can be divided into three time periods: early, middle, and late. As with most surgeries, complications vary between surgeons, techniques used, patient populations, and hospitals. However, there are some complications that are consistent throughout all institutions as they seem to be part of the surgery type itself. Early complications include anastomotic leak, thromboembolism, obstruction, urinary tract infection, bleeding, wound infection, and adverse cardiopulmonary events [17]. Many of these complications can be minimized or avoided through successful pre-operative care. Attempts to minimize and possibly avoid thromboembolism are carried out with routine injectable subcutaneous anticoagulant, pneumatic compression boots, and early ambulation. Similarly, patients with a history of obstructive sleep apnea receive aggressive post-operative pulmonary aid and are encouraged to bring their C-PAP machine with them to the hospital and use it when sleeping there. Urinary tract infections are avoided with sterile catheter placement and prompt removal once no longer required. Some surgeons do not use a catheter at all in order to further minimize this risk [17].

Middle complications usually occur during the first one to two-years post-surgery. Middle complications typically include kidney stones, gallstones, anastomotic stenosis, internal hernias, and marginal/anastomotic ulcers. The rates of these complications differ based on institution. Some reports of stenosis range widely from 1.6 to 27 %, based on stapler versus sewing technique. Stenosis at the gastrojejunal stoma is oftentimes treated with endoscopic dilatation. Gallstone formation is often observed after rapid weight loss, and can be treated with Ursodiol post-surgery. Routine cholecystectomy with LRYGB remains controversial but still occurs regularly with patients who are living with extreme obesity. Anastomotic ulcers are also frequently seen post-operatively. Most commonly, these ulcers are identified in patients who continue to smoke cigarettes and/or take nonsteroidal anti-inflammatory drugs (NSAID) following surgery. With smoking cessation, elimination of NSAIDs, and proper ulcer treatment, these anastomotic ulcers can be resolved. Moreover, internal hernias may be identified in this post-operative period as well. There are several common areas of herniation that are usually closed during primary surgical intervention. If these hernias were to open or loosen with rapid weight loss, patients may present with obstructive symptoms. Careful clinical evaluation will demonstrate these hernias and provide an opportunity to easily repair them [17].

Late complications include staple line breakdown which can lead to gastric leaking, vitamin deficiencies, and dumping syndrome. For patients who complain of post-surgical problems, vitamin levels are checked yearly and these symptoms can be avoided. Likewise, dumping syndrome is easily lessened by either minimizing or completely eliminating the oral intake of high fat or high carbohydrate foods. Other complications like fistulas often require surgical repair [17].

1.1.3.4.2 Effects of Weight Loss on Co-morbidities

For individuals living with extreme obesity and type-2-diabetes, bariatric surgery resulted in better glucose control than did medical therapy [73]. Moreover, improvements in diabetes and obstructive sleep apnea have been documented after all types of bariatric procedures. One study, which examined over 22,000 patients post-bariatric surgery, found resolution of diabetes in 77 % of patients, and generalized improvements in 86 %. Other co-morbidities evaluated were hyperlipidemia with improvement in 70 % of patients, hypertension with improvement in 78.5 %, and resolution of obstructive sleep apnea in 85.7 % [18]. O'Brien et al. also found that for adults living with obesity and type-2-diabetes, bariatric surgery leads to remission 75 % of the time [60]. Albers et al. demonstrated that there is enhanced insulin signaling in human skeletal muscle and adipose tissue following gastric bypass surgery which may explain the diabetes remission that is traditionally observed [74].

Alizai et al. have found that metabolic surgery leads to a significant functional recovery of the liver for individuals living with non-alcoholic fatty liver disease prior to surgery [75], results are supported by Tai et al. for Chinese adults as well [76]. Bucerius et al., examining a group of 10 individuals before and one year after RYGB found that surgery leads to a normalization of carotid artery inflammation and a beneficial impact on the metabolic activity that is related to the metabolic syndrome [77].

Roux-en-Y-gastric bypass also alters brain activity in areas involved in reward expectation and sensory (taste) processing when anticipating a palatable fatty food. Thus, RYGB may lead to changes in brain activity in regions that process reward and taste-related behaviours. Specific cerebellar regions with altered metabolism following RYGB may help identify novel therapeutic targets for treatment of obesity [78]. Moreover, profound weight loss after surgery, seeking treatment for depression, and absence of medical co-morbidities all predict better quality of life and self-reported improvements in physical function [15].

Sjostrom et al. investigated a group of individuals who underwent RYGB and compared them to a control group of individuals living with obesity. After two years, the weight had increased by 0.1 % in the control group and had decreased by 23.4 % in the surgery group. After 10 years, weight had increased by 1.6 % and decreased by 16.1 %, respectively. Energy intake was lower, and the proportion of physically active participants increased in the surgery group compared to the control group throughout the observation period. The surgery group had lower two- and 10-year incidence of diabetes, hypertriglyceridemia, and hyperuricemia compared to the control group [20]. This study demonstrates the effectiveness of bariatric surgery for reducing co-morbidities compared to conventional methods over the long-term.

1.1.3.4.3 Mortality

Obesity is strongly associated with an increased risk of mortality. Life expectancy is affected by obesity and is confounded by both race and sex. However, research clearly demonstrates that obesity lessens life expectancy, especially among younger adults. For example, in African American and Caucasian populations ages 20 – 30, with a BMI > 45 kg/m^2, there is a reduction in lifespan that ranges from five to 20 years as a result of obesity alone [79]. In a study of 112 patients who deferred surgery, their mortality of 14.3 % was markedly higher when compared to the 2.9 % mortality seen in the 908 patients who went through with surgery. Authors described a 50–85 % mortality reduction benefit when data were adjusted for age, gender, and BMI [79].

Many research studies have examined the effect of obesity and bariatric surgery on mortality. A review of cases examining mortality in 4047 Swedish obese subjects recently demonstrated that bariatric surgery is associated with weight loss at 10.9 years post-surgery, accompanied by a decrease in overall mortality (5 % overall mortality in the surgical group as compared to 6.3 % in the medically managed control group) [80]. The most common cause of death was cardiovascular disease (53 deaths in the control group, 42 in the bariatric group). Cancer was the most common non-cardiovascular cause of death for both groups [80].

Flum et al. performed a prospective, multicenter, observational study of 30-day outcomes in patients undergoing bariatric surgical procedures at 10 clinical sites in the United States from 2005 through 2007. A composite end-point in the 30-day trial was any major adverse outcomes (including death; venous thromboembolism; percutaneous, endoscopic, or operative re-intervention; and failure to be discharged from the hospital) which were evaluated among patients undergoing first-time bariatric surgery. The 30-day rate of death among patients who underwent RYGB or a laparoscopic AGB was 0.3 % with a total of 4.3 % of patients incurring at least one major adverse outcome. Extreme values of BMI were significantly associated with an increased risk of a major adverse event, whereas age, sex, race, ethnic group, and other co-existing conditions were not [81]. Recent studies showed that the risk of death over time was approximately 35 % lower among extremely obese patients who underwent bariatric surgery than among those who did not. Flum et al. have concluded that the overall risk of death and other adverse outcomes post-bariatric surgery was low and varied considerably per patient characteristics. In helping patients make appropriate choices, short-term safety should be considered in conjunction with both the long-term effects of bariatric surgery and the risks associated with living with extreme obesity [81].

1.1.3.4.4 Predictors of Successful Weight Loss and Maintenance Post-Surgery

The first post-operative year is a critical time that must be dedicated to changing old behaviours and forming new lifelong habits in order to ensure long-term success [82]. King et al. have demonstrated that more physical activity pre-operatively independently predicted more physical activity post-operatively [82]. Furthermore, less pain, not having asthma, and the self-report of increasing physical activity as a weight loss strategy pre-operatively independently predicted more high-cadence time post-operatively [82]. Evans et al. found that participation in a minimum of 150 minutes per week of MVPA was associated with greater post-operative weight loss and change in BMI at six- and 12-months post-surgery. The percentage of EBW lost was 56.0 ± 11.5 % versus 50.5 ± 11.6 % and 67.4 ± 14.3 % versus 61.7 ± 17.0 % for the group meeting and not meeting the activity requirements at six- and 12-months post-RYGB, respectively [83]. Through a survey of 100 individuals who had undergone RYGB, Edwards et al. demonstrated that 69 % weighed themselves at least weekly. By weighing often and allowing themselves only a few kg of fluctuation, patients stayed in control. Those individuals who were able to maintain weight loss expressed a general feeling that maintaining their weight was indeed their own responsibility and that the surgery was a tool that they used to reach and maintain a healthy weight [84].

Edwards et al. have identified six main lifestyle habits that proved to lead to successful weight loss maintenance post-RYGB. Firstly, successful individuals documented eating three well-balanced meals and two snacks per day. Next, successful weight maintenance was marked by the consumption of water and no carbonated beverages. On average, individuals drank 40 to 64 oz of water per day: 58 % of individuals did not drink carbonated beverages of any kind, 55 % did not drink juices or sweetened beverages, 53 % did not drink caffeinated beverages, and 74 % did not drink alcoholic beverages. In addition, successful individuals took daily multi-vitamins, calcium, and iron if needed. Furthermore, successful individuals indicated an average sleeping period of seven hours per night, and recommended exercising regularly to maintain their weight; 77 % exercised. The average exercise regime was four times per week for at least 40 minutes per session. Most individuals reported exercise as a key factor in their ability to maintain weight. Predictors of weight regain were a lack of exercise, poorly balanced meals, constant grazing and snacking, and drinking carbonated beverages [84].

1.1.3.4.5 Weight Recidivism

Although all types of bariatric surgery exhibit excellent initial reductions in weight and co-morbidities, some individuals do start regaining weight post-surgery mostly in the medium to long-term [6]. There are certain factors present pre-surgery that have been identified as predictors of post-surgical success and failure. For instance, higher pre-surgical weight is associated with higher pain, higher functional impairment due to pain across the domains of physical activity, mood, walking ability, relationships, and enjoyment of life. Findings from Wedin et al. suggest that bariatric surgery candidates report a moderate amount of pain prior to surgery and that pre-surgical weight is associated with higher pain, increased functional impairment due to pain, and increased anxiety [85]. Unfortunately, the chronic pain experienced pre-surgery may carry forward post-surgery and continue to constrain physical activity and limit weight loss.

Another factor that may be affecting long-term weight regain is the excessive use of alcohol. Alcohol is a very energy dense substrate, second only to fat for its energy density (seven kcal per g vs nine kcal per g). In 2012, King et al. demonstrated that the prevalence of alcohol use disorders was greater in the second post-operative year than the year prior to surgery, or in the first post-operative year [86]. After surgery, due to metabolic changes that effect the individual's ability to metabolize alcohol, less total alcohol is required to begin feeling its effects. This consequence of the surgery may potentially mask the over-use of alcohol compared to non-operated individuals. In a recent study by Reid et al., examining a group of patients on average 12 years after RYGB, it was discovered that individuals who regained most of their lost weight post-surgery consumed significantly greater amounts of alcohol than those who were able to maintain their weight loss [87].

1.2 SEDENTARY BEHAVIOUR

1.2.1 Sedentary Behaviour

Sedentary behaviour (from the Latin sedere, ''to sit'') is the term now used to characterize those behaviours for which energy expenditure is low in all aspects of life (transport, occupation, home, and leisure) [88]. More specifically, sedentary behaviour refers to activities that do not increase energy expenditure substantially above the resting level and includes activities such as sleeping, sitting, lying down, watching television, and other forms of screen-based entertainment. Sedentary behaviour includes activities that involve energy expenditure at the level of 1.0 to 1.5 metabolic equivalent units (METs) (One MET is the energy cost of resting quietly, often defined in terms of oxygen uptake as 3.5 mL/kg/min). Light physical activity, often is grouped with sedentary behaviour, but is in fact a distinct activity construct, involving energy expenditure at the level of 1.6 to 2.9 METs. Light activity includes slow walking, cooking food, and washing dishes [89]. Although sleep is technically defined as a sedentary behaviour, sleep is important for proper physiological functioning and is associated with multiple health benefits, and is therefore different from day time sedentary behaviour in its effect on cardio-metabolic health.

Conceptualizing sedentary behaviour as distinct from a lack of physical activity is necessary. Approaches to reducing sedentary behaviour may be different from those designed to increase physical activity [88]. For example, Tremblay et al. (2007) illustrated how reductions in sedentary behaviour may be achieved through almost limitless micro-intervention opportunities designed to promote energy expenditure, whereas physical activity or exercise interventions have more constraints (e.g. time, location, equipment, logistics). For those who have not embraced an organized or structured program of physical activity, reducing sedentary behaviour may be a more achievable and viable approach for increasing movement and overall energy expenditure [90].

1.2.1.1 Pathophysiology

Daytime sedentary behaviour is a relatively new area of health research. Research has shown that sedentary behaviour is associated with deleterious health outcomes, which differ from those that can be attributed to a lack of MVPA [88]. Research has been conducted examining specific types of sedentary behaviours, such as television watching which was associated with significantly elevated risk of obesity and type-2-diabetes, independent of physical activity levels [91]. Sedentary behaviour is a risk factor for all-cause mortality that is independent of physical activity [25]. Simply, this means that cardio-metabolic risk is elevated when an individual engages in excessive daytime sedentary behaviour, regardless of the amount of physical activity (meeting physical activity guidelines) that they engage in. The physiological responses and adaptations to sedentary behaviours are not necessarily the opposite of exercise and may differ within and between physiological systems (e.g. cardiovascular vs. musculoskeletal) [88]. Epidemiological analysis by Katzmarzyk et al. demonstrates a dose response relationship between sitting time and mortality from all causes, independent of leisure time physical activity [92]. Furthermore, it has been shown that the duration of each bout of sitting time, and not solely total daily accumulated sedentary behaviour, is associated with cardio-metabolic risk [25]. Current research indicates that clinical communication and preventive health messages for reducing and breaking up sedentary time may be beneficial for cardiovascular disease risk [93].

On average, the normal weight population spends more than 7.7 hours per day engaging in sedentary behaviours [3]. Therefore, it is not uncommon for people to spend one-half of their waking day sitting, with relatively idle muscles. The other half of the day includes the often large volumes of non-exercise physical activity (light intensity activities of daily living) [94]. One of the first series of controlled laboratory studies providing evidence for a molecular reason to maintain high levels of daily low-intensity and intermittent activity came from examinations of the cellular regulation of skeletal muscle lipoprotein lipase (LPL). Experimentally reducing normal spontaneous standing and ambulatory time had a much greater effect on LPL regulation than adding vigorous exercise training on top of the normal level of non-exercise activity [94]. Those studies also found that inactivity initiated unique cellular processes that were qualitatively different from the exercise responses. As

LDL is more prevalent in the blood stream due to extended bouts of chronic sedentary time, and not being taking up by cells, cholesterol can aggregate on the walls of large blood vessels causing arterial and deep vein thrombosis, contributing to atherosclerosis plaque, higher resting blood pressure, and a heart attack or stroke [50]. Reductions in lipoprotein lipase activity resulting from the disuse of slow twitch fatigue resistant postural muscle can lead to impaired high density lipoprotein (HDL) cholesterol and triglyceride metabolism. As skeletal muscle is a major site of clearance for plasma glucose and cholesterol, non-movement of a specific muscle group can lead to a local reduction in lipoprotein lipase activity [50]. Additionally, as there is less stimulation of slow twitch fibers with excess sedentary time, the less GLUT 4 transporters on the cell. If there is less GLUT 4 transportation, more insulin will be required to allow the same amount of blood glucose to enter the cell to do work resulting in an abnormal glucose metabolism which over time can lead to type-2-diabetes [50].

In summary, there is an emergence of inactivity physiology studies. These are beginning to raise a new concern with potentially major clinical and public health significance: the average non-exercising person may become even more metabolically unfit in the coming years if they sit too much, thereby limiting the normally high volume of intermittent non-exercise physical activity in everyday life. Thus, if the inactivity physiology paradigm is proven to be true, the dire concern for the future may rest with growing numbers of people unaware of the potential insidious dangers of sitting too much and who are not taking advantage of the benefits of maintaining non-exercise activity throughout much of the day [95]. These findings indicate that the relationship between physical activity, sedentary time, and health is not as clear and simple as current national recommendations make them appear to be. Moreover, these important nuance aspects of activity, cadence and bouts of sitting time, provide further opportunities for meaningful intervention for individuals living with extreme obesity who may find adoption of regimented MVPA difficult or impossible to achieve.

1.3 PHYSICAL ACTIVITY

Bariatric surgery leads to a substantial improvement in comorbidities as well as a reduction in overall mortality by 25 – 50 % during the long-term follow-up [96]. However, immediately following bariatric surgery, it is crucial to adopt a more physically active lifestyle and better nutritional habits in order to observe these beneficial long-term effects. Studying a group of individuals who had undergone RYGB, Bond et al. observed that those who became active post-operatively were able to achieve weight loss and health related quality of life improvements that were substantially greater than those experienced by individuals who remained inactive post-surgery [22]. Furthermore, Vatier et al. demonstrated that with increased leisure time physical activity combined with reductions in sedentary time, individuals could achieve favorable changes in body composition following RYGB compared to those who remained sedentary [97]. Evaluating the three-year (short-term) effects of a lifestyle intervention on patients following vertical banded gastroplasty, Papalazarou et al. found that lifestyle interventions favorably affect weight loss and maintenance following bariatric surgery [98]. These findings support the continued efforts to encourage and support patients' involvement in post-surgery physical activity; however, further research is necessary to determine the recommended activity and sedentary time guidelines for this patient population [99].

1.3.1 Physical Activity

1.3.1.1 National Guidelines and Recommendations

The term physical activity contains numerous complex elements but is typically classified as bodily movement via skeletal muscles, resulting in energy expenditure, and is positively correlated with physical fitness [100]. Through decades of evidence based health research it has become clear that regular physical activity designed to improve fitness will substantially reduce all-cause mortality [101]. Given these findings, the Canadian Government has released guidelines concerning the amount, frequency, and intensity of physical activity that Canadians should be engaged in to achieve optimal health benefits. Current recommendations encourage all Canadian adults to acquire a minimum of 150 minutes of MVPA per week[102]. Further recommendations from the literature suggest that 10,000 steps per day may be enough to acquire these health benefits [103].

Although MVPA and steps are important aspects of regular physical activity, it is important to also consider other nuance characteristics of physical activity less described to the public. Research has shown that extreme obesity negatively influences the basic kinematic parameters of gait, resulting in a reduced stride length and decreased cadence, or walking speed, as compared to normal weight individuals [104]. Moreover, chronic decreased cadence represents a reduction in the overall intensity of daily activities, leading to a greater risk of weight gain [105]. Cadence is an important factor to consider when describing physical activity. Evidence from weight loss interventions in overweight, obese, and other very low active populations have indicated that cadence is an important aspect to monitor as improvements in cadence are often seen despite observing no significant changes in total daily steps [106]. High cadence levels (≥ 100 steps/min) throughout the day can indicate periods of MVPA [106], which may be just as physiologically important when compared to total daily steps, as this intensity of physical activity is recommended for health enhancing benefits [107].

As described earlier exercise prescription for obtaining a desired negative energy balance can vary greatly between individuals. There is substantial evidence that individuals living with obesity may require greater volumes of activity to obtain a negative energy balance similar to normal weight individuals. There are many recommendations concerning the appropriate quantity of physical activity required for weight loss in individuals living with obesity. The American Society for Metabolic and Bariatric Surgery (ASMBS) recommends mild exercise (including aerobic conditioning and light resistance training) 20 minutes per day, three to four days per week prior to surgery to improve cardiorespiratory fitness, reduce the risk of surgical complications, facilitate healing and enhance post-operative recovery [108]. The American Heart Association recommends a similar mild preoperative exercise regimen of low- to moderate-intensity physical activity at least 20 minutes per day, three to four days per week. Joint guidelines from the ASMBS, the Obesity Society, and the American Association of Clinical Endocrinologists recommend that post-operative patients adhere to general recommendations for a healthful lifestyle, including exercising for at least 30 minutes per day, to achieve optimal body weight and improve body composition [109]. However, evidence-based physical activity guidelines for healthy adults and those living with overweight and obesity suggest that greater amounts of physical activity are needed for controlling body weight. For instance, the American College of Sports Medicine recommends ≥ 250 minutes of MVPA per week for individuals living with obesity who wish to lose weight [110]. Although there is no exact consensus concerning the exact amount of physical activity necessary for weight loss, or weight maintenance for individuals living with obesity, it is at least agreed upon that more activity is better than less.

1.3.1.2 Lifestyle Physical Activity

1.3.1.2.1 Occupational and Leisure Time Physical Activity

Lifestyle physical activity can be broken down into three main areas: Leisure, occupational, and transportation. As individuals living with overweight and obesity typically describe a lack of time, knowledge, and resources as barriers to regimented physical activity, lifestyle physical activity may be a more appropriate venue to promote energy expenditure [111]. Research has concluded that structured leisure time physical activity regimens have multiple health benefits; however, the other domains of occupational and transport related physical activity provide further opportunities for lifestyle physical activity to take place, affording a plethora of opportunities for energy expenditure which will contribute to a healthier lifestyle and affect obesity severity.

Socio-economic status is characterized as the social standing or social position in relation to other individuals, based on income, education and occupation [112]. Low individual earning and education levels have been associated with blue collar jobs and increased obesity levels. Supporting this statement, a study conducted in 2015 by Gans et al., randomly selected employees from 24 North American worksites and conducted in-person surveys while gathering anthropometric measures. The research group stratified their sample population into white collar, blue collar, and service workers. Their findings suggested that blue collar occupations were associated with lower individual earnings and higher levels of obesity [113]. Furthermore, similar findings were found in a study conducted by Salmon and colleagues in 2000. Their goal was to better understand the relationships between SES and its association with occupational and home-based physical activity among an Australian population. Information obtained through questionnaires and anthropometric measurements (height and weight) allowed researchers to conclude that higher education levels were associated with professional workers, whereas less-skilled workers were more likely to have less than 12 years of education for both men and women. In addition, a greater proportion of individuals living with overweight and obesity were identified as home-makers followed by less skilled workers [114]. Another study conducted by Andreenko et al. 2015, in Bulgaria, classified their population of study by intellectuals (moulders, fitters, carpenters), and service workers (office workers, programmers). Results from this investigation stated that male intellectual workers were associated with a higher education and SES [115]. Collectively, these studies demonstrate that there is a clear relationship between obesity, SES, and type of occupation. Although these studies came to similar conclusions, it is important to consider the manner in which each study categorized their sample. These differences in occupational classification techniques may lead to possible inappropriate generalized assumptions concerning occupation and obesity levels. Certain reports did not make the distinction between white collar and white collar professional workers whereas others did. This differentiation is suggested as income and job tasks vary between these two groups, further affecting the other variables studied.

