Accuracy of Common Prediction Equations and Cross-Validation of Population Specific Equations in Individuals with Spinal Cord Injury

by

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TABLE OF CONTENTS

ABSTRACT

Purpose: The primary aim of this study was to assess the accuracy of common prediction equations, the Harris-Benedict and the Mifflin St. Jeor equations, for estimating resting energy expenditure among people with spinal cord injury against actual resting energy expenditure measurements. The secondary aim was to cross-validate Buchholz et al. energy prediction equation created for people with spinal cord injury.

Methods: A metabolic cart with canopy was used to measure the actual resting energy expenditure. The Harris-Benedict, Mifflin St. Jeor and the Buchholz et al. equations were used for the prediction of resting energy expenditure.

Results: Thirty-nine participants (31 males and 8 females) were enrolled in this cross-sectional study. The resting energy expenditures significantly differed from one another, $F(1.52, 57.68) = 52.04$, $p<.001$, where both the Harris-Benedict ($M = 1703.06$, $SD = 265.1$) and the Mifflin St. Jeor ($M = 1628.92$, $SD = 233.8$) energy predictions were significantly higher ($p<.001$) than the measured resting energy expenditures ($M = 1394.05$, $SD = 298.7$). In contrast, the Buchholz et al. equation did not differ from the measured resting energy expenditure.

Conclusion: Our data show that the Harris-Benedict and Mifflin St. Jeor equation do not accurately predict the energy needs of this community. Using a spinal cord injury specific equation would improve estimates of resting energy expenditures, such as the Buchholz et al. equation. Nevertheless, more research into specific energy equations for this population may help healthcare professionals tailor dietary and physical activity to help this population better manage their weight and avoid any secondary health consequences associated with obesity.

ABSTRAIT

Objectif: Le premier objectif de cette étude était d'évaluer l'exactitude des équations de prédiction communes de Harris-Benedict et de Mifflin St. Jeor pour l'estimation de la dépense énergétique au repos, parmi les personnes atteintes d'une lésion de la moelle épinière contre des mesures de dépense d'énergie réelle. Le deuxième objectif était de valider l'équation Buchholz et al. qui prédit l'énergie créé par les personnes atteintes d'une lésion de la moelle épinière.
Méthodes: Un panier métabolique avec canopée a été utilisé pour mesurer les dépenses d'énergie de repos réelles. Les équations de Harris-Benedict, Mifflin St. Jeor et Buchholz et al. ont été utilisées pour la prédiction de la dépense énergétique au repos.
Résultats: Trente-neuf participants (31 hommes et 8 femmes) ont été inclus dans cette étude transversale. Les dépenses énergétiques au repos différaient significativement les un des autres, $F(1,52, 57,68) = 52,04$, $p <.001$. Les énergies estimés par les équations Harris-Benedict (M = 1703,06, SD = 265,1) et Mifflin St. Jeor (M = 1628,92, SD = 233,8) étaient significativement plus élevés ($p <.001$) que les dépenses d'énergie de repos mesurées (M = 1394.05, SD = 298,7). Par contre, l'équation Buchholz et al. ne diffère pas de la dépense énergétique au repos mesurée.
Conclusion: Nos résultats montrent que les équations Harris-Benedict et Mifflin St. Jeor ne prédisent pas avec précision les besoins en énergie dans cette communauté. L'utilisation d'une équation uniquement créé pour les personnes avec moelle épinière pourrait améliorer les estimations des dépenses énergétiques au repos, comme l'équation Buchholz et al. Néanmoins, plus de recherches sur les équations énergétiques spécifiques pour cette population pourrait aider les professionnels de la santé à améliorer les mesures alimentaires et physiques de manière à mieux contrôler leur poids et éviter les conséquences secondaires associés à l'obésité.

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PREFACE AND CONTRIBUTION OF AUTHORS

Christina Apostolakis: I have recruited and tested the majority of the participants in this study. I have written the thesis and manuscript to its completion.

Florence Sydney (RD at the Lucie Bruneau Rehabilitation Center): Florence has made this project possible. She was involved in the planning and submission of the grant, the ethics approval and finding the initial participants.

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CHAPTER 1: INTRODUCTION

I am doing my thesis on resting energy expenditure in people with spinal cord injury. After looking over the research, there is a lack of nutritional guidelines for this population[1]. Much of the research explores the accuracy of abled-bodied energy equations when applied to this SCI population[2]. There is even less research creating and validating energy equations specifically for this population[3, 4]. In order to advance research, I tested two energy equations to re-verify previous research and add to the current literature. I also cross-validated an energy equation specifically created for people with spinal cord injury, which has yet to be evaluated.

1.1. Paraplegia and Tetraplegia

A spinal cord injury constitutes an injury to the spinal cord or attached nerves resulting in the loss or decrease of strength, sensation and other physiological functions under the site of lesion. There are two common forms of paralysis that result from a spinal cord injury (SCI), paraplegia and tetraplegia. Paraplegia is an injury to the spinal cord anywhere under the thoracic vertebrae, which can affect the trunk, legs and pelvic organs. Tetraplegia is an injury to the spinal cord located only in the cervical vertebrae, which can disturb the arms, trunk, legs and pelvic organs[5-7].

1.2. Prevalence

The World Health Organisation has estimated that every year there are approximately 250 000 to 500 000 people that suffer a SCI globally[8]. It has been recognised by SCI Canada that there are more than 86,000 people living with a SCI and that each year there are roughly 4,300 new injuries emerging[9].

Furthermore, the prevalence of SCI is higher among males, in specific, a 2:1 ratio between males and females. Additionally, between the ages of 20 to 29 years old and 70 and over, males are more likely to get a SCI, whereas between 15 and 19 years old and 60 and over, females are more likely to get a SCI [8].

1.3. Metabolic Deconditioning

Total daily energy expenditure (TDEE) is made up of roughly 65% of resting energy expenditure (REE), 5-10% of thermic effect of food (TEF) and 25-30% of physical activity (PA)[10, 11]. Resting energy expenditure is the amount of energy used when an individual is in a rested awake state[2]. After a SCI, it has been noted that REE tends to decrease[3, 10].

There are energy equations, which predict REE, however in this population, these equations tend to overestimate REE by 5-32%[10]. It is postulated that SCI have a lower REE because they lose fat-free mass (FFM), known to explain roughly 50-80% of REE, and their sympathetic nervous system is changed[3, 10, 12-14].

1.4. Body Composition

After a SCI, there are prominent changes in body composition including a loss of fat-free mass (FFM), a gain in fat mass (FM) and a decreased bone mineral density (BMD)[15-17]. These changes are attributed to factors such as reduced PA and muscle paralysis and atrophy[15, 18, 19].

In people with SCI, there is a physiological characteristic loss of FFM and an increase in FM. Spungen and colleagues determined that the total lean mass decreased at approximately 3.9kg every 5 years, independent of age, in monozygotic twins where one twin had a SCI. This results in a degeneration of nearly 8kg of lean mass every 10 years[20].

As for FM, it has been seen that roughly 23 to 35% of FM is present in people with SCI. Compared to controls, percent fat mass in people with SCI has been noted to be 8-18% more[21]. Specifically, Edwards and colleagues established that when individuals with SCI were compared to AB controls, they had an additional 42% extra of visceral adipose tissue every centimeter of waist circumference[19].

For bone, after a SCI, there is a calcium imbalance caused by an augmented calcium resorption in the body[15]. It has been noted 3 years after a SCI, up to 50% of BMD is depleted[22]. At first, BMD is lost throughout the whole body, but subsequently the bone loss is mainly affecting the bones under the site of injury[15]. As the time increases after the injury, the depletion of BMD decreases to a more stable and lower equilibrium, however bone resorption still continues at a slower degree[15, 22]. This continual loss of BMD often leads to osteoporosis, consequently raising the risk of fractures among this population due to the fragility of the bone[22, 23].

1.5. Emerging Concerns of Obesity and Its Consequences

There is limited information on obesity rates in people with SCI, since measurements of body composition have been validated in people without SCI and cannot accurately estimate body fat in this population. Nonetheless, Gater estimates that there is over 60% of people with SCI who are obese, based on previous research[24]. Additionally, Weaver and his colleagues noted that obesity was most likely in people with mobility problems. He concluded that, although the rate of obesity was found to be lower to the general population, it was suggested that BMI under-represented obesity within this population because FM was not taken into account. Therefore, this could place this population at higher risks for developing co-morbidities such as cardiovascular disease[25].

As was previously stated, a person with SCI experiences a number of characteristic changes including loose of FFM, decreases in EE and lower levels of exercise. Such changes makes obesity a common issue facing people with SCI, which is accompanied with related co-morbidities[18]. People with SCI have greater chances of CVD because of their high rates of obesity. In fact, CVD is developed earlier in this population; it has been documented that CVD can affect individuals with SCI as early as 30 years old. Moreover, the risk factors associated with CVD seem to be higher in this population. In particular, risk factors such as diabetes, low levels of high-lipoprotein (HDL) and high levels of low-lipoprotein (LDL) affect the SCI population more so than their AB controls. Furthermore, when the proportion of diabetes in people with SCI was compared to the general population, it was found that non-insulin-dependent diabetes mellitus affected paraplegics (22%) more so than the general population (11%). Additionally, related problems such as increased levels of plasma glucose and insulin resistance and diminished glucose tolerance have been noted in this population[15]. Obesity not only provides negative physiological problems, but also contributes to pulmonary emboli, further reduction in movement, in addition to pain specific to this population[10].

1.6. Resting Energy Expenditure

By understanding body composition and energy expenditure, SCI patients at risk for obesity and its secondary complications will be able to modify their diet or lifestyle to reduce their higher risk of morbidity and mortality. However, with the added reduction in movement due to paralysis, PA is restricted; as a result, understanding energy intake in this population will allow nutritionists' accurate information to provide a healthy caloric diet to their patients to prevent and/or treat obesity.

1.6.1. Primary Aim

There is very little data on the nutritional needs and exercise science in this population[1, 5]. Equations aimed at predicting REE have been shown to overestimate energy needs by 5 to 32% for the SCI population[10]. It has been deemed that the energy equations taken from the abled-bodied (AB) population are unsuitable for this population[2]. Therefore, the primary aim of this research project was to objectively measure REE and assess the accuracy of the common predictive energy equations (the Harris-Benedict (HB) and Mifflin St. Jeor (MSJ) Equations) for this population. The measure of REE in relation to the predicted energy needs should yield similar results as previously shown. In other words, the common energy equations tested should over-predict energy needs in people with SCI [2].

1.6.2. Secondary Aim

To help with weight management in this population, energy prediction equations must be derived to suit the specific needs of this population to help predict healthy caloric intake. Buchholz and his team are one of the only researchers to date to have created an energy estimation equation for people with SCI. This equation was derived from 28 adults with paraplegia and has yet to be cross-validated. Therefore, the secondary aim of this study is to cross-validated the Buchholz et al. equation in a SCI population containing a combination of paraplegic and tetraplegic participants [3].

