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Physiological Effects of a Novel FES Cycling Protocol on a 34-Year-Old Individual with Chronic Paraplegia

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Honors College Thesis: Physiological Effects of a Novel FES Cycling Protocol on a 34-Year-Old Individual with Chronic Paraplegia

by

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ABSTRACT

Background and Purpose: Individuals with spinal cord injury (SCI) are at a higher risk of sedentarism and the health risks that are associated with inactivity (Gorgey, Dolbow, Dolbow, Khalil & Gater, 2015). Because this population has limited exercise options due to paralysis, a new protocol of resistance-guided, high intensity interval training functional electrical stimulation (FES) cycling was developed to allow people with SCI to utilize their paralyzed legs as opposed to their overused arms. This new protocol is important as it provides an opportunity to restore body composition to a more favorable muscle to fat ratio decreasing obesity and increasing cardiovascular health.

Case Description: A 34-year-old male with a complete T9 SCI.

Intervention: The participant underwent resistance-guided high intensity interval training (RG-HIIT) FES cycling three times a week for 8 weeks. Before and after this training, the participant's, body composition was measured using a dual energy x-ray absorptiometry (DXA) scanner, cardiovascular health was assessed via flow mediated dilation testing with Doppler ultrasound, and average blood sugar/glycated hemoglobin (HbA1c) levels were estimated.

Results: The participant showed an increase in leg-lean mass by 8.6%, increased blood flow (reactive hyperemia) by 59.5%, and decreased fasting blood glucose levels (glycemic control) by 1.2%.

Discussion: The changes in the participant's leg-lean mass, reactive hyperemia, and glycemic control show that RG-HIIT-FES cycling had a positive effect on the participant's body composition and cardiometabolic health. However, these results could have been better controlled had the participant undergone nutritional counseling; future studies will aim to add this control.

Key Words: Spinal Cord Injury, Resistance-Guided High Intensity Interval Training, Dual-Energy X-ray Absorptiometry, Flow Mediated Dilation, Case Study

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LIST OF ABBREVIATIONS

BMI	Body Mass Index
BP	Blood Pressure
DBP	Diastolic Blood Pressure
DXA	Dual-Energy X-ray Absorptiometry
FES	Functional Electrical Stimulation
FMD	Flow Mediated Dilation
HbA1c	Average Blood Sugar/Glycated Hemoglobin
HDL	High-Density lipoprotein
HR	Heart rate
RG-HIIT	Resistance-Guided High Intensity Interval Training
SBP	Systolic Blood Pressure
SCI	Spinal Cord Injury
VL	Vastus Lateralis Muscle

CHAPTER 1

INTRODUCTION

People with spinal cord injuries (SCI) often have limited access to exercise due to physical limitations and external barriers (Dolbow, Gorgey, Gater & Moore, 2014). The inability to regularly exercise increases the likelihood for people with SCIs to develop a variety of health complications including obesity, type II diabetes mellitus, dyslipidemia, cardiovascular diseases, and metabolic syndrome (Gorgey et al., 2015). These complications correlate with changes in the metabolic profiles of individuals' post-injury— taking affect in as little as a few weeks after the injury (Gorgey, Dolbow, Dolbow, Khalil, Castillo & Gater, 2014). In order to combat these metabolic changes, adaptive exercises are critical in preventing health complications for individuals with paralysis (Gorgey et al., 2014). Functional electrical stimulation (FES) cycling has proven to be a successful form of exercise for people with SCI's (Dolbow, Gorgey, Moore & Gater, 2012).

Activity-based restorative therapies are exercises that use repetitive motions and often electrical stimulation in order to promote stimulation of the peripheral and central nervous systems (Sadowsky & McDonald, 2009). FES cycling is an important component of activity-based restorative therapies as it utilizes the large paralyzed muscle groups of the legs while sparing the often overused arms. FES cycling has been proven to increase muscle/lean mass, lower body fat, and have a positive effect on the metabolic health of participants (Griffin, Decker, Hwang, Wang, Kitchen, Ding & Ivy, 2009; Dolbow et al., 2012; Scremin, Kurta, Gentili, Wiseman, Perell, Kunkel, & Scremin, 1999). In addition to enhancing body composition and the restoration of metabolic health, FES cycling has been reported to increase arterial blood flow in individuals with SCI (De Groot, Croziar, Rakobowchuk, Hopman & MacDonald, 2015). This suggests that cardiovascular health can be improved in a relatively short period of time, and can improve overall health long term.

