UNDERWATER TREADMILL TRAINING WITH ADULTS WHO HAVE TYPE 2 DIABETES

by

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I would like to dedicate my dissertation to all my grandparents and relatives that have passed away. All of you played a vital role in my life and paved the way for my future. Without you, and all of your help, I would have never made it to where I am now. I love you and miss you with all my heart.

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ABSTRACT

This dissertation consisted of two studies designed to evaluate the effectiveness of an underwater treadmill (UT) training program in improving the health and fitness of adults with type 2 diabetes. The aim of the first study was to determine if an UT walking program would improve glycemic control and health-related fitness in 7 adults (mean age = 55 years). Participants completed 8 weeks of training (3 days a week). Glycosylated hemoglobin (HbA1c) decreased an average of 0.7% and body mass (BM), body fat percentage (BF%), and waist circumference (WC) significantly decreased. In addition, resting heart rate (RHR) decreased, estimated maximal aerobic capacity increased, and peak torque of both the hamstrings and quadriceps muscles improved. These preliminary findings indicated that participating in UT training is a safe and effective exercise modality for controlling blood glucose and improving body composition, cardiorespiratory function, and leg strength in adults with type 2 diabetes.

In the second study, 26 adults (mean age = 58 years) completed a 12 week UT walking program within a randomized cross-over design. Following training, there was a significant decrease in HbA1c of 0.8%. There were also significant improvements in high-density lipoproteins (HDL), low-density lipoproteins (LDL), triglycerides (TG), and high-density lipoprotein to triglyceride ratio (HDL/TG) values compared to baseline levels. Body composition and cardiovascular measures also improved following UT training, as indicated by decreases in BM, BF%, WC, RHR, resting blood pressures (systolic and diastolic), and an increase in distance walked during the 6-minute walk for distance test. Leg strength in both the quadriceps and hamstring muscle groups were

improved following UT training in addition to daily average caloric expenditure. The comprehensive improvements observed, coupled with a lack of adverse and hypoglycemic events, demonstrate that UT walking is an effective and safe modality for improving metabolic and cardiovascular health in adults with type 2 diabetes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

DISSERTATION INTRODUCTION

Diabetes is a group of metabolic diseases characterized by pronounced elevations of plasma glucose produced by defects in insulin production and/or insulin action (American Diabetes Association [ADA], 2013). In the United States, the financial burden of diabetes exceeded 245 billion dollars in 2012 (ADA, 2013) and it is projected that 1 in 3 Americans born after the year 2000 will develop diabetes at some point during his or her lifetime (Colberg et al., 2010). Additionally, the World Health Organization (WHO) predicts that by the year 2030, over 366 million people worldwide will have diabetes (Wild, Roglic, Green, Sicree, & King, 2004).

Type 2 diabetes accounts for 90 to 95% of all cases among adults (ADA, 2013). Glycemic control amongst adults with type 2 diabetes is essential because failure to maintain safe levels of blood glucose and glycosylated hemoglobin (HbA1c) can lead to an increased prevalence of macrovascular and microvascular health problems (Coker et al., 2006). Type 2 diabetes is one of the leading causes of premature mortality and morbidity due to cardiovascular disease (CVD) and other related medical conditions (Colberg et al., 2010). Adults with type 2 diabetes have a 2- to 8-fold higher risk of CVD compared to adults that do not have type 2 diabetes (Papa et al., 2013).

Other common health problems observed in adults with type 2 diabetes include vision loss, renal failure, amputations, and loss of functional independence (Coker et al., 2006). A lifestyle intervention that has been shown to diminish the incidence and severity of these health and functional conditions is regular physical activity. Engaging in daily physical activity exerts a positive effect on glycemic control by improving insulin sensitivity, lowering insulin levels, and enhancing glucose tolerance (Sigal, Kenny, Wasserman, & Castaneda-Sceppa, 2004). Taken together, these adaptations result in a decrease in the severity of diabetic complications and a better overall quality of life in people with type 2 diabetes (American Association of Diabetes Educators, 2012). However, most adults with type 2 diabetes will not benefit from the positive effects of physical activity because they are not physically active on a regular basis (Morrato, Hill, Wyatt, Ghushchyan, & Sullivan, 2007).

Previous research has demonstrated that aerobic exercise is an effective intervention for preventing and treating type 2 diabetes (Hughes et al, 1993; Mourier et al., 1997). Endurance-based activity is beneficial in type 2 diabetes because it improves glycemic control and insulin action and promotes fat metabolism (Polikandrioti & Dokoutsidou, 2009). Resistance exercise is also beneficial in improving insulin sensitivity due to increases in muscle mass and glucose storage and facilitation of glucose clearance from the circulation (Cauza et al., 2005; Dunstan et al., 2002; Holten et al., 2004; Ivy, 1997). The combined use of aerobic and resistance exercise has been shown to be even more effective in improving glycemic control and insulin sensitivity compared to performing either aerobic or resistance exercise because different physiological mechanisms of action promoting better glycemic control can be operative in a single activity-based intervention (Larose et al., 2010; Loimaala et al., 2009; Maiorana et al., 2002; Snowling & Hopkins, 2006).

Limited mobility and/or musculoskeletal problems are commonly associated with being overweight or obese and often restrict the ease of walking among individuals with type 2 diabetes (Jones, Meredith-Jones, & Legge, 2009). One solution to this problem is to exercise in an aquatic environment, as the buoyancy of the water aids in reducing the amount of total body weight being supported and decreases the ground reaction forces placed on the lower extremities. Aquatic exercise has also been shown to increase cardiovascular fitness, muscle strength, metabolic fitness (Chu et al., 2004; Healy et al., 2007; Tanaka, Bassett, & Howley, 1997), exercise adherence, and exercise enjoyment in adults with and without type 2 diabetes (Healy et al., 2007; Lind, Joens-Matre, & Ekkekakis, 2005; O'Donovan et al., 2005).

A specific type of aquatic exercise that may be particularly beneficial to adults with type 2 diabetes is walking in an underwater treadmill. Walking is generally recommended as a preferred method of physical activity because it is practical in nature, easy to perform by individuals who are overweight or obese (Alkurdi, Paul, Sadowski, & Dolny, 2010), and decreases stress placed on the knee and ankle joints (Griffin & Guilak, 2005). A person walking on a treadmill submerged in water is also able to exercise at a higher relative exercise intensity compared to walking on dry land because he or she simultaneously experiences the aerobic component of walking and the added resistance of moving the limbs through water (Alkurdi et al., 2010). Consequently, an underwater treadmill walking program may improve glycemic control and various aspects of physical fitness among individuals with diabetes.

Overall Purpose

Two studies were conducted to quantify the effectiveness of an underwater treadmill walking program in improving the metabolic health and health-related fitness of adults with type 2 diabetes. **The purpose of the first study** was to establish the feasibility and safety of an underwater treadmill walking program for adults with type 2 diabetes. Glycemic control, body composition, cardiovascular fitness, and leg strength were tested prior to and following 8 weeks of underwater treadmill training. **The purpose of the second study** was to employ a cross-over design to quantify the effects of an extended period (24 weeks) of underwater treadmill training on glycemic control, metabolic control, body composition, cardiovascular fitness, leg strength, and caloric expenditure in adults with type 2 diabetes.

Significance of Studies

The increased prevalence of type 2 diabetes and the economic impact it is having on the world continues to make it an area where new treatment options are needed. Exercise is an established treatment, but due to the increased comorbidities and complications with type 2 diabetes, these adults have difficulty being physically active. An aquatic walking program could be a promising and optimal environment for adults with type 2 diabetes to be physically active. It would allow for adults to perform a combination of aerobic and resistance exercise, while possibly reducing the chance of hypoglycemic events. An underwater treadmill walking program also provides a safe medium for exercise while reducing possible complications and comorbidities associated with type 2 diabetes. Thus, current research is needed to determine the effect of an underwater treadmill walking program on glycemic control and other health-related fitness variables amongst adults with type 2 diabetes.

CHAPTER II

REVIEW OF THE LITERATURE

This review begins with a discussion of the prevalence of diabetes and, in particular, type 2 diabetes mellitus. Next, the prevalence, economic burden, and pathophysiology of type 2 diabetes are discussed. Current methods of treatment of type 2 diabetes are then covered with specific emphasis on the evolution of exercise modes used to help treat adults with type 2 diabetes. Lastly, the use of aquatic exercise is emphasized with references to the benefits, physiological outcomes, and the use of exercise as a mode of training in adults with type 2 diabetes mellitus.

Diabetes Prevalence

Diabetes mellitus is described by the ADA (2013) as a group of diseases that result from the body's inability to produce and/or use insulin. The two classifications of diabetes mellitus are type 1 and type 2 diabetes. Type 2 diabetes is a chronic illness which manifests by decreased insulin sensitivity and poor glucose control (Marcus et al., 2008). Type 2 diabetes accounts for 90% of all cases of diabetes worldwide. Type 1 diabetes is more prevalent in younger generations and is characterized by an inability to produce insulin (ADA, 2013).

The World Health Organization (WHO) has labeled diabetes as being an international epidemic of chronic disease (Fu, Qiu, Radican, Yin, & Mavros, 2010). Worldwide, it has been estimated that over 180 million people have diabetes and that the disease accounts for approximately 5% of deaths on an annual basis (WHO fact sheet, 2006). The level of both type 1 and type 2 diabetes in the United States has reached epidemic levels. The 2011 National Diabetes Fact Sheet showed that all combined cases of diabetes affects 25.8 million people (8.3%) and that number is expected to triple over the next few decades (Boyle, Thompson, Gregg, Barker, & Williamson, 2010). Of the 25.8 million people who have both type 1 and type 2 diabetes, 18.8 million people have been diagnosed and it is estimated that 7.0 million people are undiagnosed. The 2005-2008 National Health and Nutrition Examination Survey (NHANES) showed that the largest percentage of Americans (40.6% of 25.8 million cases) that had diagnosed and undiagnosed occurrences of diabetes were adults 45 years of age and older (Centers for Disease Control and Prevention, 2011). Although previous research has shown that the majority of diagnoses of diabetes are occurring in older adults, the NHANES data have also shown that both type 1 and type 2 diabetes are becoming more prevalent in younger segments of the population, with 13.0 million men, 20 - 44 years of age having been diagnosed with diabetes and 12.6 million women, 20 - 44 years of age having the metabolic disorder (Castaneda et al., 2002).

While there are no prevalence differences between the sexes with type 2 diabetes, racial and ethnic differences are evident. The Latino population has a type 2 diabetes prevalence that is twice that of Caucasians in the United States (Harris, Eastman, Cowie, Flegal, & Eberhardt, 1999). Also, African Americans and Asians have higher prevalence rates of type 2 diabetes and are more likely to have diabetic complications as opposed to people who are Caucasian (Shah, Dolan, Kimball, & Urbina, 2012). As a result of the higher prevalence and health complications from diabetes, there is a high economic burden being placed on the United States by type 2 diabetes.

Economic Burden

In addition to the large prevalence of both type 1 and type 2 diabetes in the United States, diabetes also has a large economic impact. When controlling for age and sex differences, those individuals with diabetes have average medical expenses that are 2.3 times higher compared to individuals that do not have diabetes (ADA, 2013). In 2012, the total cost of both type 1 and type 2 diabetes was 245 billion dollars, with 69 billion dollars of this total associated with loss of productivity (ADA, 2013).

In conjunction with the health consequences, the large economic burden associated with diabetes emphasizes the need to properly treat type 2 diabetes. Previous research has shown that it is cost-effective to have strict glucose control and reduced diabetes-related complications in adults with type 2 diabetes (Caro, Ward, & O'Brien, 2002; Clarke et al., 2001; Gray & Clarke, 2008; Minshall et al., 2005). Specifically, Minshall et al. (2005) showed that a reduction of HbA1c nationwide to 7% would result in a decrease of 64.5 billion dollars in medical expenditures for diabetic-related complications over a period of 20 years. Due to the large reduction in cost as a result of a small change in HbA1c, different treatment options for type 2 diabetes must be examined. One of the reasons there is such a high economic burden from type 2 diabetes is the large number of comorbidities that have an effect on various parts of the body. To better understand the complexity of type 2 diabetes and the effects it has on the body, one must be familiar with the pathophysiology of this metabolic disorder.