CHAPTER 2: LITERATURE REVIEW

2.1 Paraplegics and Tetraplegics

2.1.1 Defining Paraplegics and Tetraplegics

A SCI can happen in seconds; however, the ramifications of such an event can affect a person's life dramatically thereafter[5]. A SCI is known to interrupt the signals that are delivered from the brain to the body and vice versa[26]. It is defined as the "damage to the vertebrae, ligament or disks of the spinal column or the spinal cord itself."[27] There are two ways in which a spinal cord injury can be incurred: traumatically or non-traumatically. A traumatic SCI is when there is an abrupt shock to the spine creating a fracture, dislocation or compression of the vertebrae as from a car accident or a fall. A non-traumatic SCI is when there is damage to the spinal cord triggered by an illness such as arthritis, cancer or an infection[8, 27-29].

The location and completeness of the SCI provides information about the sensation and motor functioning the individual may experience. Tetraplegia affects the cervical region of the spine, which can affect the movements and sensations in the arms, legs, trunk and pelvic region. Paraplegia is when there is an injury specifically from the thoracic region of the spine or lower. The sensation and movement damage depends on the region affected; therefore the trunk, legs and/or pelvic region may be impaired. The completeness of a SCI affects whether there is sensation and motor functioning in the person under their lesion. A complete SCI is when under the level of lesion, the individual can no longer move or feel anything. An incomplete injury is when under the level of lesion, a SCI person can perform some movement and/or feel sensation[5, 6].

2.1.2 Prevalence of Spinal Cord Injuries

2.1.2.1 Global and International Data

It is estimated that there are 250 000 to 500 000 new cases each year of SCIs worldwide. Generally, these injuries are primarily linked to traumatic SCIs, such as motor vehicle accidents and falls. Traumatic SCI have even been recognized to cause up to 90% of SCI of these incidences. Alternatively, non-traumatic injuries are steadily rising due in part to the older age population[8, 29]. As for the division of SCI, there is data suggesting that there are more paraplegic than tetraplegic injuries[30]. The World Health Organisation also noted that the people most susceptible to SCIs were men who were most at risk during their twenties and seventies[8].

2.1.2.2 Canadian Data

More locally, it has been reported that in 2010 there were 85, 556 people in Canada with a SCI which has been predicted to increase to 121, 000 in 2030. It is estimated that each year 4, 300 new injures are suffered by the Canadian population[31, 32]. Fifty-one percent of the SCIs were caused by traumatic injuries, whereas the other 49% were because of non-traumatic injuries. Additionally, there are more paraplegics than tetraplegics, 56% vs 44%, respectively. Based on age, there is data demonstrating most younger adults experience a SCI because of traumatic injuries. Conversely, it seems that the older population get SCIs from non-traumatic injuries[28]. It was also noted that men were more likely to get a SCI; a 3:1 ratio for men and women has been documented[33].

2.2 Common Health and Metabolic Consequences after a Spinal Cord Injury

Although technological advances in medicine have improved life expectancy after a SCI, there are still health problems associated specifically to this population, in addition to the health consequences of aging[22]. Therefore, the following section will discuss common health problems and modifiable risk factors associated with a SCI.

2.2.1 Common Health Consequences

The following will discuss common health consequences including pressure sores and venous thromboembolism.

2.2.1.1 Pressure Sores or Pressure Ulcers

Pressure sores or pressure ulcers are caused by constant pressure creating abrasions to the skin, which subsequently damage the deeper layers of tissue [34, 35]. Pressure sores are considered a serious common secondary health complication after a SCI[34-36]. There is roughly 30% of people with SCI in Canada that are currently experiencing pressure sores[36]. It has even been noted that nearly 85% of people with SCI get a pressure sore at some point in their lives after this type of injury[36, 37].

There are a number of factors, which contribute to the cause of pressure sores. These factors include pressure, friction, moisture, malnutrition, lack of mobility and insufficient personal and economical resources[34]. A study by Vidal & Sarrias identified that being paraplegic, male and being transferred from hospitals contributed to a higher susceptibility of pressure sores among other factors[38].

Pressure sores can affect the person's life by disrupting work or school. In addition, pressure sores can pose an economic burden from money lost due to days taken off work or additional medical care needed to treat the pressure sores, to name a few[35].

2.2.1.2 Venous thromboembolism

Deep vein thrombosis (DVT) and pulmonary embolism (PE) has been referred to venous thromboembolism (VTE). People with SCI who have not been given any medical treatment for VTE, have an incidence rate ranging from 48% to 100%[39]. In Western countries, the incidence rates have been noted to surround 5% to 90%[40].

Shortly after a SCI, DVT is a common problem that can affect 14% to 100% of individuals suffering from this injury[41]. Other studies have noted incidence rates, ranging from 10% to 30%[42, 43]. Additionally, in a nationwide cohort prospective study in Taiwan, advancing age seemed to have a higher incidence rate of DVT[40].

Pulmonary embolism is the primary source of mortality rates in this population[39]. Within the first three to six months after a SCI, PE has a prevalence of 2%. After a year of paralysis, there is a decrease in the prevalence of PE, lowering its likelihood as more time passes since the injury[44].

The two primary elements that can contribute to DVT and pulmonary thromboembolism are stasis and hypercoagulation[40]. The risk of venous stasis is increased by factors including pregnancy, age and obesity, whereas surgeries and tumors are a few factors that can increase the risk of hypercoagulation[43]. Some other risk factors for VTE include being male, being paraplegic with a complete injury, being African American and having multiple health issues[39].

2.2.2 Modifiable Risk Factors

These modifiable risk factors includes cardiovascular and cardiometabolic disease, obesity, blood pressure abnormalities, carbohydrate and lipid metabolism and anxiety and depression.

2.2.2.1 Cardiovascular Disease and Cardiometabolic Disease

Although medical advancements have been able to increase the life expectancy in this community, it has come with the elevated rate of cardiovascular disease occurrence[45]. Cardiovascular disease (CVD) is a health consequence in people with SCI[46, 47]. Moreover, it has been documented to account for 46% of the deaths for people that have sustained their SCI for more than 30 years and 35% of deaths for people with a SCI over the age of 60 years old[48]. Additionally, CVD in people with SCI tends to develop at an earlier age and at an accelerated pace[46, 49].

Cardiometabolic syndrome (CMS) has been " thought to better characterize CVD and endocrine risks."[48, 50] It can be defined as a combination of related CVD risk factors, such as obesity and hypertension[48, 50, 51]. People with SCI are highly prone to such risk factors further exacerbating the risk of CVD[47]. The "Heart of Diabetes" was even created to take action against risk factors related to diabetes and CVD because they have become so alarming[48].

A number of factors are responsible for the elevated risk of CVD and subsequent CMS in this population[47, 48]. Sedentary behaviour and diminished mobility due to paralysis contributes to this CVD risk. An impaired autonomic cardiovascular control mechanism has recently become acknowledged as increasing the risk of CVD[47]. A study by Groah and colleagues investigated the effect of varying levels and severities of SCI on the risk of CVD in

545 people with chronic SCI. They found that CVD risks were indeed affected by these variables. Moreover, there was a correlation between the higher levels of injury and a higher chance of having all CVD, cerebrovascular disease, dysrhythmia and valvar disease. The higher level of injury, however, was related to lower CHD, myocardial infarction, and hypertension risk[52].

2.2.2.2 Obesity

Obesity can be "defined as an excess accumulation of body fat."[53]. In the 1990s, it was reported that obesity affected people with disabilities (25%) more so than the general population (15%). More specifically, the highest risk of obesity was credited to people with mobility problems[25]. In another article, Gater suggested that obesity affected over 60% of this population[24]. Furthermore, when compared to their AB counterparts, it was not surprising that people with SCI were noted to have more body fat[25]. This information is concurrent with a review by Bauman who recognizes that higher portions of FM and a lower lean mass are characteristic physiological changes that occur after a SCI[54].

There are a number of changes occurring after a SCI that could contribute to the problem of obesity. Gater noted that the site of injury, the amount of FFM and PA the individual performs contributes to the decrease in TDEE[24]. FFM is correlated with REE, therefore the characteristic loss of FFM in person with SCI could contribute to the reduction in REE. Further decreases in energy can be attributed to higher levels of lesion possibly due to the even lower amounts of FFM[54]. Moreover, after this type of injury, exercise is normally reduced which likely decreases FFM and subsequent EE[18].

Obesity makes people in this population more at risk for other disorders including abnormal lipid and carbohydrate metabolism, as well as other issues such as pulmonary emboli and lowered mobility[10].

2.2.2.3 Blood Pressure Abnormalities

After a SCI, blood pressure is not only altered, but is also affected by the level and severity of the injury. There is a higher rate of hypertension in paraplegics[25, 55]. However, there is no conclusive data explaining this phenomenon[25]. Conversely, low BP is seen in tetraplegics[55]. This low BP has been explained as a consequence of the reduced sympathetic signalling from higher levels lesions and complete injuries[56]. Furthermore, a historical perspective study by Groah and colleagues assessed the risk of high BP based on several variables including age, severity and level of injury, as part of their study. They found that people with SCI under the age of 20 had no signs of hypertension. With increasing age, especially between the ages of 60-69, people with paraplegia (AIS A, B, C and D) and tetraplegia (AIS D) had a higher occurrence of hypertension. Advancing age was not clearly linked to people with tetraplegia (AIS A, B and C); noting that higher levels of injury provided a safeguard against hypertension. If the tetraplegics did experience hypertension, it was over the age of 30[52].

Bauman and Spungen suggested that people with paraplegia have a higher risk of developing CHD, in comparison to people with tetraplegia because of the characteristic hypertension[55]. The higher levels of SCI have been suggested to shield against CHD risk[52].

2.2.2.4 Carbohydrate Metabolism

Problems with carbohydrate metabolism are commonly reported in people with SCI, specifically diminished glucose tolerance and diabetes mellitus (DM)[54, 57]. A study by

Bauman and Spungen administered 75g oral glucose tolerance test to 100 participants with SCI and 50 controls. Half of the participants were paraplegic and the other half was tetraplegic. The controls were their age and BMI AB counterparts. It was noted that there was irregular glucose tolerance levels for roughly 50% of the paraplegics and 67% of the quadriplegics. Furthermore, it was established that the participants with SCI had a higher frequency of DM than the controls, 22% versus 6% for the respective populations. It was proposed that environmental factors prompted the DM in the SCI group, since their first relatives had a lower frequency of this condition compared to the AB controls[58].

2.2.2.5 Lipid Metabolism

Cholesterol levels in people with chronic SCI pose a particular concern, since they tend to have characteristically higher levels of LDL and total cholesterol and lower levels of HDL. People with SCI, in comparison to their AB counterparts, seem to be more susceptible to such abnormalities[47]. These abnormal levels of HDL and LDL have been noted to contribute to the development of CVD[25].