The purpose of this case study was to determine the effects of a newly developed resistance-guided FES cycling protocol on the body composition (lean mass and body fat percentage), peripheral vascular health (flow mediated dilation) and fasting blood glucose profiles or glycated hemoglobin (HbA1c) of an individual with chronic motor complete paraplegia. This case study provides the first documented report of the effects of a resistance-guided high intensity interval training (RG-HIIT) FES cycling protocol for an individual with SCI. The RG-HIIT-FES cycling protocol was performed for 30 minutes, thrice weekly for 8 weeks. It was hypothesized that the participant in this study would experience an increase in lean mass, a decrease in overall body fat percentage, increased arterial health, and improved fasting blood glucose values. The results of this case study provide new information that, when replicated in future studies for verification, will assist clinicians and other healthcare professionals in developing best-practice programs.

CHAPTER 2

LITERATURE REVIEW

Physical activity is a key factor in maintaining a healthy lifestyle and preventing cardiovascular disease (Strath, Kaminsky, Ainsworth, Ekelund, Freedson, Gary et al., 2013). When individuals with SCI are admitted into a rehabilitation facility, immediately following an injury, they are more likely to be involved in more physical activity than the average able-bodied person (Berg-Emons, Bussmann, Haisma, Sluis, Woude, Bergen et al., 2008). However, one year post-discharge, individuals with SCI, on average, experience a dramatic decrease in physical activity when compared to able-bodied persons (Berg-Emons et al., 2008). Physical inactivity, or sedentarism, causes people with SCI to have a higher risk for developing health complications—specifically cardiovascular disease (Buchholz, McGillivary & Pencharz, 2003); in addition to this, sedentarism causes detrimental changes in an individual's metabolic profile, body composition, and arterial health (Dolbow et al., 2012; Thijssen, Groot, Bogerd, Veltmeijer, Cable, Green & Hopman, 2012). This is especially true for the SCI population, for the risk of heart disease, stroke, and type II diabetes are elevated to more than twice that of the able-bodied population (Cragg, Noonan & Krassioukov, 2013). However, a major consenquence of SCI is that paralysis makes voluntary exercise with the legs impossible. In addition, the 60-90% prevalence of shoulder pain in persons with chronic SCI often limits the possibility of regular arm exercise (Erils-Hoogland, Hoekstra, de Groot, Stucki, Post & van der Woude, 2014). This creates an essential need for individuals with SCI to have greater access to adaptive exercise equipment or forms of exercise in order to decrease the risk of secondary health complications.

Evidence has also shown that metabolic disorders and body composition changes share a strong relationship with physical inactivity and decreases in anabolic hormones following a SCI

(Dolbow et al., 2012). Elder, Apple, Bickel, Meyer and Dudley (2004) conducted a study to determine the relationship between intramuscular fat and plasma glucose or plasma insulin amongst non-exercise trained individuals with SCI. In this study, magnetic resonance images and body mass index were used to determine intramuscular fat. Additionally, an oral glucose tolerance test was conducted to identify tolerance of plasma glucose and plasma insulin. The results showed nearly a four-fold difference in intramuscular fat compared to able-bodied individuals; the glucose and insulin levels were also higher among the individuals with SCI. These data suggest that there is a correlation between intramuscular fat and glucose intolerance (Elder et al., 2004).

Spungen, Adkins, Stewart, Wang, Pierson, Waters and Bauman (2003) found that people with SCI had more fat when compared to the general population, and they had significantly more adipose tissue and less lean mass, regardless of age. Lipid levels of individuals with SCI have shown a decrease in cardio-protective high-density lipoprotein (HDL) cholesterol level. Additionally, serum triglyceride and plasma insulin are directly correlated, and as serum triglyceride increases HDL cholesterol decreases, providing evidence of an inverse correlation (Bauman & Spungen, 1994). These changes in metabolic profiles and consequently body composition can largely be contributed to lack of physical activity (Bauman et al., 1994).

De Groot, Bleeker, Kuppevelt, Woude and Hopman (2006) examined the changes that occurred within the vascular system of individual’s legs for a duration of six weeks following injury. A Doppler echo was used to examine the participant’s common femoral artery, superficial femoral artery, brachial artery, and carotid artery. Each of these arteries’ diameter, blood flow, and basal shear rate levels were investigated. The femoral artery was found to significantly decrease in diameter over time; basal shear rate levels increased about 64% after three weeks; and leg volume decreased about 22% after three weeks. These results show that arterial health can be significantly changed in as little as three weeks, suggesting that sedentarism results in negative adaptations in arterial function and makeup (de Groot et al., 2006).

In order to prevent the adverse effects of sedentarism, FES cycling has been studied extensively. Body composition deteriorates significantly following a SCI; however, FES cycling has been shown as a viable way to ameliorate these effects. FES cycling resulted in increased lean body mass, decreased fat body mass, and increased muscular endurance for people with SCI (Hjeltnes, Aksnes, Birkeland, Johansen, Lannem & Wallberg-Hendriksson, 1997). In addition to this, a cross-sectional study showed a significant proportional increase in muscle to adipose tissue ratios after FES cycling (Scremin et al., 1999).