Pathophysiology of Type 2 Diabetes

Type 2 diabetes mellitus is the most common form of diabetes and is a disorder characterized by hyperglycemia (ADA, 2013; Ostenson, 2001). Hyperglycemia can be defined as high glucose levels (100-126 mg/dl fasting plasma glucose) in blood plasma and is the primary symptom associated with type 2 diabetes (Nathan et al., 2009). Hyperglycemia is caused by multiple organ dysfunctions such as: insulin resistance in muscle tissue, unrestrained hepatic glucose production, a decline in pancreatic insulin secretion, decreased insulin sensitivity, as well as deficiencies in specific hormones. Chronic hyperglycemia may cause further injury by damaging endothelial and pancreatic-beta cells (Campos, 2012). Chronic hyperglycemia traditionally results from poor diet and a lack of physical activity. However, another suggested leading cause of type 2 diabetes is the passing on of a genetic link from generation to generation.

Unlike type 1 diabetes, there are no clear genetic markers for non-insulin dependent diabetes mellitus, but there does seem to be a strong genetic component (Kahn, Vincent, & Doria, 1996). If a parent or sibling has type 2 diabetes, first generation relatives are 2 to 6 times more likely to develop the disease than someone who does not have a family history. Additionally, the majority of adults (70%-85%) that have type 2 diabetes also have a genetic component that interacts with other poor lifestyle choices, such as being physically inactive, poor diet, and using tobacco products, which can lead to the development of glucose intolerance. Both genetic predisposition and environmental interaction combine to have an effect on the insulin response to glucose by the pancreatic Beta cells (β-cells) and impairment of the pancreatic β-cells response to glucose is a requirement for type 2 diabetes to develop (Ostenson, 2001).

Type 2 diabetes is defined as a heterogeneous disease, because there are multiple factors involved with the metabolic disorder. Furthermore, type 2 diabetes is usually characterized by one of three metabolic dysfunctions: impaired insulin secretion, increased liver glucose production, and peripheral insulin resistance (Ostenson, 2001). Currently, order of acquisition of these three conditions is still unknown, but it is known that insulin secretion and action are impaired in adults with type 2 diabetes. Insulin is a vital peptide hormone, produced by the β-cells of the pancreas, that is needed for the uptake of glucose by skeletal muscle tissue cells and to decrease hepatic glucose production.

Although adults with type 2 diabetes usually have difficulties with secreting adequate amount of insulin, the results of a study by Osteonson (2001) showed that the fasting plasma insulin levels in adults with type 2 diabetes are generally normal or slightly increased. The slightly increased levels of fasting plasma insulin are a sign of a person's body developing insulin resistance. However, even though the fasting plasma insulin levels are within normal range this doesn't prevent high levels of blood glucose from occurring in adults with type 2 diabetes. Hyperglycemia after ingestion of carbohydrates can be potentially due to impaired insulin release (Ostenson, 2001).

The overall mechanism of impaired insulin release is currently unknown for type 2 diabetes. It is not known if type 2 diabetes is due to a reduction in β-cell mass, dysfunction of a number of normal β -cells, or a combination of both issues. The loss of β-cell mass can be due to the down regulation of a pancreatic transcription factor that is essential for the normal β-cell differentiation (Nolan, Damm, & Prentki, 2011). Autopsies performed on adults with type 2 diabetes have shown a β-cell mass reduction of 40%-60%, compared to adults that do not have type 2 diabetes (Gepts & Lecompte, 1981). The loss of β-cell mass does not occur in all adults with type 2 diabetes and therefore, it could also be due to the dysfunction of normal β-cells.

The β-cells in the pancreas monitor nutrient concentrations in the blood, sense neurohormonal signals, and execute the release of insulin granules via exocytosis (Nolan et al., 2011). β-cell dysfunction occurs when compensation is needed for ingested fuel excess and can result in nutrient damage to the cells. Research performed by Ostenson (2001) suggested that type 2 diabetes may be due to changes in islet morphology, including islet fibrosis and amyloid deposition. The complex events that cause the β-cell to go from depolarization to the exocytosis of insulin and the moderating potentiating factors could all play a role in the resulting impaired insulin release (Osteonson, 2001).

In addition to impaired insulin release, insulin resistance is also one of the core defects that results in the development of type 2 diabetes (Barr, Myslinski, & Scarborough, 2008). Insulin resistance is the need for higher than normal plasma insulin levels to maintain normal blood glycemic levels. The major sites of insulin resistance that occur in the adult human body are skeletal muscle tissue, liver, and adipose tissue (Gerich, 1998; Shulman, 2000). Possible reasons for hyperglycemia could be the increased glucose production after a night of fasting and reduced suppression of the production of glucose after a meal. The reasons why these occurrences takes place are complex and could be due to the increased supply of gluconeogenic substrate from peripheral tissues, an effect caused by high concentrations of non-esterified fatty acids, that activate hepatic gluconeogenesis (Nolan et al., 2011). However, it does not appear that the liver is the predominant cause of type 2 diabetes (Nolan et al., 2011).

In adults with type 2 diabetes, abnormalities exist in the insulin signaling cascading pathways in skeletal muscle tissue and adipose tissue. The abnormalities lead to the impairment of the insulin-regulated glucose transporter, GLUT-4 (Osteonson, 2001). The issue lies with the inability of the GLUT-4 transporter to be recruited to the surface of the muscle cell when glucose is present in the blood. As the skeletal muscle, adipose tissue, and other tissues become less sensitive to the insulin that is being released by the body, there is an increase in blood glucose levels, and β-cells of the pancreas are forced to produce more insulin. As a result of the insulin resistance progressing, the β-cells will eventually produce less insulin than is necessary to preserve normal glycemic control (Barr, Myslinski, & Scarborough, 2008). Research performed in the United Kingdom Diabetes Study showed a loss of ~ 50% of β-cell function at the time of diagnosis of type 2 diabetes (UK Diabetes Study, 1998).

Concurrent with the dysfunction of the β -cells, increased hepatic glucose production is another possible cause of type 2 diabetes (Barr et al., 2008). The increased production in glucose causes plasma glucose levels to remain elevated in adults with type 2 diabetes. To lower blood glucose, insulin needs to be secreted from the β-cells to stop the production of glucose by the liver. This increased need for insulin also contributes to increased insulin resistance. However, the lower level of insulin circulation and lower level of insulin production by the β-cells causes the liver to continue gluconeogenesis. Thus, β-cell dysfunction, insulin resistance, and the overproduction of glucose by the liver all lead to chronic hyperglycemia and the eventual development of type 2 diabetes (Barr et al., 2008). Chronic hyperglycemia and eventually type 2 diabetes that is not properly treated can lead to health complications.

Health Consequences of All Cases of Diabetes

A person that has diabetes is at higher risk of microvascular and macrovascular diseases (Barr et al., 2008). Microvascular diseases are those that affect the finer blood vessels in the human body and consist of such conditions as renal disease, retinopathy, and polyneuropathy. Complications from having diabetes are the leading causes of kidney failure in the United States (National Diabetes Fact Sheet, 2011). Additionally, in 2008, more than 200,000 people with diabetes had end-stage kidney disease and were living on chronic dialysis or with a kidney transplant.

Neuropathy is one of the more common complications associated diabetes. According to the ADA, more than half of all diagnosed patients with diabetes have had some form of nerve damage and it is more common in those who have had the disease for a prolonged period of time (National Diabetes Fact Sheet, 2011). Over time, hyperglycemia affects the walls of the blood vessels that nourish peripheral nerves leading to tingling, increased pain, increased sensitivity, numbness or weakness in the extremities, and even ulcers (ADA, 2013). Autonomic neuropathy leads to conditions such as: diarrhea, bloating, erectile dysfunction, urinary tract infections, and gastroparesis (ADA, 2013). Currently, the cause of autonomic neuropathy is unknown.

Retinopathy, blindness, and eye problems are examples of microvascular diseases that can occur as a result of complications from diabetes. The two major forms of retinopathy that people with all cases of diabetes have are nonproliferative and proliferative retinopathy. Nonproliferative retinopathy is caused when capillaries in the back of the eyes become inflamed and form pouches. The inflammation causes the blood vessels in the back of the eyes to become blocked and can range from mild to moderate to severe (ADA, 2013). Nonproliferative retinopathy causes the capillaries in the back of the eye to lose the ability to control the passage of fluids from the blood to the retina. As a result, fluid flows into the macula and causes macula edema to form. This can result in blurred vision or a total loss of vision (ADA, 2013).

Proliferative retinopathy is less common compared to nonproliferative retinopathy. It is caused from several years of retinopathy and is the more severe of the two cases. Proliferative retinopathy develops when the blood vessels are damaged to the point of being completely closed. Therefore, new blood vessels form in the retina, leading to complications. The new and weakened blood vessels can leak blood into the eye causing a vitreous hemorrhage (ADA, 2013). Often, signs and symptoms of proliferative retinopathy progress beyond corrective treatment in adults with diabetes.

Diabetes is also the leading cause of new cases of non-traumatic blindness among adults aged 20-74 years of age (Diabetes Fact Sheet, 2011). People with both types of diabetes are also 40% more likely to develop glaucoma compared to people who are not diabetic. Glaucoma occurs when there is a build-up of fluid inside of the eye that does not drain properly. The fluid can then put pressure on the nerves and blood vessels of the eye, which can result in a change in a person's vision. Having diabetes can increase the amount of intraocular pressure inside the eye and increase the risk of developing glaucoma (Pasquale et al., 2006). Another eye condition that is prevalent in adults with diabetes is cataracts. Cataracts are a clouding of the lens of the eye. The clouding of the lens makes vision more difficult and can occur in one or both eyes. Individuals with the diagnosis of diabetes are 60% more likely to develop cataracts during their lifetime.

Macrovascular diseases are complications that occur to the larger blood vessels of the body and result in conditions such as coronary artery disease, peripheral artery disease, and stroke (Barr et al., 2008). Macrovascular diseases have a higher mortality rate than microvascular diseases. Adults with diabetes are more susceptible to macrovascular diseases because they have a higher occurrence of dyslipidemia due to insulin resistance, increases in tumor necrosis factor, and higher prevalence of hypertension (Libby & Plutzky, 2002).

In adults with diabetes, cardiovascular complications are the leading cause of morbidity and mortality (Papa et al., 2013). The risk of developing cardiovascular disease (CVD) is 2 to 4 times higher in adults with diabetes compared to adults without diabetes of the same sex, age, and race (Papa et al., 2013). Coronary heart disease (CHD) develops earlier in adults with all cases of diagnosed diabetes and the disease is more severe compared to age-and sex-matched adults that do not have diabetes (Barr et al., 2008). Additionally, adults with diabetes have an increased tendency for clot formation. Similar to CHD, another macrovascular disease that affects adults with type 2 diabetes is peripheral artery disease (PAD).

Peripheral artery disesase, is a condition that occurs as a result of the partial or complete occlusion of the blood vessels of the legs due to the build-up of fatty deposits on the arterial walls (ADA, 2013). The presence of PAD also makes adults with diabetes susceptible to having a myocardial infarction or a cerebrovascular accident. Research performed by Hiat (2001) showed that more than 50% of people who have PAD are asymptomatic or show signs/symptoms that are uncharacteristic of the disease. Having PAD is a risk for CVD and the risk of CVD increases linearly with the increase in the severity of the PAD.

Another macrovascular disease that has a higher likelihood of occurring in adults with all cases of diabetes is a cerebrovascular accident, commonly known as a stroke.