There are a number of factors that play a role in abnormal lipid levels. Some factors such as increased adipose tissue, BMI and percent body fat has been associated with a decrease HDL concentrations[59]. The increase of triglycerides was also found to decrease HDL-C concentrations. It was suggested that triglycerides could have been increased due to high levels of insulin. In an attempt to moderate the triglycerides, HDL concentrations would consequently be decrease[49]. Another factor affecting lipid metabolism is the level of SCI. Paraplegics have a better lipid profile than tetraplegics[47]. Furthermore, an unhealthy diet with too many calories and fats contributes to abnormalities in triglycerides and HDL levels[49]. Alcohol has been said to affect HDL. Healthy amounts of alcohol can increase levels of HDL[49, 59]. However, decreases in HDL concentrations can occur if too much alcohol is consumed[49]. Finally, genetics can play a role in a healthier or worse lipid profile[49].

2.2.2.6 Anxiety and Depression

A SCI comes with life-altering changes, which can create social (i.e. altering family dynamics) and occupational challenges (i.e. job loss)[60-63]. Depending on the severity of the injury, a person can face a loss of mobility and sensation[60, 63]. Impaired sexual functioning, incontinence and pain are other consequences of a SCI[60]. Craig, Tran and Middleton have cited research which noted that people with SCI have a higher risk of substance abuse and suicide[63].

A meta-analytical review noted that the prevalence of depression in people with SCIs was 22%. These findings suggest that people with SCI have a higher chance of this psychological disorder when compared to the 16% of the general population that would suffer from depression in their life[64]. A systematic review explored the psychological morbidity in both a rehabilitation and community setting in people with SCI. It was found that from a review of five studies in a rehabilitative setting, depressive disorder affected roughly 20% to 40% of the people with SCI, which was noted to represent a small portion of this population. Moreover, this proportion of depression suffered by people with SCI was similar to other patients in the hospital environment. In the community, 11-60% of people with SCI suffered from depressive mood symptoms or states. Furthermore, it was noted that depression was accompanied with higher chances of pain and infection in this population[63].

Since Sir Ludwig Guttmann believed that PA could help people with SCI in rehabilitation, exercise has been used as a method to improve physical and psychological well-being among people with disabilities[65]. A study by Hicks and colleagues monitored people with SCI in a 9 month exercise program consisting of aerobic and resistance training components, two times a week. It was found this exercise intervention was enough to improve stress, pain, depression and overall quality of life[66].

2.3 Methodological Techniques

2.3.1 Body Composition Assessments

The higher proportions of dyslipidemia, insulin resistance and obesity in people with SCI are likely contributing to the development of CVD[67]. Although there are many methods of measuring body composition to obtain information on health risks in the AB population, the applicability of these measurements for people with SCI is altered due to a variety of factors. The following will describe the purpose, advantages, limitations and/or practicality of various body composition measurements: skinfold measurement, waist circumference, body mass index, CT and MRI scans and dual-x-ray absorptiometry.

2.3.1.1 Skinfold Measurements

Skinfold measurement is a common technique, which uses calipers to measure subcutaneous fat at various parts of the body to give an approximation of body fat. Although this tool is relatively economical in cost, its precision is inconstant and dependent on the user[68, 69].

2.3.1.2 Waist Circumference

Waist circumference is a tool used to estimate visceral fat[53]. This measuring technique of abdominal obesity is easy to perform, low-cost and does not need a height measurement, which is particularly difficult to measure in this population[46, 53, 67]. It has also been found that waist circumference is the best estimate of CVD risk associated with obesity in people with SCI due to its strong associations with CVD risk factors, total and abdominal fat[46]. Another study by Edwards and colleagues reported waist circumference as having a strong association with visceral fat[19]. In fact, it was noted as an alternative to BMI due to its sensitivity and usefulness[46]. Comparatively, the limitations of this method can be denoted in the following. Waist circumference does not directly measure central fat since it encompasses a combination of fat, muscle, bone and organs[67]. Evidence demonstrates the strong relationship between waist circumference and visceral fat in this population, however since people with SCI have a higher fat mass than the AB population where they were derived, it was proposed to lower the cut-offs of waist circumference[46]. Additionally, there are still several matters that have yet to be established. For instance, the "best" measuring site and position (supine or sitting) to assess waist circumference has not been determined yet. Furthermore, confounding variables such as abdominal distension and lowered muscle tone have not been studied on the influence of this measurement[21, 53, 67].

2.3.1.3 Body Mass Index

Body mass index has been used to estimate body fat and obesity by dividing body weight (kg) over height (m) squared. Body mass index defines weight as being normal between 18 and 24.9kg/m^2, overweight between 25 and 29.9kg/m^2 and obese over 30kg/m^2 [24, 53]. This body composition assessment is relatively practical, simple and inexpensive. However, it does not have the ability to separate FM and FFM[24, 69]. Additionally, studies have shown that BMI tends to underestimate body fat and obesity for people with SCI[21, 24, 25, 53, 54]. In fact, Weaver and colleagues noted an approximate 13% higher fat mass for every unit of BMI in people with SCI when compared to the AB group[25]. A possible reason for this underestimation in body fat is due to physiological changes incurred after a SCI. It is well-known that after a SCI, there is a loss of muscle mass and a gain of fat mass which is much higher in people with SCI when compared to a weight- and height-matched controls[46]. Another potential reason for the underestimation of BMI in this population may be due to the problems associated with height measurements[21, 46, 53]. People with SCI have difficulty placing themselves in a supine position due to a number of factors such as joint contractures, spine disfigurements or spasticity[46, 53]. Therefore, it has been stated that BMI cannot be considered a useful or accurate surrogate of body fat when used in people with a SCI[46].

2.3.1.4 CT and MRI Scan

Computed tomography (CT) and magnetic resonance imaging (MRI) are instruments that are used in research to analyse body composition, including the assessment of FM, muscle, internal tissues and organs[70, 71]. These instruments are thought of as the gold standard. They can be used to assess fat in any region of the body and are capable of separating subcutaneous and visceral fat. Unfortunately, both methods of analysis are expensive. Furthermore, an MRI is time-consuming and motion artifact creates many errors. A CT scan can be done rather quickly, however the equipment required is very sophisticated and uses high amounts of radiation[67].

2.3.1.5 Dual-Energy X-Ray Absorptiometry

The dual-energy X-ray absorptiometry (DXA) is a common tool used to evaluate body composition[67, 72]. Through low emissions of X-rays, the DXA is able to provide information on FM, FFM, BMC and BMD for specific regions of the body or the whole body[67, 72, 73]. This instrument has been shown to deliver accurate and reproducible measurements of body composition[71]. It has also been deemed as easy, safe, fairly economical, non-invasive and time-efficient[67, 69, 74]. Lee and Gallagher have even noted that the DXA is thought of as the gold standard in detecting bone diseases (i.e. osteoporosis)[71]. The limitations of this instrument are that it cannot discern the difference between subcutaneous and visceral fat and it does not take into consideration the hydration of the individual[67]. In addition, scanning people with SCI has been slightly challenging due to difficulty in positioning (i.e. spasticity) and motion artifact[75].

2.3.2 Methods Measuring Resting Energy Expenditure

A healthy population with identical physical characteristics (i.e.: sex, gender, weight) can have differences in energy expenditure (EE) because of genetic and environmental factors (i.e.: diet, exercise). Therefore, it is not surprising that people with diseases have a different EE due to the effect of their illness[76]. Specifically, people with SCI have been noted to have a lower REE due primarily to the loss of FFM and impaired sympathetic nervous system caused by this injury[10]. This demonstrates the importance of accurately measuring EE. Total daily energy expenditure is made of 3 elements; PA, TEF and REE. The best way of estimating TDEE is to measure REE since it represents approximately 65% of TDEE and is commonly used in the prediction of TDEE[77]. The following will describe the instrument used to measure REE and the energy equations used to predict it.

2.3.2.1 Indirect Calorimetry

An indirect calorimetry measures REE by monitoring the consumption and production of oxygen and carbon dioxide, respectively[78]. An indirect calorimeter is considered the most accurate technique of obtaining REE[79]. It has been recognised to give reliable, precise and non-invasive assessments of REE[80]. This method not only accounts for the majority of TDEE, but is even considered the best way to calculate TDEE[77]. The only disadvantages that can be noted are that it requires skilled professionals, it is not time-efficient and it is costly. Therefore, its availability is limited[79].

2.3.2.2 Energy Prediction Equations

Healthcare professionals often use energy prediction equations to substitute for the lack of accessibility to an indirect calorimeter[81]. Many prediction equations have been derived and validated for populations without SCI[2, 10]. Considering the fact that people with SCI have a significantly lower REE when compared to their AB counterparts, it is not surprising that the applications of these equations have been shown to significantly over-predict energy needs in the SCI population[2, 17].

Only a handful of studies have looked at predicting energy within this population. We are aware that there are only two articles to date that address the estimation of REE, specifically. The first being a study by Patt et al., who derive an energy equation for REE in children with SCI[4]. The second was an equation created by Buchholz et al., which estimated the REE in people with paraplegia[3]. Neither equation has been cross-validated to date. The other studies focus on determining energy costs of activities[82, 83].

2.4 Changes in Body Composition after a Spinal Cord Injury

There are physiological changes that occur soon after a SCI, the most notable of which are decreases in FFM and BMD and increases in FM[16].

Shortly after such an injury, decreases of roughly 20% to 50% of muscle cross-sectional area have been observed[84]. In fact, MM is lost under the level of injury and inversely correlated with time since injury[20, 84, 85]. Furthermore, in a study by Edwards and colleagues, when people with SCI were compared to their AB controls, it was demonstrated that they had approximately 40% more vascular fat for every centimeter of waist circumference[19]. Unfortunately, these physiological changes can occur more rapidly than aging will do itself[85]. There are some other elements that have been identified to affect body composition. Factors such as physical inactivity, unhealthy diet, muscle paralysis and atrophy all contribute and relate to the physiological changes after a SCI[19, 86]. Furthermore, it has been suggested that these physiological changes impact secondary metabolic disorders and a higher chance of mortality present after this injury[19, 20, 85].

Immediately after a SCI, there is a loss of bone throughout the whole body, which is later limited to the regions of paralysis. This stems from the higher calcium resorption following the injury. The first year after this injury has been shown to generate the highest bone loss. After which a lower equilibrium is established – with a smaller, yet steady loss of calcium in bone. The degree of bone loss is based on several factors including duration since injury, level of lesion and degree of paralysis (complete, incomplete). For the time since injury, Kocina found that the longer the person has a SCI, the more bone loss is experienced under the area of lesion[15]. Moreover, the lack of gravitational forces under the level of injury contributes to the bone reabsorption[86]. Therefore, it is not surprising that people with paraplegia have bone loss in their lower limbs, whereas people with tetraplegia are also affected in their upper limbs and trunk. Finally, people with incomplete paralysis are noted to have more bone than people with complete paralysis[84]. This bone loss contributes to osteoporosis and subsequent fractures in this population[22, 23].