In addition to lower observed educational levels, blue collar workers have been reported to make poorer lifestyle choices including a preference to more fat-rich foods and smoking [116-118]. Blue collar workers have been categorized as having greater BMI values and are less likely to engage in leisure time physical activity [117]. To this day, there are still tendencies for men to be engaged in manual task oriented occupations than women [119]. In contrast, women tend to select more sedentary jobs with lower activity requirements than men [120]. In addition to the higher occupational activity seen among men, they also have higher levels of participation in leisure time physical activity compared to women [121,122]. Findings from Leino-Arjas et al., also suggested that blue collar workers that are involved in strenuous work tasks demonstrate a reduction in physical functioning in later life. Being subject to physically demanding tasks increases the risks of chronic pain and related musculoskeletal disorders, such as osteoarthritis. Jobs that require lot of kneeling and squatting such as nursing and roofing which are blue collar occupations have elevated associations with osteoarthritis in the knee joint [123]. In addition to job strain, excessive body weight has been associated with major chronic illness and increased risks for musculoskeletal pain [122]. The combination of increased physical job strain and chronic pain related to blue collar jobs may be some of the contributing factors to the lack of participation in leisure time physical activity observed, further increasing the risks related to obesity. In other words, these dynamics, may be contributing to increased sedentary behaviour and decreased quality of life. In sum, lower SES, work environment, decreased leisure time physical activity, and poor lifestyle decisions are all associated with blue collar jobs.

In contrast to blue collar work, higher income and education was attributed to white collar jobs and especially professional-white collar work [115]. These jobs characteristically consist of lower occupational physical activity; however this population has been identified to participate in higher levels of leisure time physical activity [114,120].

A study conducted in 2015 by Steeves et al., showed that in addition to having lower levels of obesity, participants with higher levels of leisure time physical activity were more likely to be college-educated and non-smokers. Structured physical activity (regimented exercise) has been identified as beneficial for health and substantially modifies an individual's health risk profile leading to increased life expectancy [124]. As seen from Assannelli et al., in 1999, researchers concluded that there was an inverse relationship between total cholesterol, triglycerides, fibrinogen, and blood pressure with leisure time physical activity in men [116]. Furthermore, increased levels of HDL were directly related to leisure time physical activity. Therefore, these studies confirm that white collar workers tend to be more educated, have higher individual earnings, and are engaging in regular leisure time physical activity which is an effective preventative measure for a variety of health risks and obesity.

Over the past five decades, industrialization in our society has contributed to a shift from manual labor occupations towards service industry jobs [29,118]. A general decrease in overall energy expenditure of the working population has also been identified over this period, partially due to increased sedentary time and decreased physical activity. There is a profound proportion of the population that does not meet either current national recommendations of steps per day or physical activity. Reported by the Centers for Disease Control (CDC), only 20 % of the US population is meeting the aerobic and muscle strengthening components of the federal government's physical activity recommendations [125]. More shockingly, current estimations among adults (20 to 59 years of age), in the United States indicate that only 3.5 % are meeting physical activity guidelines [125]. In Canada, the percent of adults meeting physical activity guidelines decreased with increasing age. There was a significant drop seen in among adults aged 40 to 59 with only

18 % that met guidelines. Furthermore, the extreme obese population reports having even lower participation rates in physical activity than their non-obese counterparts [121].

In 2011, Josbeno and colleagues found that two to five years post-surgery, only 10 % of the subjects met the national physical activity recommended guidelines of ≥ 150 minutes per week of MVPA in bouts of ≥ 10 minutes [126]. Additionally, a study by Bond et al. examining patients pre-surgery showed that 66 % of their population did not achieve any MVPA in bouts of 10 minutes and only 4.5 % of obese patients met the weekly MVPA recommendation versus 40 % of the controls [2].

A great amount of sitting time among the extreme obese population (BMI > 40 kg/m^2) has been attributed to paper or computer work [127]. As mentioned previously, the average population is relatively sedentary during work due to their job-specific tasks. Office workers have been estimated to spend about 80 % of their working hours engaged in sedentary behaviour [128]. Sedentary behaviours, independent of physical activity, are associated with increased risk of diabetes, cardiovascular disease, some cancers, and premature mortality [129]. Recently, a study by Yang and colleagues, in 2014, analyzed sitting time in 1,891 participants from four different Missouri metropolitan companies. They found that increased sitting time was associated with increased obesity levels seen only among the female participants [130]. Similar results were identified from The Danish Work Environment Cohort Study, where increased sitting time was associated with increased BMI in women after a five-year period. However, this relationship was not found among men, possibly due to the method of measurement used. Body mass index is one method to classify obesity; however, it is not the most accurate technique, as it does not differentiate between fat mass and lean muscle mass, potentially leading to false results

[131]. This method misinterprets results in athletes and pregnant women as they have elevated weight, but are not necessarily excessively fat. Therefore, better measures of body composition that provide information on fat percentage such as DXA may potentially increase the accuracy of these findings. In addition, self-reported data results may decrease the internal validity of the study as participants typically overestimate height and underestimate weight, resulting in a lower BMI than when directly measured [132]. It has been stated previously that some individuals may compensate the excessive sedentary behaviour experienced at work with physical activity during their leisure time in order to maintain a balance between energy expenditure and energy consumption; however, this is not always the case [133]. Thus, a portion of the weight gain being observed may be due to the lack of increase in leisure time physical activity which had failed to meet the dramatic increase in sedentary time, especially seen in occupational settings.

Participation in physical activity varies from one individual to another based on a multitude of factors. When considering the lack of participation in physical activity observed among the extreme obese population, a general trend is due to social discrimination and physical pain [134,135]. Before undergoing bariatric surgery, individuals usually live through years of extreme obesity, causing irreparable damage to joints through osteoarthritis, altering the perception of their bodies in relation to social norms, as well as damaging their self-efficacy concerning physical activity. Therefore, for individuals who have undergone bariatric surgery, moderate and high intensity exercise might be unappealing, too painful and overwhelming, regardless of weight loss [136]. In 2004, the economic burden associated with obesity was $ 4.3 billion ($ 1.6 billion of direct costs and $ 2.7 billion of indirect costs) [45]. Workers classified as obese reportedly file costlier compensation health claims and have more lost workdays than do their normal weight co-workers [137]. Obesity is also associated with substantially increased rates of absenteeism, in other words, workers living with obesity take more days off work and have lower productivity during working hours compared to their non-obese co-workers [138]. Workers living with obesity report socially isolating themselves from co-workers and close friends. Faced with high expenses related to obesity, health organizations and private companies are implementing interventions and incentive-based health promotion programs to motivate employees to manage their own health, increase daily physical activity, all in an effort to decrease obesity associated costs [139].

A variety of health initiatives such as motivational posters, multi-session programs, standing or treadmill desks, and educational programs have been implemented in an aim to increase physical activity and help reduce absenteeism related to obesity. These incentives have been implemented in occupational settings in order to determine which program would best benefit this population and the company.

Therefore, occupation is a major domain that should be studied when considering daily physical activity levels. There are many types of interventions implemented in worksites which have shown positive results in relation to increased health awareness and decreased sedentary time. Given that pre-surgically, individuals awaiting bariatric surgery find themselves unemployed or on extended leave as a result of their obesity it is important to determine if post-surgery their occupational activity is influencing their long-term weight maintenance or surgical success.

1.3.1.2.2 Neighborhood Walkability and Transportation-Related Physical Activity

Walking is the most common moderate-intensity activity performed by overweight adults, and is associated with considerable health benefits [140]. Walking for transport, recreation, or exercise all contribute to total daily physical activity [141]. Until recently, individuals obtained most of their physical activity during work, household chores, and transportation. Today, these demands have been critically reduced due to automation and computers at work, labor-saving devices at home, as well as built environment and transportation practices that require driving for most journeys [142]. The built environment, is made up of three main characteristics: urban design, land use, and the transportation system. Urban design refers to the design of a city and the physical elements within it, including both their arrangement and appearance, focused on function and appeal of public spaces. Moreover, land use refers to the distribution of activities across space, including the location and density of different activities [143]. Finally, the transportation system includes the physical infrastructure of roads, sidewalks, bike paths, railroad tracks, bridges and the level of service provided as determined by traffic levels, and bus frequencies. Overall, the built environment encompasses patterns of human activity within the physical environment [143]. Research has shown that characteristics associated with the built-environment are regularly related to overall physical activity and active transportation in particular [144]. In more walkable environments, it is typical to observe a difference in walking for errands and transportation, and few differences in walking for exercise compared to less walkable environments [27]. Similarly, the built environment can affect energy balance by offering opportunities for physical activity, resulting in a lower prevalence of obesity in more walkable neighborhoods compared to less walkable ones [27].

The assessment of neighborhood built-environments, especially neighborhood walkability (a measure of how friendly a neighborhood is to walking), has recently been the focus of public health research and practice [145]. There is a lack of agreement on how the built-environment should be measured and modeled, making it difficult to determine to what degree it is influencing obesity [146]. However, it has been found that making changes to the built-environment can influence physical activity and by association, reduce obesity rates [147]. Recently, Walk Score® (www.walkscore.com), a publicly available website, was found to be valid and reliable for estimating access to nearby walkable amenities [148] and is a fast, free, and easy to use proxy of neighborhood density, access to nearby destinations, and neighborhood walkability [149]. Walk Score® uses publicly available data to assign a score to a location based on the distance to a variety of nearby commercial and public frequently-visited facilities. Facilities are divided into five categories: educational, retail (e.g. grocery, drug, bookstores), food, recreational (e.g. parks and gyms), and entertainment. The result is normalized to fit a 0 to 100 scale, with 0 being the lowest walkability and 100 being the most walkable. Walk Score® then groups these scores into four categories: Car-Dependent 0 to 49, Somewhat Walkable 50 to 69, Very Walkable 70 to 89, and Walker's Paradise 90 to 100. More in depth technical information on Walk Score® has been previously published [145].

The normal weight population emphasizes a lack of time as a major barrier to physical activity [28]. As such, it is logical that neighborhood walkability, which allows for individuals to complete more tasks on foot, (retail, education, transport) yields an increase in overall physical activity mostly from active transport [27]. However, for the bariatric population, pain has been reported to be the most significant barrier to physical activity [24]. A high prevalence of advanced osteoarthritis and use of pain medication post-surgery support this finding [36]. If chronic pain brought on by movement is the primary barrier to physical activity, then increasing neighborhood walkability through decreasing distances to retail, education, and work environments will not likely increase daily activity for this population. In addition to pain, individuals who undergo RYGB face other population-specific barriers to physical activity. There is a strong psychological barrier to being active which is based on fear of public humiliation, negative attention, and lack of self-efficacy [24]. In the Canadian province of Ontario, Chiu et al. concluded that living in an area of low-walkability was associated with a higher prevalence of overweight and obesity [30]. The findings by Chiu et al. agree with those by Saelens et al. since they both attributed these lower obesity rates to active transport, and not exercise. Although more walkable neighbourhoods may be associated with higher steps in Europe and Japan [150], it is still not clear if there is such an association either in the Canadian general population [151] or in adults with type-2-diabetes [152]. In Canada, some studies have even identified an inverse association between neighbourhood walkability and BMI, with Creatore et al. demonstrating an inverse association between walkability and diabetes incidence [153]. Considering the potentially positive effects of neighborhood walkability, and the varying effect of this construct on different populations, it seems important to investigate the effects of neighborhood walkability on weight regain, physical activity, and sedentary behaviour in individuals who have undergone RYGB and may prefer lifestyle physical activity over traditional vigorous exercise.

1.4 PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR MONITORING

Physical activity and sedentary behaviour can be measured and monitored in a variety of different ways. Each method has its individual benefits and drawbacks. The issue of measuring sedentary behaviour is complicated by the simple fact that sedentary pursuits occur in a varied and sporadic manner throughout the day. It is important to consider that no one method of activity monitoring can be considered optimal for all studies, only the most appropriate method for one study. The method of activity monitoring chosen should be based on the specific aims of the research study.

1.4.1 Subjective

1.4.1.1 Questionnaire

Questionnaires are an effective tool for subjectively monitoring physical activity. Questionnaires such as the International Physical Activity Questionnaire and the Sedentary Behaviour Questionnaire have been employed in research studies around the world and have been found to be reliable and valid in several languages [154]. When assessing activity or sedentary behaviour through written questions, it is important to ensure that the language of the tool is appropriate. Even the slightest change in wording from one language to another can greatly affect the meaning of the question and may alter results obtained from the subject. This can make worldwide comparisons of physical activity levels challenging. One of the greatest benefits of using a questionnaire is that it allows for descriptive and qualitative data to be collected. Through questionnaires we can determine what types of activities are being done, or even how the individual felt while performing these activities. This information can be very helpful when attempting to create specific public health policy. Another benefit is that questionnaires are one of the least expensive devices that can be used to monitor activity. Therefore, it is also the ideal device to be used when attempting to monitor large groups of individuals such as population surveillance studies. In the past, the major cost associated with questionnaire data was the paper and ink for printing and the postage for delivery and recovery of the data. Now with the continued increase of personal computers in the home, and the widespread usage of internet, questionnaires can be administered to individuals via email or an online web survey. This not only dramatically reduces the cost of an already relatively inexpensive assessment tool, but also enhances the likelihood of receiving completed questionnaires. As soon as the questionnaire is completed online, the information can be directly digitally sent to the researcher. This method also reduces transcription time for the data, as it never leaves a digital state and can be easily imported into statistical software for analysis. Depending on the research question, it may be important to determine how active a certain population believes they are and then compare that subjective data to objective activity monitoring. There are also several drawbacks to this method of activity assessment. Questionnaires rely heavily on the subject's own ability to perceive activity. Individuals who are new to physical activity may find it difficult to accurately quantify or classify their amount or intensity of activity [155]. Again, stressing the importance of the wording of the question, perhaps accompanied by explanations of terms in the question such as what the sensation of moderate activity may feel like in order for the subject to better comprehend. The potential for intentionally inaccurate reporting needs to also be considered. As this is a subjective assessment, subjects may intentionally falsify information in order to appear less inactive than reality. Due to this unfortunate situation, all subjective measures have the potential for low levels of reliability and validity [156]. Moreover, questionnaires are limited to more general activity monitoring such as individual days or weeks as compared to second by second data offered by more objective measures.

1.4.2 Direct Observation

Direct observation is a method of activity monitoring that involves researchers watching and taking notes about other individuals being active. This can be accomplished by either the researcher being in the same room and observing the activity in real time, or can have the subject's activity video recorded for later viewing. The benefit of this method is that more precise data concerning the type, intensity, frequency of activity, and the amount of time spent doing the activity and intensity can be quantified. The drawbacks of this method, it requires highly trained personnel to observe activity for hours, making the observations expensive to carry out. Realistically, due to the cost of observers, only small groups can be observed at a time. Finally, reactivity is a major drawback of this assessment technique [157]. Observation will have an effect on a subject's activity choices, intensity, and time spent in the activity. The fact that they are being observed may affect patterns of activity leading to unnatural activity choices and patterns that observers are seeking to determine.

1.4.3 Objective

1.4.3.1 Doubly Labeled Water

This technique measures a subject's carbon dioxide production during the interval between first and last body water samples. When cellular respiration breaks down carbon-containing molecules to release energy, carbon dioxide is released as a byproduct. Carbon dioxide (CO_2) contains two oxygen atoms and only one carbon atom, but food molecules such as carbohydrates do not contain enough oxygen to provide both oxygen atoms found in CO_2 [158]. One of the two oxygen atoms in CO_2 is derived from body water. If the oxygen in water is labeled with ^{18}O, then CO_2 produced by respiration will contain labeled oxygen. In addition, as CO_2 travels from the site of respiration through the cytoplasm of a cell, through the interstitial fluids, into the bloodstream and then to the lungs some of it is reversibly converted to bicarbonate [159]. After consuming water labeled with ^{18}O, the ^{18}O equilibrates with the body's bicarbonate and dissolved carbon dioxide pool (through the action of the enzyme carbonic anhydrase). As CO_2 is exhaled, ^{18}O is lost from the body [159]. However, ^{18}O is also lost through body water loss (such as urine and evaporation of fluids). However, deuterium (the second label in the doubly labeled water) is lost only when body water is lost. Thus, the loss of deuterium in body water over time can be used to mathematically compensate for the loss of ^{18}O by the water-loss route [159]. This leaves only the remaining net loss of ^{18}O in carbon dioxide. This measurement of the amount of carbon dioxide lost is an excellent estimate for total carbon dioxide production. Once this is known, the total metabolic rate may be estimated from simplifying assumptions regarding the ratio of oxygen used in metabolism to carbon dioxide eliminated. From deuterium loss, we know how much of the tagged water left the body as water, and because the concentration of ^{18}O in the body's water is measured after the labeling dose is given, we also know how much of the tagged oxygen left the body through water. Measurement of ^{18}O dilution with time gives the total loss of this isotope by all routes (by water and respiration) [158]. Since the ratio of ^{18}O to total water oxygen in the body is measured, we can convert ^{18}O loss in respiration to total oxygen lost from the body's water pool via conversion to carbon dioxide. How much oxygen left the body as CO_2 is the same as the CO_2 produced by metabolism, since the body only produces CO_2 by this route [158]. The CO_2 loss tells us the energy produced, if we know or can estimate the respiratory quotient ratio of CO_2 produced to oxygen used) [158]. Doubly labelled water provides a measure of energy expenditure over a length of time. However, this assessment is still very expensive owing to the cost of heavy water itself accompanied by the costs of the laboratory analyses. Moreover, unlike other objective measures of activity, such as accelerometers, doubly labelled water is non-reusable. This method also has a reasonable amount of participant burden to consider as the participant must collect fluid samples throughout the assessment period. Finally, the greatest drawback to this method is that is incapable of providing information about type of exercise, or duration of exertion. These details are crucial in determining an individual's daily habits and very useful in tailoring interventions to improve daily activity habits.

1.4.3.2 Pedometers

Pedometers are small devices, usually worn on the hip, that provide objective measures of steps taken, distance travelled, and estimates of energy expenditure. Concerning principles of operation, electronic pedometers use three basic mechanisms for recording steps. The original and most basic is a spring-suspended horizontal lever arm that moves up and down in response to vertical displacement of the waist. The lever arm opens and closes an electrical circuit with each step, and the number of steps are counted (e.g., Yamax Digiwalker SW-701 and Sportline 345) [160]. Some newer models have incorporated a glass-enclosed magnetic reed proximity switch (e.g., Omron and Oregon Scientific). The third type has an accelerometer consisting of a horizontal beam and a piezoelectric crystal (e.g., New Lifestyles and Lifecorder); steps are determined from the number of zero-crossings of the instantaneous acceleration versus time curve [160]. Pedometers are available in a wide range of prices and quality. More features can be found on more expensive models; however, it is rare that pedometers are accurate at measuring variables other than steps regardless of price [160]. Pedometers are the least expensive objective means of measuring physical activity. As they are relatively inexpensive, reusable, and easy to use devices, they can be easily employed in larger research studies. As the data acquired is simply steps per day, the outputs are relatively easy to comprehend and require less training for data processing compared to more sophisticated accelerometers. Pedometers can be used as motivational tools for use in interventional work [161]. Pedometers provide immediate feedback to the wearer by use of an easy to read digital display which can help participants self-monitor and pace their activity if they have been given daily goals to meet. Some drawbacks of the device are that they provide very limited information about activity (e.g. no context, duration, time, or intensity of exercise is provided). Moreover, all but the most expensive devices cannot store daily step values on a day by day basis and will normally require either daily logging by the participant or researchers using an average score based on the total daily steps acquired over the wear period. This makes it difficult to understand the day to day habits of the wearer. Moreover, most pedometers have no means of exporting or time stamping data. Again, this makes pedometers ineffective at providing detailed activity-related information about the wear period. This can make it difficult to pin point problem areas during specific days or times and provide feedback to the wearer about where improvements could be made.

1.4.3.3 Accelerometers

Accelerometers are small wearable devices which are capable of measuring many facets of physical activity and sedentary behaviour. Within the gross spectrum of accelerometry, there are various qualities of devices, some suited for research, while others are marketed exclusively as consumer-based devices.

1.4.3.3.1 Research

The ActivPAL™ is a tri-axial accelerometer and is considered to be the optimal research-quality device for measuring sedentary behaviour [162]. This accelerometer is used to differentiate among postures and classify participants' behaviour into sitting time, standing time, stepping time, measure the number of transitions from seated to standing, the number of steps taken, as well as provide an estimation of energy expenditure (PAL Technologies Ltd., Glasgow, UK). The ActivPAL™ has the memory and battery life capacity to collect data for up to eight days and store data for 98 days and the battery can recharge from full discharge within a short two-hour period. For use, this device is placed in a latex sleeve to prevent sweat from penetrating the connection port and is attached to the wearer's mid-thigh using a clear Tegaderm adhesive patch. This device connects to a personal computer via a USB port and a proprietary docking station that allows the accelerometer to be initialized and downloaded using proprietary software produced by the manufacturer. This software generates pictorial representations of behaviour by day or by week, and raw data can be exported to a spreadsheet for analysis. Data are detected and summed during a preset 15-second epoch which are then summed to derive accumulated time spent in each posture or behaviour. Additional out-puts provided by the software also include time in stepping by cadence (i.e., steps per minute). More detailed technical specifications for ActivPAL™ are provided elsewhere [163].

The ActivPAL™ has been validated for use in laboratory and free living conditions [163] making it an excellent device for researchers to use in the field. The most recent version of the ActivPAL™ monitor also has the ability to vibrate while attached to the wearer's leg, reminding the wearer to break up a period of sitting time. One major problem with this monitor is that the ActivPAL™ is not able to differentiate sitting from lying down. A journal must be used for the duration of the wear-period to help differentiate between day sedentary time, sleeping time, and whether the wearer removed the device for any reason. Overall the ActivPAL™ does have certain limitations: requires skill to process the data, is not water proof limiting its use for individuals who enjoy aquatic activities, and provides no feedback to the wearer as it has no external screen. However, the ActivPAL™ still provides useful information regarding walking and sedentary behaviour but because of its drawbacks and relatively high cost (570 Euro) may be more challenging to use in large-scale applications [162].