Having diabetes has been linked in some studies as being an independent risk factor of having a stroke (Hu, Jousilahti, Peltonen, Lindstrom, & Tuomilehto, 2005; Hu, Jousilahti, Sarti, Antikainen, & Tuomilehto, 2006). Hu et al. (2006) showed that adults with type 2 diabetes are at 5 to 7 times greater risk of stroke mortality compared to men and women of the same age who do not have type 2 diabetes.

Diabetes places adults at a higher risk level to obtain both macrovascular and microvascular diseases as compared to adults who do not have diabetes. The consequential complications can range from glaucoma to peripheral artery disease. As a result of the higher levels of health consequences for adults with diabetes, the effective treatment of diabetes is essential. Specifically, for type 2 diabetes three cornerstones of treatment have been identified by physicians and diabetes educators (ADA, 2013).

Nutritional-Based Treatment of Type 2 Diabetes

The three cornerstones of type 2 diabetic therapy have been defined as a proper diet, the use of diabetic medication, and exercise. Proper nutrition involves adults making appropriate food choices that help to ensure and maintain good health (Polikandrioti & Dokoutsidou, 2009). Improper food choices and poor eating habits gained from childhood contribute to an adult acquiring type 2 diabetes. It has also been shown that the consumption of the westernized diet over the past decades has been the main risk factor for increased morbidity and mortality (Steyn et al., 2004; Swift & Boucher, 2006). Medical nutrition therapy (MNT) is important, in not only helping to manage type 2 diabetes, but to also slow the development of several complications in adults with type 2 diabetes.

The goals of MNT is to help a person with non-insulin dependent diabetes to achieve and maintain blood glucose levels in the normal range (ADA, 2007). The goals of MNT also address the personalized needs of the patient and to maintain the satisfaction of eating by only limiting certain food choices that have been shown to be negative through scientific research (ADA, 2007). Medical nutrition therapy should be personalized and is different for those individuals who have type 1 diabetes and those who have type 2 diabetes.

Due to the relevance of proper MNT, the ADA released a position statement on nutrition recommendations for adults with diabetes in 2007. The first category of nutritional recommendations from the ADA is carbohydrate ingestion. It is suggested that a person with diabetes consume carbohydrates that come from fruits, vegetables, whole grains, and legumes (ADA, 2007). Consuming these types of carbohydrates will help contribute to good health and provide energy, vitamins, and minerals. It is recommended by the ADA (2007) that adults with type 2 diabetes count the amount of carbohydrates consumed because the amount of glucose that will be present in the plasma of the blood is affected by the number of carbohydrates consumed.

The current nutritional guideline for the adult population is 130 grams of carbohydrates consumed per day (Institute of Medicine, 2002). The type of carbohydrate can also affect the amount of glucose in the blood following the ingestion of a meal. The glycemic index of foods was created to rate the change in blood glucose following the ingestion of different carbohydrate-containing foods (Jenkins et al., 1981). The glycemic index is the increase in fasting blood glucose 2-hours after ingesting food containing carbohydrates relative to the response to a reference food (white bread). The glycemic load that a person ingests is obtained by multiplying the glycemic index of a food by the amount of carbohydrate in each food and then totaling all the food that was eaten by the person that day. It is recommended by the ADA (2007) that a person that has type 2 diabetes consume a diet that is comprised of low-glycemic index foods. In addition to eating a low-glycemic index diet, adults with type 2 diabetes should match the amount of insulin or insulin-like medication they are taking to that of the carbohydrate content of the meal.

Similar to people that do not have type 2 diabetes, people that have type 2 diabetes are also instructed to eat a diet that is comprised of fiber-containing foods. Eating a high-fiber diet can be achieved through the consumption of fruits, vegetables, fiber-containing cereals, and whole-grain products (ADA, 2007). Diets that are higher in fiber help with the digestive process and also encourage healthy bowel movements (ADA, 2007). Research performed by Irwin, Franz, and Bantle (2002) showed that a high-fiber diet for adults with type 2 diabetes leads to a decrease in hyperglycemia, hyperinsulinemia, and lipemia. As a result, the ADA (2007) suggests the consumption of 14 grams of fiber per 1,000 kcals for a person with diabetes.

The other important cornerstones in MNT are the amounts of dietary fat and cholesterol that person consumes. The primary goal in regards to dietary fat in people with type 2 diabetes is to reduce the amount of saturated fatty acids, trans-fatty acids, and cholesterol intake so as to reduce the likelihood of CVD (ADA, 2007). As a result, the ADA (2007) has suggested the consumption of minimal trans-fatty acids, less than 7% of total energy from saturated fats, and a cholesterol intake of less than 200 mg daily. The biggest concern in regards to a diet that is high in saturated and trans-fatty acids is the negative effect it can have on the amount of low density lipoproteins (LDL). Yet, the ingestion of long chained polyunsaturated fatty acids has been shown to help lower plasma triglyceride levels and LDL levels (ADA, 2007). Thus, it is recommended by the ADA (2007) that adults with type 2 diabetes eat two or more servings of fish per week to obtain the beneficial omega-3 fatty acids. In addition to dietary fat and cholesterol, the management of the intake of protein is also important in adults with type 2 diabetes.

Protein ingestion is also important, because ingested protein can increase insulin response without causing an increase in plasma glucose concentrations (ADA, 2007). As a result, protein should not be used to help counteract a hypoglycemic event or nighttime episode of hypoglycemia. The consumption of protein for a person that has type 2 diabetes should be similar to that of an adult that does not have type 2 diabetes (< 20% of energy intake). High protein diets are also not recommended for weight loss in adults with type 2 diabetes. It is not suggested because the long-term side effects of a high protein diet on diabetic management and its complications are unknown. Although protein is one of the major fuel sources consumed, along with fats and carbohydrates, the optimal mix of the macronutrients needed for a person that has type 2 diabetes is still unknown (ADA, 2007).

Due to the special dietary requirements needed for adults that have type 2 diabetes, the “Mediterranean Diet” has been shown to be one of the best options for a nutritional plan to help control blood glucose and also prevent CVD (Riccardi & Rivellese, 2000). The fat from this diet comes from olive oil and also involves the consumption of moderate amount of fish, fruits, vegetables, and legumes (Polikandrioti & Dokoutsidou, 2009). Even though the Mediterranean diet is one of the best options available, the optimal diet will vary depending upon each person's individual circumstances (ADA, 2007).

Adults with type 2 diabetes could benefit from meeting with a personal dietician or diabetes specialist to make sure that they are consuming a diet that is based upon he or she's individual needs. However, if this is not possible, adults could follow the Dietary Reference Intakes for chronic diseased people (Institute of Medicine, 2002). The Dietary Reference Intake suggests that adults consume 45-65 % of their total energy from carbohydrates, 20-35% of their total energy from fat, and 10-35% of their energy from protein (Institute of Medicine, 2002). The total caloric intake is also important due to the weight-management goals that he or she may have (ADA, 2007). Although dietary recommendations are important in controlling diabetes, research studies have shown that there is poor adherence to dietary changes in adults with type 2 diabetes (Thanopoulou et al., 2004; Toeller et al., 1996). As a result, it is suggested that not only should their diet be altered, but also to take insulin or an insulin-like medication to allow for safer glycemic control (ADA, 2007).

Pharmacological Treatment of Type 2 Diabetes

The use of pharmacological treatments is based on the understanding of treating diabetes with as little medication as possible (Unger & Parkin, 2010). The use of medication needs to be individualized and safe when trying to gain glycemic control in adults with type 2 diabetes. Multiple mechanisms cause a person to go from a normal glycemic state to prediabetes and eventually into type 2 diabetes. As a result, multiple medications may be needed to reverse the abnormal pathophysiologic state (Unger & Parkin, 2010). There are several classifications of oral diabetic medications that are commonly used to treat adults with type 2 diabetes, including: insulin sensitizers, insulin secretagogues, and other oral agents. Injectable medications such as incretin mimetic, amylinomimetic, and insulin are also used in the treatment of type 2 diabetes.

Insulin sensitizers are composed of two main classes: biguanides and thiazolidinediones (LaLiberte & Neumiller, 2010). A person with diabetes loses the ability to respond to insulin and insulin sensitizers increase the sensitivity of cells to insulin. They result in a reduction of plasma glucose levels, increased uptake of glucose by the cells, and a decrease in the amount of glucose released by the liver into the blood stream (LaLiberte & Neumiller, 2010). Thiazolidinediones increase insulin sensitivity by increasing adiponectin levels, redistributing visceral adipose tissue to subcutaneous adipose tissue, and lowering plasma free fatty acid levels (Unger, Hinnen, Schreiner, & Parkin, 2013).

Insulin secretagogues are another classification of diabetic medications. The goal of insulin secretagogues is to overcome insulin resistance by stimulating the pancreas to release additional insulin into the blood stream (LaLiberte & Neumiller, 2010). This class of drug works to assist the cells in increasing the amount of glucose that is taken up into the cells from the blood stream, resulting in lower blood glucose levels to be present (LaLiberte & Neumiller, 2010).

Besides insulin sensitizers and insulin secretagogues, other oral agents are used to treat type 2 diabetes. Glucosidase inhibitors are a type of drug that are taken immediately following the ingestion of a meal (LaLiberte & Neumiller, 2010). Glucosidase inhibitors operate by binding to the alpha-glucosidase enzyme and slowing the breakdown of complex carbohydrates. As a result, there is less of a spike in blood glucose immediately following the digestion of a meal or snack (LaLiberte & Neumiller, 2010).

Dipeptidyl peptidase-4 inhibitors have also been used as an oral agent in the treatment of type 2 diabetes. After consuming a meal or snack, the body will traditionally stimulate the release of insulin from the beta-cells of the pancreas (LaLiberte & Neumiller, 2010). This occurs because hormones are released from the small intestine that causes insulin to be produced. Adults with type 2 diabetes usually have a reduction in small intestine hormones compared to adults that do not have type 2 diabetes. The hormones that are released from the small intestine have a short life and are inactivated by the enzyme dipeptidyl peptidase-4. The role of the dipeptidyl peptidase-4 inhibitors is to hamper the effects of dipeptidyl peptidase so that the hormones from the small intestines have a longer time of action (Neumiller, Odegard, White, Setter, & Campbell, 2008).

The last classification of oral medications is bile acid sequestrants. Bile acid sequestrants improve blood glucose control and lower HbA1c (Sonnett, Levien, Neumiller, Gates, & Setter, 2009). Bile acid sequestrants are effective because they are able to decrease the amount of carbohydrates that are absorbed in the digestive system (LaLiberte & Neumiller, 2010). Similar to that of dipeptidyl peptidase-4 inhibitors, this classification of drugs must also be taken following the consumption of a meal or snack.

Injectable medications. In addition to oral medications, injectable medications are also used in the treatment of diabetes. Incretin mimetic is one of the classifications of injectable medications (LaLiberte & Neumiller, 2010). Incretin mimetics are given as subcutaneous injections and are beneficial because they increase the amount of insulin secreted following a meal, regulate glucagon secretion from the alpha-cells of the pancreas, and cause decreased gastric emptying time (LaLiberte & Neumiller, 2010).

Pramlintide is another injectable medication commonly used to treat diabetes. Pramlintide is an analog of a hormone that is co-secreted with insulin from the pancreas (LaLiberte & Neumiller, 2010). Pramlintide is used in adults who have difficulty obtaining proper glycemic control with mealtime insulin. This injectable drug works with insulin to help regulate post meal glucose levels and results in a decrease in the amount of glucagon that is secreted after a meal (LaLiberte & Neumiller, 2010). Pramlinitide is also injected subcutaneously and is taken immediately after a meal or snack.

The last major injectable drug, and the most popular, is insulin (Unger, Hinnen, Schreiner, & Parkin, 2013). Synthetic insulin is produced in laboratories and used to treat both type 1 and type 2 diabetes (LaLiberte & Neumiller, 2010). The three main categories of insulin that are prescribed and used by people with both type 1 and type 2 diabetes are short-acting, intermediate-acting, and long-acting. The insulin drugs bind to receptors on skeletal muscle, liver, and fat cells and increase uptake of glucose into the cells (LaLiberte & Neumiller, 2010). All three categories of injectable insulin are different in their onset and duration of action. Although injectable medications are having positive impacts on the lives of people with type 2 diabetes, there are still side effects to pharmacological treatments.