Griffin et al. (2009) conducted a 10-week study that examined the effects of FES cycling on body composition, metabolic profile, and neurological function. The results showed an increase in lean mass, improved motor and sensory scores (using American Spinal Injury Association assessment), lower glucose and insulin levels during oral glucose tolerance testing, and lower IL-6, TNF-a, and CRP levels as well (Griffin et al., 2009). These results provide evidence supporting that FES cycling can be used as an effective tool in reducing the effects of inactivity.

Regarding cardiovascular disease, Stoner, Sabatier, Mahoney, Dudley and McCully (2006) found that FES exercise could drastically improve the arterial health of people with SCI. After eighteen weeks of training, participants experienced significant improvements in both flow mediated dilation and arterial range. These data show that FES can be used as a viable tool to improve the cardiovascular health of individuals with SCI, which in turn could serve to prevent cardiovascular disease as participants age (Stoner et al., 2006).

FES cycling, has been traditionally prescribed at a moderate to high cadence (i.e., 30-50 rpm). High cadence FES cycling, has been shown to improve cardiometabolic health in people with SCI. For instance, as mentioned above, Griffen et al. (2009) used 10 weeks of moderate to high cadence FES cycling to produce increase lean mass and lower fasting blood glucose values. Interestingly, low cadence (10 rpm) FES cycling has also demonstrated increase muscle size in those with SCI, and to a much greater extent than high cadence FES cycling. Mid-thigh girth change was greater following 6 weeks of low cadence FES cycling as compared to high cadence FES cycling (50 rpm). The authors attributed this difference to be the result of a greater level of cycling resistance permitted by the lower cycling cadence (Fornusek, Davis & Russold, 2013). While these previous studies have been conducted on both high cadence FES and low cadence FES cycling, there has been an absence of investigation into the effects of FES cycling on paralyzed muscles when high cadence is combined with high resistance in an interval fashion. This is important because HIIT programs in non-paralyzed individuals have been shown to provide greater cardiometabolic benefits with less time commitment and lower exercise volume (Karstoft, Winding, Knudsen, Nielsen, Thomsen, Pedersen & Solomon, 2013; Gillen, Martin, Macinnis, Skelly, Tarnopolsky and Gibala, 2016). This may be particularly significant for those with SCI as this population has been characterized as sedentary with "time commitment" being a commonly cited barrier (Jacobs & Nash, 2004).

However, instead of using the individual's maximal heart rate to guide exercise intensity, maximal resistance was used to determine intensity levels for this novel FES cycling protocol. Participants cycled against 80% of their test determined maximal resistance cycling capacity for 30 seconds while using the maximal electrical stimulation tolerated for the high intensity interval and then cycled against the lowest resistance allowed by the cycle (1.0 Nm) during the low intensity interval. Electrical stimulation intensity was also decreased by 50% during the low intensity interval. The participant alternated between high and low intensity intervals for 30 minutes. Typically, heart rate would be used to monitor exercise intensity; however, Valent, Dallmeijer, Houdijk, Slootman, Janssen, Hollander and Woude (2007) found that there is not a correlation to heart rate and oxygen uptake levels for most people with SCI. Therefore, a novel protocol for HIIT was developed for this study.

The DXA scanner is an important tool that can be used to evaluate body composition (Laskey, 1996). The DXA scanner utilizes two different photon energies that react differently with body composition, resulting in a quantitative measurement of the bone mineral density and soft tissue content of the scanned area (Laskey, 1996). Specifically, the DXA scan is used to provide data to show changes in body fat percentage, lean mass percentage, and bone mineral density. This tool was used in this case study to show changes in overall body composition body fat percentage, fat mass, total body lean mass and leg-lean mass. While bone mineral density values were measured by the DXA in this study, these data were not useful as bone metabolism is typically very slow and requires several months to develop a measureable change.

Flow mediated dilation testing is an established method of examining arterial endothelial function; this non-invasive testing method can accurately determine the health of the cardiovascular system— through endothelial reactions to stress (Raitakari & Celermajer, 2000). A blood pressure cuff temporarily restricts arterial blood flow. After the restricted blood flow is released, arterial response to the surge of blood is measured using a high-resolution external vascular ultrasound. This diameter is compared to a base-line diameter in order to determine how the endothelial cells reacted under stress. This is an important test because it indicates how the participant’s vascular strength changes throughout the study. For this case report this test was performed on the brachial artery of the right upper extremity.

Based on the data of previous studies, it was hypothesized that the participant in this case study would see an improvement in lean mass, overall fat distribution, and arterial strength. Specifically, an increase in lean/muscle mass as a result from exercise in the lower limbs was expected. Additionally, as muscle and lean mass increase it was expected that fat percentage would also decrease. Likewise, arterial strength was expected to improve as well as glycemic control.