2.5 Potential Mechanisms of Weight Gain after a Spinal Cord Injury

There are several potential mechanisms that may predisposition and explain the high prevalence of obesity in people with SCI. A review by Rajan and colleagues summarised that weight gain could stem from the changes in metabolism, the decline in MM and bone loss after the injury and the added restriction of mobility[53].

People with SCI have a difficult time with balancing a healthy diet, since metabolism is severely affected after the injury. Three main components, consisting of the level of lesion, FFM and exercise habits, have been identified as contributing to this 12-54% reduction in TDEE[24]. Fat-free mass has been documented to explain roughly 50-90% of REE[12]. The loss of FFM after a SCI is suggested to have a negative effect on REE[87, 88]. Moreover, it is suggested that basal EE is lower in higher levels of lesions, most likely characterised with less FFM[54]. Finally, the lack of PA in addition to the metabolic reductions in this population can further exacerbates the decrease in EE[53].

This recognized decrease in EE can create weight gain and obesity in this population[17]. Szlachchic and colleagues understood that PA alone could not resolve the excess weight and lowered metabolism[51]. In order to lose 1 pound, a person would have to burn 3, 500kcal[89]. The inability to use large muscle groups due to the paralysis makes it that much more challenging to burn calories. Therefore, diet will be the focus of this thesis in order to try and reverse the obesity epidemic plaguing this population. However, it must be stated that it is difficult to administer dietary restrictions to this population, since TDEE for an individual cannot be readily obtained. Gater suggested an indirect calorimeter be used to measure individual REE, however this method takes long and is financially costly, if one were to use it to obtain REE for every person[24, 79]. Additionally, REE prediction equations used for people with SCI have been found to over-predict caloric needs from 5-32%. This is not surprising, considering these predictive equations have been confirmed in the AB population[10]. Using SCI-specific equations will be able to help with obesity and associated secondary health complications. Therefore, a cross-validation of the population-specific energy equation created by Buchholz et al. will be performed, in order to help with this secondary effect associated with SCI.

2.6 Total Daily Energy Expenditure

The balance of energy is extremely delicate, if an individual exceeds their energy requirements, weight gain and subsequent health complications ensue. Energy requirements can be described by TDEE containing 3 elements, REE, TEF and PA[10]. To adopt a portion of

TDEE, which will be used to analyse EE in this population, the metabolic changes incurred after this injury were assessed.

Physical activity makes up roughly 25-30% of TDEE[10]. Unfortunately, this injury is characterised with a reduction of PA and sports participation[10, 53]. It has also been recognized that the inactivity is based on the degree of paralysis[90]. Therefore, people with paraplegia are more active than people with tetraplegia[10]. Furthermore, this reduction in exercise can be linked to the loss of FFM, which may indirectly reduce REE and subsequently TDEE of the person with SCI even more[18].

Roughly 5-10% of TDEE is explained by TEF. This component of EE has some controversy surounding it, in terms of the effect of SCI on TEF[10]. A previous study reported that there was a significant difference in TEF between the controls and the participants with SCI. People with SCI had a smaller TEF. However, they compared themselves to a study by Aksnes et al. who found no change in TEF in people with tetraplegia and controls[17]. Another study by Buchholz et al. found similar outcomes to Aksnes et al. with no significnat difference in TEF in paraplegics versus controls. It has been suggested that the varyng results in these studies are caused by the differences in methodologies and participant characteristics[3, 10].

Finally, REE explains roughly 65% of the variation in TDEE. It has been established that people with SCI have 14-27% lesser REE when compared to their AB counterparts. Dimished FFM and changes in sympathetic nervous system (SNS) after the injury are two possiblilities which explain this change in REE. Primarily, FFM is said to explain more than 70% of REE, contributing to the energy needs of muscles and other processes such as biochemical cycles. This characterised loss of FFM after a SCI is hypothesized to contribute to the reduced REE[10]. However, once FFM is controlled for, this difference in energy needs seems to disappear indicating that FFM is metabolically similar to the AB controls[3, 10]. In a study by Monroe and colleagues, it was recognised that even after controlling for confounding variables, REE was still lower, therefore the changes to the sympathetic activity after a SCI could be contributing to this decline in REE[17]. Subsequently, sympathetic activity is said to affect REE based on the level of injury; lower sympathetic activity is related to higher levels of injury[10].

To be able to prevent and/or treat obesity and its adverse health consequences in this population, REE is the best component to construct a healthy caloric prescription, since it explains the majority (65-70%) of TDEE. Although both PA and TEF explain roughly 35% of TDEE, this is a small percenatge of the TDEE. Additionally, it is difficult to expend sufficient energy through exercise given the inability to use large muscle groups (i.e. legs and/or arms) because of paralysis. Therefore, REE is the best method in delivering an estimate for TDEE and henceforth is used[77].

2.7 Resting Metabolic Rate

2.7.1 Common Energy Prediction Equations

Energy prediction equations are often used to determine a healthy caloric diet because direct measures of REE are not always accessible. However, these prediction equations have not been tailored for people with SCI, as they have been created and validated for AB individuals without SCI[10, 81]. Buchholz et al. noted that predictive equations overestimate the energy needs of this population[10]. There is only one study that found a predictive energy equation, the Quebbeman equation, that did not over-predict energy needs in people with SCI. This equation is for people without a SCI that are obtaining total parenteral nutrition. Although, the estimated REE from this equation did not differ from objective measures, the authors noted that the correlation between both methods were very low[1]. Other energy predictive equations such as the HB equation have been evaluated before with caloric estimations over predicting energy needs, however the MSJ equation has yet to be assessed[1]. Therefore, both Harris-Benedict and Mifflin St. Jeor equations will be assessed to confirm the fact that predictive energy equations used for the general population should not be applied to estimate caloric needs in individuals with SCI.

2.7.2 Specific Energy Prediction Equations

Furthermore, there are very few articles creating and validating energy equations specific to this population. Among the few is Patt et al. who created two gender specific prediction energy equations from a sample of 59 children with a SCI. These equatons used both height and level of lesion to estimate REE[4]. We are not aware that it has yet to be evaluated. Finally, another equation that has yet to be evaluated is from Buchholz et al. His equation was derived from 28 participants with paraplegics using age, height, sex and FFM to estimate REE[3].

Other studies have centered their efforts on energy needs during actions such as activties of daily living. A study by Hiremath et al. created energy prediction models based on the input of a common motion sensor, SenseWear, for wheelchair-related activities[82]. However to estimate energy, a monitor would need to be obtained, therefore narrowing the accessibility of these models. Another study by Hayes and his team of researchers explored the relationship of heart rate in people with SCI as a predictor of energy in activities of daily living[83].

CHAPTER 3: METHODS

3.1 Participants

This cross-sectional study was based on 39 participants with SCI from the Greater Montreal area in Quebec, Canada. The inclusion criteria is as follows: (a) participants had to be ≥18 years old, (b) had to be living with paraplegia or tetraplegia for more than 1 year, and (c) use a wheelchair as a main mobility aid and use it for most of their daily tasks. The participants were recruited through word of mouth from other participants and local area health care facilities and sports organisations such as Lucie-Bruneau Rehabilitation Center and Sledge Hockey. One participant could not be categorized as having paraplegia or tetraplegia because of paralysis due to infection and little information was provided regarding their condition. This participant was still included in the study, even though he/she did not fit a category. The McGill University School of Medicine Institutional Review Board approved this protocol before testing begun. Informed consent was obtained, from individuals who were interested in and eligible to participate, before testing occurred.

The data collection was performed in the Health and Fitness Promotion Laboratory at McGill University. The laboratory had accommodations for people with SCI.

3.2 Methodological Approach

The primary aim of this study was to objectively measure REE and assess the accuracy of common predictive energy equations for this SCI population. An indirect calorimetry with a canopy was used to measure the actual REE. The common energy prediction equations used were the HB and MSJ equations.

The secondary aim was to cross-validate a population-specific equation created by Buchholz et al. to predict REE. The prediction equation requires height, weight, age and FFM in order to estimate energy needs. A questionnaire was used to obtain information such as age, medical history and condition. A scale was used to measure the weight of the individual. The height was taken using a tape measure. The DXA, specifically the Lunar iDXA, was used to obtain measures of body composition such as FFM.

3.3 Weight

Weight was recorded using a calibrated balance-beam scale. If the participant was unable to move themselves, a chair was placed on a ¾ inch plywood (80x120cm) on top of the scale. The participant was then lowered on the chair using a lift. Both the plywood and the chair were tarred before the participants were placed on the scale. Additionally, the sling that was used to carry them into the chair was subsequently deducted from their total weight. If the participant was able to move him or herself, they would role onto the plywood using their wheelchair. The overall weight of the wheelchair, the plywood and any additional weight not a part of the participant were deducted from the total weight obtained on the scale.

3.4 Height

Height, due to the inability to stand, was measured when the participants were placed on the DXA in a supine position using a measuring tape.

3.5 Body Composition

The DXA uses radiation in small doses to determine FM, FFM, BMD and BMC for individual segments or the entire body[67, 69, 71]. The DXA is considered a safe, precise, accurate and non-invasive tool[69, 71]. Therefore, this DXA was used to measure 3 components: body composition, BMD for the lumbar region and the femur. Participants either moved themselves onto the DXA or requested help from us. The participant was either moved using our lift (a towel was placed under the participant to help guide them with ease to be placed inside the white-rimmed box and moved into position) or received a helping hand from our lab colleagues. Any metal was removed before starting any of the scans.

For the body composition, the participants were placed inside the white-rimmed box on the DXA in a supine position. To ensure that their spine was aligned with their body, the participants were gently tugged from the shoulders because of the sensitivity of their lower limbs (e.g. spasticity). A black Velcro tie was placed around their ankles, if their legs did not tremor. The scan took a total of 5-10 minutes. This body composition scan was of particular importance considering the need for FFM and other participant characteristic information such as fat percent. To re-iterate, the FFM was used for the Buchholz et al. prediction equation. The fat percentage was used for the characteristics of the participants.

To measure BMD of the lumbar region, the participants remained in the same position. The scanner, however, was moved over their umbilicus to measure their lumbar region. The scan took approximately 5 minutes.

For the final measure of the BMD of the femur, the participants' feet were placed on a triangular prism held by Velcro, if their legs did not tremor. Their left thigh was scanned for the BMD of the femur. The left thigh was rotated 5 degrees before being scanned. The scanner was placed over the middle upper part of their thigh (i.e. usually centered around the pocket of their pants) before the scan was started. This scan took approximately 5 minutes.

3.6 Resting Energy Expenditure

To measure objectively REE, a SensorMedics V_{max} metabolic cart (Florida) with canopy (indirect calorimetry) was used. It is considered an accurate, reliable, precise and non-invasive measure of REE[79, 80]. This machine estimates REE based on measures of oxygen consumption and production of carbon dioxide[78, 80].