Side effects of medications. Insulin sensitizers, insulin secretagogues, and other oral medications have been linked to gastro-intestinal tract distress, nausea, diarrhea, and alterations in taste (LaLiberte & Neumiller, 2010). Insulin sensitizers and insulin secretagogues have also been linked to weight gain and water retention (LaLiberte & Neumiller, 2010). Weight gain can be detrimental in the treatment of type 2 diabetes, especially in those who are overweight or obese. Water retention can increase blood pressure and place stress on blood vessels (LaLiberte & Neumiller, 2010).

Insulin secretagogues and other oral medications have been shown to cause hypoglycemia (LaLiberte & Neumiller, 2010). This can cause an increase in the number of hypoglycemic events during daily activities and exercise. Insulin secretagogues and other oral medications have to be taken with food or they are not effective and could lead to an increased chance of a hypoglycemic event (LaLiberte & Neumiller, 2010). The use of insulin secretagogues has also been linked to weakness, potentially increasing fall risk in older adults that take these medications.

Injectable medications also have negative side effects. Injectable medications require a person to inject a foreign substance into the body and there is a chance of potential rejection. Also, by breaking the barrier of the skin, there is a chance that the site can become infected if not properly cared for (Bennett et al., 2011). Injectable medications have also been linked to headaches, dizziness, constipation, and nausea (LaLiberte & Neumiller, 2010). Similar to some of the oral medications, the use of injectable medications has also been linked to hypoglycemia and gastrointestinal upset. The injectable medications, such as insulin, must also be stored in a refrigerator. This could make transport and storage difficult for a person that has an active lifestyle (Bennett et al., 2011).

In addition to the potential side effects, there is also a financial impact to patients taking medications. A pharmacological treatment is usually a long-term solution and can be a financial burden if a person does not have insurance or proper income to afford medications (Unger et al., 2013). A national diabetic study showed 19% of adults with type 2 diabetes, > 50 years of age, stated that they had not used their proper medication due to financial issues (Piette, Heisler, & Wagner, 2004). These data suggest that another form of treatment needs to be reviewed to allow for a treatment of type 2 diabetes with less financial burden and negative side effects.

Exercise as a Treatment for Type 2 Diabetes in Adults

The third and final cornerstone used in the treatment of type 2 diabetes is exercise (Boule, Haddad, Kenny, Wells, & Sigal, 2001). Exercise can be defined as physical activity that is planned, structured, and includes repetitive movements that are performed to improve or maintain one or more components of physical fitness (Caspersen, Powell, & Christenson, 1985). Performing exercise is associated with reduced CVD risk and all-cause mortality risk in the general population and in adults with type 2 diabetes (Balducci et al., 2012). For adults with type 2 diabetes, exercise helps to reduce the metabolic risk factors that contribute to diabetic complications (ADA, 2013). The use of exercise as a treatment of type 2 diabetes is also appealing due to the fact that it is low-cost and is a non-pharmacological basis of treatment (Boule et al., 2001).

Exercise is an important component in the treatment of type 2 diabetes because it results in the reduction of hyperglycemia and a reduction in body fat (Boule et al., 2001). These are two of the major goals of any treatment program for adults with type 2 diabetes. The reduction of hyperglycemia will help to decrease the long-term complications of diabetes and the reduction in obesity leads to decreased insulin resistance (Yki-Yarvinen, 1998). A meta-analysis by Boule et al. (2001) showed that adults with type 2 diabetes that perform exercise training have a reduction of HbA1c by an amount that should decrease overall risk of diabetic complications. The meta-analysis also showed that exercise training in adults with type 2 diabetes resulted in a decrease in two measures of abdominal obesity (waist circumference and waist-to-hip ratio). Yet, there was no change in body mass when adults with type 2 diabetes were in exercise groups compared to those that were in control groups (Boule et al., 2001).

Exercise is also important for people with type 2 diabetes because it helps to achieve and maintain optimal glycemic control, blood pressure, and lipid levels that can help to prevent further health complications (ADA Standards of Medical Care, 2010). Due to the multiple benefits of performing exercise, the ADA and the American College of Sports Medicine (ACSM) issued a joint position statement in regards to the recommended exercise guidelines for people with type 2 diabetes. The position statement includes recommendations for aerobic exercise, resistance exercise, and a combination of aerobic and resistance exercise (Colberg et al., 2010).

Aerobic exercise. The first mode of exercise that is recommended by the ACSM and the ADA joint position statement by Colberg et al. (2010) is aerobic exercise. It is recommended that aerobic exercise be performed at least 3 days a week by adults with type 2 diabetes. Aerobic exercise should be done consistently with no more than 2 days between exercise bouts due to the transient nature of exercise-induced benefits to insulin action (King et al., 1995). The aerobic exercise program should be at least a moderate level of intensity (40%-59% of $VO_{2\ max\ reserve}$). The majority of individuals that have type 2 diabetes can achieve this level of intensity by walking at a brisk pace. Performing a vigorous intensity aerobic exercise program ($\geq$ 60% of $VO_{2max\ reserve}$) can also be beneficial in adults with type 2 diabetes because the intensity of exercise predicts improvements in overall blood glycemic control as compared to overall volume (Boule et al., 2003). In addition to the importance of the intensity of exercise performed by an adult with type 2 diabetes, the duration of the aerobic exercise program is also imperative.

An adult with type 2 diabetes should perform a minimum of 150 minutes of exercise per week at a moderate level of intensity. The bouts of aerobic exercise should be at least 10 minutes in duration and should be performed throughout the week (Physical Activity Guidelines Advisory Committee, 2008). Meeting these guidelines of at least 150 minutes a week of moderate to vigorous exercise is needed to help reduce the risk of CVD and result in optimal glycemic control (Colberg et al., 2010). To meet the duration recommendations, an adult with type 2 diabetes can perform any form of aerobic exercise. The mode of exercise should include activities that use large muscle groups and results in sustained elevations in heart rate (Hu et al., 2001).

Due to the strong epidemiological evidence linked to the performance of aerobic exercise in the reduction of the risk and treatment of type 2 diabetes, a prospective study was performed by Hu et al. (1999) to investigate the effects of walking and vigorous levels of physical activity on the risk of type 2 diabetes in women. The study was a long term cross-sectional design that followed a total of 70,102 female nurses that ranged in age from 40 to 65 years. The study followed the nurses for a total of 8 years and accounted for age, smoking, alcohol use, history of hypertension, history of cholesterol levels, and other covariates (Hu et al., 1999). Greater amounts of leisure time aerobic physical activity resulted in a decreased likelihood of being diagnosed with type 2 diabetes. There was also an inverse association between the energy expended by walking and the risk of type 2 diabetes. The large cohort study also showed that the greater the increase in exercise intensity, the larger the reduction in the risk of type 2 diabetes (Hu et al., 1999).

To help support the importance of performing aerobic exercise, researchers have investigated the effects of cardiovascular exercise on adults with type 2 diabetes. A research study performed by Hughes et al. (1993) involved 18 older participants, whom were glucose intolerant, performing 12 weeks of aerobic exercise. The participants performed the aerobic training at an intensity that would elicit 50-75% of their hear rate reserve, 55 minutes a day, 4 days a week. This long-term, moderate to high intensity aerobic program caused a significant increase in muscle glycogen stores and resulted in an average increase of 60% in the number of GLUT-4 transporters (Hughes et al., 1993). Thus, performing an aerobic training program helps to improve the peripheral insulin action in older adults that have type 2 diabetes.

Similar to the use of an aerobic training protocol by Hughes et al. (1993), Cuff et al. (2003) investigated the effect of an aerobic training program on adults with type 2 diabetes. The study by Cuff et al. (2003) included 9 females with a mean age of 59.4 years who took part in an aerobic based exercise program for a total of 16 weeks. The participants exercised 3 days per week for a total of 75 minutes per exercise session, which included a warm-up and a cool-down. The women with type 2 diabetes performed aerobic exercises that were low-impact and low intensity (Cuff et al., 2003). Participation in the aerobic-based exercise program resulted in a significant decrease in weight after 16 weeks and a decrease in total abdominal obesity. However, there was not a significant difference in the HbA1c levels compared to the age-matched control participants. The results of the study indicated that an aerobic exercise program is beneficial for the decrease in body mass and abdominal obesity in adult females with type 2 diabetes.

O'Donovan, Kearney, Nevill, Woolf-May, and Bird (2005) investigated the impact of intensity of a 24 week aerobic training program on insulin resistance in sedentary males aged 30 to 45 years. The participants were randomly placed into a control group, moderate intensity exercise group, or a high intensity exercise group. The participants in the moderate intensity exercise group performed cycling on a stationary bicycle, 3 days a week at 60% of their $VO_{2\ max}$. The high intensity exercise group also performed cycling 3 days a week at an intensity level of 80% of each participant's $VO_{2\ max}$ (O'Donovan et al., 2005). Overall, there was a significant reduction in the participant's insulin concentration and insulin resistance. The participants' that performed moderate or vigorous exercise also had a significant increase in insulin sensitivity compared to the age-matched control group (O'Donovan et al., 2005). However, there were no significant differences in these factors between those participants who performed moderate-intensity aerobic exercise routine and those who performed a high intensity exercise routine. The results of the study indicate that aerobic exercise is beneficial in the treatment of factors that are related to type 2 diabetes and a moderate exercise program is equally sufficient as a high intensity exercise program.

Coker et al. (2006) investigated the effects of exercise intensity on changes in insulin action and glycogen metabolism in elderly adults. A total of 21 overweight, elderly participants (mean age of 74 years) were randomized into a control group, a moderate intensity, or a high intensity aerobic exercise group. The moderate exercise group consisted of a cycling routine that involved a total of 12 weeks (4-5 days of exercise per week) at 50% $VO_{2\ max}$. The high intensity group performed a similar number of training sessions for a total of 12 weeks at an intensity of 75% $VO_{2\ max}$.

The results of the study performed by Coker et al. (2006) indicated that compared to the control group, the overweight elderly participants who performed moderate or high intensity work had a significant increase in maximal exercise capacity. Furthermore, the high intensity group was the only group that had a significant change in the amount of insulin-stimulated glucose disposal by skeletal muscle tissue.

Aerobic exercise summary. Aerobic exercise plays a vital role in the treatment of type 2 diabetes in the adult population. Walking is the suggested mode in which adults with type 2 diabetes should perform aerobic exercise due to the ease of the activity and walking in this population usually occurs at a moderate intensity level (Colberg et al., 2010). Aerobic exercise may lead to an increase in whole-body insulin sensitivity and may increase the responsiveness of skeletal muscle tissue to insulin. Aerobic training has also been shown to increase the lipid storage in muscle and increase fat oxidation capacity.

Based upon the guidelines set by the joint position statement by Colberg et al., (2010) aerobic exercise should be performed at least 3 days a week with no longer than 48 hours between consecutive workouts (Colberg et al., 2010). The intensity of the aerobic program should be at least a moderate level of intensity (50% of VO_{2max}), but performing a higher intensity ($\geq$ 60% of $VO_{2\ max}$) workout can have additional benefits to changes in the amount of glucose disposed by skeletal muscle tissue (Coker et al., 2006;

O'Donovan et al., 2005). Moderate intensity aerobic training also results in an increase in glycogen synthase activity and an increase in the amount of GLUT-4 protein expression. Performing a vigorous intensity aerobic exercise program ($\geq$ 60% of $VO_{2max\ reserve}$) can also be beneficial in adults with type 2 diabetes because the intensity of exercise predicts improvements in overall blood glycemic control as compared to overall volume (Boule et al., 2003). Therefore, moderate to high intensity aerobic needs to be performed by adults with type 2 diabetes. The duration of an aerobic exercise program should be a minimum of 150 minutes per week (Colberg et al., 2010). The minimum duration for a bout of aerobic exercise is 10 minutes. A total duration of at least 150 minutes a week has been shown to reduce morbidity and mortality in all adult populations (Physical Activity Guidelines Advisory Committee, 2008). Due to the benefits of exercise, it is important to understand the benefit of diet and exercise, as well as being able to investigate the number of calories that are being ingested and expended.