CHAPTER 3

METHODS

Participant

The participant was a 34.5-year-old African-American male with chronic (11 years post) T9 complete SCI, American Spinal Injury Association Impairment Scale A (Table 1). The participant's SCI resulted from a motor vehicle accident that occurred in 2005. The participant has no sensation or voluntary motor activity below nerve segment T9 (mid-torso) and is wheelchair reliant, although independent or modified independent in all aspects of his life—including family life and occupation.

This case study occurred over an 8-week period. During these 8 weeks, the participant completed three, home-based thirty-minute, RG-HIIT-FES cycling sessions each week. The participant owned his own RT300 FES-Cycle which allowed for home exercise with internet monitoring because the FES cycle was internet connected. However, for the first session, a baseline ride was conducted at the Integrative Cardiometabolic and Exercise Physiology Laboratory located at the University of Southern Mississippi's Kinesiology Building in order to set safe high intensity and low intensity training parameters for the continued at home sessions.

TABLE 1: American Spinal Injury Association Impairment Scale

Category	Description
A = Complete	No motor or sensory function is preserved in the sacral segments S4-S5
B = Incomplete	Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5
C = Incomplete	Motor function is preserved below the neurological level, and more than half of the key muscles below the neurological level have a muscle grade of less than 3
D = Incomplete	Motor function is preserved below the neurological level, and at least half of the key muscles below the neurological level have a muscle grade of 3 or more
E = Normal	Motor and sensory function are normal

Methods Overview

The participant's body composition and overall cardiovascular health was measured before and after 8 weeks of FES cycling in the Integrative Cardiometabolic and Exercise Physiology Laboratory located at the University of Southern Mississippi's Kinesiology Building. During the entirety of the data collection, the patient was in a controlled environment of 21-23 degrees Celsius. Additionally, all data was collected between 8 am and 10 am. The patient had been fasting overnight and had not consumed caffeine in 12 hours or alcohol in 24 hours. Firstly, the participant's weight and height, blood pressure, and heart rate were measured. Next, a flow mediated dilation (FMD) test was used to assess the participant's arterial health and overall cardiovascular health. Then, the ultra sound was used to assess specific muscle architecture of the vastus lateralis (VL) to determine if there were measureable signs of muscle hypertrophy. Finally, changes in blood glucose regulation was conducted by using a Hb1AC average glucose test. Finally, a DXA scan was performed to obtain an accurate description of the participant's body composition.

Weight and Height

Weight was measured as the participant sat in his wheelchair using a Scale-Tronix Wheelchair Scale (Welch Allyn, Skaneatelest Falls, NY). Then, the participant was safely transferred to the laboratory examination table using an Invacare, Reliant 450 electrical power lift. After this, the wheelchair alone was weighed. Then, the weight of the chair was subtracted from the weight of the participant and wheelchair to determine the participant's weight. After this, the participant's height was measured while in a supine position, using a standard measuring tape, from the bottom of the left foot, while the ankle was dorsiflexed, to the top of the head. Weight was measured at the beginning of the program, and again at the end of the program, while height was only measured at the start of the program. These results were recorded in Tables 2 and 3.

Blood Pressure and Heart Rate

After resting in the dimly lit silent room for 20 minutes while in supine position, heart rate (HR) and blood pressure (BP) were measured continuously for 5 minutes. HR was recorded using a lead-II surface electrocardiography (AD Instruments, Powerlab). BP was recorded using an automated sphygmomanometry (AtCor Medical, SphygmoCor XCEL). The sphygmomanometer was placed on the upper-left arm. After 5 minutes of recoding, an average systolic blood pressure (SBP) and diastolic blood pressure (DBP) were recorded, as well as, an average HR. These results can be found in Tables 2 and 3.

HbA1c Test

To monitor changes in glucose sensitivity, a HbA1c test was given using an automated portable HbA1c testing device (PTS Diagnostics, A1cNow^{+}). The testing device was used in correlation with a drop of the participant's blood which was produced by a finger stick from the left hand. These measures are found in tables 2 and 3.

Vascular Endothelial Functional Testing

A high resolution, duplex-Doppler ultrasound unit (GE Logiq P5) equipped with a linear array transducer operating at a frequency of 12 MHz was used to find the longitudinal pictures of the participant's brachial artery. The transducer probe was clamped in order to ensure that the image stayed within the image parameters of 2–5 cm above the antecubital fossa. Additionally, the transducer's probe was in pulse wave mode, operating at a frequency of 5-MHz and an insonation angle of 60º. With the purpose of including the entire vessel lumen, a large sample size was used. Furthermore, in order to ensure consistency and accuracy when determining the edge of the artery, an edge-detection and wall tracking software (Quipu: FMD Studio, Cardiovascular Suite) was used while determining arterial diameter. After identifying the artery's baseline, resting position, diameter (mm) and blood velocity (Vm; $cm \cdot s^{-1}$), the FMD technique was used to determine vascular endothelial function. To start, a blood pressure cuff was placed around the participant's right forearm and was inflated to 220 mmHg for 5 minutes. During these pressurized 5 minutes, the diameter and blood velocity was continuously recorded. Upon release, the recordings continued for 3 minutes. The following equation was then used to calculate the % change in the FMD:

$$\text{FMD \%-change} = (\text{peak diameter} - \text{baseline diameter}) / (\text{baseline diameter} * 100)$$

The results of these measures are found in both Tables 2 and 3.