The ActiGraph™ GT3X+ (ActiGraph, Pensacola, FL) is the most commonly used tri-axial accelerometer for the assessment of physical activity in free-living conditions [164,165]. This is a wearable, small (4.6 cm x 3.3 cm x 1.5 cm), lightweight (19 g) device capable of measuring number of steps and the amount of time spent in sedentary, low, moderate, and vigorous activity levels. The ActiGraph™ measures perturbations in movement or what is more commonly referred to as counts to classify activity levels. The most commonly used classifications come from Troiano et al. in 2008 where: 0 to 99 counts per minute (CPM) denotes sedentary behaviour, 100 to 2019 CPM is light intensity activity, 2020 to 5998 CPM is moderate intensity activity, and 5999 plus CPM is vigorous intensity activity [166]. It is important to note that there are also different cut points required for different populations (e.g. Children, Adults, Elderly, etc.) as values recorded can be drastically different depending on the cut points used. Customarily, the ActiGraph™ is set to record at 80 Hz or more. Information on the device can be downloaded in 1 second epochs (periods of time) and can then be re-integrated into any sized epoch (e.g. 20 seconds, 1 minute, 5 minutes, etc.) to suit the purpose of the research project. The battery is substantial, allowing for 20 days or more of monitoring, making it any ideal research device for long-term free-living conditions. Although traditionally worn around the waist with the use of an elastic belt, it is a very versatile device and can be worn on the thigh, ankle, and wrist, depending on which location best suits the population under study. Again, with varying cut-points to be considered for each wear-location. The newest iteration of the ActiGraph™ device (GT3X+ BT) can be paired with a heart rate monitor and global positioning system (GPS) unit, further enabling researchers to understand the activity measures in context. For example, multiple hours of sitting time near a cinema and vigorous activity near a school. This technology also allows for topographical information to be integrated into the activity monitoring. This allows researchers to explain why heart rates may vary depending on the intensity of activity by providing information concerning hills and steep inclines. The ActiGraph™ provides accurate and extremely detailed information which can be easily disentangled using a proprietary computer program known as ActiLife™. A drawback of this device is that it is relatively expensive, requires the use of expensive software, and requires trained professionals to use. Moreover, as it does not measure activity directly, and relies on cut points to classify activity, there has been some debate as to which set of cut points provides the most accurate information for each wear-location. Even though multiple validity and reliability studies have been performed there is still a lack of consensus on the best set of cut points to use in all situations [167,168].

1.4.3.3.2 Consumer

Recently, there has been an emergence of inexpensive consumer-based activity monitors marketed towards individuals interested in tracking their health and fitness (e.g. Fitbit One, Jawbone Up, Nike Fuel Band, Garmin Vivofit). These consumer-based devices claim to offer effective, low-cost, activity monitoring similar to expensive research-based devices, such as ActiGraph™ GT3X+, which were used in developing current national physical activity recommendations [164]. The popularity of these consumer-based monitors is growing as it is estimated that 19 million were used in 2014 and that this number is predicted to triple by 2018 [169]. Furthermore, over 50 % of the three million new activity monitors that were purchased between 2013 and 2014 were from Fitbit who remains the sales leader for this segment [169]. Compared to ActiGraph™, which is mostly worn on the hip in a research setting, Fitbit One activity monitors can be worn on the hip or bra, and Fitbit Flex activity monitors worn on the wrist [170]. This ability to vary device location allows for a more discrete and comfortable wearing experience. Consumer based devices, such as Fitbit devices, also offer unique features such as web-based and mobile phone applications, making activity monitoring easier to integrate into one's daily routine. They have potential to be an inexpensive alternative to prevailing research-based monitors. Fitbit activity monitors (Fitbit Inc., San Francisco, CA) are tri-axial, accelerometer-based devices that can measure steps taken, floors climbed, distance traveled, calories burned, sedentary time, time spent in different intensities of activity (light, moderate, and vigorous), and sleep quality. These monitors are small (4.8 cm x 1.9 cm x 1.0 cm), lightweight (8 g) wearable wireless activity monitors [170]. These devices have a microelectromechanical tri-axial accelerometer that converts acceleration to step counts using proprietary algorithms that allow measurement of the amount of time spent in sedentary, low, moderate, and vigorous activity levels. The battery life of the Fitbit activity monitors is five to 10-days with internal memory storing up to 23 days [170]. Although studies have investigated the validity of some consumer-based activity monitors (Nike Fuelband, Jawbone Up, Fitbit Ultra), few studies are available to substantiate the validity of these monitors under free-living conditions [171,172]. Free-living conditions are different from laboratory conditions as they offer a wider array of activities and situations for activity monitors to accommodate. Free-living validity information is important for health-care professionals, fitness coaches, and consumers to choose the most appropriate device for their day-to-day needs. One of the greatest benefits of these devices is their ease of use. Data is easily extractable, involves no processing, and allows for easy interpretation. Data is extracted via Bluetooth using a personal computer or mobile device, automatically processed using their proprietary online software found at Fitbit.com and real time reports of all activity measures are generated. These devises offer a unique feature previously unseen amongst research-focused activity monitors. In particular, the Fitbit company created a web-based social networking site that allows for groups of individuals to form communities in which multiple people can have access and view others' online activity and food logs. Therefore, these devices have the potential to be used in support groups and facilitate activity competitions, improve adherence to physical activity guidelines, and promote a physically active environment. Moreover, these devices can be used with individuals and their personal trainers. This technology allows an individual's personal trainer to either monitor their activity related progress on a day by-day-basis or as a weekly summary at their next in person meeting. Personal trainers can use this objectively determined information to optimize behavioural changes that will promote better adherence to activity goals and improve overall quality of life in the long-term. In addition, as these devices and programs can be paired to a smartphone, motivational messages can be sent through the app to the user's home screen. These consumer-based devices may not be the gold-standard in activity monitoring; however they can still provide more detailed feedback to the user than simply the person's own perception of daily activity. This feedback may be helpful in setting physical activity goals, and monitoring progress over time.

1.4.3.3.3 Mobile Device (Smartphone) Applications

Recently, there has been an emergence of independent applications that use internal mobile device accelerometers to measure motion [173,174]. This means that anyone with a mobile device (Android and iPhone) can seamlessly monitor their daily activity through the use of their cellular telephone. A benefit to this method of assessment is that individuals do not need to adopt a new form of technology to embrace it, as most teenagers and adults carry a cellular telephone on a daily basis anyways. As they provide very sophisticated reports to the user in which steps, distance traveled, and intensity of activity are clearly laid out, these applications may act as a gateway into greater interest concerning an individual's own activity. These functions could be the gateway to other more sophisticated activity monitors for consumers and promote healthier lifestyle habits. These applications can be activated and left to log data almost indefinitely. This provides the opportunity to self-monitor long-term activity patterns and identify areas of habitual inactivity. These applications can also send motivational messages to the user's home screen when it identifies long periods of inactivity. As these applications are functioning through a computing device, instructional videos can be embedded within the application to teach users how to perform certain novel activities [173]. The main drawback of this assessment technique is that it is difficult to determine wear-time. Although not necessarily a problem when trying to identify amounts of activity, being unsure of wear time will impact the devices ability to accurately monitor sedentary time. As mentioned earlier, sedentary time is a cardio-metabolic risk factor which is independent of physical activity, and therefore needs to be monitored closely as well.

1.5 PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR AFTER BARIATRIC SURGERY

1.5.1 Pre-surgery

Bariatric surgery candidates spend over 80 % of their time in sedentary behaviours [175], 20 % more than the national average [3]. Examining a group of individuals scheduled for bariatric surgery, King et al. determined that 20 % were sedentary (< 5000 steps/day), 34 % low active (5000 to 7499 steps/day), 27 % somewhat active (7500 to 9999 steps/day), 14 % active (10,000 to 12,499 steps/day), and only 6 % were highly active (≥ 12,500 steps/day) [1]. Of interest, BMI was inversely related to steps per day and steps per minute (cadence) during the most active 30 minutes each day. The most commonly reported activities were walking, 44 %; gardening, 11 %; playing with children, 10 %; and stretching, 7 %. Self-reported minutes of exercise accounted for only 2 % of the variance in objectively determined steps [1]. This lack of continuity between objectively determined and subjective physical activity demonstrates candidates' inability to properly perceive the amount of physical activity that they are doing. This will make meeting activity guidelines near impossible unless self-monitored by more objective means. Overall, few individuals report a regular pre-operative exercise regimen suggesting most physical activity is accumulated from activities of daily living [1].

One goal of bariatric surgery is to promote physical functioning through weight loss in order to improve candidates' ability to perform physical activity. Results from Josbeno et al. suggest that post-surgery, individuals are capable of performing most mobility activities such as walking and running [126]. However, the lack of an association between physical functioning and MVPA post-surgery suggests that a higher level of physical functioning does not necessarily correspond to a higher level of MVPA participation. Thus, it seems that the barriers to adoption of a more physically active lifestyle may not be fully explained by the individual's physical limitations [126]. In 2015, Zabatiero et al. found that many of the perceived barriers and facilitators to physical activity in bariatric surgery candidates are not obesity related (e.g. lack of motivation, environment, and restricted resources) and are therefore unlikely to change as a result of bariatric surgery [176]. Regardless of the barrier, it is evident that physical activity is not being well adopted post-surgery. In 2012, Hatoum et al. found that higher pre-surgical BMI and limited post-surgical physical activity were the strongest predictors of decreased excess weight loss following RYGB. Limited physical activity may be particularly important because it represents an opportunity for potentially meaningful pre- and post-surgical intervention to maximize weight loss following RYGB [177]. In 2015, results from the Bari-Active program: a randomized controlled trial of a pre-operative intervention to increase physical activity in bariatric surgery patients found that with behavioural intervention, patients can significantly increase MVPA before bariatric surgery compared to standard pre-surgical care [178] Moreover, the Bari-Active intervention produced greater improvements in physical activity-related enjoyment, self-efficacy, and motivations as compared to standard pre-operative care [179], resulting in improved physical and mental health related quality of life in bariatric surgery candidates [180].

1.5.2 Short-Term

In the short-term following surgery, patients subjectively believed that they were being more active than before surgery, even though objective measurements indicate that they were at the same level of activity or less than pre-surgery [181]. This finding is interesting as in 2008, King et al. reported that pre-surgery individuals were unable to provide a reliable indication of their physical activity level [1]. Moreover, Berglind et al. evaluated a group of women pre, three, and nine months post-RYGB. They found that pre- to post-surgery, there was an increase in self-reported physical activity which was not confirmed by accelerometer-measured values [182]. Moreover, Berglind et al. found no differences in objectively measured physical activity or sedentary time from pre, three, and nine months post-surgery among women undergoing RYGB [21]. However, in 2012, King et al. published research showing that patients had a greater self-selected cadence during treadmill walking in a laboratory setting and in a free-living environment [82] compared to pre-operative levels.

Although self-reports of physical activity remain unreliable in the short-term post-surgery, self-reported evidence suggests that physical activity increases after bariatric surgery and that physical activity is associated with surgically induced weight loss [183]. More precisely, Egberts et al. found that indeed regular physical activity improves weight loss immediately after RYGB [184]. Moreover, findings from one year after RYGB indicated that light physical activity along with reductions in sedentary time were associated with better maintenance of lean body mass and reductions in fat mass [97] Furthermore, Wiklund et al. gave 55 patients undergoing RYGB a step counter on the first week following surgery. Patients were then informed to try to reach a daily goal regarding the number of steps to be taken. Wikilund et al. found that providing set goals for steps taken per day increased the number of steps walked. This shows that step counters and pre-defined goals can be used to facilitate mobilization after obesity surgery in some patients [185].

Even though dramatic weight loss does improve physical functioning and one's ability to be more physically active, following weight loss there can be excess skin on each member of the body. Through an investigation by Baillot et al. it was found that although excess skin after bariatric surgery is a barrier to the practice of physical activity for some women, it does not in itself prevent the regular practice of physical activity. The main reason women with excess skin avoid physical activity seems to have less to do with the magnitude of excess skin itself and more with psychosocial inconveniences [186]. This may signify that although the majority of metabolic co-morbidities are improved immediately post-surgery, some aspects of the psychological consequences of chronic obesity may linger. A study by Wilms et al. demonstrated that, when compared to a group of normal weight women, accelerometry indicated that women that had undergone RYGB were less physically active. Of interest, there was no difference between women who had undergone RYGB and women currently living with obesity for physical activity. Sport-related activities were reduced in RYGB as compared to normal weight women, while there was still no difference between RYGB and women currently living with obesity [187]. These results may indicate that the feelings towards being physically active remain largely unchanged after surgery, regardless of weight loss.

Results from the LABS-2 investigation demonstrated that almost two thirds (64 %) of patients reported limitations with walking several blocks, 48 % had an objectively defined mobility deficit, and 16 % reported at least some walking aid use. Walking limitations are common in bariatric surgery candidates, even among the least severely obese and youngest patients. Physical activity counseling must be tailored to individuals' abilities. Although several factors identified in the present study (e.g. BMI, age, pain, co-morbidities) should be considered, directly assessing the patient's walking capacity will facilitate appropriate goal setting [188].

1.5.3 Medium-Term

Although it is clear that there is some weight regain three to five years post-surgery, overall weight loss is reasonably well maintained at this time point [189]. Even though obesity status and weight regain have been well documented in the medium-term following surgery, objectively monitored physical activity and sedentary habits have been less well documented. King et al. followed a group of individuals from pre-surgery to three years post-surgery and outfitted them with a wearable accelerometer at three time points (pre-surgery, one year post-surgery, and three years post-surgery) in order to objectively measure their physical activity and sedentary time. Findings from this study indicated that on average, individuals who have undergone bariatric surgery make small reductions in sedentary behaviour and equally small increases in physical activity during the first post-surgery year, which are maintained through the next three years. Therefore, as with pre-surgery, and in the short-term following surgery, we see activity levels fall short of physical activity guidelines for general health or weight control [190].

1.5.4 Long-Term

There are few studies that have examined weight regain long-term post-surgery. In the long-term assessment of 97 individuals who had undergone RYGB, Yanos et al. found that weight regain was significantly associated with adherence-related behaviours, mood symptoms, and pathological patterns of food and alcohol use, all of which are potentially modifiable. These findings underscore the importance of long-term behavioural and psychosocial monitoring after surgery [191]. To date, there have been no objective assessments of physical activity or sedentary behaviours five or more years following bariatric surgery. This information is critical in order to determine whether the weight regain seen at this time point is associated with a consistent lack of behaviour change.

1.6 CONCLUSIONS FROM LITERATURE REVIEW

Individuals who have undergone bariatric surgery believe that they are more active post-surgery than before. Indeed, evidence shows that being more active will promote better weight loss post-surgery and should be encouraged. Furthermore, if given activity monitors and daily goals to meet, patients are capable of increasing their physical activity. However, objective research shows that on average, most individuals who undergo RYGB begin to regain weight in the medium term post-surgery, where we continue to see a lack of behaviour change concerning physical activity and sedentary behaviour. There is currently insufficient information concerning the physical activity and sedentary behaviours of patients long-term post-surgery, but what is known is that weight regain continues to occur at this time point. Therefore, the primary aim of this thesis is to investigate the physical activity and sedentary habits of bariatric patients in the long-term following surgery and determine its effect on weight regain. The secondary aim of this thesis is to determine if physical activity habits related to the built environment, seen in the normal weight population, are present in the bariatric population long-term post-surgery (e.g. neighborhood walkability and occupational vs leisure habits). The tertiary aim of this thesis is to compare the accuracy of a popular inexpensive commercially available activity monitor with a research grade accelerometer.

2.0 Chapter 2:

2.1 Manuscript 1: Physical Activity and Sedentary Behavior in Bariatric Patients Long-Term Post-Surgery

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2.1.1 PREFACE TO MANUSCRIPT 1

This literature review demonstrates that pre-surgery, patients are living with obesity, are insufficiently active [190], and overly sedentary [175]. These patterns do not change in the short-term following surgery despite significant weight loss [4]. In order to determine the impact of physical activity and sedentary time on weight regain long-term post-RYGB, these variables must first be measured. Therefore, the purpose of the following manuscript is to objectively measure the sedentary behaviours and physical activity of individuals who had undergone RYGB, long-term post-surgery, and to determine if they are meeting national physical activity guidelines that would promote favorable long-term weight loss maintenance.

2.1.2 Abstract

Purpose: To measure sedentary behaviors and physical activity using accelerometry in participants who have undergone bariatric surgery 8.87±3.78 years earlier and to compare these results with established guidelines. Materials and Methods: Participants weight, and height were measured, an ActivPAL™3 accelerometer and sleeping journal were used determine day sedentary time, transitions from sitting to standing, as well as steps/day, and participants were asked to indicate if they felt that they were currently less, the same, or more active than before surgery. Results: Participants averaged: 48 ± 15 transitions/day; 6375 ± 2690 steps/day; and 9.7 ± 2.3 hrs/day in sedentary positions. There was a negative correlation between steps/day and sedentary time (r = -.466, $p \leq .001$), 11.27% of participants achieved 10000 steps/day. Participants who reported being more active prior to surgery averaged 6323.4±2634.79 steps/day, which was not different from the other two groups of self-perceived change in level of physical activity (F (2, 68) = .941, $p \leq .05$) from pre- to post-surgery. Conclusions: Participants were inadequately active and overly sedentary compared to established guidelines and norms. Healthcare workers should be taking physical activity and sedentary time into account when creating post-surgical guidelines for this population to ensure the best long-term weight loss maintenance and health outcomes.

2.1.3 Introduction:

Overweight and obesity are quickly becoming serious public health concerns around the world. In Canada, the prevalence of individuals categorized as class III obese (BMI ≥ 40Kg/m^2) has risen by over 700% from 1990 [10] to 2009 [188]. Obesity is associated with several other chronic conditions including: coronary artery disease, type-2-diabetes, certain cancers [35], sleep apnea [192], anxiety and depression [193,194], making severe obesity a major concern for health care systems.

Currently, bariatric surgery is the preferred treatment option for severely obese individuals who have also been diagnosed with any other obesity related co-morbidity [60]. In Canada, the number of bariatric surgeries performed annually has increased by over 90% since 2004 [19]. In the US, the incidence of bariatric surgeries increased from approximately 13,000 surgeries in 1998 to 220,000 surgeries ten years later [69]. Bariatric surgery is known to result in, not only excellent initial short-term weight loss and reduction in co-morbidities, but reasonably good long-term weight loss maintenance as well [20]. However, several studies have shown that over the longer-term, many bariatric surgery patients experience some weight re-gain and the return of certain obesity related co-morbidities [6,35].

Although there are national recommendations denoting 10,000 steps/day as being considered active [103,192], many studies have shown that higher levels of physical activity improve weight loss maintenance for bariatric patients in the long-term post-surgery compared to lower levels of physical activity [99,183]. Recently, sedentary behaviors have been identified as a risk factor for obesity [195], weight gain [91], and poorer metabolic profiles independent of physical activity [196]. When sedentary behavior was assessed among bariatric surgery candidates, it was found that 81.4% of their waking hours were sedentary time [175]. A recent study indicated that up to 6-months post-surgery, there are little to no changes in sitting time or the number of steps taken per day compared to pre-surgical values [197].

To date, little is known about the sedentary habits of bariatric patients long-term post-surgery. The purpose of this study was to objectively measure the sedentary behaviors and physical activity using accelerometry in a cohort of participants who had undergone bariatric surgery 8.87± 3.78 years earlier and to determine if they are meeting national physical activity guidelines that would promote favorable long-term weight loss maintenance.

2.1.4 Materials and Methods:

A total of 89 individuals who had previously undergone bariatric surgery (1 to 16 years prior to assessment) at the Bariatric Clinic of the Royal Victoria Hospital in Montreal, QC, Canada were recruited for this study through contact by telephone. Only participants between the ages of 25 and 70 were included in this study. Former patients were contacted by telephone in-order to complete a long-term post-bariatric surgery follow-up questionnaire on behalf of their surgeon, and those interested in taking part in this additional study then visited the Health and Fitness Promotion Lab at McGill University for the assessment. The nature, purpose, risks, and benefits of the investigation were described to participants and informed consent was obtained prior to start of assessment. This research study was approved by the McGill University Medical Ethics Institutional Review Board Office. Participation in this study was voluntary and participants were not compensated in any way for their contributions.

Height was measured to the nearest 1 cm using a Seca 216 wall-mounted stadiometer and weight was assessed to the nearest 10th kg using a Seca 635 platform and bariatric scale (Seca, Birmingham, UK). Lightweight, indoor clothing and no shoes were worn during testing. An ActivPAL™3 tri-axial accelerometer, was used to differentiate among postures and classify participants' activity into: sitting time, standing time, stepping time; and measure the number of transitions from seated to standing as well as the number of steps taken in a day (PAL Technologies Ltd., Glasgow, UK). This device was placed in a finger clot to prevent sweat from penetrating the connection port and was attached to the participant's mid-thigh using a clear Tegaderm adhesive patch. A sleeping journal was used for the duration of the wear period in order to help differentiate between day sedentary time and sleeping time and whether or not the participant removed the device for any reason. Before wearing the device, participants were asked to indicate if at the time of assessment, they felt that they were either less, the same, or more active than they were before their surgery.

The accelerometer data was extracted using the ActivPAL™ Software version 17.18.1 and saved in 15sec epochs for each participant's 7-day wear period. A valid day was considered to be at least 22hours of wear time, and a valid wear period was 4-6 days including at least 1 weekend day [33]. The ActivPAL™3 data and self-reported sleeping journal information were entered into a MATLAB™computer program that used this information to effectively isolate the day-wear time from the 24 hour/day accelerometer recordings. This step is necessary given that the ActivPAL™3 software it is not capable of distinguishing between day-time sedentary behavior with sleeping time. Participants' steps/day were classified into 5 categories based on Tudor-Locke's 2004 recommendations, with ≤ 5000 steps/day being considered sedentary, 5001-7499 being low active, 7500-9999 being moderately active, 10000-12499 being active, and ≥ 12500 being very active [103].