Caloric expenditure and exercise. Wing et al. (1988) investigated if the addition of an exercise program resulted in greater benefits to adults with type 2 diabetes compared to a standard diet treatment. The study by Wing et al. involved 30 middle-aged obese participants with type 2 diabetes. Half of the participants were assigned to a traditional dietary program and the other 15 participants performed the aerobic exercise and were placed on dietary restrictions. The members of the diet and exercise group performed a 3-mile walk, three times a week, for a total of 10 weeks at a moderate level of intensity (Wing et al., 1988). Individuals that were in the exercise and diet group had significantly greater reductions in body weight and improvements in HbA1c compared to the diet only group. The results of this study strengthen the notion that an aerobic exercise component is needed in the proper treatment of middle-aged adults with type 2 diabetes.

The main concern in regards to adults with type 2 diabetes and sedentary behavior is total daily caloric expenditure. One of the largest contributors to someone being obese and developing type 2 diabetes is being physically inactive and engaging in sedentary behavior (Alkurdi et al., 2010). Sedentary behavior can generally be defined as time spent seated or lying down due to the fact that low energy requirements are needed for these types of activities (Marshall & Ramirez, 2011; Owen, Healy, Matthews, & Dunstan, 2010). Sedentary time has been positively linked to increases in waist circumference, triglycerides, fasting plasmas glucose, and a decrease in high-density lipoproteins (Wijndaele et al., 2007). Thus, adults with type 2 diabetes that partake in sedentary behaviors are at higher risk of developing uncontrolled diabetes and/or diabetic complications due to the lack of caloric expenditure that is taking place (Cuff et al., 2003).

An increase in caloric expenditure is linked to improved glycemic control as well as an increase in health-related fitness in adults with type 2 diabetes (Sigal et al., 2007). To identify the amount of time that a person is involved in sedentary behavior time and the amount of calories that they are expending throughout the day, self-report and device-based measurements are recommended to obtain subjective and objective behavior measurements (Healy et al., 2007). While helpful in identifying the type of physical activity, subjective measures of activity, such as self-report questionnaires, have difficulty comprehensively evaluating sedentary behavior (Pate, O'Neill, & Lobelo, 2008). On the other hand, objective measurement devices are useful in identifying time spent in sedentary behavior, and low, moderate, and vigorous levels of physical activity. Traditionally, evaluating the postural position of a participant and verifying his or her actions with the physical activity compendium is one of the criterion measures used in determining the metabolic equivalent level at which a person is physically performing. However, using postural position and the physical activity compendium is not a criterion measure of overall caloric expenditure (Ainsworth et al., 2011). As a result, calorimetry has been used to evaluate metabolic expenditure at rest and at different intensity levels (Ainsworth et al., 2011; Jakicic et al., 2004).

Direct calorimetry involves a person exercising in a temperature controlled chamber and assessing the amount of heat that is gained or lost in water that is running in a pipe system throughout the chamber (Battley, 1995; Jequier & Schutx, 1983). While direct calorimetry is an accurate assessment tool of caloric expenditure, it is expensive, it involves specific equipment, and it is not practical to obtain accurate information on the energy expended during free-living activities (Battley, 1995). Indirect calorimetry can also be used to determine energy expenditure by using direct amounts of oxygen consumption and carbon dioxide production to determine the amount of energy expended (Branson & Johannigman, 2004). One indirect calorimetry technique that is used is doubly labeled water and it is used to assess the amount of energy expenditure during free-living conditions over a period of 4-21 days. It involves a person consuming a dosage of water that contains isotope-labeled oxygen and hydrogen. The amount of doubly labeled water that is still left in the body is then reassessed at the conclusion of the study and is used to estimate the amount of total energy expenditure that has taken place (Schoeller, 1988). The technique of doubly labeled water is accurate for overall total energy expenditure in a free-living condition, but can be expensive and requires trained technicians. Additionally, using the doubly labeled water technique does not provide information specific to the intensity, duration, or frequency of the physical activity that is being performed (Ainslie, Reilly, & Westerterp, 2003). There are activity monitors and other techniques designed to assess energy expenditure, intensity, and sedentary time.

The Intelligent Device for Energy Expenditure and Physical Activity (IDEEA; MiniSun, CA, USA) and the SenseWear Pro3 Armband (SWA Pro3; BodyMedia, Pittsburgh, PA, USA) have been validated to express caloric expenditure during rest and physical activity (Johannsen et al., 2010; St-Onge, Mignault, Allison, & Rabasa-Lhoret, 2007; Welk, McClain, Eisenmann, & Wickel, 2007). The IDEEA monitor is an energy expenditure monitoring device that consists of 5 accelerometers and a microcomputer (Jiang & Larson, 2013). The computing device is worn on the belt of each participant and the wired sensors are located on the anterior portion of each thigh, the inner portion of each foot, and the center of the chest. The device is worn throughout the day and the computing device records the amount of time spent in activities and estimates the postural position they are performed in so that a total amount of energy expenditure can be estimated based upon the participants daily activities (Jiang & Larson, 2013). The IDEEA monitor is reliable in assessing energy expenditure during fundamental movements, but it can be difficult to use during free-living conditions because of the wired leads that are attached to the limbs (Welk et al., 2007). The SWA Pro3 has been validated for use in assessing free-living energy expenditure and it is easily worn on the upper left arm (Welk et al., 2007). The SWA Pro3 does not use wired leads and is more practical for longer durations. The device uses equations based upon the multiple inputs such as the accelerometer, skin temperature sensor, galvanic skin response, and heat flux to be able to estimate energy expenditure (Welk et al., 2007). The SWA Pro3 has been shown to be accurate when measuring resting energy expenditure and when measuring energy expenditure in laboratory and free-living conditions (Barry et al., 2011; Malavolti et al., 2007; Papazoglou et al., 2006). The use of the SWA Pro3 can be helpful in adults to identify the total amount of energy expenditure that is taking place throughout the day and to assess if energy expended changes following an exercise intervention.

The SenseWear Mini Armband (SWA mini; BodyMedia Inc., Pittsburgh, PA) has also been validated to assess energy expenditure under free-living conditions. It is similar to the SWA Pro3 but it is smaller and thinner (Johannsen et al., 2010). The SWA mini also includes a three-axis accelerometer instead of a two-axis model that is used in the SWA Pro3. In a research study performed by Johannsen et al. (2010), researchers investigated the accuracy of the SWA mini versus the SWA Pro3 in adults under free-living conditions. A total of 30 adults ranging in age from 24 to 60 years old participated in the study. The participants were instructed to wear the devices for a total of 14 days, including while they were sleeping, and were asked to remove the devices while showering or performing any water-based activity (Johannsen et al., 2010). The participants maintained a log of the times when the activity monitor was not being worn. During the 14 day data collection period, the participants also underwent a doubly labeled water technique. The doubly labeled water technique was used to provide a criterion measure of total energy expenditure. At the conclusion of the 14 weeks, all data from both the SWA Pro3 and the SWA mini were evaluated to determine energy expenditure versus the doubly labeled water technique. The SWA Pro3 estimated energy expenditure within 112 kcal per day and the SWA mini was within 22 kcal per day of the doubly labeled water technique. Additionally, the absolute error rate for the two monitors was similar. Therefore, the SWA mini is an effective measurement tool for determining energy expenditure in adults in a free-living environment.

The use of a device to measure energy expenditure can be useful in combination with aerobic exercise to determine the amount of energy that is being expended by a group of adults. Performing aerobic exercise increases the amount of calories expended while exercising but it is also important to determine the amount of caloric expenditure taking place outside of the time where exercise is being performed. A study performed by Healey et al. (2007) investigated the effects of an aerobic exercise program on caloric expenditure in adults with type 2 diabetes. Performing aerobic exercise helps to reduce the amount of time that adults are sedentary. However, the total amount of time and energy that is being spent while a person is performing aerobic exercise is less compared to the amount of time spent in non-exercise activity (Hamilton, Hamilton, & Zderic, 2007).

Healy et al. (2007) investigated the amount of energy expenditure by 169 middle-aged Australian adults with type 2 diabetes using an accelerometer. An accelerometer (ActiGraph model 7164; ActiGraph, Pensacola, FL) was worn by each of the participants for all waking hours during a 7 day time period. The information provided from the accelerometers was then divided up into time spent in non-exercise activity, low-intensity level of exercise, and moderate to vigorous levels of exercise. The amount of time spent in low-intensity and non-exercise activity was positively related to waist circumference and a variety of metabolic risk factors. The adults in the study who performed at least a low-intensity level of exercise had a strong inverse relationship with their glucose concentration compared to those adults that spent a majority of their time in low levels of energy expenditure. The study showed that increasing the amount of physical activity performed and the amount of energy that is expended can be beneficial in lowering blood glucose values in adults with type 2 diabetes.

Caloric expenditure and exercise summary. An increase in caloric expenditure is linked to better glycemic control in adults with type 2 diabetes (Sigal et al., 2007). Whether it is through an exercise program or increasing the amount of physical activity that is performed during normal free-living conditions, increasing daily caloric expenditure has positive benefits on health-related fitness in adults (Cuff et al., 2003). Calorimetry is the technique used to evaluate energy expenditure at varying levels of physical activity (Ainsworth et al., 2011; Jakicic et al., 2004). Indirect and direct calorimetry are the two methods used to properly assess energy expenditure. Using indirect methods of calorimetry, such as the SWA mini allows for a determination of daily caloric expenditure.

The SWA uses equations based upon the multiple inputs such as the accelerometer, skin temperature sensor, galvanic skin response, and heat flux to estimate energy expenditure (Welk et al., 2007) The SWA has been shown to be accurate when measuring resting energy expenditure and when measuring energy expenditure in adults during both laboratory and free-living conditions (Barry et al., 2011; Malavolti et al., 2007; Papazoglou et al., 2006). This assessment tool can be applicable in identifying the amount of caloric expenditure in adults with type 2 diabetes and to track the effectiveness of an exercise program. One type of training that can be tracked with the SWA and is important for adults with type 2 diabetes is resistance training.

Resistance exercise. Another form of exercise which is recommended by the ACSM and the ADA is resistance exercise. Resistance exercise should be performed at least two times a week on non-consecutive days (Albright et al., 2000; Sigal, Kenny, Wasserman, & Castaneda-Sceppa, 2004; Sigal, Kenny, Wasserman, Castaneda-Sceppa, & White, 2006) and it is ideal for a person with type 2 diabetes to perform resistance exercise 3 days a week (Dustan et al., 2002; Snowling & Hopkins, 2006).

The level of intensity that a person with type 2 diabetes should perform resistance exercise should be either moderate (50% of 1RM) or vigorous (75-80% of 1-RM). Performing resistance activities at a moderate or vigorous level allows for a person to achieve both optimal strength gains and improvement in insulin action (Albright et al., 2000; Sigal et al., 2004; Sigal et al., 2006). It has also been shown that supervised resistance exercise programs are better than home-based programs for maintaining effective blood glycemic control (Dunstan et al., 2002).

According to the joint position statement written by Colberg et al. (2010), adults with type 2 diabetes should partake in resistance exercise training sessions that include at least 5-10 exercises involving the major muscle groups. A resistance training program should focus on the lower body, upper body, and the core. Adults should perform 10-15 repetitions at 50% of 1RM to near fatigue per set and progress to increased resistances at a range of 75-80% of their 1RM that can be lifted 8-10 times (Colberg et al., 2010). A goal of at least three to four sets per exercise is recommended to obtain strength gains. Research performed by Dunstan et al. (2002) and Willey and Singh (2003) showed that the use of machines and free weights resulted in gains in strength and mass of the targeted muscle groups and that heavier resistances may have to be used by a person to obtain optimization of insulin action and blood glycemic control in adults with type 2 diabetes. The necessity for a person with type 2 diabetes to perform resistance exercises is not only stated by the joint position statement by Colberg et al. (2010), but it also supported in the research studies investigating the benefits of resistance exercise (Dunstan et al., 2002; Willey & Singh, 2003).