Muscle Architecture

Structural characteristics of the right VL were determined using B-mode ultrasound (GE, Logiq-P5), similar to previously published reports (Stoner, Credeur, Dolbow & Gater, 2015). Using the linear probe (10 MHz) VL muscle thickness, skin and sub-cutaneous fat thickness (Sub-Q), and total thigh thickness (VL+Sub-Q) were examined. To do this, the probe was positioned longitudinally and perpendicular to the VL of the right leg along the halfway point between the lateral epicondyle of femur and greater trochanter of the hip (1/8th of the thigh circumference, lateral). For each study visit, a 10 second recording was performed on the ultrasound. Within each recording, static images were selected in triplicate at equal time intervals (i.e., every 3 seconds). These images were then analyzed using integrated digital measurement calipers at 3 equidistant points of the VL. Sub-Q thickness was defined as the distance between the skin surface and the superficial fascia of the VL. The VL muscle thickness was defined as the distance between the superficial fascia and the deep aponeurosis, and total thigh thickness was defined as the distance between the skin surface and the deep aponeurosis. This method was selected to account for changes in connective tissue rather than summing the Sub-Q and the VL thickness. All muscle architecture data are presented as an average across the 10 second recording in Table 2 and 3 for pre- and post-intervention measures.

Body Composition via DXA Scan

The DXA Lunar software version 10.5 was used to determine the participant's bone density, total body fat percentage, fat mass, and lean muscle mass. First, the participant was transferred via electrical power lift to the DXA scanner housed by the University of Southern Mississippi's Kinesiology Department. Before being placed in the scanner, all metal or obstructing objects were removed from the participant to prevent interference with the test. Once being safely transferred to the DXA scanner, the participant was placed in a supine position. In order to promote the safety of the participant in the event of an untimely muscle spasm, the participant's legs were secured with Velcro straps at the distal and proximal regions with a slight angle rotation of the torso by manipulation of the hips— thus following the guidelines of the Society for Clinical Densitometry. During the test (which was approximately 7 to 10 minutes), the participant was asked to remain as still as possible. All results regarding body composition can be found in Tables 2 and 3.

FES Cycle Resistance Maximal Test

Before the start of the baseline-maximal test, the participant was asked to empty his bladder in an adjacent restroom. Following this, the FES-cycle electrodes were placed on the following muscle groups: the quadriceps, the hamstrings, and the gluteus maximus. On the quadriceps one electrode was placed on the vastus medialis muscle about 2-5 cm above the patella. The next quadriceps electrode was placed 25-30 cm above the patella on the vastus lateralis muscle. This was repeated for the other leg. For the hamstrings, the first electrode was placed 2-3 cm above the popliteal fossa and the next electrode was placed 25-30 cm on the same muscle. This was then repeated for the other leg. Both of the gluteus maximus' electrodes were placed approximately 3-5 cm apart from each other in a parallel fashion, while being on the largest part of the muscle.

Next, the participant remained in his own wheelchair while the wheelchair was secured to the FES cycle via safety hook attachments, and his feet were secured to the bike's peddles at the forefoot, heel, and just below the knee via Velcro straps. The electrodes were then connected to their corresponding electrical leads on the FES cycle stimulator. After this, this participant's HR and BP were checked, and then rechecked every 5 minutes throughout the test, to make sure they stayed in a normal range for exercise.

To start, the research staff began by gradually increasing the electrode stimulation to each muscle group separately to determine optimal stimulation for strong muscle contractions. This was done in slow increments until the participant reached a threshold that remained comfortable but still produced a strong palpable and visible muscle contraction for each muscle group. However, this particular participant never experienced any sensation at all. This peak level of stimulation was recorded and would then be used as the parameter for the participant while he is in the high intensity interval. Next, resistance was found by starting first with a 2-minute warm up on the bike. During this warm-up, the electrodes were stimulated gradually until they reached the peak parameters that were found in the last test. After this, resistance was added to the bike starting at 1.0 Nm and gradually increasing 0.5 Nm every minute until the monitor indicated that the participant could no longer pedal the bike without the cycle motor assistance. The monitor indicates that assistance is needed when a wheel icon on the screen changes from blue to grey. This indicates that muscle contractions alone are no longer pedaling the bike, and the cycle motor has stepped in to assist. Once the participant reached the level of resistance requiring motor assistance a cool-down exercise cycling phase was initiated with electrical stimulation turning off allowing transition to passive cycling via the cycle motor. This passive cool-down continued until the BP and HR of the participant returned to their resting values. The maximal cycling resistance reached and maintained for 30 sec without motor support was recorded. Eighty percent of the achieved maximal cycling resistance was then used in conjunction with the maximal electrical stimulation to serve as the 30-second high intensity interval during the participant's at-home training sessions. The cycling speed during testing was set at 35 rpm throughout. This speed was selected because during preliminary test development it was discovered that the paralyzed muscles of some individuals were so deconditioned that they were unable to cycle against the lowest resistance possible at speeds 40 rpm or more even with maximum electrical stimulation.