The participants were placed in a reclining chair in a supine position in a quiet room with the lights turned off. A canopy hood was placed over their head to measure their oxygen consumption. They were instructed not to speak throughout the steady-state and once the test begun. Once they reached a steady state (~10minutes), oxygen consumption was monitored and recorded for 30 minutes to obtain REE.

The prediction equations to estimate REE used in this study are as follows:

1) Harris-Benedict Equation[81, 91]:

   Women: REE (kcal/d) = 655 + 9.5(kg) +1.9(cm) – 4.7(yr)

   Men: REE (kcal/d) = 66 + 13.8(kg) + 5.0(cm) – 6.8(yr)

2) Mifflin-St. Jeor Equation[77, 81]:

   Women: REE (kcal/d) = 9.99(kg) + 6.25 (cm) – 4.92(yr) – 161

   Men: REE (kcal/d) = 9.99(kg) + 6.25 (cm) – 4.92(yr) + 5

3) Buchholz et al. Equation[3]:

   REE (kJ/d) = 10682-1238(ln(age))-521(sex)-24(cm)+87(FFM)

*The Buchholz et al. equation was originally expressed in kJ/day, it was converted to kcal/day to maintain consistency among all measures of REE.

3.7 Waist Circumference

Waist circumference measurements were taken based loosely on the Heart and Stroke Foundation specification. To start, the measuring tape was placed parallel to the floor aligned with the umbilicus. Subsequently, the measuring tape was tightened around the participant's waist without constriction and the measure was recorded[92]. When the waist circumference was obtained, the participants were in their wheelchair, in a seated position.

3.8 Blood Pressure

Blood pressure was taken in a relaxed seated position in the reclining chair or in their wheelchair with an automated electronic sphygmomanometer. Blood pressure was taken three times. The last two values of blood pressure were averaged.

3.9 Questionnaires

A self-reported questionnaire was provided to the participants. This questionnaire contained questions on medical condition and history and PA levels. Part of the medical condition in the questionnaire asks about the American Spinal Injury Association Impairment Scale (AIS), which provided information on the participants physical functioning and their level of sensation. To monitor PA levels a Leisure Time PA Questionnaire for people with SCI (LTPAQ-SCI) was used. This questionnaire has been validated and found to be reliable in this population[93].

Based on the information obtained from the LTPAQ-SCI, the participants were separated into groups based on the PA guidelines for SCI and the AB population. The following explains what the PA guidelines were and where they were taken from:

The Canadian Society for Exercise Physiology (CSEP) guidelines for people with SCI recommends a minimum of 20 minutes of cardiovascular training (moderate- to vigorous-intensity), twice weekly. They also recommend “strength training exercises 2 times per week, consisting of 3 sets of 8-10 repetitions of each exercise for each major muscle group.”[94] Participants were separated based on the cardiovascular training time, since it was well defined. Therefore, participants were placed in one of two groups: 1) : ≥40min of moderate- to vigorous-intensity cardio per week, or 2) <40min moderate- to vigorous- intensity cardio per week.

The Canadian PA Guidelines for the AB population recommends a minimum of 150 min of cardiovascular training (moderate- to vigorous- intensity) each week and two days of resistance training for major muscle groups[95]. Again, since the cardiovascular training was clearly defined, the resistance training recommendations were not used. The participants were placed in either group: 1) ≥150min of moderate- to vigorous- intensity cardio per week, or 2) <150min moderate- to vigorous- intensity cardio per week.

3.10 Statistical Analyses

The data was analysed using IBM SPSS, Version 23. Both primary and secondary aim used a one-way Repeated-Measures Analysis of Variance (RM-ANOVA) to compare differences between objective measures and the energy estimates (from HB, MSJ and Buchholz et al. equations). To further analyse the level of agreement between the objective and predictive measures and systematic bias, Bland-Altman plots were created for all predictive measures[96]. Significance was based on $p<.05$.

CHAPTER 4: MANUSCRIPT

4.1 Title Page

Accuracy of Common Prediction Equations and Cross-Validation of Population-Specific Equations in Individuals with Spinal Cord Injury

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4.2 Abstract:

Purpose: The primary aim of this study was to assess the accuracy of common prediction equations, the Harris-Benedict and the Mifflin St. Jeor equations, for estimating resting energy expenditure among people with spinal cord injury against actual resting energy expenditure measurements. The secondary aim was to cross-validate Buchholz et al. energy prediction equation created for people with spinal cord injury.

Methods: A metabolic cart with canopy was used to measure the actual resting energy expenditure. The Harris-Benedict, Mifflin St. Jeor and the Buchholz et al. equations were used for the prediction of resting energy expenditure.

Results: Thirty-nine participants (31 males and 8 females) were enrolled in this cross-sectional study. The resting energy expenditures significantly differed from one another, $F(1.52, 57.68) = 52.04$, $p<.001$, where both the Harris-Benedict ($M = 1703.06$, $SD = 265.1$) and the Mifflin St. Jeor ($M = 1628.92$, $SD = 233.8$) energy predictions were significantly higher ($p<.001$) than the measured resting energy expenditure ($M = 1394.05$, $SD = 298.7$). In contrast, the Buchholz et al. equation did not differ from the measured resting energy expenditure.

Conclusion: Our data show that the Harris-Benedict and Mifflin St. Jeor equations do not accurately predict the energy needs of this community. Using a spinal cord injury specific equation would improve estimates of resting energy expenditures, such as the Buchholz et al. equation. Nevertheless, more research into specific energy equations for this population may help healthcare professionals tailor dietary and physical activity to help this population better manage their weight.

4.3 Introduction:

In Canada, more than 86 000 individuals are living with a spinal cord injury (SCI) with roughly 4,300 new injuries occurring yearly[9]. Alarmingly, an estimated 67% of individuals with SCI are classified as obese[24]. This high proportion of obesity is related with typical disorders such as insulin resistance, in addition to pressure sores, pulmonary emboli and further reductions in movement[10, 15, 17].

After a SCI, metabolism is compromised, lowering total daily energy expenditure by 12-54%. The level of lesion, characteristic loss of fat-free mass (FFM) (due to muscle atrophy and paralysis) and lowered exercise levels all contribute to these reductions. Therefore, it is not surprising that obesity tends to affect people with a SCI[18, 19, 24].

Due to the paralysis and atrophy of muscles and reduced physical activity (PA) after such an injury, weight management is challenging[18, 19]. Dieticians are a set of health care professionals that can help with weight management. In prescribing ideal dietary plans for a population, dieticians will commonly use predictive energy equations to estimate healthy caloric needs of the individual when direct measures are not accessible. Energy predictive equations such as the Harris-Benedict (HB) and the Mifflin St.-Joer (MSJ) are commonly used by the abled-bodied (AB) population to help with weight management[77, 81, 91]. Most of these predictive equations have been created and validated using an AB population[10, 77, 81]. When these equations are applied to people with SCI, they have been reported to overestimate energy needs by 5-32%[10]. A relatively recent study by Buchholz et al. created an energy predictive equation for estimating resting energy expenditure (REE) from 28 participants with paraplegia. This energy equation is the only prediction equation that has been found to estimate caloric needs in adults with SCI. However, a cross-validation study has yet to be executed to verify the usefulness of this equation for this population[3].

In previous research, the HB equation has been shown to over-estimate the caloric needs in this population, whereas the MSJ equation has yet to be evaluated in this community[2]. Therefore, the primary purpose of this article is to objectively measure REE and assess the accuracy of the commonly used energy equations, HB and MSJ equations, for the SCI population. Since the Buchholz et al. equation has yet to be evaluated, the secondary purpose of this article will be to cross-validate this SCI-specific energy equation.

4.4 Methods:

This cross-sectional study included 39 participants (31 males and 8 females) with a SCI from the Greater Montreal area in Quebec, Canada. The inclusion criteria to be a participant was to: (a) be ≥ 18 years old, (b) be living with paraplegia or tetraplegia for more than 1 year, and (c) to use a wheelchair as the main mobility aid, and use the wheelchair for most of the daily tasks. Recruitment was based on three facets, word of mouth from the participants, local area health facilities and sports organisations specifically for people in wheelchairs (e.g., sledge hockey). Table 1 provides detailed information on participant characteristics. One participant could not be categorized as either having paraplegia or tetraplegia because he/she became paralysed by an infection and knew very little on their condition. He/she remained a participant, but was not placed in either category.

The testing was performed in the Health and Fitness Promotion Laboratory at McGill University. This laboratory had wheelchair accommodations. The McGill

University School of Medicine Institutional Review Board approved this protocol and written informed consent was obtained before any testing was performed.

Anthropometric measures such as height and weight were taken. Height was measured when participants lay down in a supine position. A piece of wood was placed on the scale to allow for sufficient room for the participant to go on the scale with their wheelchair or lowered by a lift onto a chair. The excess weight of the material (i.e. wheelchair) was subtracted from the overall weight to obtain the weight of the participant. The Leisure Time Physical Activity Questionnaire for people with Spinal Cord Injury (LTPAQ-SCI) was used to measure PA, in minutes per week, for mild, moderate, and heavy intensities. This questionnaire has been shown to be both reliable and valid for this population[97]. Based on the LTPAQ-SCI, the participants were divided into groups using the Canadian SCI and AB PA guidelines. The SCI PA guidelines was based on the Canadian Society for Exercise Physiology (CSEP) which recommended a minimum of 40 minutes of cardiovascular exercise weekly (moderate- to vigorous-intensity)[94]. Participants were separated into one of two groups: 1) ≥40min of moderate- to vigorous- intensity cardio per week, 2) <40min moderate- to vigorous- intensity cardio per week. The AB PA guidelines was based on the Canadian Physical Activity Guidelines endorsing a minimum 150 minutes of cardiovascular exercise weekly (moderate- to vigorous-intensity)[95]. Participants were again separated into one of two groups: 1) ≥150min of moderate- to vigorous- intensity cardio per week, 2) <150min moderate- to vigorous- intensity cardio per week. A Dual X-ray Absorptiometry (DXA) scanner was used to obtain body composition measurements such as fat-free mass, which is used as a predictor in the Buchholz et al. equation, and fat percent, for the descriptive statistics. This instrument has been assessed in a SCI population to be a useful and accurate measure of body composition[98]. To obtain an objective measure of REE, a SensorMedics V_{max} metabolic cart (Florida) with canopy was used. This indirect calorimeter is considered a highly accurate measure of REE[2, 79, 99]. Participants were asked to lie in a relaxed supine position for roughly 45 minutes to obtain REE.