Some adults that have type 2 diabetes might not be able to perform aerobic exercise and hence resistance training may be a viable option (Evans, 1992). Dunstan et al. (1998) investigated the effect of a short-term circuit weight training program in adults with type 2 diabetes. The study involved 27 untrained males and females with type 2 diabetes with a mean age of 51 years. The participants were randomized into a circuit weight training group or a control group. The circuit weight training group performed resistance training 3 times a week on non-consecutive days and performed the following exercises: leg extensions, bench press, leg curls, dumbbell biceps curls, behind neck pull-downs, calf raises, dumbbell overhead press, seated rowing, forearm extension, and abdominal curls (Dunstan et al., 1998). The participants initially completed 2 sets (10-15 repetitions) of the circuit at a level of intensity that was 50-55% of their 1RM for each exercise. After the first 2 weeks of the study, the participants performed a total of 3 sets of the circuit. The same number of repetitions was performed (Dunstan et al., 1998). The training program lasted around 60 minutes per exercise session and the total duration of the study was 8 weeks. Following the short-term resistance circuit style workout, the participants had significant improvements in both glucose and insulin levels. The results indicate that a short resistance training program can be a beneficial lifestyle option in the treatment of type 2 diabetes (Dunstan et al., 1998).

Similar to the research performed by Dunstan et al. (1998), Baldi and Snowling (2003) also performed research on resistance exercise in adults with type 2 diabetes. Baldi and Snowling also noted that there is an issue with the ability for adults with type 2 diabetes to meet the exercise guidelines for aerobic exercise as stated by the ADA (2002) and investigated resistance exercise as an alternative. The investigators performed a study involving 18 men with type 2 diabetes that had an average age of 47.9 years (Baldi et al., 2003). Participants in the study were randomly assigned to a 10 week resistance training program or a control group. The resistance training protocol involved the participants performing 3 days of a combined upper and lower body program (10 exercises) performed on non-consecutive days.

The participants were instructed to use the maximal amount of resistance for each exercise that allowed them to complete 10 repetitions for each upper body exercise and 15 repetitions for each lower body exercise. A 60-second rest interval was taken by each participant between exercises. The first 2 weeks of the program involved the participants performing only one set of each exercise per session and this was increased for week 3-10 of the study (Baldi et al., 2003). Following the 10 weeks, the participants in the resistance training group had significantly lower fasting glucose and insulin levels. The resistance training participants also showed decreases in HbA1c following training (Baldi et al., 2003). Following the resistance training protocol, participants also had a significant increase in lean body mass and did not have an increase in fat mass. Overall muscular strength and endurance increased by 25 to 52% in the resistance training group and did not change in the control group. The findings of the study by Baldi and Snowling showed that resistance training is an appropriate form of exercise for improving glycemic control and insulin levels among adults with type 2 diabetes.

Dunstan et al. (2002) investigated the effects of a high-intensity resistance training protocol in patients with type 2 diabetes. The study involved a sample of 36 sedentary men and women. The participants underwent a high-intensity, progressive resistance training program or a control protocol. Participants performed the resistance training program 3 days a week on non-consecutive days of the week. The exercise routine consisted of a 5 minute warm-up, 45 minute dynamic high intensity concentric and eccentric based resistance exercise, and a 5 minute cool-down (Dunstan et al., 2002). The first 2 weeks of the study involved the participants working at 50-60% of their 1RM to obtain the proper intensity of the workout. Participants used free weights and weight machines to perform a total of nine exercises: bench press, leg extension, upright row, lateral pull-down, standing leg curls, seated shoulder press, seated bicep curls, abdominal curls, and tricep kickbacks (Dunstan et al., 2002). A total of three sets of 8-10 repetitions were performed throughout the duration of the study. After the first 2 weeks, the intensity was increased so that each participant was using a resistance that was between 75 and 85% of his or her 1RM. The study lasted 6 months, but measurements were also taken after 3 months. Compared to the control group, the older adults that underwent high-intensity resistance exercise had significantly improved glycemic control and lean body mass after 3 months (Dunstan et al., 2002). Therefore, the results of the study showed that compared to a control group performing resistance exercises in older adults leads to improved glycemic control, improved muscular strength, and lean body mass in older adults with type 2 diabetes. The use of resistance exercise can be a feasible and effective treatment of type 2 diabetes (Dunstan et al., 2002).

The joint position statement on exercise written by Colberg and colleagues (2010) recommended that resistance exercise programs be performed at least two times a week on non-consecutive days. If possible, a person with type 2 diabetes should perform 3 days of resistance training a week, but this may be difficult due to the comorbidities associated with type 2 diabetes. The level of intensity of the resistance training program should be at least a moderate level (50% 1RM), however, research has shown that a higher intensity (75-80% 1RM) is optimal for strength gains and improved insulin action. An adult with type 2 diabetes should perform 5-10 resistance training exercises that include the major muscle groups of the body. A total of 10-15 repetitions should be lifted per muscle group and a total of 3 to 4 sets of each exercise should be completed per resistance training workout session (Colberg et al., 2010).

Resistance exercise summary. The benefits of performing resistance training at least 2-3 days per week are the improvement in glycemic control and the increase in lean body mass. A regularly performed moderate to high level intensity resistance training program has also been shown to improve insulin action in adults with type 2 diabetes (Dunstan et al., 1998; Dunstan et al., 2002; Baldi et al., 2003). The study by Dunstan et al. (1998) showed that significant changes in glycemic control can occur in less than 8 weeks in a short-term weight training program. Circuit training is a form of resistance training with a potential aerobic component, and added benefits in glycemic control lead to additional research with this type of exercise in adults with type 2 diabetes.

Circuit training. Circuit training is a resistance-based activity that utilizes a set of resistance exercises with an aerobic component (Kang et al., 2009). This can be accomplished through a short rest time between differing exercises and/or including aerobic exercise as one of the exercises in the circuit. The results of previous studies, such as Dunstan et al. (2002), helped to guide the idea of using circuit resistance exercise in the treatment of type 2 diabetes. Kang et al. (2009) investigated a circuit resistance exercise program as compared to a walking exercise program in adults with type 2 diabetes. The participants in the study consisted of 15 post-menopausal, Korean females with type 2 diabetes. The participants were in the circuit training exercise group or the walking exercise group, both which exercised for a total of 12 weeks. The walking exercise protocol consisted of 1 hour of walking at an intensity of 60% of the participants' heart rate reserve, three times per week. The circuit exercise protocol consisted of stair climbing, stationary cycling, and both upper and lower body resistance exercises. A total of 12 repetitions of each exercise was completed at an intensity of 60% of heart rate reserve and was also performed for a duration of 1 hour, 3 times per week.

Participants in the circuit resistance exercise group had significant decreases in body mass and percentage of body fat following the 12 weeks of training (Kang et al., 2009). Also, there was a significant increase in the amount of lean muscle mass as compared to pre-intervention testing in the circuit resistance exercise group. Participation in the circuit-resistance training program also lead to an increase in $VO_{2\ max}$ compared to pre-experimental data (Kang et al., 2009). As opposed to the walking exercise group, those participants who were involved in the circuit resistance training group had a significantly greater decrease in percent body fat, but not in overall body mass. The circuit resistance group had a significant drop in HbA1c, as compared to the walking exercise group.

The results of the study indicate that a circuit-based resistance training program is as effective as a traditional aerobic exercise program in improving glycemic control and body composition (Kang et al., 2009). The results of the study indicated that the improvement in glycemic control and decrease in insulin resistance are due to the increase in the amount of lean muscle mass and decrease in adipose tissue. Additionally, the results of the study were seen from having adults with type 2 diabetes exercising only three days a week.

Circuit training summary. The circuit training studies were the first to utilize both aerobic and resistance exercise together for adults with type 2 diabetes. The aerobic component of the exercise routine has been shown to help increase caloric expenditure and increase $VO_{2\ max}$. The resistance training component has been shown to increase muscular strength and increase the amount of skeletal muscle tissue. The combination of aerobic and resistance training used in circuit training offers improvements in insulin resistance and glycemic control in adults with type 2 diabetes. Thus, these findings lead to further research on the potential added benefit to adults with type 2 diabetes performing both aerobic and resistance exercise.

Combination of aerobic and resistance exercise. The use of both aerobic and resistance training is recommended by the joint position statement on exercise for adults with type 2 diabetes (Colberg et al., 2010). The combination of the two types of exercise performed 3 times a week may result in better glycemic control compared to performing aerobic or resistance training alone (Sigal et al., 2007).

One of the first ground-breaking studies to investigate an effective exercise modality for adults with type 2 diabetes was performed by Cuff et al. (2003). The researchers aimed to investigate the effects of a combined aerobic and resistance training program compared to a program that only consisted of an aerobic training component. The participants were 28 post-menopausal, obese women with type 2 diabetes (Cuff et al., 2003). All of the participant's that met the inclusion criteria were randomly assigned to a control group, an aerobic component group, or a group that performed both aerobic and resistance exercise.

The aerobic exercise protocol consisted of 75 minutes of low-intensity supervised aerobic exercise performed three times a week (Cuff et al., 2003). The aerobic and resistance protocol consisted of an exercise class that included both a resistance and aerobic portion that lasted 75 minutes. The aerobic component was performed at an intensity of 60-75% of heart rate reserve and included a variety of different modes of exercise (elliptical, stationary bicycle, and treadmill). The resistance component was comprised of 5 different exercises (leg curl, leg press, hip extension, chest press, and latissimus pull downs) and the participants performed 12 repetitions and 2 sets of each exercise (Cuff et al., 2003). The researchers investigated the effect of different exercise interventions on insulin sensitivity, abdominal adipose tissue, and muscle cross-sectional area following the 16-week treatment program.

The first major finding of the study was that the group that performed the combination of aerobic and resistance exercise was the only group to have a significant change in glucose infusion rates following the training protocol (Cuff et al., 2003). Both exercise groups did have a significant reduction in abdominal fat, subcutaneous fat, and visceral fat as compared to the sedentary control group. However, the aerobic and resistance training group showed a significantly greater increase in muscle cross-sectional area compared to the aerobic training group. The amount of improvement in glucose disposal was also independently associated with the reduction in subcutaneous fat, visceral fat, and muscle cross-sectional area. Adding a resistance component to an aerobic exercise protocol resulted in an increased level of glucose disposal in women with type 2 diabetes. Furthermore, the increase in insulin sensitivity was due to a combination of both a decrease in fat mass and an increase in the amount of muscle cross-sectional area (Cuff et al., 2003).

Another research study that explored the effects of a combination of resistance and aerobic exercise on glycemic control in adults with type 2 diabetes was performed by Sigal et al. (2007). This study was done in community-based facilities and involved a larger participant population as opposed to the study done by Cuff et al. (2003). The randomized-controlled trial performed by Sigal et al. involved 251 adults with type 2 diabetes ranging in age from 39 to 70 years. The participants were randomly assigned by sex and age to the control, aerobic, resistance, or a combination exercise group. The study lasted 26 weeks, but involved 22 weeks of exercise training for the adults with type 2 diabetes.

The aerobic protocol for the study performed by Sigal et al. (2007) consisted of training performed on a treadmill or a cycle ergometer 3 times a week. The aerobic training was performed for 20 minutes per session, between 60-75% of the participants' maximum heart rate. The resistance training protocol consisted of 7 different exercises performed on exercise machines. A total of 2 to 3 sets of each exercise were performed with the amount of resistance set at a weight that could be lifted 7 to 9 repetitions. The combination treatment group performed both the entire aerobic and resistance aforementioned protocols. The main outcome of the study was to detect the changes in glycemic control as noted by a change in HbA1c across the training period.