RG-HIIT-FES Cycling Program

The RG-HIIT-FES cycling parameters established during the FES cycling resistance maximal test where uploaded into the participant's RT300 FES cycle in his home during a home visit by research staff. The participant was provided instruction concerning electrode placement and safety precautions which included skin check and discontinuance of the activity with the manifestation of any adverse symptoms i.e. chest pain, other pain, dizziness, excessive perspiration, excessive fatigue and the like. The participant was then instructed to conduct his own at-home-training sessions three times a week for 30 minutes in addition to a two minute warm-up and cool-down phase. The core program alternated between high and low intensity intervals of 30 seconds each. For 30 seconds the high intensity intervals, 80% of the maximal cycling resistance, was used and for the low intensity 30 second intervals, the resistance was decreased to the lowest resistance that the cycle allowed (1.0 Nm). The electrical intensity was dropped to 50% of that used during the high intensity intervals. Cycling performance was monitored via internet connection with his RT300 FES cycle. The participant was also contacted by telephone for feedback concerning the program periodically throughout the 8 weeks.

CHAPTER 4

RESULTS

RG-HITT-FES-Cycling Parameters

The participant's high intensity interval resistance was set at 2.10 Nm and the low intensity cycling resistance was set to 1.0 Nm, for this is the lowest resistance setting of the RT300 FES cycle being used by the participant. During the high intensity intervals, the electrical parameters were as follows: an intensity (mA) of 140 for all muscle groups (quadriceps, hamstrings, and gluteal), a pulse width (μs) of 300, and a frequency (Hz) of 33.3. The electrical stimulation for the low intensity interval was as follows: intensity 70 mA, pulse duration 300 μs, and frequency 33.3 Hz. Cycling speed was maintained at 35 rpm through the cycling sessions. The participant successfully completed 24 RG-HIIT-FES cycling sessions during the 8-week period. The participant expressed no complaints of ill effects during the program and expressed interest in continuing the RG-HIIT-FES cycling protocol beyond the 8 week study.

Body Composition

Body weight decreased from 131.4 to 129.7 kg; however, body fat percentage increased from 45.0% to 47.3% during the 8 week period. Additionally, fat mass (kg) increased from 54.0 to 58.6, and total body lean mass (kg) decreased from 66.04 to 65.2. However, during the 8-week training sessions lean mass (kg) regionalized to the legs increased 8.7% from 11.2 to 12.2 kg. Body mass index (BMI=kg/m^2) also decreased, but in a negligible fashion, from 38.7 to 38.3—the participant remains in the BMI category of obese. Bone marrow density (1.517 g/cm^2) also decreased from 1.517 to 1.435; however, this has been marked as a negligible change because there was no change in bone t-score (normal). Bone mineral density was recorded as measured by DXA, however, was not considered a variable for change within this study as it typically takes several months or longer to produce bone mass changes when stressing bone via physical activity (Dolbow, Gorgey, Daniels, Adler & Gater, 2011). Bone metabolism is slow compared to the body's soft tissues and it is not likely that an 8 week exercise program would produce change.

Cardiovascular Health Measures

There was not a notable difference between resting HR and systolic BP, but there was a decrease in DBP (mmHg) from 83 to 75. The normalized FMD value showed that there was not much change in overall vascular-function on the macro level at a decrease of 4%. However, micro-vascular health showed a major improvement of a 59.8% increase in reactive hyperemia (the transient increase in organ blood flow that occurs following a brief period of arterial occlusion).

Muscle Architecture

Muscle Architecture of the thigh (mid-way between the greater trochanter and the lateral epicondyle of the femur) showed some minor decreases in thickness. VL thickness decreased by 1.4%, Sub-Q thickness decreased by 2.5%, and there was a total decrease in thigh thickness of 0.3%.

Glucose Control

Glycated hemoglobin (HbA1c) levels showed minimal change from 6.2 to 6.1—a decrease of 1.6%. There was no change in glycated hemoglobin classification as both pre- and post-program HbA1c measures fell within the "pre-diabetes" category. According to the participant's medical history, the participant did not carry a diagnosis of diabetes or pre-diabetes.