The following energy predictive equations were used for this analysis:

1) Harris-Benedict Equation[81, 91]:

   Women: REE (kcal/d) = 655 + 9.5(kg) +1.9(cm) – 4.7(yr)

   Men: REE (kcal/d) = 66 + 13.8(kg) + 5.0(cm) – 6.8(yr)

2) Mifflin-St. Jeor Equation[77, 81]:

   Women: REE (kcal/d) = 9.99(kg) + 6.25 (cm) – 4.92(yr) – 161

   Men: REE (kcal/d) = 9.99(kg) + 6.25 (cm) – 4.92(yr) + 5

3) Buchholz et al. Equation[3]:

   REE (kJ/d) = 10682 –1238(ln(age)) – 521(sex) – 24(cm) + 87(FFM)

*The Buchholz et al. equation was originally expressed in kJ/day, it was converted to kcal/day to maintain consistency among all measures of REE.

A repeated-measures (RM) ANOVA was used to explore differences between the objective measure of REE and the energy prediction equations (HB, MSJ and Buchholz et al. equations). Bonferroni was used for the post-hoc tests. Bland-Altman plots were applied to identify the level of agreement between the prediction measures of REE and the objective measure of REE and evaluate systematic bias[96].

The IBM SPSS, Version 23, was used for statistical analyses. When $p<.05$, the data was considered significantly different.

To reduce the effect of the outliers, the measured REE was windsorized and in turn became more normal. After the RM-ANOVA was applied, it closely mirrored the RM-ANOVA using the original measured REE data. Therefore, in the interest of clinical relevance, we presented the non-normal data of the measured REE. More detailed information is provided in the appendix.

4.5 Results:

The PA levels in this SCI sample were reported are as follows. The minutes of light, moderate and heavy intensity activity per week are 663.45 ± 1106.3, 302.34 ± 504.8, 374.82 ± 749.8, respectively.

There is a main effect of REE**,** $F(1.52, 57.68) = 52.04$, $p < .001$. Both common predictive energy equations, HB ($M = 1703.06$, $SD = 265.1$) and MSJ ($M = 1628.92$, $SD = 233.8$), had higher energy predictions than the measured REE ($M = 1394.05$, $SD = 298.7$). The Buchholz et al. energy equation ($M = 1410.04$, $SD = 188.5$) was not different from the measured REE ($M = 1394.05$, $SD = 298.7$). Figure 1 plots the predicted REE from the HB, MSJ and the Buchholz et al. equations and the objective measure of REE.

Figure 2 and 3, show that HB, $t(38) = 7.55$, $p < .001$, and MSJ, $t(38) = 5.79$, $p < .001$, equations are not in agreement with the objectively measured REE. The mean difference for the HB and MSJ equation are 309.01 kcal/d and 253.24 kcal/d, respectively. The levels of agreement for the HB equation ranges from -192.16 kcal/day to 810.18 kcal/day. The levels of agreement for the MSJ equation ranges from -261.48 kcal/day to 731.22 kcal/day. There is no systematic bias for both MSJ, r = .15, and HB, r = .29, equations with measured REE.

Figure 4 illustrates that the Buchholz et al. equation, $t(38) = .46$, $p = .65$, is in agreement with the objective measure of REE. The mean difference is 15.98 kcal/day. The level of agreement ranges from -409.71 kcal/day to 441.67 kcal/day. There is a systematic bias, r = .55, $F(1, 37) = 16.04$, $p<.001$. The bias is negative, therefore as the caloric mean (calories a person would consume) increases in value, the difference in calories between both methods will decrease. In other words, the Buchholz et al. equation will underestimate caloric needs in people who require more calories.

4.6 Discussion:

The aims of this investigation were to assess the accuracy of common energy predictive equations, HB and MSJ equations, to the objective measure of REE in the spinal cord community and to cross-validate against the population-specific Buchholz et al. equation.

Both HB and MSJ equations did not accurately predict the energy needs within this SCI population (Figure 1 and 2). The HB and MSJ equations tend to over-estimate the objective measure of REE by 22% and 17%, respectively. Similar findings have been observed in previous research. A study dating back to 1950, reported a lower basal metabolic rate (10% to 21% based on duration of injury) in 16 males with SCI (methods were unclear)[100]. An article by Cox et al. reported that several energy equations for basal and resting EE, including HB equation, overestimated caloric requirements by as much as 46% in the SCI sample. Although, the Quebbeman equation, meant for individuals without a SCI being fed only by intravenous, seemed to be the only equation that did not differ from the objective measures of REE, it was made evident that both variables were not well correlated[1]. A review by Buchholz et al. reported that predictive equations used for SCI population tend to over-predict energy needs from 5-32%[10]. Therefore, it is evident that energy needs in this population cannot be estimated using common predictive energy equations meant for the AB population.

The Buchholz et al. equation for adults with paraplegia was found to accurately estimate the caloric needs in this sample, after cross-validation. Although, it was derived from adults with paraplegia (n = 28), the equation appeared to accurately predict REE in our slightly more varied sample (paraplegia, n = 30; tetraplegia, n = 8). Nevertheless, the Bland-Altman plot (Figure 4) showed some dispersion highlighting that this equation may need more refinement to better estimate energy needs. This dispersion may be corrected by using a larger sample size. Additionally, this equation required the input of FFM, making it of less value to clinicians working in the field. To assess FFM, a dietician would need access to expensive, sophisticated and mostly unavailable equipment to get an accurate estimation. More research is needed to develop more practical and generalised equations derived from a larger sample size that can be applied in real world practices.

Furthermore, this is one of the first studies to cross-validate an energy equation specifically created for this population. There are very few SCI-specific equations that have been created. Apart from the Buchholz et al. equation used in this study, Patt et al. also derived an equation for REE, however it was made specifically for children with SCI[4]. Moreover, a study by Hiremath et al. created energy models, which required the use of a multisensory activity monitor, for wheelchair-related activities[82]. As a result, practical equations need to be derived and cross-validated to improve healthy nutritional guidelines for the SCI community.

Obesity rates have been estimated to exceed 60% for the SCI population[24]. There are a number of physiological adaptations after a SCI including, but not limited to diminution in muscle mass and a gain in fat mass[17, 20]. The loss of FFM, in addition to the decreased levels of exercise in this community have been said to contribute to lowering of EE, which can place the individual at higher risk of obesity and its related health consequences[18]. In contrast, the participants in this investigation were very active, with 82% of the participants meeting the SCI PA guidelines and 69% of the participants meeting the AB PA guidelines[94, 95]. The activity level in this sample exceeds the 50% of adults with SCI who do not participate in any PA and the 20% of the Canadian AB population who are meeting current guidelines[101, 102]. Based on the activity levels within this population, it is important to note that PA may indirectly increase REE because of a higher FFM associated with exercise[18]. Therefore, this study may underestimate the true difference between the real and predictive values of REE due to the sedentary nature that takes place in this population. Interestingly, while on average, the participants of this study exceed both SCI and AB PA guidelines, PA alone does not protect them from their already high fat percentage. This emphasizes two important realities. Firstly, that these individuals may require additional assistance with meal planning and an overall reduction in energy intake to better manage their weight, re-affirming the need for prediction equations. Secondly, both dieticians and exercise specialists must work together to help bridge the gap between such closely related fields.

The strength of this study is that it is reflective of the male to female proportions present in the SCI population, in that the males make up the majority (~80%) of the SCI participants[33]. Additionally, the equipment, such as the DXA and the indirect calorimeter, that are used are of the highest calibre, in that they are thought of as the gold standard[2, 71].

There are also limitations that we wish to acknowledge. Firstly, this study had a relatively small number of participants (*n* = 39), but this study is one of the larger studies conducted to date. Secondly, the majority of the sample recruited for this study was quite active, which would likely underestimate the metabolic differences between the measured and predicted REE due to the feasibly higher FFM obtained from a physically active lifestyle[18].

To conclude, common energy prediction equations, HB and MSJ, do not accurately estimate energy needs within the SCI population. As a result, dieticians may want to move away from using predictive energy equations created from the AB community. The equation created by Buchholz et al. specifically for people with paraplegia seems to provide a more accurate prediction of energy needs within this sample than other equations. However, this equation still requires more work. The application of a larger sample size would help improve its precision. Additionally, it requires a measure of FFM, which can be difficult to obtain for those working in clinical settings. More research is necessary to derive more versatile and practical equations that can be used for SCI weight management in the practical setting. Future collaborations amongst investigators to increase sample size could provide a useful SCI-specific equation, in addition to the cross-validation of such equations.

4.7 Relevance to Practice

Healthcare professionals that treat patients in this population need to be aware that common energy equations created for the AB population may not produce accurate energy predictions for people with SCI and may further contribute to the high rate of obesity in this population. Additionally, the equation created by Buchholz et al. may be able to help dieticians in Canada, who have access to the FFM of their clients, to closer predict their energy needs. Deriving more practical SCI-specific energy equations represents a public health priority because it would help health professionals better meal plans and health interventions to prevent weight gain.

Furthermore, dieticians and exercise specialists need to become integral parts of trans-disciplinary teams that help SCI manage their health and weight. Preventing weight gain after SCI represents a significant health precedence.

4.8 Appendix

4.8.1 Statistics

For the measured REE, the windsorization technique was applied to reduce the effect of the outliers and in turn normalized the data (the two outliers were replaced with a value 1 and 2 unit greater than the highest value that was not an outlier). Once the data was windsorized, it became normal and a RM-ANOVA was applied, the results closely mirrored the RM-ANOVA using the original measured REE data. The main effect of REE remained significant, $F(1.56, 59.40) = 57.00$, $p = .00$. The measured REE ($M = 1388.62$, $SD = 285.4$) was still significantly lower than the HB ($M = 1703.06$, $SD = 265.1$) and MSJ ($M = 1628.92$, $SD = 233.8$) equations. The measured REE was not significantly different from the Buchholz et al. prediction. The F value and degrees of freedom were slightly different, however the results remained the same. Therefore, to maintain clinical relevance from this point, the original data of the measured REE was used.