The findings of the study performed by Sigal et al. (2007) were similar to those of the study performed by Cuff et al. (2003). All three exercise protocols resulted in improvements in glycemic control. However, the combined exercise protocol resulted in a significantly increased glycemic improvement compared to the strictly one component exercise protocols. This finding was especially prominent in those participants that started with a lower HbA1c value (Sigal et al., 2007). Consequently, a combined exercise program is better for those adults with type 2 diabetes that have better glycemic control. There was no significant difference in blood pressure, total cholesterol, or triglyceride levels among the three exercise protocols. There were significant changes to body composition following the training protocols. The aerobic training group had significant decreases in both body weight and BMI as compared to the control group. Waist circumference was significantly lower in both the aerobic and resistance training groups compared to the control group (Sigal et al., 2007). The involvement in an aerobic or resistance training program also resulted in an increase in quadriceps muscle cross-sectional area. The changes that occurred in the combination of aerobic and resistance exercise did not differ between those of the aerobic and resistance only training groups (Sigal et al., 2007). Overall, all three modes of exercise were beneficial in the improvement of glycemic control and other cardiovascular comorbidities. However, the improvement in glycemic control was greatest with the combination of aerobic and resistance exercise (Sigal et al., 2007).

Following the study performed by Sigal et al. (2007), a study was performed by Marcus et al. (2008) who also looked at the effect of a combined aerobic and resistance exercise program in adults with type 2 diabetes. Marcus et al. (2008) used an eccentric resistance program at a moderate level of intensity determined by the rate of perceived exertion by each participant. The comparison of a combination exercise treatment to an aerobic exercise protocol involved 15 middle-aged adults and lasted 16 weeks. All participants had type 2 diabetes and were randomly assigned into the aerobic or combination exercise groups.

The aerobic protocol in the study performed by Marcus et al. (2008) consisted of 3 days a week of aerobic exercise for 50 minutes. The participants were able to use a variety of aerobic equipment and exercised at an intensity between 60-85% of their aged-predicted max heart rate. The combination resistance and aerobic program consisted of the participants performing the above mentioned aerobic program as well as 20 minutes of resistance exercise on a recumbent eccentric stepper. The recumbent stepper involved eccentric contractions of both the knee and hip extensor muscles. The target intensity for the eccentric exercise was one that would elicit a “somewhat-hard” rating of perceived exertion. The outcome measures for the study included HbA1c, BMI, 6-minute walk for distance, and the amount of thigh lean muscle tissue.

Both the aerobic and combination exercise treatments resulted in significant changes in the amount of HbA1c as compared to pre-intervention results (Marcus et al., 2008). However, there was no significant difference between the two exercise protocols.

The use of the eccentric combination exercise protocol did result in a greater increase in the amount of lean muscle tissue (determined using magnetic resonance imaging) in the thigh compared to the aerobic exercise protocol. The aerobic and resistance training group had a greater decrease in BMI as compared to the aerobic exercise participants (Marcus et al., 2008). Nonetheless, there are further benefits to the amount of lean muscle tissue in the thigh and decreases in BMI in those individuals who perform a combination of aerobic and eccentric resistance exercise (Marcus et al., 2008). This is important because the increase in skeletal muscle tissue could result in increased resting metabolic rate, exercise tolerance, and the amount of functional mobility in adults that have type 2 diabetes (Marcus et al., 2008). Therefore, both the aerobic and combination treatment were beneficial in the improvement of glycemic control and physical performance measures following the 16-weeks of supervised training.

Balducci et al. (2012) continued this line of research into the effectiveness of a combination of aerobic and resistance exercise by investigating the effects of different intensity programs. Balducci et al. investigated the effects of a moderate to high intensity program versus a low to moderate intensity aerobic and resistance program on risk factors in adults with type 2 diabetes. The study involved 303 sedentary adults with type 2 diabetes that were living in Italy. The participants were randomly assigned to either a low to moderate combination exercise program or a moderate to high intensity combination exercise program. The intensity of the resistance training program for both groups was the same. The only difference between the low to moderate intensity group and the moderate to high intensity group was the intensity of the aerobic component. Both exercise protocols involved the participants exercising 2 days a week for 12 months.

The main outcome measures for the study were HbA1c, fasting blood glucose, modifiable cardiovascular risk factors, and quality of life (Balducci et al., 2012).

The participants in the low to moderate intensity group performed aerobic training at 55% of their $VO_{2\ max}$ and resistance training at an intensity of 60% of their predicted 1RM (Balducci et al., 2012). The moderate to high intensity exercise protocol consisted of the participants performing aerobic training at 70% of their $VO_{2\ max}$ and resistance exercises that were equivalent to 60% of their predicted 1RM. The total duration of the aerobic training and the number of sets of resistance training were varied to make sure that the same amount of caloric expenditure per kg of body mass was obtained between the low to moderate combination exercise group and the moderate to high combination exercise group (Balducci et al., 2012).

The main outcome of the study by Balducci et al. (2012) was the change in HbA1c following the exercise protocols. Both groups showed a decrease in HbA1c but the deductions in the moderate to high intensity group were larger compared to the low to moderate intensity group. Both the low to moderate group and the moderate to high intensity groups showed significant changes in high-density lipoproteins (HDL), low-density lipoproteins (LDL), and systolic blood pressure (Balducci et al., 2012), with larger significant differences in the moderate to high intensity group for total cholesterol and triglyceride levels.

In addition to the changes in cardiovascular risk factors and glycemic control, the number of adverse events was not increased by being in the moderate to high intensity exercise group compared to the low to moderate intensity exercise group. The overall findings of the study by Balducci et al. (2012) indicated that although there was a slight improvement in cardiovascular risk factors (fasting blood glucose, serum insulin, waist circumference, body mass index, HDL, and LDL), the fact that they were not large significant differences, indicates that performing a moderate to high intensity combined exercise protocol does not provide significant incremental benefits to CVD risk factors compared to a low to moderate intensity exercise protocol in adults with type 2 diabetes (Balducci et al., 2012). Performing a moderate to high level intensity aerobic component as part of a combined aerobic and resistance exercise protocol does provide a significant improvement in HbA1c, total cholesterol, and triglyceride levels in adults with type 2 diabetes. The significant improvements in glycemic control from a moderate to high intensity combination exercise protocol support the idea of adults with type 2 diabetes performing exercise above moderate intensity levels to obtain optimal glycemic control results.

An increase in the number of studies involving exercise in adults with type 2 diabetes resulted in a meta-analysis by Snowling and Hopkins (2006). The meta-analysis included 27 articles that examined the effects of aerobic training (16 studies), resistance training (6 studies), and a combination of both treatments (5 studies) on adults with type 2 diabetes. All three forms of exercise showed a small and beneficial reduction in HbA1c (mean reduction of 0.8%) following training (Snowling & Hopkins, 2006). There was also a small decrease in plasma glucose (mean reduction of 1.5 mmol/l) levels following all three forms of training. Overall, there was a small added benefit in glycemic control and in other CVD risk factors in the studies that included a combination of aerobic and resistance training. The reductions in HbA1c were similar to the reductions seen with dietary, drug, and insulin treatment (Snowling & Hopkins, 2006). The added benefit of performing a combination exercise treatment should be further investigated for use in adults with type 2 diabetes.

Combination of aerobic and resistance exercise summary. If a combination of resistance and aerobic exercise can be performed three times a week it can result in greater glycemic control in adults with type 2 diabetes, according to the position statement on exercise by Colberg et al. (2010). Performing both aerobic and resistance training has been shown to be more effective in glycemic control compared to an aerobic or resistance based program. Studies have shown that a combination exercise program is more effective in increasing glucose disposal, muscle cross-sectional area, and insulin sensitivity in adults with type 2 diabetes (Cuff et al., 2003; Marcus et al., 2008; Sigal et al., 2007). A combination treatment also results in a significant reduction in subcutaneous fat, body weight, and BMI (Cuff et al., 2003; Marcus et al., 2008). The study by Balducci et al. (2012) also examined the effect of the intensity of the combination exercise program. A high intensity combination treatment is the most effective for glycemic control in adults with type 2 diabetes. Therefore, a combination of resistance and aerobic exercise results in greater improvements in glycemic control and reduction in CVD risk factors compared to performing aerobic or resistance training programs in isolation.

Exercise research summary. In addition to improvements in glycemic control from performing exercise (Loimaala et al., 2009; Maiorana et al., 2002; Sigal et al., 2007), exercise has been shown to have additional benefits in adults with type 2 diabetes. Adults with type 2 diabetes that perform exercise have been shown to have improved aerobic capacity-$VO_{2\ max}$ or $VO_{2\ peak}$ (Cauza et al., 2005; Larose et al., 2010; Loimaala et al., 2009; Maiorana et al., 2002), body composition (Sigal et al., 2007), lipid profiles (Cauza et al., 2005;Dunstan et al., 1998), and skeletal muscle function (Cauza et al., 2005; Larose et al., 2010). Performing aerobic exercise has also been beneficial in lowering the amount of sedentary time that adults participate in on a daily basis. Being involved in aerobic exercise also helps to increase energy expenditure and lessen the comorbidities associated with type 2 diabetes.

One way to assess caloric expenditure from both daily activities and from exercise is the use of direct and indirect calorimetry. Direct measures of calorimetry can be expensive and require technicians with extensive training (Battley, 1995). The use of indirect measures, such as the SWA, incorporate equations and other measures to assess overall energy expenditure. The SWA can be worn by adults during free living conditions and in a laboratory setting. The use of a SWA allows for an accurate and less expensive monitoring system of the effectiveness of a workout program and the effects it is having on the amount of physical activity being performed outside of the laboratory (Barry et al., 2011; Healey et al., 2007; Malavolti et al., 2007; Papazoglou et al., 2006).

In addition to the importance of aerobic exercise and caloric expenditure for adults with type 2 diabetes, resistance training has also been to shown to be an effective mode of exercise. Performing resistance exercise in adults with type 2 diabetes has been linked to an increase in muscle force and in skeletal muscle size (Cauza et al., 2005). Interventions featuring resistance-type exercises have also been shown to lower HbA1c, enhance insulin sensitivity, and improve skeletal muscle mass in adults with type 2 diabetes, thus increasing whole-body glucose-disposal capacity. Moreover, gains in muscle strength in adults with type 2 diabetes enable activities of daily living to be performed with less relative physical strain (Praet & VanLoon, 2007). Overall, both aerobic and resistance exercise have been shown to increase glycemic control and insulin sensitivity in adults with type 2 diabetes (Cauza et al., 2005; Holten et al., 2004).

A combination of both aerobic and resistance exercise modalities has also been shown to have positive outcomes on adults with type 2 diabetes (Larose et al., 2010; Loimaala et al., 2009; Maiorana et al., 2002). Circuit training is one form of exercise that has been suggested to be performed by adults with type 2 diabetes because it incorporates both aerobic and resistance exercise (Jones et al., 2009). The performance of a combined aerobic and resistance program has been shown to lead to significant decreases in HbA1c compared to aerobic or resistance only training programs (Sigal et al., 2007).

However, despite the crucial role of regular physical activity in the optimal management of diabetes, more than 36% of persons with type 2 diabetes do not engage in regular physical activity and an additional 38% report less than recommended levels of physical activity (American Association of Diabetes Educators, 2012). This may be due to the fact that performing these types of exercise programs could potentially lead to an increase in overuse injuries, especially among individuals who are relatively sedentary, overweight, display low exercise capacity, or experience musculoskeletal pain while participating in traditional forms of aerobic exercise and strength training (ACSM, 2014). As a result, additional forms of exercise need to be investigated so that adults with type 2 diabetes can perform a combination of aerobic and resistance training in a safe environment.