TABLE 2: Participant's RG-HIIT-FES- Program Results

	Baseline	8 Wks. FES
Body Composition		
Height (m)	1.84	1.84
Body Weight (kg)	131.4	129.7
BMI (kg/m^2)	38.7	39.3
Body Fat (%)	45	47.3
Lean Mass (kg)	66.04	65.2
Fat Mass (kg)	54.02	58.6
Legs Lean mass (kg)	11.2	12.2
Bone Mineral Density (g/cm^2)	1.5	1.4
Resting Hemodynamics		
HR (bpm)	67	67
SBP (mmHg)	129	130
DBP (mmHg)	83	75
Vascular Health		
Resting Artery Diameter (mm)	3.4	3.6
Peak Diameter (mm)	3.7	4.1
FMD (mm)	0.32	0.44
FMD (%)	9.5	12.1
Shear Stimulus (AUC)	34545	45528
FMD normalized (AU)	0.28	0.26
Reactive Hyperemia (AUC)	50199	80047
Muscle Architecture		
VL Thickness (cm)	2.19	2.16
Sub-Q-Thickness (cm)	1.6	1.57
Total Thickness (cm)	3.90	3.89
Glycemic Control		
HbA1c	6.2	6.1

TABLE 3: Participant's % Change Before and After 8 wks of RG-HIIT-FES Cycling

	Δ Before and After 8 wks of RG-HIIT-FES Cycling
Body Composition	
Body Weight (kg)	-1.2
BMI (kg/m^2)	-1.03
Body Fat (%)	+5.1
Lean Mass (kg)	-1.2
Fat Mass (kg)	+8.4
Legs Lean mass (kg)	+8.6
Bone Mineral Density (g/cm^2)	-5.3
Resting Hemodynamics	
HR (bpm)	0
SBP (mmHg)	+0.78
DBP (mmHg)	-9.6
Vascular Health	
Resting Artery Diameter (mm)	+7.3
Peak Diameter (mm)	+9.7
FMD (mm)	+35.7
FMD (%)	+26.5
Shear Stimulus (AUC)	+31.8
FMD normalized (AU)	-4
Reactive Hyperemia (AUC)	+59.5
Muscle Architecture	
VL Thickness (cm)	-1.4
Sub-Q-Thickness (cm)	-2.5
Total Thickness (cm)	-0.3
Glycemic Control	
HbA1c	-1.6

CHAPTER 5

DISCUSSION

It was expected for the participant to see a decrease in bodyweight, a decrease in fat mass, an increase in total lean mass, an increase in leg-lean mass, a decrease in HbA1c, a decrease in resting hemodynamics, and an increase in FMD measures. While some of these characteristics were observed, others were not, thus, the results were mixed in this case study. The participant's body composition showed decreases in body weight and BMI while showing an increase in leg-lean mass which was expected. However, there was also an increase in body fat percentage, fat mass, and a decrease in total body lean mass which were not expected. At first glance it appears counterintuitive to have decreased in body weight and simultaneously increased in body fat percentage, however, there was an overall decrease in total body lean mass as well which would be associated with both decreased weight and an increase in body fat percentage.

The 8.6% increase in lean mass in the legs is likely the result of the electrically induced exercise to the chronically paralyzed leg muscles causing an adaption that resulted in increased muscle mass. A possible explanation for the decrease in total body lean mass is that, even though physical activity increased in the legs, there may have been an overall decrease in total body physical activity resulting in a net loss total body muscle. The increased body fat and increased body fat percentage may have resulted from increased food consumption and possible poor food choices during the 8 week program. This study did not provide nutritional counseling. It is possible that an overall decrease in physical activity and poor eating habits contributed to muscle atrophy in the upper body beyond the muscle gains in the legs and increased adiposity throughout the body. While the participant was instructed to maintain his regular daily routine while adding the 8 week RG-HIIT-FES cycling program, his food intake was not monitored, and it was documented that the participant confessed to over-consumption, especially at a picnic the weekend before his final testing.

The results in body composition in this case report are similar to a case study conducted with a 53-year-old man with tetraplegia who underwent traditional constant resistant FES cycling for 6-months (Dolbow et al., 2012). While the program length for the current case report was much shorter, both participants showed similar results of increased leg-lean mass and increased body fat percentage. However, a key difference is that the 53-year-old participant also showed an increase in body weight and BMI, and did not undergo the novel RG-HIIT-FES cycling program. Additionally, the 53-year-old participant showed a less drastic change in leg-lean mass at 7.1% change. These changes could be explained by two factors: the RG-HIIT-FES training program for our participant was successful in creating an effective program in a less amount of time or nutritional intake played a significant role for these results.