Nine participants wore their accelerometer for 2 days, leaving them without enough valid days to be included in the analysis, 4 participants were given the device but did not wear it due to skin irritation, and 5 devices failed to record any data, leaving a total of 71 (19 men and 52 women) participants to be included in the analysis. In order to characterize sedentary behavior and physical activity habits, participants' steps/day, sedentary time, and number of transitions/day were individually summed for each day and averaged across the number of valid days in each participant's wear period. A Pearson's r-correlation was performed in order determine the relationship between sedentary time and steps/day. Two ANOVAs were performed to determine if participants' perceived change in pre- to post surgery level of physical activity differed by steps/day or sedentary time. Moreover, participants that indicated themselves as being more active than they were before surgery were dichotomized into two groups, those that achieved more that 7500 steps/day at the time of assessment and those that did not. Independent t-tests were then used to compare the sedentary time and steps/day between these two groups. Statistical tests were considered significant if $p \leq .05$ and all tests were performed using version 22 of IBM's SPSS statistical software.

2.1.5 Results:

Participants averaged 48.20 ± 15.40 transitions/day and 6375 ± 2689 steps/day during the week of monitoring.

Figure 1 displays the number of participants categorized into each of Tudor-Locke's steps/day activity classification levels. By classifying each participant's average steps/day into these categories, it can be seen that one participant (female) achieved greater than 12500 steps/day and 11.27% of participants (5 females, 3 males) achieved the recommended 10000 steps/day. Overall, 36.62% (9 males and 17 females) of participants achieved less than 5000 steps/day.

Based on perceived change in pre- to post-surgery physical activity, 71.8% of participants said that they were more active than they were before surgery, 21.1% of participants said that they were just as active as they were before surgery, and 7% of participants said that they were less active than they were before surgery. Those who reported being more active than they were before surgery averaged 6323 ± 2634 steps/day, which was not different from the other two groups ($F(2, 68) = .941$, $p = .395$).

Figure 2 illustrates participants' self-perceived change in pre- to post-surgery physical activity dichotomized into whether or not they achieved 7500 steps/day. For participants that described themselves as being more active than they were before surgery; 66.6% did not achieve 7500steps/day, and displayed more sedentary time ($t(49) = 2.11$, $p \leq .05$) and less steps/day ($t(49) = -11.31$, $p \leq .001$) than those who did achieve 7500 steps/day.

Participants spent between 3.76 hrs/day and 16.03 hrs/day in sedentary behaviors and averaged 9.74 ± 2.29 hrs/day in sedentary time. There was a negative correlation between steps/day and sedentary time ($r = -.466$, $p \leq .001$). Those that reported being more active post-surgery spent 9.69 ± 2.21hrs/day in sedentary behaviors which was not different from the other two groups of perceived change in physical activity from pre- to post surgery ($F(2, 68) = .052, p = .950$).

2.1.6 Conclusion:

The most important finding of this study was that severely obese individuals who underwent bariatric surgery on average 8.87 years ago do not currently meet national step/day activity guidelines. In total, 88.5% of women and 84.2% of men were not meeting the 10000 step/day national recommendations [103] and it is for this reason that most comparisons in this analysis used 7500 steps/day instead of 10000 steps/day. On average participant's steps/day were in a low-active category which was similar to other chronically ill patient populations such as chronic obstructive pulmonary disease, multiple sclerosis, cancer and other special populations [198]. These results are concerning since higher physical activity levels are known to be associated with better long-term weight loss maintenance after bariatric surgery [98]. These results indicate participants are at an increased risk of re-gaining more weight and possibly, over the long-term, some of the weight related co-morbidities that are commonly seen pre-surgically in this population.

Another important finding was that regardless of participants' perceived change in activity level from pre- to post-surgery, long-term post-bariatric surgery, patients do not differ in average steps/day or sedentary time. A concerning finding is that 66.6% of participants that considered themselves to be more active than before surgery were still averaging less than 7500 steps/day. These findings demonstrate that participants may not be able to accurately estimate their daily level of physical activity. Thus, when possible, clinicians taking care of this population should strive to use accelerometry in conjunction with other tools in order to help their patients adopt a more active lifestyle. Appropriate levels of physical activity remain a cornerstone for optimizing weight loss maintenance. It is critical that patients be able to accurately quantify their level of daily physical activity in order to ensure that they are meeting current physical activity guidelines and avoiding behaviors that would compromise their post-surgical success.

Sedentary behaviors are an important emerging risk factor for weight gain, obesity [199], and poorer metabolic profiles independent of physical activity [25] but are rarely considered when describing this at-risk population. On average, 88.3% of participants' waking hours were spent engaged in sedentary behaviors which is more than the national average of 60% of waking hours [3], and perhaps more concerning, on pare with previously documented pre-surgical levels of 81.4% [175]. Steps/day were found to be negatively correlated with sedentary time. Sedentary behavior needs to be addressed by healthcare professionals in addition to physical activity in order to facilitate the best long-term post-surgical results.

It has been shown that physical activity after bariatric surgery is an important part of long-term weight loss maintenance and an improved health related quality of life [22]. Education concerning physical activity and sedentary behaviors must become more important in the post-surgical care of these individuals. Surgeons and support staff need to provide more detailed information about physical activity and sedentary behaviors to their patients. Over time health care providers should include objective monitoring of these habits in order to ensure lifelong adherence to the post-surgical program. This technology allows for more doctor-patient interaction, better monitoring of patient activity and hopefully an increase in patient daily physical activity as well as a reduction in sitting time post-surgically.

The principal strength of this study was that it incorporated objectively determined sedentary time into the analysis of these participants' complete daily activity. Sedentary time is rarely assessed in similar studies due to the difficulty in accurately measuring it. In this study, we used a state of the art wearable tri-axial accelerometer specifically designed to objectively measure sedentary behavior [200]. Moreover, a clear difference was made between 24 hr sedentary time and waking sedentary time. A sleeping journal was incorporated into the accelerometer protocol which allowed sleep and non-wear time to be removed from the 24 hrs/day accelerometer output, leaving the physiologically important waking sedentary time to be analyzed. Finally, this group of participants represents a unique window of time, relatively long after surgery that few others have been able to objectively monitor. Bariatric surgery is becoming an increasingly common method of dealing with severe obesity and more needs to be known about the long-term effects of the procedure itself as well as the effectiveness of the post-surgical care that patients are receiving.

We acknowledge that a limitation of this study was the subjective description of the participants' current physical activity level in comparison to their activity level pre-surgically. Self-perceived level of physical activity can be less reliable than objective measures due to personal biases or poor recall especially in populations with limited knowledge of physical activity [155]. However, we feel that the addition of this subjective information added to the overall richness of the objectively monitored physical activity data. Although this study may have been slightly underpowered with a sample size of 71, it is comparable to or exceeds the sample typically observed in other studies of this type [5,175] and importantly we feel that it accurately depicts activity trends in this population.

This study found that, long-term post-bariatric surgery, patients were inadequately active and far too sedentary compared to established guidelines and norms. Moreover, regardless of the participants' perceived change in activity levels from pre- to post-surgery, there was no difference in average steps/day or sedentary time at time of testing. These findings suggest that we need new strategies to promote physical activity and reduce sedentary behaviors in this population. Although physical activity remains a cornerstone of weight management strategies in this population, this unique long-term window gives new insights that seem to indicate that sedentary time may be worthwhile to consider when designing new weight management approaches. Longer-term follow up is needed in order to further investigate the effects of this surgery over time. Individuals involved in health policy need to be taking physical activity and sedentary time into account when creating new guidelines for this population in order to ensure the best long-term results.

Table 1. Long-Term Post-Bariatric Surgery Patient Characteristics

	Mean	Std. Deviation
Pre-Surgical Age	41.40	9.45
Current Age	50.27	9.38
Pre-Surgical BMI	53.11	13.01
Lowest BMI Post-Surgery	29.68	8.37
Current BMI	35.64	9.86
Pre-Surgical Weight (kg)	145.91	31.38
Lowest Weight Post-Surgery (kg)	81.58	21.0
Current Weight (kg)	97.83	24.75
% Weight Regain	26.69	18.95
Time Since Surgery (yrs)	8.87	3.78
Lean Mass (kg)	51.67	10.85
Tissue % Fat	43.89	11.83
Fat Mass (kg)	42.94	13.49
Visceral Fat (kg)	1.47	1.08

Figure 1. Classification of Participant Steps/Day with Established Norms

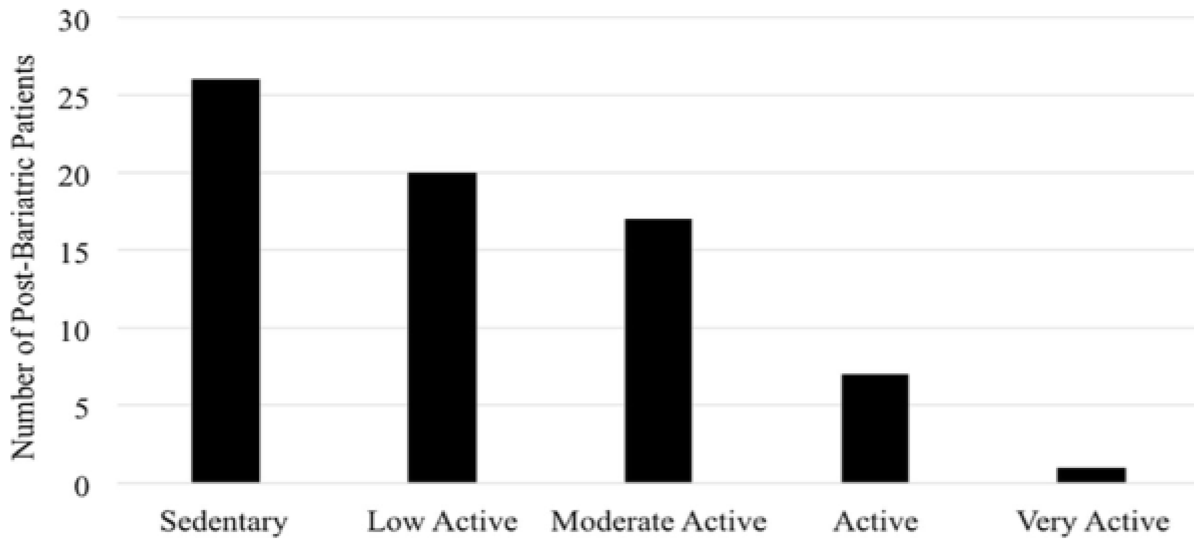
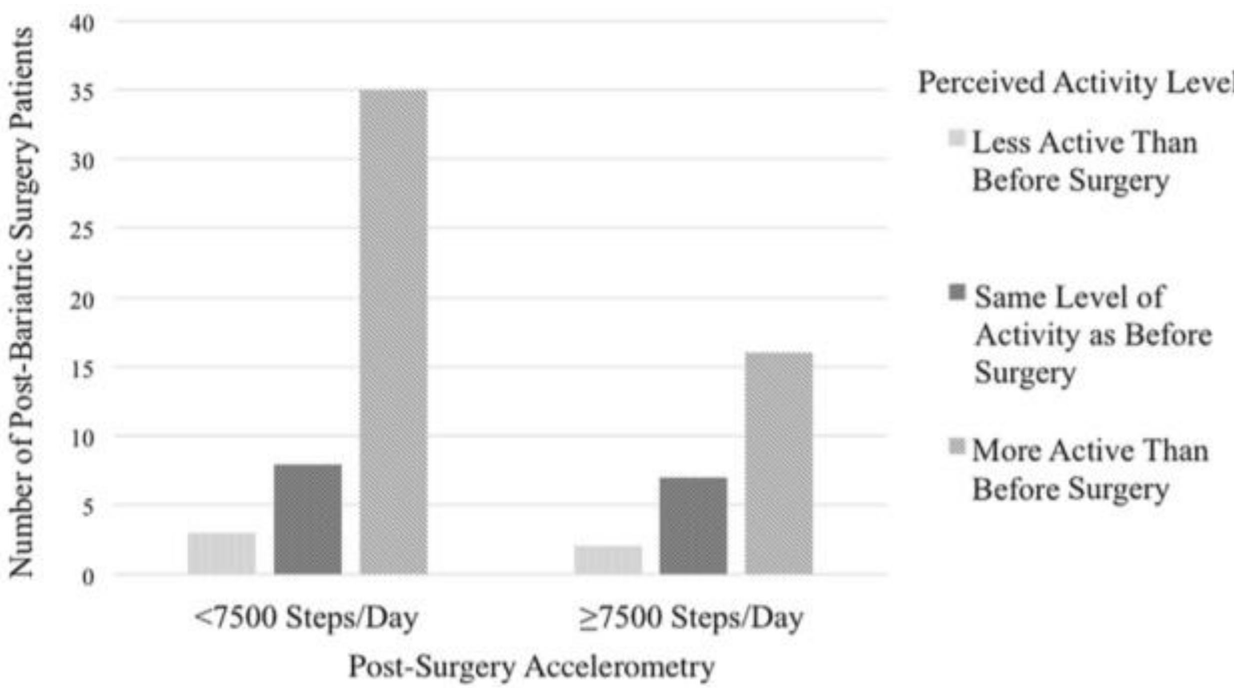


Figure 2. Perceived Post-Surgery Activity Level and Objectively Determined Values



2.2 Manuscript 2: Walking Cadence Among Bariatric Patients Long-Term Post-Roux-en-Y Gastric Bypass Surgery

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2.2.1 PREFACE TO MANUSCRIPT 2

The previous manuscript confirmed that long-term post-RYGB, patients are still not meeting step guidelines, are more sedentary than the national average by 20-30 %, and are regaining weight that they had initially lost post-surgery. However, physical activity is more than simply steps per day. Cadence patterns offer a much more detailed description of daily activity. Walking speed is indicative of MVPA which has its own unique recommendations for health and weight maintenance. Therefore, the purpose of this study was to objectively examine the cadence of individuals who had undergone RYGB long-term (≥ five years) post-surgery, and determine how time in different cadence bands will relate to body composition, weight re-gain, and sedentary time.

2.2.2 Abstract:

Obesity can negatively influence walking cadence. This chronic decrease in cadence represents a reduction in overall intensity of daily activities, leading to a risk of weight gain, and type-2-diabetes. Purpose: Objectively determine the cadence patterns and explore their effects on body composition and weight regain among long-term post-bariatric surgery patients. Methods: 59 participants, 51.19 ± 8.91 years, BMI 34.64 ± 10.11 kg/m^2, 9.98 ± 3.09 years post-surgery underwent a full body composition (DXA) scan to determine fat and lean mass, and wore an ActivPAL™ accelerometer for 7-consecutive days. Daily steps and stepping time were quantified in the following cadence bands: 20–39 (sporadic movement), 40–59 (purposeful movement), 60–79 (slow walking), 80–99 (medium walking), 100–119 (brisk walking), and 120+ steps/min (fast locomotor movements). Results: Average peak cadence band was 150-160 steps/min. Majority of stepping time was spent in a medium walking pace. Participants spent the least amount of stepping time (6.04 ± 3.07 min/day) in sporadic activities and faster locomotion (6.00 ± 9.20 min/day). Participants expended most of their daily steps (29.32 ± 7.30 %) in medium walking followed closely by brisk walking (25.63 ± 11.49 %). Body fat percentage was moderately inversely correlated with percentage of time (r = -.328, p = .011) and steps in faster locomotion (r = -.344, p = .008). Conclusions: Faster locomotion is associated with healthy body composition long-term post-surgery. Physicians and exercise scientists should further evaluate interventions that interrupt extended periods of sedentary time, promote purposeful walking, while maintaining the MVPA levels in this population.

2.2.3 Introduction:

Obesity has become an epidemic throughout North America. In Canada alone, there has been a ten-fold increase in the prevalence of Class III obesity (BMI $\geq$ 40 kg/m^2) from the year 1990 (0.4 %) [10] to 2015 (4.0 %) [12] in the adult population. Meanwhile, there have been similar increases in the United States with Class III obesity increasing from 0.8 % [10] in 1990 to 6.0 % in 2008 [201]. Severe obesity is associated with excessive sitting time [175], low activity levels, mobility impairments [202], and several other debilitating metabolic co-morbidities [203]. Research has shown that this level of extreme obesity negatively influences the basic kinematic parameters of gait, resulting in a reduced stride length, widened base of support, and decreased cadence, or walking speed, as compared to normal weight individuals [104]. This chronic decrease in cadence represents a reduction in the overall intensity of daily activities, leading to a greater risk of weight gain [105], coronary artery disease [204], and type-2-diabetes [205].

Currently, bariatric surgery is the preferred treatment option for severely obese individuals with related co-morbidities [60]. In Canada, the number of bariatric surgeries performed annually has increased by over 90% since 2004 [19]. These surgical procedures are not only known to result in excellent initial weight loss [72], but a greater self-selected cadence during treadmill walking in a laboratory setting [206] and in a free living environment [82]. It is hypothesized that these alterations are mostly due to improvements in physical functioning [5] as compared to pre-operative levels.

Cadence is an important factor to consider when describing patterns of physical activity. Due to the technical difficulties and financial costs involved in objectively monitoring cadence, most descriptions of physical activity are limited to step counts alone or self-report measures [183]. Evidence from physical activity interventions in overweight, obese, and other very low active populations have indicated that cadence is an important aspect to monitor as improvements in cadence are often seen despite the lack of any significant changes in total daily steps [106]. Furthermore, high cadence levels (≥ 100 steps/min) throughout the day can indicate periods of moderate to vigorous physical activity (MVPA) [106], which may be just as physiologically important when compared to total daily steps, as this intensity of physical activity is recommended for health enhancing benefits [107].

As with pre-surgical values [207], long-term post-surgery, most patients remain inadequately active [126]. Although steps per day and sedentary behavior have been documented [208], to the best of our knowledge there have been no reports describing the walking cadence patterns of this population in the long-term (≥ 5 years) after surgery. An examination of cadence in this population may offer new insights into the physical activity patterns that emerge long-term post-surgery. Therefore, the primary aim of this study was to objectively examine walking cadence patterns in a free-living environment for individuals who have undergone roux-en-Y gastric bypass (RYGB). The secondary aim was to explore the relationship among cadence, body composition and weight regain in long-term post-bypass surgery patients.

2.2.4 Materials and Methods:

A total of 89 participants, who had previously undergone RYGB were recruited for this study. On behalf of their surgeon, these patients were contacted by telephone and were asked to complete a long-term post-RYGB follow-up questionnaire. Those who were interested in taking part in this additional study then visited our campus laboratory. The nature, purpose, and risks of the investigation were described to participants and written informed consent was obtained prior to the start of assessment. This research study was approved by the McGill University Medical Ethics Institutional Review Board. Participation in this study was voluntary and participants were not compensated for their participation.

Height was measured to the nearest 1 cm using a Seca™ 216 wall-mounted stadiometer and weight was assessed to the nearest tenght kg using a Seca™ 635 bariatric platform scale (Seca, Birmingham, UK). Body composition was assessed using the Lunar iDXA (GE Healthcare™, USA) whole body composition scanner using procedures previously described [31]. Lightweight, indoor clothing and no footwear were worn during assessments. Obesity was defined as a fat percentage of 30 % for males and 35 % for females [209] and/or a BMI of ≥ 30 kg/m^2 for both sexes. An ActivPAL™ tri-axial accelerometer/inclinometer was used to differentiate among postures while classifying participants' movement into: sedentary time, steps, upright time, stepping time, and transitions (PAL Technologies Ltd., Glasgow, UK). The ActivPAL™ is a valid and reliable measure of steps [210] and has been validated to measure cadence accurately with $< 1\%$ error against direct observation in free living and laboratory treadmill conditions [211]. This device was placed in a latex sleeve to prevent sweat from penetrating the connection port and was attached to the participant's mid-thigh using a clear Tegaderm™ adhesive patch. The device was worn 24 hours per day, a wear-time journal was used for the duration of the wear-period to help differentiate between day sedentary time, sleeping time, and whether or not the participant removed the device for any reason.

Accelerometer data was extracted using ActivPAL™ software version 17.18.1 and saved in 15 second epochs for each participant's 7-day wear period. A valid day was considered to be at least 22 hours of wear-time (including sleep time), and a valid wear period was 4 – 6 days including at least 1-weekend day [33]. ActivPAL™ data and self-reported wear-time journal information were entered into a MATLAB™ computer program which used this information to effectively isolate the wear-time from the 24 hour per day accelerometer recordings. This step is necessary as ActivPAL™ software is not capable of distinguishing between day sedentary behaviors and sleep.

Incidental movement (1-19 steps/min) was considered to be standing non-movement, whereas zero cadence was considered to be sedentary time. This is in contrast to the commonly employed protocol for reporting free-living cadence in human subjects [212] where zero cadence is considered non- movement during wearing time and incidental movement is considered as movement. This difference is based upon our use of the ActivPAL™ activity monitor for measuring cadence compared to other national cohort studies that customarily use the ActiGraph™ accelerometer [212].

Nine participants wore their accelerometer for only two days, leaving them without enough valid days to be included in the analysis, four participants were given the device but did not wear it due to skin irritation, five devices failed to record any data, seven participants were excluded from our analysis since they had surgery less than five-years prior to the date of assessment (therefore not meeting the criteria of long-term post-surgery) [213], and five participants had no weekend day monitoring. Thus, a total of 59 (15 men and 44 women) participants met the inclusion criteria for this investigation. Participant characteristics are displayed in Table 1.

We quantified daily time (minutes) and steps accumulated in the following cadence bands: 0 (sedentary time), 1–19 (standing non-movement), 20–39 (sporadic movement), 40–59 (purposeful steps), 60–79 (slow walking), 80–99 (medium walking), 100–119 (brisk walking), and 120+ steps/min (fast locomotor movements), as previously described [212,214]. Average time (min/day) spent in the various categories of cadence were calculated for week days, weekend days, and total week respectively. All activity data are expressed in both absolute and relative terms (Table 2; Table 3). Time and steps accumulated at ≥ 100 steps/min (MVPA) were calculated. Delta BMI was computed by subtracting their current BMI from their pre-surgery BMI. Percent weight regain was calculated as follows: [(current weight – nadir weight) / (pre-surgery weight – nadir weight)] * 100.