4.8.2 Table 1

Patient Characteristics

Characteristics	Male (*n* = 31)	Female (*n* = 8)	Combined (*n* = 39)
Age (yrs)	42.4±10.5	43.8±19.3	42.7±12.5
Height (cm)	177±6.1	162.6±6.9	174.0±8.6
Weight (kg)	80.7±15.5	69.5±19.2	78.4±16.7
Tissue Percent Fat (%)	33.8± 7.8	41.8±10.8	35.5±9.0
Time Since Injury (yrs)	11±10.6	7.8±7.3	10.4±10.0
Tetraplegia (cervical lesion)	8 (26%)	0 (0%)	8 (21%)
Paraplegia (thoracic, lumbar & sacral lesions)	23 (74%)	7 (88%)	30 (77%)
AIS Score			
A	19 (61%)	4 (50%)	23 (59%)
B	3 (10%)	1 (13%)	4 (10%)
C	6 (19%)	2 (25%)	8 (21%)
D	2 (6%)	0 (0%)	2 (5%)
Number of Participants Meeting the CSEP SCI PA Guidelines (≥ 40min/wk of	26 (84%)	6 (75%)	32 (82%)

mod. to vig. intensity)			
Number of Participants Meeting the Canadian AB PA Guidelines (≥150min/wk of mod. to vig intensity)	21 (68%)	6 (75%)	27 (69%)

Note: PA = physical activity, AB = able-bodied, AIS = American Spinal Injury Association Impairment Scale

4.8.3 Figures

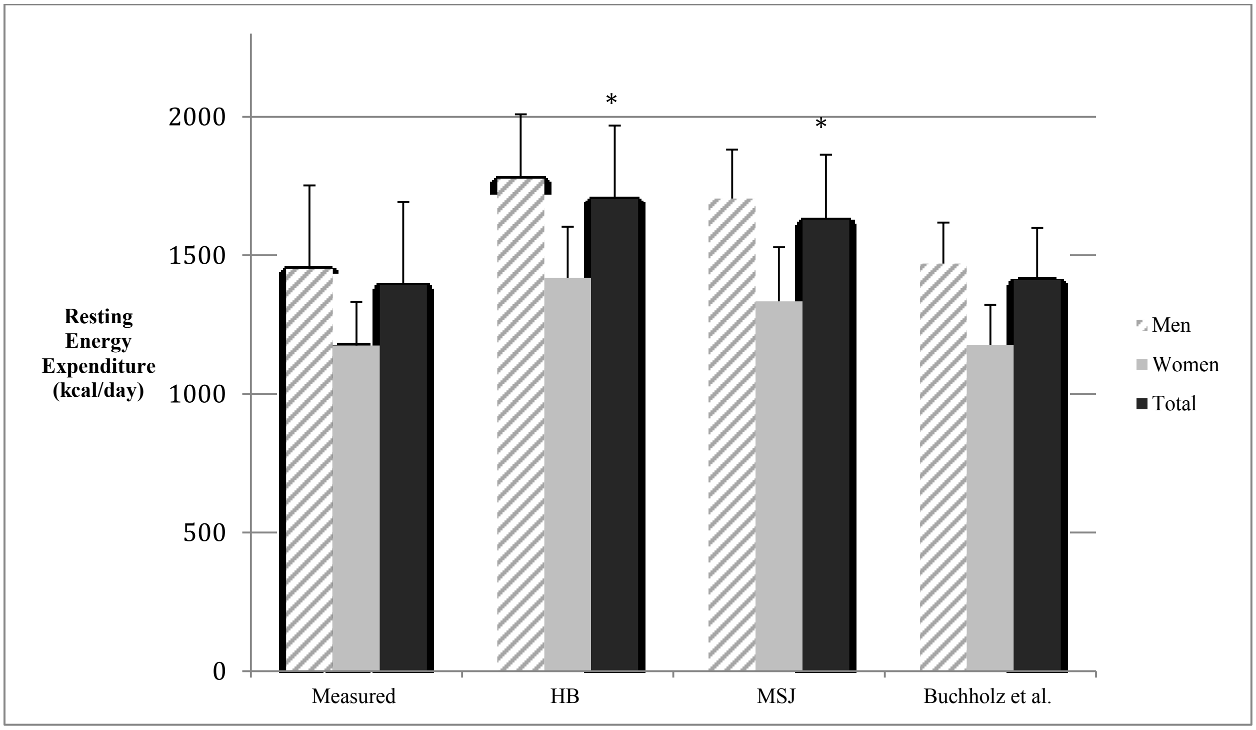

FIG 1. Measured and Predicted REE (using the HB, MSJ and the Buchholz et al. prediction equations) in men, women and all participants. Expressed in $\bar{X} \pm SD$. *, significantly different from total measured REE, *p*<0.05.

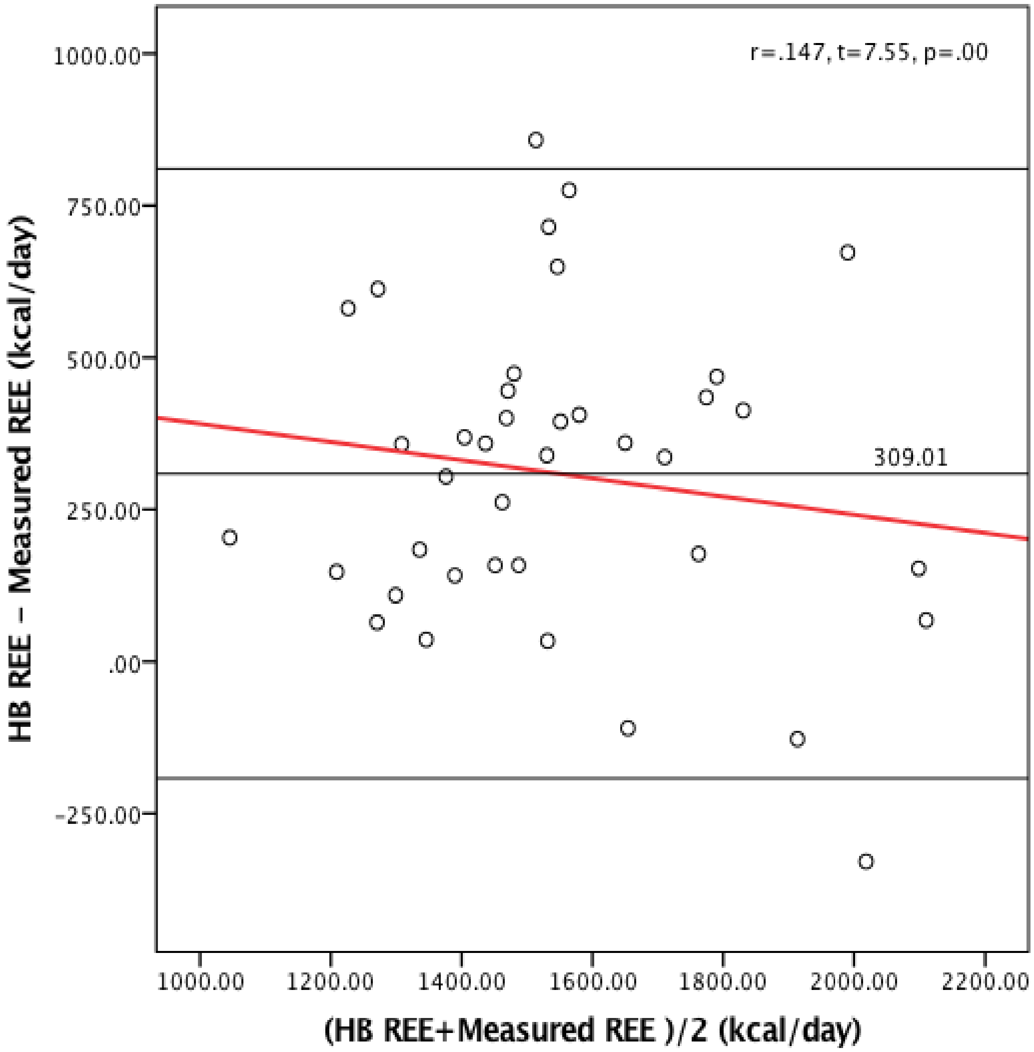

FIG 2. Difference Between Measured REE & HB Predicted REE, Bland-Altman Analysis.

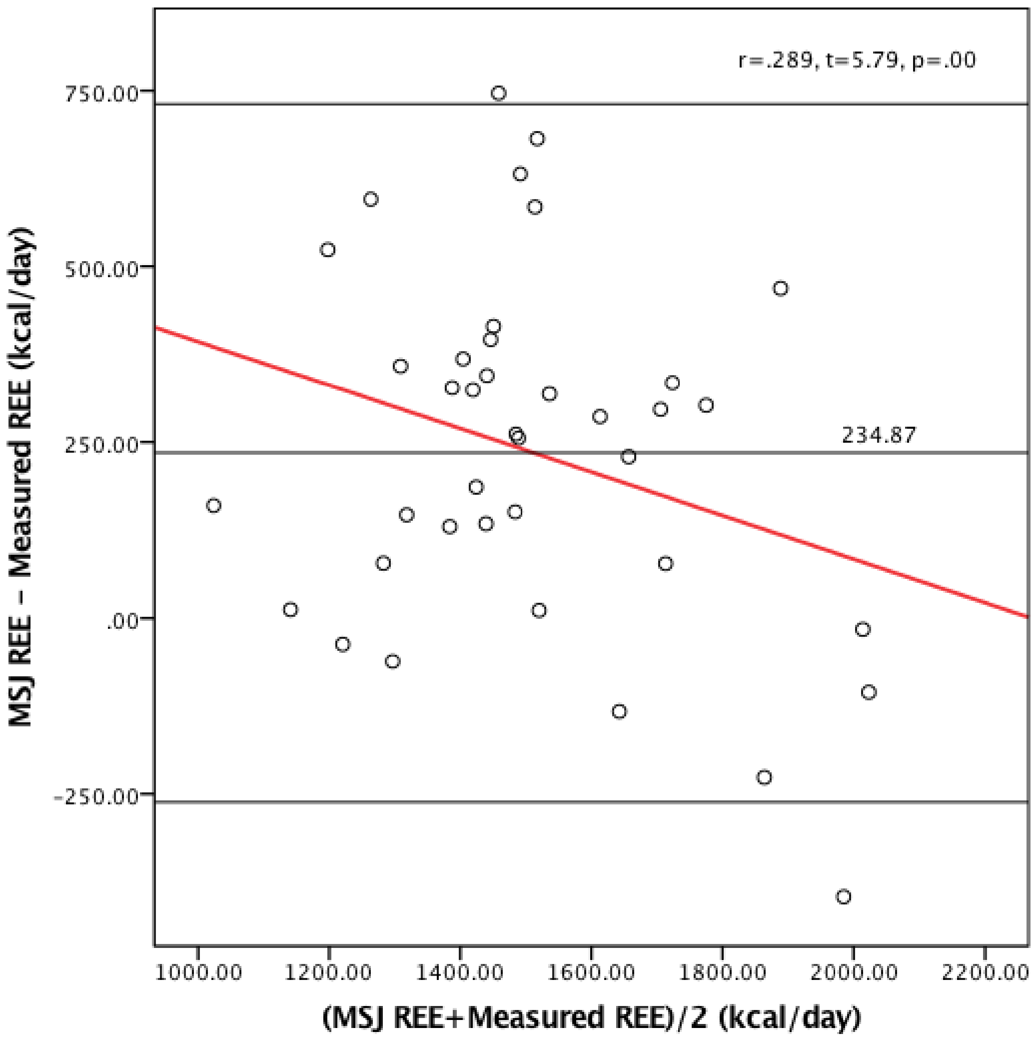

FIG 3. Difference Between Measured REE & MSJ Predicted REE, Bland-Altman Analysis.