To further support this comparison, similar changes were also seen in body composition when compared to a case-study conducted with a 60-year-old woman with paraplegia (Dolbow et al., 2014). This study was conducted over a period of 12 months, and she was also not using a RG-HIIT-FES cycling program but rather a traditional constant resistance non-interval FES cycling protocol. In a similar manner to the 53-year-old participant, this woman also saw an increase in leg-lean mass at a lower rate of 4.1%. She also showed an increase in weight, BMI, and fat mass. However, since she also experienced a lower change of lean mass in the exercised area (the legs), whilst still conducting the exercise program for a much longer time, this comparison could also support the theory that a RG-HIIT-FES exercise regimen might be more effective, in the exercised region, in shorter periods of time. However, more studies will need to be conducted for confirmation.

Next, the changes seen in this participant's cardiovascular health were most evident in the reactive hyperemia test. This test is correlated to the micro-vascular anatomy of the participant's cardiovascular system. A large increase of 59.5% shows that the participant, after exercising for 8 weeks, was much better at increasing blood flow after restriction during the FMD test, a sign of increased vascular health. These results are important because this shows that micro-cardiovascular health can be significantly improved over a short period of time. Additionally, the macro-arteries during the FMD test did not show a significant increase. In fact, for this participant the normalized results showed a decrease of 4%.

Furthermore, these results are supported by a study conducted with four women with SCIs that underwent traditional non-interval FES cycling for three months (Zbogar, Krassioukov, Scott, Esch & Warburton, 2008). While these four women were not experiencing a RG-HIIT-FES program and their program was a month longer, all four women still only experienced a significant percent change in their micro-arteries and a negligible change in their macro-arteries, with an average change of 63% and 5% respectively. Since there are marked differences in the types of exercise programs used in each of these experiments, future studies will have to be conducted with different parameters, possibly a longer or shorter time frame of HIIT, in order to determine if a RG-HIIT-FES cycling program could have the potential to affect the macro- and microanatomy of individual's cardiovascular health. It is interesting to note that high-intensity interval training has been shown to decrease cardiovascular and metabolic risk among able-bodied individuals in a shorter period of time than standard non-interval exercise programs (Karstoft et al., 2013; Gillen et al., 2016).

Finally, the participant showed a hypothesized result of a decrease in HbA1c. Although, the decrease was negligible at 1.6%, future studies might be beneficial to learn if a longer time-period of RG-HIIT-FES cycling would show a larger increase in glycemic control.

Limitations

The first limitation to address is the frame of the participant. The participant's body type is obese, so the researchers conducting this study had difficulty placing the participant inside the DXA scanner for the body composition tests. While lying in the supine position, the participant was too large to fit inside the DXA scanning parameters with both of his arms lying flat by his side. To overcome this obstacle, his arms were placed over his abdomen. The stacking of the participant's arms over body tissue could have had an adverse effect on the DXA scanner's ability to accurately access the participant's overall body composition. However, since the participant's arms were only over the torso area, it can be assumed that the positive leg-lean mass measures were correct. Also, while the positioning was not optimal, pictures were used to duplicate the positioning during pre- and post-program DXA scans, so that derived body composition changes would be accurate.

An additional limitation was found in the participant's nutritional intake. The participant himself claimed to have overconsumed high caloric low nutrition foods during the study which may have impacted body fat percentage and fat mass. Since the participant was obese at the beginning of the study, it was expected for dietary intake to be a challenge for this individual; therefore, in future studies it will be essential to assist participants with controlled caloric intake through nutritional counseling and monitoring. Finally, as in all case studies, it is not possible to generalize the results shown in this participant to the overall population of individuals with SCI, nevertheless, these results do demonstrate that these results are possible.

Conclusion

This case study showed that the chronically paralyzed legs of this individual had a sizeable increase in leg-lean mass. This is important because, even in the case of an obese individual, an increase in lean mass in paralyzed legs is possible through electrically induced exercise. When compared to studies using a constant resistance with no intervals, it appears that the increase in leg-lean mass in the current case report was achieved in a shorter time frame. Additionally, this participant showed a significant increase in reactive hyperemia. This shows that the participant's micro-arteries demonstrated an increase in artery dilation after restriction which is generally considered a characteristic of improved arterial health. This is also crucial in showing that it is possible for an individual's cardiovascular health to have positive changes after only 8 weeks of RG-HIIT-FES cycling. Finally, an increase in glycemic control was shown by a 1.2% decrease in HbA1c. This supports the hypothesis that even hemoglobin glycemic control can be improved, after 8 weeks of the novel FES cycling protocol examined in this study.

Overall, this participant alone supported the new high intensity protocol by showing positive results in leg-lean mass, micro-arterial health, and glycemic control, which provides preliminary results leading to further study. However, further study needs to include nutritional counseling to better control the results that should be seen over an 8-week course. Optimally, completion of a randomized control study with a large number of participants able to support statically significant differences. Further study is required and encouraged to determine if RG-HIIT-FES cycling truly improves upon body composition, cardiovascular health, and glycemic control.

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