Pearson's product moment correlations were calculated for time spent and steps expended in different cadence bands compared with lean tissue mass, fat tissue mass, fat percentage, visceral adipose tissue, and BMI. Differences in walking cadence across levels of obesity severity were explored using ANCOVA adjusting for age, sex, current BMI, and time since surgery. Differences in percentage of steps and time between week day and weekend days were evaluated with Wilcoxon non-parametric tests. All statistical tests were considered significant if $p \leq 0.05$ and analyses were performed using version 22 of IBM's SPSS statistical software.

2.2.5 Results:

The average peak cadence band achieved by all participants was 150-160 steps/min. Overall, the majority of participants' upright/stepping time was spent in standing non-movement (248.10 ± 120.88 min/day) followed by medium walking (25.52 ± 10.85 min/day). Participants spent the least amount of their stepping time (6.04 ± 3.07 min/day) in sporadic activities and faster locomotion (6.00 ± 9.20 min/day). Participants expended most of their daily steps (29.32 ± 7.30 %) in medium walking followed closely by brisk walking (25.63 ± 11.49 %) cadence bands (Table 2).

Participants spent a significantly greater percentage of time and steps in lower cadence bands on weekend days (sporadic, purposeful, slow, and medium walking) compared to week days (Table 2). Conversely, compared to week days, participants spent a significantly reduced percentage of time and steps in brisk walking and faster locomotion on weekend days (Table 2). Furthermore, on average, 39 % of participants (3 men, 20 women) accumulated at least 30 min/day ≥ 100 steps/min, leaving 61 % of the sample (12 men, 24 women) not meeting the recommended level of daily physical activity. There were no differences in weight regain for those who achieved 30 minute per day national guidelines for MVPA, ($F(1,55) = 2.021$, $p = .161$), controlling for age, sex, current BMI, and time since surgery.

There were no differences in cadence patterns between obese and non-obese participants (Table 3). The fat percentage of participants living with obesity according to BMI (≥ 30 kg/m^2) classification was 45.43 ± 7.48 % (min: 29.70 %; max; 59.00 %). In comparison, participants with a BMI of < 30 kg/m^2 (non-obese) demonstrated an average fat percentage of 40.98 ± 5.03 % (min: 29.90 %; max: 48.40 %), which was statistically lower, $t(57) = -2.54$, $p = .014$.

Significant correlations between cadence bands and anthropometric measures are presented in Table 4.

2.2.6 Discussion:

Throughout the week, participants spent a greater percentage of their stepping time at a medium to brisk cadence as compared to slower speeds of walking. When separating the data by week and weekend days, participants spent less time walking and expended fewer steps in higher cadence bands on the weekend relatively compared to week days. Similarly, the same trend exists for percentage of steps expended. While a substantial portion of their total activity is spent at a high cadence, their overall absolute activity level remains well below the recommended 10,000 steps per day, suggesting that healthcare professionals need to spend more time encouraging active living in patients after obesity surgery [103]. An investigation performed using NHANES data noted that with a nationally representative cohort, in a free-living environment, the highest percentage of stepping time was spent in incidental movement (1-19 steps/min), with sporadic movement (20-39 steps/min) as a distant second [212]. This contrast between populations may be a result of changes in the gait pattern of the bariatric population, who as classified by fat percentage, are still living with obesity. Studies have indicated that living with obesity can lead to reductions in stride length, limitations in range of motion at the hip, and expansions to the width of the base of support [215]. It is possible that the changes in gait pattern may lead to the increases in cadence, as an individual living with obesity would need to take faster steps to cover the same distance, in the same time as a normal weight individual.

An additional important finding of this study was the lack of differences in cadence or total step count between non-obese participants and those living with obesity. Research indicates that more time spent in MVPA is a protective measure against obesity [216], with current national recommendations advocating 150 minutes per week of MVPA [26]. Although we found no differences in walking cadence between obese and non-obese individuals after surgery, it is important to consider the obesity categorization technique that was used. Obesity is normally defined as a BMI of ≥ 30 kg/m^2, but when considering fat percentage, an argument could be made that 95 % of our participants were classified as obese (compared to 59 % by BMI) making such comparisons impossible with our sample. However, there was a clear trend of faster locomotion influencing favorable changes in body composition. This is in agreement with non-bariatric literature which demonstrates periods of faster locomotion, or MVPA, favorably influencing body composition and other health measures [216]. Given our findings with weight regain and time spent in MVPA, it seems evident that new strategies are needed to help this population increase their activity levels and ultimately achieve the desired effect of a healthy body composition for individuals long-term post-RYGB.

A strength pertaining to our study was the use of the ActivPAL™ accelerometer. The ActivPAL™ is a valid and reliable device for objectively monitoring posture and motion [32]. Moreover, this was the first study to demonstrate that the bariatric population, while not meeting the recommendations for daily step counts, does spend a greater percentage of their stepping time in faster locomotion, meeting the national recommendations for MVPA.

We also acknowledge several limitations in this investigation. The number of male participants was too low to allow between-sex comparisons. It would be beneficial to evaluate any differences between sexes in the bariatric population as differences in cadence in the United States population have been identified [212]. Additionally, the use of the ActivPAL™ accelerometer to measure cadence in our bariatric population made comparisons to nationally representative samples difficult. To date, NHANES data has been limited to ActiGraph™ measurements of cadence. As the ActiGraph™ and ActivPAL™ activity monitors have different criteria for classifying activity levels, consistency of devices in future measurements of both the bariatric and nationally representative cohorts will improve the precision of forthcoming comparisons.

In conclusion, this study has demonstrated that, long-term post-surgery, the bariatric population walks at a medium to brisk cadence for the majority of their total stepping time. Furthermore, this study confirmed that achieving the recommended physical activity guidelines did not avert participants from unfavorable body composition and weight gain. Physicians and kinesiologists should further evaluate interventions that interrupt extended periods of sedentary time, promote light activity, while sustaining MVPA levels in this population. A better understanding of what factors affect the shift towards faster movement during week days as compared to weekend days may help patients achieve or exceed desired levels of activity which will certainly help individuals with long-term weight control.

Table 1. Participant characteristics

	Non-Obese (*n* =24)	Obese (*n* = 35)	Total (*n* = 59)
Pre-surgery age (yrs)	39.72 ± 8.48	42.24 ± 9.73	41.21 ± 9.25
Age (yrs)	50.91 ± 8.64	51.39 ± 9.21	51.19 ± 8.91
Time since surgery (yrs)	11.20 ± 2.90*	9.15 ± 2.97	9.98 ± 3.09
Pre-surgery weight (kg)	128.6 ± 21.95**	157.4 ± 32.85	145.7 ± 32.05
Nadir weight (kg)	64.01 ± 9.87**	91.86 ± 20.41	80.53 ± 21.75
Current weight (kg)	75.45 ± 10.01**	108.8 ± 23.10	95.24 ± 25.01
Weight regain (%)	18.56 ± 10.15*	25.96 ± 15.09	22.95 ± 13.70
Pre-surgery BMI (kg/m^2)	44.26 ± 7.22**	58.75 ± 13.23	52.85 ± 13.22
Nadir BMI (kg/m^2)	22.02 ± 3.21**	34.21 ± 7.87	29.26 ± 8.77
Current BMI (kg/m^2)	26.03 ± 3.55**	40.54 ± 8.81	34.64 ±10.11
Delta BMI (kg/m^2)	18.23 ± 5.83	18.21 ± 7.36	18.22 ± 6.73
Current body fat (%)	40.98 ± 5.08*	45.43 ± 7.48	43.62 ± 6.92
Steps per day	6413 ± 2731	6229 ± 2876	6304 ± 2796

* $p \leq .05$ Different from Obese, ** $p \leq .001$ Different from Obese

Table 2. Absolute and relative stepping time and steps per day across cadence bands among long-term post RYGB patients.

	Cadence Bands (steps/min)					
	20-30	40-59	60-79	80-99	100-119	120+
	Sporadic	Purposeful	Slow Walking	Medium Walking	Brisk Walking	Faster Locomotion
Time (min/day), %						
Total Week	6.04 ± 3.07	11.57 ± 5.42	16.09 ± 7.16	25.52 ± 10.85	23.91 ± 15.30	6.00 ± 9.20
	6.91 ± 2.13	13.28 ± 3.59	18.58 ± 5.92	29.17 ± 7.39	25.84 ± 11.64	6.21 ± 7.56
Week Day	5.86 ± 3.30	11.30 ± 5.82	16.00 ± 7.89	25.47 ± 11.73	25.18 ± 16.38	7.15 ±12.46
	6.61 ± 2.21	12.76 ± 3.83	18.16 ± 6.15	28.54 ± 7.59	26.83 ± 12.64	7.10 ± 9.03
Weekend Day	6.38 ± 3.30	12.12 ± 5.82	16.29 ± 7.27	25.63 ± 12.09	21.38 ± 16.38*†	3.70 ± 4.78*†
	7.78 ± 2.74**	14.68 ± 4.35**	19.65 ± 6.08*	30.55 ± 7.64*	23.13 ± 11.81*	4.21 ± 4.86*
Steps/Day, %						
Total Week	428.9 ± 198.7	824.8 ± 350.8	1150.7 ± 469.3	1846.3 ± 760.8	1816.0 ± 1264.4	474.1 ± 796.0
	7.03 ± 2.16	13.45 ± 3.65	18.73 ± 5.87	29.32 ± 7.30	25.63 ± 11.49	6.21 ± 7.42
Week Day	424.0 ± 214.1	818.6 ± 376.3	1159.6 ± 515.8	1865.1 ± 803.8	1936.4 ± 1379.2†	575.0 ± 1100.2†
	6.61 ± 2.21	12.76 ± 3.83	18.16 ± 6.15	28.54 ± 7.59	26.83 ± 12.64	7.10 ± 9.03
Weekend Day	438.9 ± 209.8	837.1 ± 380.4	1132.9 ± 487.5	1808.7 ± 892.8	1575.1 ± 1306.8*†	272.4 ± 370.3 **†
	7.88 ± 2.87**†	14.84 ± 4.54**†	19.86 ± 6.26**†	30.87 ± 8.01**†	23.22 ± 11.71**	4.42 ± 5.71**

* $p \leq .05$ Different from Week Day, ** $p \leq .001$ Different from Week Day, † $p \leq .05$ Different for Total Week

Table 3. Absolute and relative stepping time and steps per day across cadence bands and obesity

	Cadence Bands (steps/min) 20-30 Sporadic	40-59 Purposeful	60-79 Slow Walking	80-99 Medium Walking	100-119 Brisk Walking	120+ Faster Locomotion
Time (min/day), %						
BMI ≥ 30 kg/m^2	5.50 ± 2.0	10.76 ± 3.82	15.47 ± 5.63	25.45 ± 10.43	24.16 ± 17.14	4.99 ±10.12
	5.16 ± 7.61	6.75 ± 2.38	13.14 ± 4.07	19.01 ± 7.19	29.82 ± 7.27	26.12 ± 13.50
BMI < 30 kg/m^2	6.82 ± 4.10	12.75 ± 7.07	17.01 ± 8.99	25.63 ± 11.68	23.55 ± 12.48	7.46 ± 7.65
	7.76 ± 7.37	7.14 ± 1.71	13.47 ± 2.79	17.96 ± 3.31	28.23 ± 7.61	25.45 ± 8.49
Steps/Day, %						
BMI ≥ 30 kg/m^2	392.6 ± 135.3	771.4 ± 260.8	1111.7 ± 384.3	1855.7 ± 763.5	1871.9 ± 1446.8	410.1 ± 898.7
	6.87 ± 2.41	13.33 ± 4.09	19.21 ± 7.12	30.13 ± 7.19	25.94 ± 13.24	5.13 ± 7.47
BMI < 30 kg/m^2	481.9 ± 260.0	902.5 ± 446.4	1207.5 ± 575.60	1832.68 ± 772.96	1734.5 ± 962.2	567.4 ± 623.2
	7.27 ± 1.77	13.64 ± 2.98	18.02 ± 3.35	28.13 ± 7.45	25.17 ± 8.57	7.78 ± 7.22

* $p \leq .05$ Different from BMI ≥ 30 kg/m^2

Table 4. Correlation martrix of cadence bands by anthropometric measures

Cadence Band	BMI (kg/m^2)	Body Fat (%)	p-Value
Faster Locomotion Steps (Total Week)	-	-0.344	0.008
Faster Locomotion % Time (Total Week)	-	-0.328	0.011
Faster Locomotion % Steps (Total Week)	-0.273	-	0.036

3.0 Chapter 3:

3.1 Manuscript 3: Effects of Neighborhood Walkability on Physical Activity and Sedentary Behavior Long-Term Post-Bariatric Surgery

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3.1.1 PREFACE TO MANUSCRIPT 3

As manuscript 2 demonstrated that patients were engaging in the nationally recommended amounts of MVPA during the week, but slowing down their walking speeds significantly on weekends, the 3rd and 4th studies were undertaken to determine if environmental or social factors may explain the physical activity and sedentary habits of this population as it does in national cohorts. Neighborhood walkability typically improves overall levels of physical activity through active transport rather than exercise [144]. It became important to determine whether or not environmental factors such as neighborhood walkability were playing a role in the physical activity, sedentary behaviour, and weight regain long-term post-surgery. Therefore, the purpose of this study was to investigate the effects of neighborhood walkability on weight regain, physical activity, and sedentary behaviour in a group of individuals who had undergone RYGB, long-term (≥ five years) post-surgery.

3.1.2 Abstract:

Chronic inactivity and weight re-gain are serious health concerns following bariatric surgery. Neighborhood walkability is associated with higher physical activity and lower obesity rates in normal weight populations. Purpose: Explore the influence of neighborhood walkability on physical activity and sedentarism among patients, long-term post-bariatric surgery. Methods: 58 adults aged 50.5 ± 9.1yrs, with a BMI of 34.6 ± 9.7kg/m^2 having undergone surgery 9.8 ± 3.15yrs earlier participated in this study. Participants were asked to wear an ActivPAL™ tri-axial accelerometer attached to their mid-thigh for 7-consecutive days, 24 hours/day. The sample was separated into those that live in Car Dependent (*n* = 23), Somewhat Walkable (*n* = 14), Very Walkable (*n* = 16), and Walker's Paradise (*n* = 5) neighborhoods as defined using Walk Score®. ANCOVA was performed comparing Walk Score® categories on steps and sedentary time controlling for age and sex. Results: Neighborhood walkability did not influence either daily steps ($F(3, 54) = .921$, $p = .437$) or sedentary time ($F(3, 54) = .465$, $p = .708$). Car-Dependent (6359 ± 2712steps, 9.54 ± 2.46hrs), Somewhat Walkable (6563 ± 2989steps, 9.07 ± 2.70hrs), Very Walkable (5261 ± 2255steps, 9.97 ± 2.06hrs), and Walker's Paradise (6901 ± 1877steps, 10.14 ± .815hrs). Conclusion: Walkability does not appear to affect sedentary time or physical activity long-term post-surgery. As the built-environment does not seem to influence activity, sedentarism, or obesity as it does with a normal weight population, work needs to be done to tailor physical activity programming after bariatric surgery.

3.1.3 Introduction:

From 1981 to 2009, the prevalence of Canadians living with obesity nearly doubled (13% to 25% respectively) [9]. This increase is alarming considering obesity is linked to numerous co-morbidities including cardiovascular disease, type-2-diabetes, and osteoarthritis [217,218]. Currently, the most effective long-term treatment for extremely obese individuals (BMI ≥ 40 kg/m^2) with associated co-morbidities is bariatric (metabolic) surgery. This procedure provides excellent initial short-term weight loss, and most importantly, a reduction in co-morbidities [219]. If individuals who have undergone bariatric surgery do not adopt a physically active lifestyle and better nutritional habits following surgery, they are more likely to regain weight over the long-term [220]. In fact, weight regain over the long-term has been commonly reported [220]. In addition, it has been found that long-term post-surgery, individuals remain insufficiently active, failing to meet established guidelines, and engage in 30% more sedentary time than normal weight populations [208].

Walking is the most common moderate-intensity activity performed by overweight adults, and is associated with considerable health benefits [140]. Walking for transport, recreation, or exercise all contribute to total daily physical activity [141]. Until recently, individuals obtained most of their physical activity during work, household chores, and transportation. Today, these demands have been critically reduced due to automation and computers at work, labor-saving devices at home, as well as the built environment and transportation practices that require driving for most journeys [142]. Research has shown that characteristics associated with the built-environment are regularly related to overall physical activity and to active transportation in particular [144]. In more walkable environments, it is typical to observe a difference in walking for errands and transportation, and few differences in walking for exercise compared to less walkable environments [27]. Similarly, the built environment can affect energy balance by offering opportunities for physical activity, resulting in a lower prevalence of obesity in more walkable neighborhoods compared to less walkable ones [27].

The assessment of neighborhood built-environments, especially neighborhood walkability (a measure of how friendly a neighborhood is to walking), has recently been the focus of public health research and practice [145]. There is a lack of agreement on how the built-environment should be measured and modeled, making it difficult to determine to what degree it is influencing obesity [146]. However, the overall consensus is that making changes to the built-environment influences physical activity and by association, obesity rates. Recently, Walk Score® (www.walkscore.com), a publicly available website, was found to be valid and reliable for estimating access to nearby walkable amenities [148] and is a fast, free, and easy-to-use proxy of neighborhood density, access to nearby destinations, and neighborhood walkability [149].

The purpose of this study was to investigate the effects of neighborhood walkability (using Walk Score®) on weight regain, physical activity, and sedentary behavior in a group of individuals who had undergone Roux-en-Y Gastric Bypass (RYGB), long-term (≥ 5 years) post-surgery.

3.1.4 Methods:

A total of 89 participants, who had previously undergone RYGB (5-16 years prior) were recruited for this study. On behalf of their surgeon, these patients were contacted by telephone and were asked to complete a long-term post-RYGB follow-up questionnaire. Those who were interested in taking part in this additional study then visited our campus laboratory. The nature, purpose, and risks of the investigation were described to participants and written informed consent was obtained prior to the start of assessment. Participants authorized the use of their residential addresses for spatial analyses. This research study was approved by the University Medical Ethics Institutional Review Board. Participation in this study was voluntary and participants were not compensated in any way for their contributions.

Height was measured to the nearest 1 centimeter using a Seca 216 wall-mounted stadiometer and weight was assessed to the nearest tenth kilogram using a Seca 635 platform and bariatric scale (Seca, Birmingham, UK). Body composition was obtained using a Dual X-ray Absoptiometry (DXA) scanner equipped with a large scanning area (198cm x 66cm) capable of accommodating participants weighing up to 200 kg (Lunar iDXA; GE Healthcare). A single technician was responsible for testing and calibration of the iDXA using a GE Lunar calibration phantom prior to each scan.

An ActivPAL™3 tri-axial accelerometer was used to differentiate among postures while classifying participants' movement into: sedentary time, steps, upright time, stepping time, and transitions (PAL Technologies Ltd., Glasgow, UK). The ActivPAL™ is a valid and reliable measure of sedentary time [200] and steps [210]. This device was placed in a latex sleeve to prevent sweat from penetrating the connection port and was attached to the participant's mid-thigh using a clear Tegaderm™ adhesive patch. A wear-time journal was used for the duration of the wear period to help differentiate between day sedentary time, sleeping time, and whether or not the participant removed the device for any reason.

Accelerometer data was extracted using ActivPAL™ Software version 17.18.1 and saved in 15-second epochs for each participant's 7-day wear period. A valid day was considered to be at least 20 hours of wear-time, and a valid wear period was 4–6 days including at least 1 weekend day [33]. ActivPAL™3 data and self-reported wear-time journal information were entered into a MATLAB™ computer program which used this information to effectively isolate the wear-time from the 24 hrs/day accelerometer recordings. This step is necessary as ActivPAL™ software is not capable of distinguishing between day sedentary behaviors and sleep.

Walk Score® was used to determine the walkability of participants' neighborhoods (https://www.walkscore.com). Walk Score® is a free, publicly available, and validated method for calculating neighborhood walkability [145,148]. Walk Score® uses publicly available data to assign a score to a location based on the distance to a variety of nearby commercial and public frequently-visited facilities. Facilities are divided into five categories: educational, retail (e.g. grocery, drug, bookstores), food, recreational (e.g. parks and gyms), and entertainment. The result is normalized to fit a 0 to 100 scale, with 0 being the lowest walkability and 100 being the most walkable. Walk Score® then groups these scores into four categories: Car-Dependent 0-49; Somewhat Walkable 50-69; Very Walkable 70-89; Walker's Paradise 90-100. More in depth technical information on Walk Score® has been previously published [145].

All participants self-reported being weight stable for a minimum of one year prior to participation in the study. Nine participants wore their accelerometer for 2 days, leaving them without enough valid days to be included in the analysis, four participants were given the device but did not wear it due to skin irritation, five devices failed to record any data, seven participants were excluded from our analysis since they had surgery less than 5 years prior to the date of assessment (therefore not meeting the criteria of long-term post-surgery)[213], and six participants had moved more than twice in the five years leading up to the assessment. As such, the analysis included a total of 58 (13 men and 45 women) participants to be included in the analysis.

Analysis of co-variance (ANCOVA) was used to assess differences in sedentary time, steps, upright time, stepping time, transitions, and weight regain between Walk Score® categories while controlling for age and sex. Due to sample size constraints in the Walker's Paradise Walk Score® category, data were collapsed into two categories: low walkable (Car Dependent + Somewhat Walkable) and high walkable environments (Very Walkable + Walker's Paradise). With α set at 0.05, power set at 0.80, and a medium to large effect size, this analysis was powered to find differences with 52 participants. Chi-square analysis was used to determine the differences in frequency of individuals living with obesity in each Walk Score® category. All statistical tests were considered significant if $p \leq .05$ and all tests were performed using version 22 of IBM's SPSS statistical software.

3.1.5 Results:

Participants ranged in age, (between 34.25 to 69.76 years) weight (between 54.43 to 95.43 kg), and total body fat (between 29.7 to 59.0 %). Further information on participant characteristics can be found in Table 1. There was not a significant difference in time since surgery or age across Walk Score® categories ($F(3, 54) = 1.24$, $p = .303$ and $F(3, 54) = .034$, $p = .991$, respectively); however participants from the Very Walkable neighborhoods weighed more and had a higher BMI than those participants living in Car-Dependent neighborhoods (Table 1). There was not a significant difference in weight regain or body fat percentage across Walk Score® categories ($F(3, 54) = 1.39$, $p = .255$ and $F(3, 54) = .410$, $p = .746$ respectively).