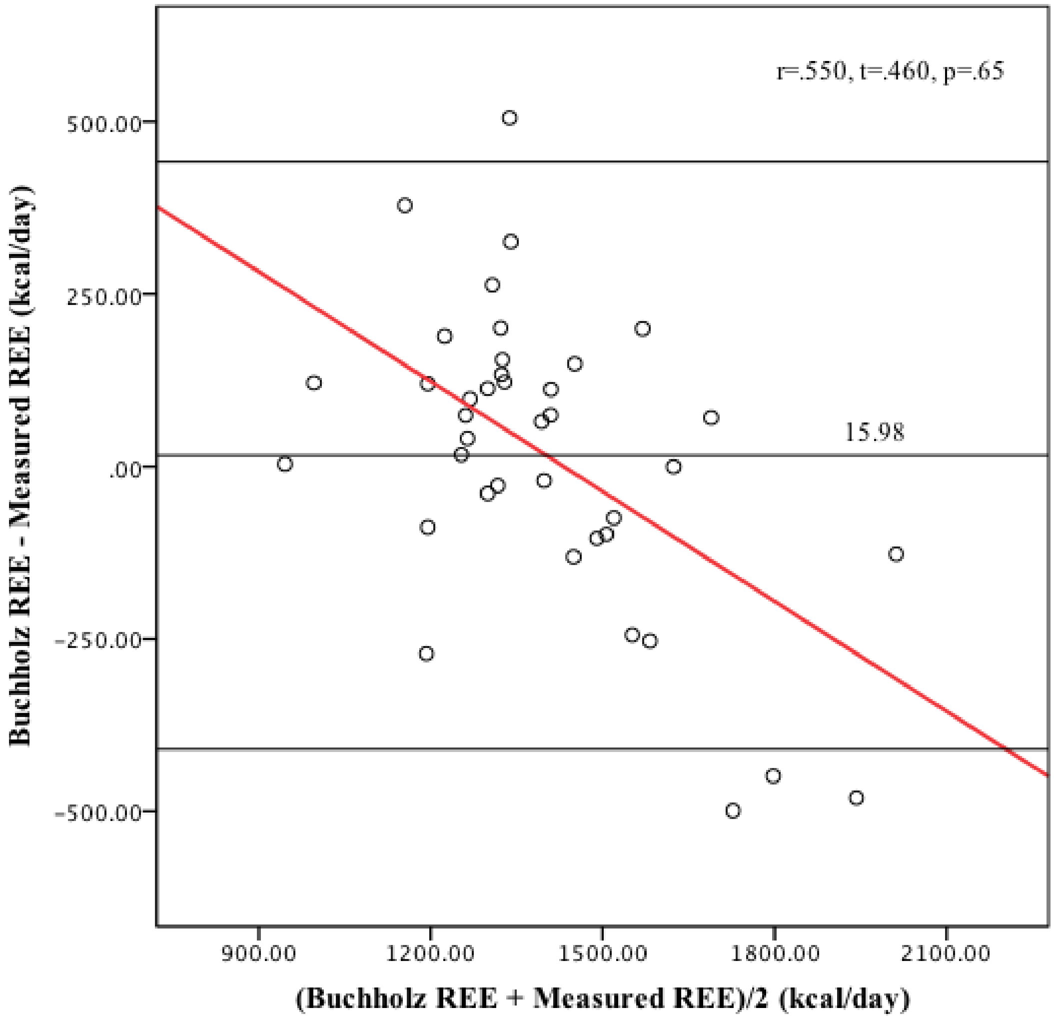

FIG 4. Difference Between Measured REE &Buchholz et al. Predicted REE, Bland-Altman Analysis.

CHAPTER 5: REMARKS AND CONCLUSIONS

5.1 Remarks:

There are two aims in this M.Sc. thesis. The first is to re-assess the accuracy of the HB equation to see if it is consistent with previous research. Additionally, scholars have yet to evaluate the MSJ equation, therefore, this equation's accuracy will be assessed to further research as to whether common energy equations created from the AB population can be used in the SCI population. It is hypothesized that these equations will be consistent with previous research, in that they will over-estimate caloric needs within this SCI population. The second is to cross-validate Buchholz et al. equation, one of the only SCI-specific energy prediction equations[3].

The HB and the MSJ equations were not able to accurately predict energy needs in this sample. In Figures 2 and 3, the Bland-Altman plots show that both predicted REEs were not in agreement with the objectively measured REE. These findings are consistent with previous research. Particularly for the HB equation, in a recent systematic review, Nevin and his team noted that the majority of the studies considered established that the HB equation over-predicts caloric needs by roughly 30% (based on comparisons to an indirect calorimeter)[2]. Such findings are within the same range that was found in this study; the HB equation over-estimated caloric needs by 22%. To date, we are not aware that there is previous research suggesting whether the MSJ equation is a valid means of energy estimation in this community. However, based on this investigation, MSJ over-predicted REE by 17%. There are a number of studies affirming similar findings. Since the 1950s, studies have suggested differences in REE in people with SCI. Specifically, a study by Cooper and his colleagues, who crudely expressed that basal metabolic rate decreased by 10%, 14% 21% in the acute, post-acute and chronic SCI, respectively[100]. In a study by Cox et al., prediction equations including two adjusted forms of the HB equation and the Spanier and Shizgal equation were significantly different when compared to measurements obtained from an indirect calorimeter (using the Weir equation). Cox et al. suggested that this drastic change in energy requirements is linked to the level of lesion and subsequent denervation of muscle. Although, the Quebbeman equation seemed to be the only equation that did not differ from the measures of REE, it was made evident that both variables were not well correlated together[1]. These findings are not surprising considering it has been well documented that after a SCI, EE is reduced due to factors including decreased levels of exercise, levels of lesion and drops in FFM[17, 18, 24]. Additionally, Buchholz & Pencharz revealed that many of these energy equations that are applied in this SCI population are validated from the AB community[10]. It is clear that based on the evidence presented that such equations should not be applied to people with SCI and adjustments or new equations need to be made to help prevent obesity and its secondary consequences.

One of the few energy predication equations to be created from a SCI population, the Buchholz et al. equation, seems to present an accurate estimation of REE in this sample (Figure 4). This equation was derived from a sample of 28 adults with paraplegia, and worked well in this investigation, consisting of 30 people with paraplegia and 8 people with tetraplegia. Although, it was not significantly different from the measured REE, it does depict some dispersion in terms of the difference between both measures (Figure 4). Perhaps using a higher number of participants would help in narrowing down the dispersion present. Moreover, its incorporation of FFM has limited the use of this equation to clinical settings, who have access to expensive equipment such as a DXA to obtain FFM. Future researchers should form collaborations to focus on creating equations that are more practical and derived from a larger sample size.

This is one of the first articles to cross-validate an REE prediction equation made specifically for people with SCI. Furthermore, it must be noted that there are relatively few energy prediction equations created for this population, in which there are even fewer studies that focus their attention on estimating REE. From the few that I have discovered, Patt et al. has derived two prediction equations of REE for both boys and girls with SCIs. These equations were derived from a population of 59 participants consisting of 31 boys and 28 girls, which has yet to be cross-validated[4]. Other SCI-prediction equations concentrate on energy used during activities or exercises. A study by Hiremath et al. formulated energy models for wheelchair-related activities based on input provided from a multisensory activity monitor[82]. Another study by Hayes and his team looked at assessing whether energy needs in activities of daily living can be predicted by heart rate[83]. This stresses the need for creating more prediction equations for people with SCI and cross-validating them to enhance the nutritional guidelines for this community.

The proportion of obesity in this SCI population has been estimated to exceed 60%[24]. There are a number of physiological adaptations after a SCI including, but not limited to diminutions in muscle mass and gain in fat mass[17, 20]. The loss of FFM, in addition to the decreased levels of exercise in this community have been said to contribute to lowering of EE, which can place the individual at higher risk of obesity and its related health consequences[18]. In this SCI sample, the participants are very active which is a contrast to a recent cross-sectional study stating that 50% of their SCI population did not perform any PA[102]. In the most recent Canadian Health Measures Survey published on PA levels in the AB population, it was stated that 20% of adults were active[101]. The participants in this study exceed the exercise guidelines of both SCI and AB populations, with 82% of the participants meeting the SCI PA guidelines and 69% of the participants meeting the AB PA guidelines[94, 95]. The participants high levels of PA may have indirectly increased REE due to their presumably higher FFM, which explains roughly 70% of REE[10, 18]. This level of exercise could be attenuating the real difference between the predicted and measured REE. Although, the majority of this population is exceeding the prescribed PA guidelines for SCI and AB populations, it is not protecting them against their excessive fat-mass. This highlights the need for energy equations needed by this population to help prevent weight gain and enforce a healthy diet. It also demonstrates that dieticians and exercise specialist should work together to help better tailor nutritional and exercise recommendations.

5.2 Strengths

The strengths in this study are as follows. Firstly, this study is reflective of the male to female proportions present in the SCI population; the males make up the majority of the sample (31 males and 8 females). It has been documented that males are at a greater risk of getting a SCI, with a 3:1 ratio[33]. Secondly, the instruments used in this study involving the DXA and the indirect calorimeter are considered very good quality, in that they are characterized as the gold standard[2, 71].

5.3 Limitations

There are a few limitations that need to be acknowledged in this investigation. Firstly, this study contained a relatively small sample size (n=39), however in comparison to other study of the same calibre, this study is one of the larger ones. Secondly, the level of PA in this sample is relatively high, which has likely increased FFM of the active participants and may have subsequently raised their REE[18]. Therefore, it is possible that this high level of PA in this population may be attenuating the difference between the predicted and measured REE.

5.4 Conclusions and Future Research

In conclusion, the HB and MSJ equations tend to over-estimate caloric needs in this sample. As with previous research and this current investigation, there is sufficient evidence showing that common energy prediction equations do not accurately predict energy needs in the SCI population. Therefore, health care practitioners should avoid such equations as a means of estimating caloric needs, since they tend to over-estimate caloric intake, which could exacerbate the already overwhelming obesity problem.

The Buchholz et al. equation was found to accurately estimate energy needs in this population. Although, the Buchholz et al. equation was shown to be an accurate measure of REE, it is not a perfect means of energy estimation. More research is necessary in terms of increasing sample size to refine this and future equations to make them more accurate and precise. Future collaborations among laboratories can come together to help this endeavour. Furthermore, the use of FFM in this equation limits its usefulness to individuals with access to specialised equipment that can measure this predictor. Therefore, research focusing on generating equations that are more practical and readily available to a larger population and cross-validating such equations is an important concern.

5.5 Clinical Importance

Dieticians and healthcare practitioners should move away from energy equations generated from the AB population, which may further intensify the obesity problem present in this population. Individuals with access to FFM information or equipment can use the Buchholz et al. equation to provide better estimates of REE.

Obesity is a problem that has a number of cascading metabolic and physiological consequences. Future research in SCI- specific energy prediction equations present a pressing healthy priority in this population. This will help dieticians prevent weight gain and provide better eating habits for this population.

Dieticians and exercise specialists need to come together to help manage health and weight in this population. Interventions that target a healthy lifestyle immediately after SCI with the help of this trans-disciplinary team can provide a means of stabilizing weight and represents a public health priority

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