The median BMI of the participants was 32.21 kg/m^2 of which 58.6 % of participants had a BMI over 30 kg/m^2. There were significant differences between the number of participants living with obesity in low walkable (Car Dependent + Somewhat Walkable) and high walkable (Very Walkable + Walker's Paradise) neighborhoods (x^2 (1) = 4.19, $p = .041$) Results from this study illustrated that areas of high walkability had more participants living with obesity than expected, $\phi = .269$, $p = .041$.

There was not a significant difference for average daily steps ($F(3, 54) = .921$, $p = .437$), sedentary time ($F(3, 54) = .465$, $p = .708$), standing time ($F(3, 54) = .266$, $p = .850$), or stepping time ($F(3, 54) = .904$, $p = .445$) (Table 2) across Walk Score® categories for week or weekend days separately (all p's $\geq .05$) (Table 2). However, there were significant differences in transitions from sitting to standing across Walk Score® categories (Table 2). No significant differences were observed when comparing low walkable (Car Dependent + Somewhat Walkable) and high walkable environments (Very Walkable + Walker's Paradise) for average daily steps ($F(1, 56) = 1.22$, $p = .274$), sedentary time ($F(1, 56) = 1.06$, $p = .308$), standing time ($F(1, 56) = .077$, $p = .783$), stepping time ($F(1, 56) = 1.29$, $p = .261$), or transitions ($F(1, 56) = .060$, $p = .808$) for week or weekend days separately (all p's $\geq .05$) (Table 2).

3.1.6 Discussion:

The most important finding of this study was that there were no significant differences in physical activity or sedentary behavior across Walk Score® categories in long-term post-surgery patients. Unlike normal weight populations, the physical activity habits of individuals long-term post-RYGB are not influenced by neighborhood walkability. Research has shown that there is very little change in physical activity and sedentary behavior short-term post-surgery despite substantial weight loss [197]. Moreover, when compared to a group of patients long-term post-surgery, both activity and sedentary habits seem relatively unchanged, again despite reasonable weight loss maintenance [208]. The normal weight population emphasizes a lack of time as a major barrier to physical activity [28]. As such, it is logical that neighborhood walkability, which allows for individuals to complete more tasks on foot (e.g. retail, education, transport) yields an increase in overall physical activity mostly from active transport [27]. However, for the bariatric population, pain has been reported to be the most significant barrier to physical activity [24]. A high prevalence of advanced osteoarthritis and excessive use of pain medication post-surgery support this finding [36]. If chronic pain brought on by movement is the primary barrier to physical activity, then increasing neighborhood walkability through decreasing distances to retail, education, and work environments will not likely increase daily activity for this population. In addition to pain, individuals who undergo RYGB face other population-specific barriers to physical activity. There is a strong psychological barrier to being active which is based on fear of public humiliation, negative attention, and lack of self-efficacy[24]. Public policy exists to reduce the common barriers of physical activity associated with neighborhood walkability; however, it is important to consider the unique barriers faced by individuals living with obesity and attempt to include their specific needs into these future plans.

An additional critical finding was that, there was not a significant difference in obesity rates across levels of neighborhood walkability. These findings are contrary to outcomes among healthy weight population [27]. For instance, in the Canadian province of Ontario, geographically located directly west of where our study took place, Chiu et al. concluded that living in an area of low-walkability was associated with a higher prevalence of overweight/obesity [30]. The findings by Chiu et al. agree with those by Saelens et al. since they both attributed these lower obesity rates to active transport, and not exercise. Regular physical activity and reduced bouts of sedentary time are excellent predictors of long-term weight maintenance [220]. As there is not a significant difference in physical activity or sedentary time across Walk Score categories in our study, it is expected that levels of obesity and weight regain do not differ either. With the increasing prevalence of individuals living with extreme obesity [221] and individuals undergoing bariatric surgery, researchers should be concerned about whether successful environmental changes are actually targeting members of the public that require the most assistance. Policy makers need to consider the unique barriers felt by individuals living with extreme obesity and target those barriers specifically. Making outdoor exercise equipment designed for low impact available, and constructing equipment designed to be used by someone living with obesity, such as public bikes with larger seats, are potential solutions. Furthermore, modifying the environment by creating grass trails that could be less impactful on joints compared to asphalt, or by adding benches so that breaks can be taken while walking, are additional intervention strategies that can be implemented.

The principal strength of this study was that objective measures of sedentary time and physical activity were recorded using a wearable tri-axial accelerometer [200]. Moreover, a clear difference was drawn between 24-hour sedentary time and waking sedentary time as a wear-time journal allowed us to remove raw data associated with sleeping sedentary time. Finally, our study focused on sedentary time and physical activity in long-term post-surgery patients, a time-frame that has been inadequately discussed in the literature.

Studies on the environmental effects on walking behavior have failed to control for neighborhood self-selection bias. It has been argued that individuals self-select neighborhoods that mirror their underlying preferences for activity. As our sample size was lowest in the neighborhoods marked as most walkable (Walker's Paradise), and since a significant difference was not found in the majority of activity related measures, this phenomenon may hold true for our population. Moreover, this study includes 22% males which could limit the generalizability of our findings. For this reason, we chose not to make between sex comparisons. Traditionally, approximately 80% of individuals who undergo RYGB are female, making our male to female ratio reasonable when compared to this population and other research studies [18].

Since the built-environment does not seem to influence physical activity, sedentary behavior, or obesity in the same way that is does with a normal weight population, it becomes evident that population-specific work needs to be implemented in order to increase physical activity levels long-term post-surgery.

An individual's home is generally considered an area of sedentarism. In fact, a high percentage of individuals living with obesity are either on sick leave or work from home [222]. Therefore, it may be appropriate to focus on intervention strategies within the home. Initial weight loss and improvement of one's physical activity self-efficacy before transitioning to an outdoor environment may be a beneficial step since psychological barriers hinder one's adoption and compliance towards physical activity. Kinesiologists need to be included as part of the multidisciplinary team that cares for this population, teaching patients about the importance of physical activity and how to engage in it safely and effectively, especially when they live in neighborhoods that support active living.

Table 1. Participant characteristics

	Car Dependent (*n* = 23)	Somewhat Walkable (*n* = 14)	Very Walkable (*n* = 16)	Walker's Paradise (*n* = 5)
Age (yrs)	50.56 ± 9.72	50.07 ± 9.04	50.89 ± 8.98	49.66 ± 6.21
Pre-Surgery Weight (kg)	138.6 ± 31.0*	134.6 ± 25.5*	161.3 ± 35.1	157.8 ± 28.07
Nadir Weight (kg)	74.94 ±16.50	74.94 ± 20.14	88.69 ± 28.16	84.0 ± 16.86
Current Weight (kg)	87.94 ± 50.71*	92.56 ± 22.47	106.4 ± 31.88	102.9 ± 12.40
Pre-Surgery BMI (kg/m^2)	50.20 ± 12.03*	47.29 ± 9.97*	59.46 ± 13.47	55.80 ± 12.92
Nadir BMI (kg/m^2)	27.19 ± 6.74*	26.33 ± 7.78*	32.60 ± 9.82	29.73 ± 7.94
Current BMI (kg/m^2)	32.03 ± 9.29*	32.68 ± 9.00	39.39 ± 11.70	36.49 ± 7.27
Current Fat (kg)	36.96 ± 13.86	39.72 ± 13.08	45.25 ± 19.16	46.46 ± 11.15
Current Body Fat (%)	42.60 ± 5.93	43.74 ± 7.07	43.59 ± 7.39	46.16 ± 6.52
Weight Re-gain (%)	20.58 ± 11.09	30.41 ± 20.38	23.63 ± 12.70	28.45 ± 19.38
Time Since Surgery (yrs)	9.74 ± 2.87	10.17 ± 4.05	10.35 ± 3.05	7.29 ± 2.25

*Different from Very Walkable $p \leq .05$

Table 2. Accelerometry by Walk Score® Category

	Walk Score® / Activity	Car Dependent (n = 23)	Somewhat Walkable (n = 14)	Very Walkable (n = 16)	Walker's Paradise (n = 5)
Total Week	Steps	6359 ± 2712	6563 ± 2989	5261 ± 2255	6901 ± 1877
	Sedentary Time (Hrs)	9.54 ± 2.46	9.07 ± 2.70	9.97 ± 2.06	10.14 ± .815
	Upright Time (Hrs)	5.39 ± 2.57	6.01 ± 2.16	5.55 ± 2.35	5.12 ± 1.59
	Stepping Time (Hrs)	1.43 ± .603	1.54 ± .677	1.22 ± .444	1.53 ± .480
	Transitions	46 ± 12*	46 ± 11*	43 ± 14*	59 ± 9
Week Day	Steps	6688 ± 2637	7233 ± 3434	5251 ± 2450	7327 ± 2054
	Sedentary Time (Hrs)	10.26 ± 2.87	9.03 ± 2.60	10.11 ± 2.15	10.67 ± 1.38
	Upright Time (Hrs)	5.35 ± 2.70	6.56 ± 2.77	5.45 ± 2.51	4.96 ± 1.38
	Stepping Time (Hrs)	1.44 ± .558	1.68 ± .812	1.21 ± .473	1.58 ± .496
	Transitions	50 ± 14	48 ± 11	45 ± 16*	60 ± 6
Weekend Day	Steps	6026 ± 3016	6145 ± 3359	5308 ± 2281	5753 ± 1838
	Sedentary Time (Hrs)	9.18 ± 2.21	9.39 ± 2.83	9.69 ± 2.69	8.59 ± 1.92
	Upright Time (Hrs)	5.58 ± 2.39	5.69 ± 2.52	5.81 ± 2.39	5.53 ± 2.57
	Stepping Time (Hrs)	1.67 ± 1.40	1.47 ± .786	1.20 ± .554	1.38 ± .509
	Transitions	43 ± 13	45 ± 13	39 ± 15*	54 ± 23

*Different from Walker's Paradise $p \leq .05$

3.2 Manuscript 4: Effect of Employment Status on Physical Activity and Sedentary Behavior Long-Term Post-Bariatric Surgery

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3.2.1 PREFACE TO MANUSCRIPT 4

Manuscript 3 demonstrated that neighborhood walkability did not affect the bariatric population's physical activity, sedentary habits, or weight regain long-term post-surgery. However, the built environment also includes the occupational environment. In North America, it is common for adults to spend 50 to 66 % of their week day waking hours at their occupation [223]. With this information, it became important to determine whether or not employment status was playing a role in the physical activity, sedentary behaviour, and weight regain long-term post-surgery. Therefore, the primary aim of this study was to describe the occupational and leisure physical activity and sedentary habits of individuals long-term post-RYGB. The secondary aim is to evaluate the differences between employed and unemployed participants' weekend and weekday physical activity and sedentary habits. The tertiary aim of this study was to determine if employment status plays a role in weight regain.

3.2.2 Abstract

Inactivity and weight regain are serious problems post-bariatric surgery. Nearly half of waking time is spent at work, representing an opportunity to accumulate physical activity and help avoid weight regain. Purpose: Evaluate potential differences in physical activity and sedentary time by employment status post-bariatric surgery. Methods: 48 adults (employed (*n*=19), unemployed (*n*=29)) aged 50.7 ± 9.4 years, BMI = 34.4 ± 10.1 kg/m^2, and 10 ± 3 years post-surgery participated. ActivPAL accelerometers measured transitions, steps, and sedentary time for 7-days. Results: Participants worked on average 8.7 ± 1.8 hrs/day. 21% of employed met step/day guidelines on work-days compared to 10% of unemployed. Employed persons transitioned from sitting-to-standing more on work-days (58.6 ± 17.8) than unemployed (45.0 ±1 5.4). Employment status did not influence activity or sedentary habits on weekend/non-working-days. Conclusions: Current employment may be associated with slightly higher levels of activity post-bariatric surgery.

3.2.3 Introduction:

More than one-third of American adults are currently living with obesity (36.5%) [224]. Bariatric surgery is considered the optimal treatment for extreme obesity resulting in reductions of excess weight and associated co-morbidities [218]. Although bariatric surgery is successful in the short-term, chronic sedentarism, insufficient physical activity, and weight re-gain become serious concerns in the long-term post-surgery [225]. Typically, individuals describe a lack of time and resources as barriers to structured physical activity. As such, lifestyle physical activity (i.e. occupation, leisure, transport, household) may offer appropriate venues to promote energy expenditure and help maintain weight loss post-surgery. The typical North American adult spends one-third to one-half of their waking time in an occupational setting [29], offering an ample amount of time out of the home to accumulate physical activity. However, over the past century, industrialization has contributed to a shift from manual labor towards service industry jobs, (31% in 1900 vs 80% of all workers in 2014), decreasing the daily energy expenditure of workers [29].

As extreme obesity is associated with extended medical leave and unemployment [138], it is important to determine how occupation is affecting daily lifestyle activity and sedentary habits long-term post-surgery. Therefore, the primary aim of this study was to describe the physical activity and sedentary habits of an average work day long-term post roux-en-y gastric bypass (RYGB) in a bariatric population. The secondary aim is to evaluate the differences between employed and unemployed weekend and weekday (work-day) physical activity and sedentary habits in this population.

3.2.4 Methods:

Data for this report came from a larger parent study which is a large, longitudinal cohort of bariatric surgery patients at a single academic site in Montreal, Quebec, Canada. More detailed information on recruitment has been previously published [208]. The nature, purpose, and risks of the investigation were described to participants and written informed consent was obtained prior to the start of assessment. This study was approved by the University Medical Ethics Institutional Review Board. Participation in this study was voluntary and participants were not compensated in any way for their contributions.

Anthropometric measures were obtained in lightweight indoor clothing without footwear. Body composition was obtained using dual x-ray absorptiometry (DXA) (GE Healthcare). Delta-BMI was calculated by subtracting participant' BMI measured at their study visit from their pre-surgical BMI, as recorded in their surgical chart.

ActivPAL tri-axial accelerometer was used to classify movement into: steps, transitions, sedentary, upright, and stepping time (Glasgow, UK). This device was placed in a latex sleeve to prevent sweat from penetrating the connection port and was attached to the participant's mid-thigh using a Tegaderm adhesive patch. A wear-time journal was used for the duration of the wear-period to help differentiate between day sedentary, sleeping, and non-wear time. Moreover, participants self-reported their job type and hours at their occupation using their wear-time journal.

Accelerometer data was extracted using ActivPAL software v17.18.1 and saved in 15-second epochs for participants' 7-day wear periods. A valid day was at least 20 hours of wear-time (including sleep-time), and a valid wear-period was 4-6 days including at least 1-weekend day. ActivPAL data and self-reported wear-time journal information were entered into MATLAB, which isolated the wear-time and self-reported occupation time from the 24-hrs/day recordings. Comparisons between employed and unemployed groups included absolute and relative values (relative to wear-time).

A total of 48 participants (12 men and 36 women) who had undergone RYGB (5-16 years) were included in the analysis. Further information on equipment malfunctions and participant retention has been previously published [208]. Participants were collapsed into two groups: employed or unemployed. The participants were classified as employed if they were working for wages, salary, commission and/or tips. For the employed group, all participants worked during weekdays and all wear-days were work days, therefore making all weekdays work-days for this group. There were 19 employed and 29 unemployed participants whose anthropometric information is detailed in Table 1. The employed group consisted of blue collar (*n* = 5), white collar (*n* = 10), and 4 undisclosed. Of the unemployed participants, 6 were retired and 5 participants were on disability leave. Seventeen participants obtained a high school degree, 19 participants' education went beyond the high school level, and one did not complete high school. Eleven participants did not disclose this information as it was not necessary for the larger parent study from which this pilot data was obtained from.

Independent *t*-tests were performed comparing steps per hour and percent sedentary time by employment status. Dependent t-tests were performed to compare weekday and weekend day activity variables within each group. All statistical tests were considered significant if $p \leq 0.05$ and all tests were performed using version 22 of IBM's SPSS statistical software.

3.2.5 Results:

On average, participants in the employed group had regained 26±15% of the weight that they had initially lost (Delta-BMI 18.7±7.1 kg/m^2) compared to 23±14% (Delta-BMI 17.1±6.6 kg/m^2) in the unemployed group. There were no statistical differences in weight regain, time since surgery or any other anthropometric measures between groups (Table 1).

The employed group reported working on average 8.7±1.8 hours per day. On average, 56±19% of steps (4379±2752 steps), 52±17% of total day sedentary time (5.6±2.4 hours), and 53±16% of transitions (33±18 transitions) occurred at work, while 44±19% of steps (3335±1823 steps), 48±17% of total day sedentary time (5.0±1.6 hours), 47±16% of transitions (26±8 transitions) occurred outside of work time on work days.

On average, 21% of the employed group achieved 10,000 steps both on weekdays and weekends as compared to 10% and 13.8% of unemployed respectively. Employed participants performed on average 14 more transitions on weekdays compared to weekend days (Table 2). There were no differences in physical activity and sedentary time between weekdays and weekend days for the unemployed group (Table 2). The employed group performed on average 14 more transitions on weekdays compared to the unemployed group. There were no differences in weekend measures of activity between groups (Table 2).

3.2.6 Discussion:

Despite spending similar amounts of time in and out of the occupational setting (8.7±1.8 hrs vs 7.6±2.3 hrs, $p = .21$), on work-days, the employed group performed 1000 more steps at their occupation as compared to outside of work. The employed group performed more transitions on weekdays (work-days) compared to weekend days. There were no differences in any physical activity or sedentary habits between week and weekend days for the unemployed group. Moreover, the employed group performed more transitions on weekdays compared to the unemployed group, and achieved step per day recommendations substantially more than the unemployed group. Typically, research demonstrates that employed individuals are more physically active during week days compared to unemployed [226]. Leaving home, commuting to work, and being engaged in a working environment may improve physical activity in this population. We hypothesize that the similarities in weekend behaviors may be attributed to common lifestyle choices related to the bariatric population who habitually demonstrate very low steps per day and excessive sedentary time compared to national samples [208]. This hypothesis is reinforced by findings that neighborhood walkability does not improve the activity of patients post-surgery as it does in normal weight cohorts [227].

Both groups had similar anthropometric measures and changes in BMI from pre- to post-surgery. Although there are some differences in weekday physical activity between groups, it remains unclear how employment status may influence weight regain long-term post-surgery. In non-bariatric cohorts, unemployed individuals report greater body weight compared to employed [228]. Velcu et al. reported no effect of employment status on weight among individuals 5-years post-bariatric surgery [229]. Importantly our study included a measure of fat percentage between groups which also demonstrated no difference. It will be important for future studies to incorporate job-type (i.e. blue collar, white collar, and white collar professional) into their analysis to fully understand the role of employment and job-type on weight maintenance post-RYGB.

The main strength of our study was the use of the ActivPAL accelerometer to measure sedentary time and activity. Objective measurements of these variables are preferred as subjective means may over- and under-report respectively in the bariatric population [225]. Moreover, to our knowledge, this is the first study to examine the relationship between employment status, physical activity and sedentary behavior among individuals long-term post-RYGB.

A limitation of this study was the small sample size and high unemployment rate. A more diverse separation of occupational categories (blue collar, white collar, and white collar professional) should be considered for future studies. Nevertheless, this study provides a vital stepping stone in the understanding of these relationships in the bariatric population. Information concerning time spent in light activity from other activity monitors would also be beneficial in better understanding the subtle differences in lifestyle activity based on employment status. Further information on job tasks and dietary choices would be beneficial in understanding the energy balance of these individuals.

In summary, these pilot data indicate that employment status may positively affect physical activity long-term post-RYGB. Future research with larger samples should investigate the effect of job-type and transportation style on physical activity, sedentary behavior, and weight regain in this population.

Table 1. Participant characteristics

	Employed (*n* =19)	Unemployed (*n* = 29)	Total (*n* = 48)
Pre-surgery age (yrs)	41.34 ± 10.12	40.85 ± 9.85	41.05 ± 9.85
Age (yrs)	50.36 ± 9.43	50.97 ± 9.54	50.73 ± 9.40
Time Since Surgery (yrs)	9.02 ± 3.13	10.12 ± 3.15	9.69 ± 3.15
Pre-surgery weight (kg)	148.66 ± 33.33	141.05 ± 33.01	144.06 ± 32.99
Nadir weight (kg)	81.24 ± 21.26	79.06 ± 22.90	79.98 ±22.06
Current weight (kg)	98.92 ± 25.83	92.92 ± 26.16	94.98 ± 25.88
Weight Regain (%)	25.75 ± 15.24	23.12 ± 13.54	24.16 ± 14.13
Pre-surgery BMI (kg/m^2)	54.97 ± 14.64	50.23 ± 12.09	52.11± 13.21
Nadir BMI (kg/m^2)	30.13 ± 9.59	28.13 ± 8.01	28.92 ± 8.62
Current BMI (kg/m^2)	36.28 ± 10.91	33.15 ± 9.47	34.39 ±10.07
Current Body Fat (%)	42.80 ± 6.74	45.43 ± 6.68	44.39 ± 6.76

Table 2. Comparison of weekday and weekend physical activity and sedentary time by employment status

	Employed (*n* = 19)			Unemployed (*n* = 29)			Difference Between Groups	
	Weekday	Weekend	*p*-value	Weekday	Weekend	*p*-value	Weekday (*p*-value)	Weekend (*p*-value)
Absolute								
Steps	7714 ± 3079	6895 ± 2928	.253	6123 ± 3158	5822 ± 2870	.429	.091	.215
Transitions	58.6 ± 17.8	44.7 ± 12.6	.007	45.0 ± 15.4	44.6 ± 13.9	.845	.007	.970
Upright Time (hrs)	5.75 ± 2.38	5.84 ± 2.14	.875	5.78 ± 3.01	5.63 ± 2.65	.612	.967	.780
Stepping Time (hrs)	1.64 ± .605	1.59 ± .626	.669	1.40 ± .692	1.58 ± 1.27	.379	.213	.983
Sedentary Time (hrs)	10.6 ± 2.27	8.84 ± 1.50	.002	9.14 ± 2.69	9.15 ± 2.76	.974	.057	.663
Relative to Total Daily Wear Time								
Steps/hr	478.0 ± 181.3	466.7 ± 184.4	.858	408.3 ± 199.3	397.3 ± 199.0	.652	.254	.231
Transitions/hr	6.42 ± 3.61	3.07 ± .908	.044	5.59 ± 3.03	3.04 ± 1.03	.947	.064	.913
Upright Time (%)	34.96 ± 12.56	39.12 ± 12.44	.202	38.18 ± 17.62	38.06 ± 16.57	.948	.494	.813
Stepping Time (%)	10.07 ± 3.63	10.73 ± 3.86	.409	9.33 ± 4.39	10.80 ± 8.75	.318	.546	.973
Sedentary Time (%)	65.04 ± 12.56	60.88 ± 12.44	.202	61.81 ± 17.62	61.94 ± 15.57	.948	.494	.813

4.0 Chapter 4:

4.1 Manuscript 5: Validity and reliability of Fitbit activity monitors compared to ActiGraph GT3X+ with female adults in a free-living environment

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4.1.1 PREFACE TO MANUSCRIPT 5

Up to this point, we have established that long-term post-surgery, patients are not stepping enough, are overly sedentary, regaining weight, and that these factors are unaffected by the built environment. We believe that physicians and exercise scientists need to work on new interventions to help bariatric patients reduce weight regain long-term post-surgery. Our findings indicate that interventions that interrupt extended periods of sedentary time, promote light activity, and maintain MVPA levels in this population should be evaluated. A better understanding of what factors affect the shift towards faster movement during week days as compared to weekend days may help in designing strategies for such interventions. One method of instituting these changes in behaviour may be through self-monitoring. Based on these findings, and the introduction of new, affordable, and easy to use personal activity monitors in the marketplace, it became important to determine if these devices could provide valid and reliable measures of activity. Consequently, the primary aim of this study is to compare the accuracy of the Fitbit™ Flex and Fitbit™ One activity monitors in measuring sedentary time, step-count, and time spent in different intensities of activity against the previously validated ActiGraph™ GT3X+ tri-axial accelerometer. A secondary aim is to evaluate the inter-device reliability of the Fitbit™ Flex and two different wear-locations of the Fitbit™ One activity monitors in measuring the aforementioned variables in free-living conditions.

4.1.2 Abstract:

Objectives: Inexpensive activity monitors have recently gained popularity with the general public. Researchers have evaluated these consumer-based monitors in laboratory-conditions. Given the current wide-spread consumer use of these devices, it is important to ensure users are attaining accurate information compared to previously validated measures. This study investigates the accuracy of Fitbit™ One and Flex activity monitors in measuring steps, sedentary time, and time spent in light, moderate, and vigorous intensity activities with ActiGraph™ GT3X+ with female adults in free-living conditions.

Design: Cross-sectional study

Methods: Twenty-two women, 21.23 ± 1.63 yrs, BMI: 22.35 ± 2.34 kg/m^2 wore two Fitbit™ Ones (bra and waist), one Fitbit™ Flex on the wrist, and one ActiGraph™ GT3X+ on the waist for seven-consecutive days. Repeated measures ANOVA was used to explore differences in steps, sedentary time, and time spent in light, moderate and vigorous intensity activities among the four devices.

Results: No differences were found in number of steps recorded across the four devices. Fitbit™ One, waist and bra, overestimated time spent in light intensity activities. Fitbit™ One (waist) and Fitbit™ Flex overestimated time spent in moderate intensity activities. Fitbit™ One, waist and bra, and Fitbit™ Flex overestimated time spent in vigorous intensity activities. All Fitbit™ activity monitors overestimated MVPA and underestimated sedentary time compared to the ActiGraph™.

Conclusions: Regardless of wear-location all Fitbit™ devices provide similar activity monitoring and users can wear the devices wherever best accommodates their lifestyle or needs. Users should not rely solely on these monitors when tracking vigorous and MVPA activities.

4.1.3 Introduction:

Regular physical activity is a cornerstone of a healthy lifestyle, helping to reduce the risk of heart disease [230], type-2-diabetes [231], and weight gain [23] over the lifespan. Although physical activity is nationally advocated with recommended daily and weekly activity goals [102], it can be difficult for individuals who are new to physical activity to accurately quantify their efforts [155]. Personal activity monitors can be useful tools, helping individuals meet or exceed physical activity recommendations.

Recently, there has been an emergence of inexpensive consumer-based activity monitors marketed towards individuals interested in tracking their own health and fitness. These consumer-based devices claim to offer effective, low-cost, activity monitoring similar to expensive research-based devices, such as ActiGraph™ GT3X+, which were used in developing current national physical activity recommendations [164]. The popularity of these consumer-based monitors is growing as it is estimated that 19 million were used in 2014 and that this number is predicted to triple by 2018.[7] Furthermore, over 50% of the three million new activity monitors that were purchased between 2013 and 2014 were from Fitbit™ who remains the sales leader for this segment [169]. Compared to ActiGraph™, which is mostly worn on the hip in a research setting, Fitbit™ One activity monitors can be worn on the hip or bra and Fitbit™ Flex activity monitors worn on the wrist [170]. This ability to vary device location allows for a more discrete and comfortable wearing experience. Fitbit™ devices also offer unique features such as web-based and mobile phone applications, making activity monitoring easier to integrate into one's daily routine.

Fitbit™ devices are relatively new in the activity monitoring community; however they are being used extensively by consumers. Proving the reliability and validity of these devices is crucial if they are to be considered as useful tools for consumers interested in self-monitoring. Furthermore, they have potential to be an inexpensive alternative to prevailing research-based monitors. Although studies have investigated the validity of some consumer-based activity monitors (Nike Fuelband, Jawbone Up, Fitbit™ Ultra), few studies are available to substantiate the validity of these monitors under free-living conditions [171,172]. Free-living conditions are different from laboratory conditions as they offer a wider array of activities and situations for Fitbit™ monitors to accommodate. Free-living validity information is important for health-care professionals, fitness coaches, and consumers to choose the most appropriate device for their day-to-day needs.

Consequently, the primary aim of this study is to compare the accuracy of the Fitbit™ Flex and Fitbit™ One activity monitors in measuring sedentary time, step-count, and time spent in different intensities of activity against the previously validated ActiGraph™ GT3X+ tri-axial accelerometer.[165] A secondary aim is to evaluate the inter-device reliability of the Fitbit™ Flex and two different wear-locations of the Fitbit™ One activity monitors in measuring the aforementioned variables in free-living conditions. We hypothesize that there will be differences between the ActiGraph™ and Fitbit™ activity monitors in the measurement of time spent in all intensities of activities and that all Fitbit™ devices will provide similar monitoring.

4.1.4 Methods:

Twenty-two active women participated in this study and all were included in the statistical analysis. Individuals were recruited from within the university by word of mouth. Approval from the institutional review board was obtained before beginning this study (IRB# A03-B18-13B). In total, thirty-eight participants were recruited for this study; however, ten of the Fitbit™ activity monitors did not properly charge and therefore did not record data, and an additional nine of the

Fitbit™ activity monitors did not record enough valid days (≥ 4 weekdays and 1 weekend day for at least 10hrs per day) in order to be included in our analysis. Participants whose devices malfunctioned were prompted to repeat the assessment. Three of the assessments were repeated successfully and included in our final analysis of twenty-two participants.

Fitbit™ One and Fitbit™ Flex (Fitbit™ Inc., San Francisco, CA) are tri-axial, accelerometer-based devices that can measure steps taken, floors climbed, distance travelled, calories burned, and sleep quality. These monitors are small (4.8 cm x 1.9 cm x 1.0 cm), lightweight (8 g) wearable wireless activity monitors [170]. These devices have a microelectromechanical tri-axial accelerometer that converts acceleration to step counts using proprietary algorithms that allow measurement of amount of time spent in sedentary, low, moderate, and vigorous activity levels. The battery life of the Fitbit™ activity monitors is 5-to-10-days with internal memory storing up to 23 days [170]. The unique feature of all Fitbit™ activity monitors is a wireless function that makes it possible to automatically upload data to the Web without synchronizing them with a computer.

The ActiGraph™ GT3X+ (ActiGraph, Pensacola, FL) is the most commonly used accelerometer for the assessment of physical activity in free-living conditions [164,165]. This is a wearable, small (4.6 cm x 3.3 cm x 1.5 cm), lightweight (19 g) tri-axial accelerometer capable of measuring number of steps and the amount of time spent in sedentary, low, moderate, and vigorous activity levels. This device is marketed exclusively as a research instrument. This is not a consumer-based activity monitor and is included in this analysis solely as a comparison device.

Participants were invited to our lab where they were given time to read the consent form. The research study was explained to them and all of their questions and concerns were addressed. All participants provided written informed consent before taking part in this study and received no compensation. Anthropometric measures were obtained at the beginning of the data collection session as this information was required for the set-up of the activity monitors. Standing height was measured to the nearest 1 cm using a wall-mounted stadiometer (Seca, Birmingham, UK) and weight was assessed to the nearest 10th kilogram using a platform scale (Seca, Birmingham, UK). Each participant was then outfitted with two Fitbit™ One ($119.95 USD each) activity monitors that were worn on the waist (right hip) and the bra respectively, a Fitbit™ Flex ($129.95 USD) worn on the left wrist, and an ActiGraph™ GT3X+ which was worn on the waist (right hip) kept in place using an elastic belt. Participants wore all above listed devices for seven-consecutive days, removing devices only for bathing and sleeping purposes. Throughout the seven-day wearing period, participants completed a wear-time journal indicating time they took the devices off at night, time they put them on in the morning, as well as time when devices were removed during the day.

All Fitbit™ activity monitors were initialized using Fitbit™ online user interface. This web-based interface was also where information stored in each Fitbit™ monitor was uploaded at the end of the wear-period. All ActiGraph™ data was processed using Actilife V6.11.0 with Troiano 2008 [166] activity cut-points (Sedentary (0 – 99 counts per minute), Light (100 – 2019 counts per minute), Moderate (2020 – 5998 counts per minute), Vigorous (≥ 5999 counts per minute). Self-reported sleep and non-wear time were removed from ActiGraph™ data as per established protocol [232]. Fitbit™ activity data was processed using their proprietary online software found at Fitbit.com. Self-reported sleep and non-wear time were manually removed from Fitbit™ activity data in order to better compare its sedentary time values to ActiGraph™'s measurements.

Repeated measures analysis of variance (ANOVA) was used to compare sedentary time, step-count, and time spent in light, moderate and vigorous intensity activities between the four devices. A post-hoc analysis of least squared difference was used to explore differences among devices. We set α at $p \leq 0.05$, minimum. Bland-Altman analysis were performed to evaluate bias between Fitbit™ One worn on the bra and waist as well as Fitbit™ Flex worn on the wrist. All analyses were performed using SPSS version 22.0.

4.1.5 Results:

Participants were 21.23 ± 1.63 yrs, 62.18 ± 8.05 kg, with a BMI of 22.35 ± 2.34 kg/m^2, categorizing them as normal weight individuals for their given height. On average, participants may be considered as active individuals as all Fitbit™ devices showed them meeting the 10,000 steps per day activity recommendations (Table 1). All activity monitors indicated that participants were acquiring the recommended 20-30 minutes of moderate to vigorous intensity activity (MVPA) per day (Figure 1).

Fitbit™ One, waist ($t(21) = -7.66$, $p \leq .001$) and bra ($t(21) = -7.95$, $p \leq .001$), overestimated time spent in light intensity activities compared to ActiGraph™ (Table 1). Fitbit™ One, waist ($t(21) = 5.17$, $p \leq .001$) and bra ($t(21) = -5.95$, $p \leq .001$), overestimated time spent in light intensity activities compared to Flex (Table 1). Fitbit™ One (waist) ($t(21) = -3.79$, $p \leq .001$) and Fitbit™ Flex ($t(21) = -2.89$, $p \leq .001$) overestimated time spent in moderate intensity activities the compared to ActiGraph™. Fitbit™ One, waist ($t(21) = -8.70$, $p \leq .001$), bra ($t(21) = -7.51$, $p \leq .001$), and Fitbit™ Flex ($t(21) = -6.23$, $p \leq .001$) overestimated time spent in vigorous intensity activities, compared to ActiGraph™ (Table 1).

Using the output provided by Fitbit.com, Fitbit™ One, waist ($t(21) = -23.32$, $p \leq .001$), bra ($t(21) = -23.14$, $p \leq .001$), and Flex ($t(21) = -13.62$, $p \leq .001$) overestimated sedentary time compared to ActiGraph^{TM}. Once having processed the sedentary time measured by the Fitbit^{TM} activity monitors in the same manner as the ActiGraph^{TM} (i.e. removing logged sleeping and non-wear time), the Fitbit^{TM} One, waist ($t(21) = 4.75$, $p \leq .001$), bra ($t(21) = 5.26$, $p \leq .001$), and Flex ($t(21) = 2.63$, $p = .016$) underestimated compared to ActiGraph^{TM} (Table 1).

A summary of mean and systematic biases are displayed in Table 2. All systematic bias is positive meaning that differences between measurements increase as time spent at each intensity of activity increases.

4.1.6 Discussion:

The present study compared the accuracy of the Fitbit^{TM} One and Fitbit^{TM} Flex activity monitors in measuring different intensities of activity against a previously validated tri-axial accelerometer (ActiGraph^{TM}) [165], while simultaneously evaluating inter-device reliability of Fitbit^{TM} devices in free-living conditions.

An important finding of this study was that all Fitbit^{TM} activity monitors are as accurate as ActiGraph^{TM} in measuring steps. This finding is in agreement with other studies that have compared the Fitbit^{TM} One, worn only on the waist, to the ActiGraph^{TM} in a controlled laboratory settings [233]. Our study is one of few that demonstrate these findings in free-living conditions, which more appropriately represent real-world usage. This specific type of information may be valuable to consumers considering purchasing these personal activity monitors. To the best of our knowledge, this study is the first to show that Fitbit^{TM} One, specifically worn on the bra, is as accurate as ActiGraph^{TM} in measuring steps. Mammen et al. have studied the bra-wear location in 2012; however they used Fitbit^{TM} Ultra, which is predecessor to Fitbit^{TM} One, and have only collected data in a laboratory environment. Mammen et al. also identified satisfactory agreement with the bra wear-location compared to ActiGraph^{TM} [234]. It is important to note that repeated measures ANOVA was used to control for type-1-error in our analysis since the Bland-Altman analysis identified differences in Fitbit™ One, bra and waist, compared to ActiGraph™, while ANOVA did not. As there is positive systematic bias between wear-locations (i.e. bra vs waist), more active individuals may need to be counseled concerning their optimal wear-location in order to obtain the most accurate activity feedback.

Another important finding of this study was that compared to ActiGraph™, Fitbit™ activity monitors overestimate time spent in all intensities of physical activity. Although some studies examined MVPA between Fitbit™ One, worn on waist, and ActiGraph™ [235], our analysis is unique as we have examined measurement of time spent in moderate and vigorous intensity activities, both individually and combined as MVPA. Our data agree with Rosenberger et al. who found poor agreement between Fitbit™ One, worn on waist, and ActiGraph™ in measuring MVPA. However, we also identified greater mean and systematic bias between ActiGraph™ and Fitbit™ One, worn on waist and bra, for vigorous intensity activity compared to moderate intensity activity. When combined as MVPA, systematic bias for all Fitbit™ devices increases. It is important that each measurement variable is assessed individually as the accuracy of each one can greatly influence a consumer's willingness to rely on the device. If a consumer is specifically monitoring high amounts of vigorous intensity training, Fitbit™ One becomes inaccurate regardless of wear-location. Therefore, information generated from these devices may be less reliable for avid exercisers looking to meet exacting activity goals. However, some studies looking specifically at energy expenditure have found that Fitbit™ One, worn on the waist, is more accurate than the ActiGraph™ [236], leaving researchers uncertain as how to interpret the remaining activity data from these consumer-based devices. Moreover, Rosenberger et al. were limited to 1-2 days of monitoring in structured conditions, while our study examined seven-consecutive days of free-living conditions, again providing better real-world feedback for the end-consumer. Fitbit™ activity monitors can be useful tools for individuals trying to increase their physical activity. Cadmus-Bertram et al. demonstrated that Fitbit™ One encouraged high levels of self-monitoring in a group of post-menopausal women [237]. Fitbit™ also provides online social networking that enables groups of people to monitor and promote each other's activity. Wang et al. demonstrated that an increase in MVPA could be achieved through self-monitoring using a Fitbit™ One activity monitor, using it for as little as one week [8]. These consumer-based devices may not be the gold-standard in activity monitoring; however they can still provide more detailed feedback to the user than simply the person's own perception of daily activity [155]. This feedback may be helpful in setting physical activity goals, and monitoring progress over time.

It is important that activity monitors accurately convey sedentary time independently from physical activity. Time spent in sedentary positions, such as sitting or lying down, is technically different from sleep and non-wear time. Excess sedentary time has negative cardio-metabolic effects, which are associated with obesity [238], heart disease [239], and type-2-diabetes [238], unaltered by physical activity levels [196]. Quality sleep time is important for proper physiological functioning of the body and should be encouraged as well [240]. Our study found that all Fitbit™ activity monitors underestimated sedentary time compared to ActiGraph™. Therefore, consumers relying on these monitors for accurate information will be shown that they are engaging in less sedentary time than reality, unknowingly increasing their risk of mortality and disease. As national guidelines for sedentary behavior are implemented [26], it is necessary that consumer-based devices accurately measure the difference between sleep time and sedentary time, and that consumers understand the dangers of excess sedentary time, as well as the potential shortcomings of these Fitbit™ activity monitors.

Regardless of wear-location, all Fitbit^{TM} activity monitors measured MVPA similarly. This demonstrates that different Fitbit^{TM} activity monitors and wear-locations can provide the user with similar information. The Fitbit^{TM} Flex shows a positive systematic bias for both moderate and vigorous intensity activities compared to Fitbit One, worn on waist. As Fitbit^{TM} Flex, worn on the wrist, is prone to more incidental movement, perhaps its location-specific activity algorithms may account for this difference. Affording the option to wear the device on the bra, hidden out of site, may be beneficial at reaching consumers who have been reluctant to wear activity monitors in the past. This possibility allows consumers to choose the most comfortable wear-location for their lifestyle. Ability to choose, as with other behaviors such as type of physical activity, improves the likelihood of long-term maintenance of behavior [241]. Wang et al. have demonstrated that adherence to self-monitoring of physical activity has a direct effect on successful long-term weight loss and maintenance [8]. Thus, being comfortable wearing the device on a daily basis may lead to better activity monitoring adherence.

We recognize this relatively small sample size could limit interpretation of our data; however as significant differences were identified using conservative analysis, this suggests that the effects observed are robust. Another possible limitation is that only females were recruited; however, this was done purposefully to include bra wear-location for comparison. It may have been possible to include men, using an elastic strap around their chest to simulate a bra; however this would have limited real-world applicability, as devices are not marketed for this wear-location on men. Generalizability of our study may be limited as all participants were healthy young adults; however, this sample provided our analysis with a wide range of behaviors to evaluate the devices' performance with. This sample provided not only high activity levels but also elevated sedentary time, helping us to compare both behaviors across devices. Moreover, Fitbit^{TM} activity monitors are accurate above 0.9 m/s walking speed, so results may not be applicable to all who are undertaking physical activity monitoring. It should be noted that over one-third of participants experienced problems with battery life or other malfunctions within the device which inhibited its ability to record activity data. This should be considered when recommending this device for usage as some individuals may become discouraged or annoyed by this which may affect long-term adherence.

The main strength of our study is that ActiGraph™ GT3X+ was used as the comparison device. ActiGraph™ is currently the most used and validated activity monitor in physical activity research [164,166], and has been used in research studies integral in creating national activity guidelines for MVPA [164] and steps [103]. Widespread use of ActiGraph™ as the gold-standard makes our findings more generalizable to other investigations involving additional commercially available activity monitors [233,236]. Furthermore, by using two of the best-selling commercially available devices, we are able to provide much needed information to researchers and consumers who may be considering these devices as alternatives to more expensive research-based monitors.

4.1.7 Conclusion:

This is the first study to examine the validity and reliability of Fitbit™ One and Flex activity monitors in free-living conditions. In real world conditions, Fitbit™ activity monitors are accurate step counters. These consumer-based devices may lack the accuracy necessary to replace the current generation of research-based accelerometers as there is evident systematic bias for all Fitbit™ monitors in measurement of vigorous and combined MVPA. Although monitoring sedentary behavior is an important aspect of Fitbit™ devices, our current study indicates that these consumer-based monitors require improvement. Moreover, there is excellent reliability between devices, allowing consumers to choose the wear-location that is most suitable for them while still obtaining similar activity monitoring results. Through Fitbit™'s growing popularity, cost-effectiveness, and host of features not offered by research-based monitors, we believe that these devices are useful for beginning exercisers and individuals who focus on steps per day and lower intensity activities. Fitbit™ activity monitors may be less accurate and reliable for exercisers focusing on high intensity training and research groups.

4.1.8 Practical Implications

- Fitbit™ One and Flex activity monitors are valid and reliable devices for measuring steps.
- Placement of Fitbit™ One activity monitor (bra or hip) does not adversely affect accuracy in measuring time spent in light, moderate, or vigorous intensity activities.
- All Fitbit™ devices become less accurate when measuring time spent in vigorous intensity activities.

Table 1. Physical Activity Estimates for ActiGraph™ GT3X+ and Fitbit activity monitors One and Flex Activity Monitors

	Mean ± SD				
	Time (hrs/day)	**Time (min/day)**			
	Sedentary	**Light**	**Moderate**	**Vigorous**	**Steps/Day**
ActiGraph GT3X+	11.04 ± 1.50	111.2 ± 53.1	57.2 ± 26.6	7.44 ± 7.87	9899 ± 3684
Fitbit activity monitors One (Waist)	9.35 ± 1.87[b]	171.9 ± 42.9[bc]	81.3 ± 34.9[b]	33.2 ± 17.2[b]	10999 ± 3573
Fitbit activity monitors One (Bra)	9.57 ± 1.56[b]	176.8 ± 45.4[bc]	75.3 ± 37.1	37.5 ± 20.8[b]	10999 ± 3833
Fitbit activity monitors Flex (Wrist)	9.75 ± 2.07[a]	116.3± 48.3	84.3 ± 48.0[b]	37.9 ± 26.1[b]	10532 ± 3995

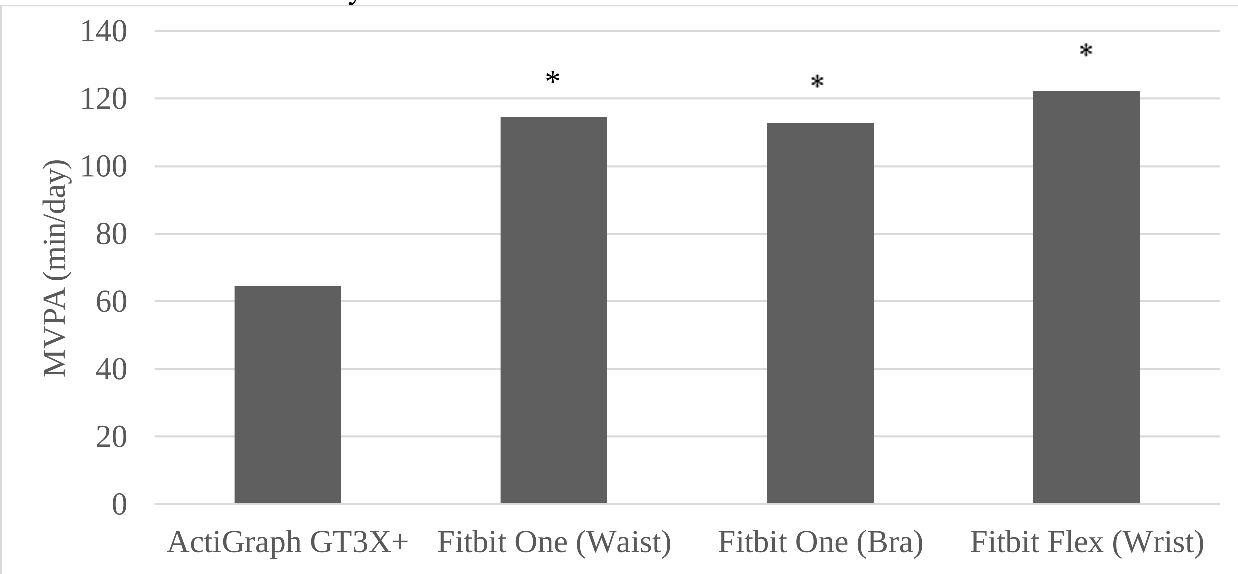
[a] $p \leq .05$ Different from ActiGraph GT3X+
[b] $p \leq .001$ Different from ActiGraph GT3X+
[c] $p \leq .001$ Different from Fitbit activity monitors Flex

Table 2. Bland-Altman plot summaries for all of the domains and all devices

Domain	Device Comparison	Mean Bias (p-value)	Systematic Bias (p-value)
Steps	ActiGraph - Fitbit One (Bra)	-1099 ± 1479 (.002) [b]	r = .103 (.649)
	ActiGraph - Fitbit One (Waist)	-1099 ± 1288 (≤ .001) [b]	r = .087 (.699)
	ActiGraph - Fitbit Flex	-632.9 ± 1600 (.078)	r = .198 (.376)
	Fitbit One (Waist) - Fitbit One (Bra)	.255 ± 470.8 (.998)	r = .553 (.008) [a]
	Fitbit One (Waist) - Fitbit Flex	467.1 ± 1908 (.264)	r = .228 (.308)
	Fitbit One (Bra) - Fitbit Flex	466.8 ± 2090 (.307)	r = .080 (.723)
Sedentary Behavior (hrs)	ActiGraph - Fitbit One (Bra)	1.47 ± 1.31 (≤ .001) [b]	r = .053 (.814)
	ActiGraph - Fitbit One (Waist)	1.69 ± 1.66 (≤ .001) [b]	r = .250 (.243)
	ActiGraph - Fitbit Flex	1.28 ± 2.28 (.016) [a]	r = .321 (.145)
	Fitbit One (Waist) - Fitbit One (Bra)	-.215 ± 1.27 (.437)	r = .266 (.231)
	Fitbit One (Waist) - Fitbit Flex	-.407 ± 2.32 (.402)	r = .106 (.637)
	Fitbit One (Bra) - Fitbit Flex	-.192 ± 1.80 (.623)	r = .323 (.142)
Light Physical Activity (min)	ActiGraph - Fitbit One (Bra)	-65.59 ± 38.7 (≤ .001) [b]	r = .216 (.335)
	ActiGraph - Fitbit One (Waist)	-60.75 ± 37.2 (≤ .001) [b]	r = .293 (.185)
	ActiGraph - Fitbit Flex	-5.12 ± 56.4 (.674)	r = .102 (.653)
	Fitbit One (Waist) - Fitbit One (Bra)	-4.84 ± 9.22 (.023)	r = .263 (.237)
	Fitbit One (Waist) - Fitbit Flex	55.6 ± 50.5 (≤.001) [b]	r = .127 (.573)
	Fitbit One (Bra) - Fitbit Flex	60.5 ± 47.7 (≤ .001) [b]	r = .072 (.751)
Moderate Physical Activity (min)	ActiGraph - Fitbit One (Bra)	-18.0 ± 32.8 (.018) [a]	r = .364 (.095)
	ActiGraph - Fitbit One (Waist)	-24.1 ± 29.8 (≤ .001) [b]	r = .312 (.157)
	ActiGraph - Fitbit Flex	-27.1 ± 44.0 (.009) [a]	r = .567 (.006) [a]
	Fitbit One (Waist) - Fitbit One (Bra)	6.03 ± 12.1 (.029) [a]	r = .186 (.407)
	Fitbit One (Waist) - Fitbit Flex	-2.99 ± 28.5 (.627)	r = .484 (.022) [a]
	Fitbit One (Bra) - Fitbit Flex	-9.03 ± 31.2 (.189)	r = .373 (.087)
Vigorous Physical Activity (min)	ActiGraph - Fitbit One (Bra)	-30.0 ± 18.8 (≤ .001) [b]	r = .780 (≤ .001) [b]
	ActiGraph - Fitbit One (Waist)	-25.8 ± 13.9 (≤ .001) [b]	r = .737 (≤ .001) [b]
	ActiGraph - Fitbit Flex	-30.4 ± 22.9 (≤ .001) [b]	r = .872 (≤ .001) [b]
	Fitbit One (Waist) - Fitbit One (Bra)	-4.26 ± 10.8 (.079)	r = .338 (.124)
	Fitbit One (Waist) - Fitbit Flex	-4.65 ± 13.7 (.127)	r = .666 (≤ .001) [b]
	Fitbit One (Bra) - Fitbit Flex	-.391 ± 19.3 (.925)	r = .302 (.172)
MVPA (min)	ActiGraph - Fitbit One (Bra)	-48.1 ± 30.4 (≤ .001) [b]	r = .496 (.019) [a]
	ActiGraph - Fitbit One (Waist)	-49.9 ± 26.3 (≤ .001) [b]	r = .461 (.031) [a]
	ActiGraph - Fitbit Flex	-57.5 ± 46.4 (≤ .001) [b]	r = .731 (≤ .001) [b]
	Fitbit One (Waist) - Fitbit One (Bra)	1.77 ± 8.12 (.317)	r = .316 (.152)
	Fitbit One (Waist) - Fitbit Flex	-7.65 ± 36.6 (.339)	r = .571 (.006) [a]
	Fitbit One (Bra) - Fitbit Flex	-9.43 ± 35.5 (.227)	r = .513 (.015) [a]

[a] $p \leq .05$, [b] $p \leq .001$

Figure 1. Daily Moderate to Vigorous Physical Activity (MVPA) for the ActiGraph GT3X+ and Fitbit One and Flex Activity Monitors



*$p \leq .05$ Different from ActiGraph GT3X+

5.0 CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 SUMMARY OF RESULTS

This doctoral work is the first to use objective measures to describe the effect of physical activity and sedentary habits on weight regain in bariatric patient's long-term post-surgery. Prior to this research, it was known that pre-surgery, patients did not participate in adequate physical activity to gain health benefits. This was found not to change in the short-term post-surgery. It was hypothesized that as weight was lost post-surgery, that physical function would improve and that physical activity would increase leading to long-term weight loss maintenance.

In manuscript 1, the physical activity and sedentary time of individual's post-bariatric surgery was objectively monitored. It was found, that long-term post-RYGB, patients do not walk enough, fail to meet recommendations for daily steps, and spend too much time being sedentary. Approximately, they spend three hours more a day being sedentary than the national average. In manuscript 2, the cadence patterns of individuals long-term post-RYGB were objectively monitored in a free-living environment. Long-term post-surgery, patients do meet national MVPA guidelines but walk slower during weekends. The first two manuscripts presented in this dissertation describe a population that does not move adequately, moves quickly when stepping, and that move slower on the weekend. As a result, the 3rd and 4th studies were undertaken to determine if environmental factors may explain the physical activity and sedentary habits of this population as it does in national cohorts.

In manuscript 3, we examined the effects of neighborhood walkability on obesity, physical activity, and sedentary habits long-term post-surgery. Unlike individuals who are normal weight, neighborhood walkability had no effect on these measures. In manuscript 4, we examined the effect of employment status on these same measures. Like neighborhood walkability, employment status had no effect on obesity, physical activity, and sedentary habits long-term post-surgery. The findings of manuscripts 3 and 4 demonstrated that the bariatric population is unique and unaffected by typical environmental factors that typically affect physical activity, sedentary time, and obesity severity in the non-bariatric population.

Up to this point, we established that long-term post-surgery, patients are not stepping enough, are overly sedentary, regaining weight, and unaffected by typical environmental factors. We believe that physicians and exercise scientists need to work on new interventions to help bariatric patients reduce weight regain post-surgery. Our findings indicate that interventions that target interrupting extended periods of sedentary time, promote light activity, and maintaining MVPA levels should be evaluated. A better understanding of what factors affect the shift towards faster movement during week days as compared to weekend days may help in designing strategies for such interventions. One way to establish these behavior changes may be through self-monitoring.

Based on these findings, and the introduction of new, affordable, and easy to use personal activity monitors in the marketplace, it became important to determine if these devices could provide valid and reliable measures of activity. In manuscript 5, we evaluated the validity and reliability of the Fitbit™ Flex and One against the ActiGraph™ GT3X+. Fitbit™ monitors were found to be valid for monitoring steps and light to moderate levels of activity as compared to the ActiGraph™. Indicating that the Fitbit™ Flex and the ActiGraph™ GT3X+ are affordable and reliable tools that physicians can prescribe to their patients to monitor their personal daily activity. Moreover, all Fitbit™ activity monitors were able to provide similar measures across three different wear-sites (hip, wrist, and bra). These findings prove that individuals can vary the wear-location of the device to improve comfort, which improves the probability of long-term, consistent self-monitoring.

5.2 CONCLUSIONS

5.2.1 Clinical implications: The role of Kinesiologists and Personal Activity Monitors in Bariatric Care

The role of the kinesiologist in the multidisciplinary care team for bariatric patients must begin pre-surgically in order to initiate behaviour change as soon as possible. The kinesiologist must work as an expert in physical activity providing up to date information and technology to their patients. Surgeons should use kinesiologists as a resource to un-burden themselves from topics that they may not feel comfortable discussing, such as physical activity. Post-surgery, kinesiologists should be included at all regular yearly follow-up visits in order to ensure physical activity guidelines are being adhered to.

A key problem with long-term care of bariatric surgery patients is the inability to maintain good adherence to long-term follow-up visits. Personal activity monitors can help improve the information exchange that is required during long-term post-surgical follow-up visits regardless of whether the patient comes to the clinic or not. This technology enables health care professionals to have access to more objective information concerning the patient's activity and nutritional habits without meeting with the patient face to face. Therefore, if the attending physician is unable to meet with the patient to discuss their physical activity levels, the recording can be given to a part-time or off-site kinesiologist who can review the activity data for the physician. They can furthermore design an appropriate exercise routine and some helpful suggestions to accompany detailed instructions to the patient. This type of document can be prepared ahead of time and given to the patient by the physician at a follow-up visit. Another option could be to e-mail the patient a

PDF document, further eliminating the need for the patient to visit the hospital to acquire this exercise counseling. Nutritionists can additionally have access to documented food logs and an estimated number of calories burned through the devices' websites, allowing them to prepare food recommendations and meal plans for patients before meeting with them at post-surgical visits, or to e-mail to them saving a trip to the hospital.

Most clinics and hospitals that conduct bariatric surgeries offer some type of pre- and post-surgical support groups. This is where groups of patients meet to discuss their experiences with the surgery, to gain information and new perspectives from other individuals who are going through a similar experience. The web-based software for these activity monitoring devices allows for groups of people to form communities in which multiple people can have access and view others' online activity and food logs. Groups of patients can use these devices in support groups to have activity competitions, improve adherence to physical activity guidelines and promote a physically active environment. Kinesiologists should make regular visits to such support groups to educate and council individuals about the importance of physical activity in their daily lives as well as the distinctive dangers posed by excessive unbroken periods of sitting.

There are some minor barriers when recommending the use of these devices. The primary problem is patient accessibility. Although $100 is much less expensive than more research focused activity monitors, it may still prevent patients from purchasing them. Secondly, in order to use these devices to their full potential, patients will need access to a computer with internet, or preferably a smartphone. Although it is not required for the basic activity monitoring function of the devices, a smartphone allows patients to log in real time and have immediate feedback concerning their tracked values. Finally, the patients using these devices must be somewhat technologically savvy. Although most adults 50 years of age and under would find these devices simple to operate, older adults may find them difficult and confusing to use.

If these more expensive and complex devices prove to be too expensive or technologically advanced, an alternative is to use a pedometer. Pedometers are an extremely simple cost effective alternative (cost under $10) that include digital displays. They can be worn and used to monitor activity effectively. Patients can record the number of steps/day for a given period on a calendar or sheet of paper. This activity log can be brought to the patient's post-surgery follow-up visit or e-mailed to the health care professional and be used in a similar manner as the web-based recordings. Although this option may be considered slightly less objective, it would still represent a viable low cost alternative to increase patients' awareness of their level of physical activity levels and allow the health care provider to further counsel the patient on some activity options for their daily life based on the results obtained.

In conclusion, these new more affordable activity monitoring devices combined with their novel web-based software offer a unique and relatively easy way for health care providers to track patients daily physical activity levels and adherence to their activity regime. Adoption of this technology in bariatric clinics pre- or post-surgery may help to reduce excess sitting time and physical inactivity. Both common in this very unique population. It is hoped that these devices can help promote better long-term weight control and healthier living.

The work in this dissertation could provide kinesiologists who have experience working with bariatric patients further information on what specific areas of activity need to be targeted and how this population differs from the non-bariatric population. The expertise and experience of kinesiologists could help create a comfortable atmosphere where the individual capabilities of severely obese individuals are understood. It would therefore be important to define and promote a new specialty, bariatric kinesiologists, who could appreciate and respond to the bariatric patient's pain related concerns, perceived physical limitations, and anxieties related to physical activity.

5.2.2 Strengths and limitations of the dissertation

This doctoral work has several strengths which sets it apart from other research in the field. The principal strength of this study was that it incorporated objectively determined sedentary time into the analysis of these participants' complete daily activity. Sedentary time is rarely assessed in similar studies due to the difficulty in accurately measuring it. In this study, we used a state of the art wearable tri-axial accelerometer specifically designed to objectively measure sedentary behaviour. Objective measurements of these variables are preferred as subjective means may over- and under-report respectively in the bariatric population. Moreover, a clear difference was made between the 24-hour sedentary time and waking sedentary time. A wear-time journal was incorporated into the accelerometer protocol which allowed sleep and non-wear time to be removed from the 24 hour per day accelerometer output, leaving the physiologically important waking sedentary time to be analyzed. Finally, these studies focused on sedentary time and physical activity in patients long-term post-surgery, a time-frame that has been inadequately discussed in the literature. This group of participants represents a unique window of time, relatively long after surgery that few others have been able to objectively monitor. The main strength of manuscript 5 was that the ActiGraph™ GT3X+ was used as the comparison device. ActiGraph™ is currently the most used and validated activity monitor in physical activity research, and has been used in research studies integral in creating national activity guidelines for MVPA and steps. Widespread use of ActiGraph™ as the gold-standard makes our findings more generalizable to other investigations involving additional commercially available activity monitors. Furthermore, by using two of the best-selling commercially available devices, we are able to provide much needed information to researchers and consumers who may be considering these devices as alternatives to more expensive research-based monitors.

Additionally, limitations were noted during these investigations (Manuscripts 1 to 4). The number of male participants was too low to provide accurate comparisons between sexes. Traditionally, approximately 80% of individuals who undergo RYGB are female, making our male to female ratio reasonable when compared to this population and other research studies. Additionally, the use of the ActivPAL™ accelerometer to measure cadence in our bariatric population made comparisons to nationally representative samples difficult. To date, NHANES data has been limited to ActiGraph™ measurements of cadence. As the ActiGraph™ and ActivPAL™ activity monitors have different criteria for classifying activity levels, consistency of devices in future measurements of both the bariatric and nationally representative cohorts will improve the precision of forthcoming comparisons.

Specifically for manuscript 3, a limitation was the lack of walkability information for different geographic locations throughout Quebec and Canada. Moreover, information concerning car ownership and active transportation would have been beneficial to better understand the trends that were observed.

Specifically for manuscript 4, a limitation was the relatively small sample size. A more diverse separation of occupational categories (blue collar, white collar, and white collar professional) should be considered for future studies. Nevertheless, this study provides a vital stepping stone in the understanding of these relationships in the bariatric population. Information concerning time spent in light activity from other activity monitors such as the ActiGraph™ would also be beneficial in better understanding the subtle differences in lifestyle activity based on employment status. Further information on job tasks and dietary choices would be beneficial in understanding the energy balance of these individuals.

As for manuscript 5, we recognize this relatively small sample size (n = 22) could limit interpretation of our data; however as significant differences were identified using conservative analysis, this suggests that the effects observed are robust. Another possible limitation is that only females were recruited; however, this was done purposefully to include bra wear-location for comparison. It may have been possible to include men, using an elastic strap around their chest to simulate a bra; however this would have limited real-world applicability, as devices are not marketed for this wear-location on men. Generalizability of our study may be limited as all participants were healthy young adults; however, this sample provided our analysis with a wide range of behaviors to evaluate the devices' performance with. This provided not only high activity levels but also provided elevated sedentary time, helping us to compare both behaviors across devices. It should be noted that over one-third of participants experienced problems with battery life or other malfunctions within the device which inhibited its ability to record activity data. This should be considered when recommending this device for usage as some individuals may become discouraged or annoyed by this which may affect long-term adherence.

5.2.3 Future directions

Based on our findings, long-term post-surgery, patients do not walk enough, spend too much time in sedentary positions, and are regaining weight. Conversely, patients are able to move at a high cadence which allows them to meet national guidelines related to MVPA during week days; however, there is a significant decrease in walking speed on weekend days. Further investigations regarding lifestyle choices should be done to determine why cadence patterns slow down significantly on weekends.

Primary characteristics of the living environment, employment and neighborhood, that impact physical activity, sedentary time, and body composition in the non-bariatric population do not affect these parameters for individuals long-term post-RYGB. As surgical weight loss and environmental characteristics are not capable of inciting behaviour change long-term post-surgery, interventions targeting these behaviours are necessary. Future investigations should target patients pre- and post-RYGB in order to determine the optimal time to initiate behaviour change interventions in this population. Moreover, interventions should be designed around population specific barriers to physical activity which differ from the non-bariatric population [24]. Interventions should be delivered by kinesiologists associated with bariatric clinics and hospitals. Moreover, interventions should focus on breaking up extended periods of, and reducing daily sedentary time, replacing this time with light intensity physical activity in order to promote stepping. Progress should be monitored in real-time via personal activity monitors and regular feedback should be provided to patients based on their daily activity choices for optimal results.

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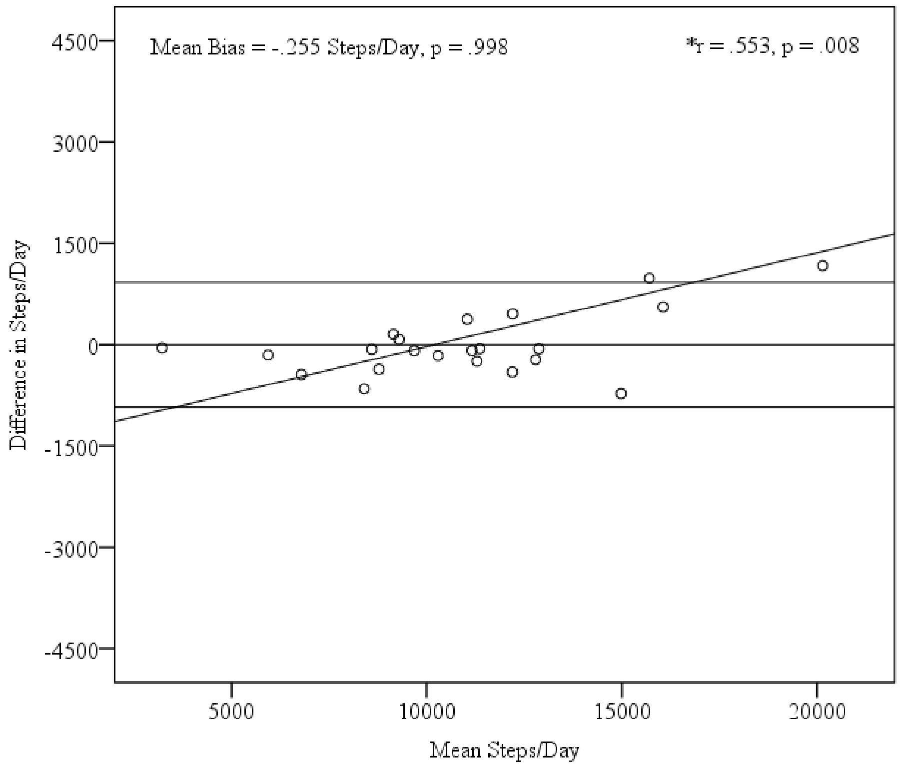
Appendix:

Figure 1. Bland Altman Plot for Steps/Day between the Fitbit activity monitors™ One Worn on the Bra and Waist



*$p \leq .05$ Systematic bias between the Fitbit activity monitors™ One worn on the bra and waist in measuring steps/day

Figure 2. Bland Altman Plot for Steps/Day between the Fitbit activity monitors™ One (Waist) and Flex (Wrist)