Aquatic Exercise and Type 2 Diabetes

Due to the comorbidities associated with type 2 diabetes, performing exercise on land and being fully weight-bearing is difficult. More than half of the adults with type 2 diabetes have neuropathies that cause weakness in the extremities and make it difficult to exercise on land (ADA, 2013). Aquatic exercise is a low-impact, aerobic exercise usually suggested by physicians for adults with type 2 diabetes. According to the WHO (2003), 90% of adults with type 2 diabetes are obese or overweight. A low-impact, aquatic exercise program is a safe environment where a moderate level of aerobic exercise can be performed.

An aquatic environment allows adults who have type 2 diabetes to partake in exercise while reducing the amount of ground reaction forces (GRF) and stress that is being placed on the load bearing joints (Takeshima et al., 2002). Furthermore, research on aquatic-based exercise has shown to be successful in maintaining and/or improving both cardiovascular fitness and strength in differing populations such as those who have had a cerebrovascular accident, have osteoarthritis, or have heart failure (Chu et al., 2004; Takeshima et al., 2002). Studies on healthy adults and adults with orthopedic complications and neuromuscular disease have demonstrated that aquatic exercise increases lower-body flexibility, postural balance, aerobic fitness, quality of life, and produces equivalent or superior responses in metabolic cost, pain reduction, and improves body composition, leg strength, and flexibility when compared to land exercise (Denning, Bressel, & Dolny, 2010; Hall et al., 2004; Hinman, Heywood, & Day, 2007; Silvers, Rutledge, & Dolny, 2007).

Jones et al. (2009) examined the effect of using a moderate-high intensity aquatic circuit exercise program in overweight women with normal glucose tolerance or with impaired glucose tolerance. The study involved the women performing a water-based circuit program, 3 days per week, at an intensity of 70-75% maximum heart rate. The program utilized a moderate-high intensity level of exercise because improvements in insulin sensitivity have been shown with this level of exercise (O'Donovan et al., 2005). Also, the idea of having overweight individuals work at an intensity level below vigorous exercise could also result in higher levels of exercise adherence and enjoyment (Lind, Joens-Matre, & Ekkekakis, 2005). The results of the study by Jones et al.(2009) showed that an aquatic based exercise program utilizing both aerobic and resistance type exercises reduced fasting insulin levels by 44% and also decreased 2-hour glucose by 30.4% in the participants with impaired glucose tolerance. The findings of the study also showed a decrease in weight circumference by 5.3%. Thus, an aquatics based aerobic and resistance program can improve both insulin and glucose response in women that have impaired glucose tolerance. One method of having adults perform a combination of resistance and aerobic exercise is to have them exercise on an underwater treadmill.

Underwater treadmill training. One useful and effective means of aquatic exercise is walking in water (Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2004). Walking is commonly prescribed by physicians for individuals who are overweight and obese because of its practicality and convenience compared to other activities (Alkurdi et al., 2010). The practicality of walking on land may be questionable because the stress placed on the lower extremities from biomechanical loading may lead to the development of osteoarthritis (Griffin & Guilak, 2005). However, walking in the water allows for a reduction in the impact force that is placed upon the lower limb joints. The amount of force that is experienced by the person walking in the water can be altered by changing the height of the water (Miyoshi et al., 2004). The need for the reduction in the GRF's is necessary for adults with type 2 diabetes because of the higher prevalence of being overweight or obese in this population (ADA, 2010). Additionally, the increased incidence of osteoarthritis and other comorbidities associated with having type 2 diabetes causes an increased amount of pain and discomfort with traditional exercise treatments. The results of a study performed by the Center for Disease Control (CDC, 2011) indicated that almost half of the adults with type 2 diabetes had also been diagnosed with arthritis. Adults with diabetes and arthritis also had a higher amount of self-reported physical inactivity. Arthritis and other complications from type 2 diabetes can be a barrier to performing physical activity (CDC, 2011).

The use of an underwater treadmill walking program is also an effective exercise treatment because it combines the aerobic portion of walking with the added resistance of moving the limbs through the water (Alkurdi et al., 2010). It appears that the optimal method of exercise for adults with type 2 diabetes in regards to improving glycemic control is one that involves a combination of aerobic and resistance exercise (Sigal et al., 2007). However, due to the low fitness levels and comorbidities associated with type 2 diabetes, people that have the metabolic disease have problems meeting the exercise guidelines listed in the position statement by Colberg et al. (2010). The added resistance when walking in an underwater treadmill takes a traditional aerobic component and makes it into a simultaneous combined aerobic mode of exercise and converts it to a combined aerobic and resistance exercise program.

Nakazawa, Yamamoto, and Yano (1994) showed that the buoyancy of water helps to decrease the amount of vertical GRF's that are placed on an individual while the participant is walking in water. Also, due to the viscosity of the water, an individual walking in the water must use more propulsion force compared to walking on dry land (Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2004). As a result of the increased propulsion forced needed to walk in the water, lower limb extensor muscles must also increase their activity relative to other leg muscles (Miyoshi, Sato, Nakazawa, Komeda, & Yano, 2000; Nakazawa et al., 1994).

Another factor that can influence whether a person adheres to a walking exercise program is the relative effort required to complete the program (Alkurdi et al., 2010). A person who is overweight/obese could spend up to 35% more energy when walking compared to a person that is of normal weight (Browning & Kram, 2005). The added metabolic cost places an overweight individual at a greater percentage of his or her aerobic capacity while walking compared to an individual who is not overweight or obese. Due to these complications, walking in an aquatic environment would be beneficial for an individual who is obese or overweight, such as is often the case in individuals with type 2 diabetes.

The use of a treadmill submerged in a self-contained tank allows for the precise control of walking speed, water depth, and water temperature, a trio of features which can markedly influence training responses. The enhanced level of body weight support supplied by the buoyant effect of water creates a more comfortable and realistic unloading of weight than that provided by typical harness unweighting systems which feature point-specific unloading (Bocalini et al., 2008; Harrison, Hillman, & Bulstrode, 1992; Noh, Lim, Shin, & Paik, 2008). This form of exercise is popular among therapists and patients because it also causes a decrease in the amount of pain during exercise, due to the reduction in vertical GRF (Alkurdi et al., 2010).

The height of the water will determine the reduction in the overall amount of GRF's and therefore, can be used to accommodate someone who is overweight or obese. Research studies performed by Gleim and Nicholas (1998) and Pohl and McNaughton (2003), showed that as water height was decreased from the waist to the ankle, a higher aerobic capacity and heart rate were required. Alkurdi et al. (2010) showed that walking in an underwater treadmill with the water height 10 cm below the xiphiod process resulted in higher energy expenditure and heart rate compared to having the water at a level of the xiphoid process. Also, rate of perceived exertion was higher when the participants walked with the level of water 10 cm below the xiphoid process compared to the water being at the xiphoid process. The changes that are seen with having the water level 10 cm below the xiphoid process are due to the relationship between drag resistance and buoyancy of water (Alkurdi et al., 2010). By having the water 10 cm below the xiphoid process it causes a resistant drag force to be applied to the arms while they swing in the enclosed aquatic environment. The increased resistive drag force causes there to be an increase in the amount of energy expenditure that occurs while walking in an underwater treadmill and makes it similar to walking on a land treadmill, even though walking in an underwater treadmill usually has a lower stride cadence compared to land treadmill use (Alkurdi et al., 2010).

Another benefit of performing underwater treadmill training is the increase in stroke volume and cardiac output. A person that is in the self-contained unit experiences higher cardiac output due to the increase in stroke volume. The increase in stroke volume occurs because of the increased central blood volume due to the increased pressure on the chest and thoracic cavity from the water (Christie, Sheldahl, & Tristani, 1990). A decrease in heart rate (upwards of 8 bpm) is also seen in underwater treadmill walking because of the increase in the stroke volume (Farhi & Linnarsson, 1977).

The speed at which a person walks in an underwater treadmill also has an effect on the intensity of the walking program. Walking at faster speeds on both dry land and in an aquatic environment, results in higher levels of caloric expenditure in adults (Denning et al., 2010). Denning et al. (2010) showed in a study with adults with osteoarthritis that walking at speeds in an underwater treadmill above 0.97 m/s resulted in increased limb velocities and fluid resistance from the water. As a result, the energy expenditure was slightly higher as compared to walking on land at the same speed. This is due to the fact that usually walking below 0.97 m/s causes for lower energy expenditure in water because the fluid resistance of the water is low due to low limb velocities. The person walking in the underwater treadmill with the water level set at the xiphoid process is being dominated by the buoyancy of the water and less energy is expended compared to walking on dry land at that speed. Thus, the walking program should be at a speed above 0.97 m/s in adults with type 2 diabetes.

Another benefit of performing underwater treadmill training is that the temperature of the water can be manipulated. Exercise is needed to be performed by adults with type 2 diabetes, but muscle soreness is a common problem in this population (Petrofsky et al., 2011). Soreness is traditionally higher and it takes a longer period of time for an adult with type 2 diabetes to recover because of the impaired blood flow and reduced endothelial function, compared to an adult that does not have diabetes (Petrofsky et al., 2011). One of the common strategies used to treat muscle soreness in adults with type 2 diabetes is heat. The use of moist heat treatment allows for better heat penetration and greater blood flow compared to the use of dry heat (Cheung, Hume, & Maxwell, 2003). Having adults with type 2 diabetes exercise in an underwater treadmill above the thermoneutral level of 29 degrees Celsius can help improve blood flow and also provide therapeutic benefits in regards to pain.

Underwater treadmill training summary. The added buoyancy of the water helps to compromise the traditional problems seen with energy expenditure in adults with higher BMI's. Underwater treadmill training might be beneficial for overweight adults, obese adults, or adults that have other common comorbidities associated with type 2 diabetes. Other advantages of walking on an underwater treadmill include generation of muscle activity and gait patterns similar to those seen in over ground walking, enhanced cardiovascular function due to the hydrostatic pressure of water, and increased leg strength caused by overcoming water resistance and turbulence (Bryne, Craig, & Wimore, 1996; Chu & Rhodes, 2001).

Literature Review Conclusion

There is substantial evidence to show that type 2 diabetes is not only becoming an international epidemic but also having a large effect in the United States of America (Boyle et al., 2010; Fu et al., 2010). Type 2 diabetes is continuing to affect people of all age groups and there are no sex difference in regards to the prevalence of this metabolic disorder (Castaneda et al., 2002). The pathogenesis of type 2 diabetes has been linked to genetic and environmental components (Hamman, 1992). Impairment of the pancreatic

B-cells, becoming resistant to the insulin that is being produced in the body, and abnormalities that exist in the insulin signaling pathways in skeletal muscle tissue and adipose tissue are potential causes of type 2 diabetes (Barr et al., 2008; Osteonson, 2001).

An individual that has type 2 diabetes is also at a higher risk of microvascular and macrovascular diseases (Barr et al., 2008). This could result in a person with type 2 diabetes developing renal disease, neuropathies, blindness, and even hemorrhaging of blood vessels (National Diabetes Fact Sheet, 2011). In addition to the health complications, there are also economic complications associated with type 2 diabetes. A person that has type 2 diabetes will generally have higher medical expense over a years' time compared to someone that does not have diabetes (National Diabetes Fact Sheet, 2011). Due to the large burden that this disease is having on the United States health care system and on the individuals that have the disease, effective treatment options for the disease are necessary.

Type 2 diabetes can be managed through a 3-sided treatment plan of proper nutrition, medication, and exercise. The use of exercise to treat type 2 diabetes is becoming a more popular option because it is cost-effective and doesn't have the negative side effects seen with traditional pharmacological treatments of the disease (Boule et al., 2001). It appears that the optimal method of exercise for adults with type 2 diabetes in regards to improving glycemic control is one that involves a combination of aerobic and resistance exercise (Sigal et al., 2007). However, due to the low fitness levels and comorbidities associated with type 2 diabetes, people that have the metabolic disease have problems meeting the exercise guidelines set by joint position statement on exercise in adults with type 2 diabetes (Colberg et al., 2010).

One way of having adults with type 2 diabetes perform a combination of aerobic and resistance training is performing exercise in an aquatic environment. Walking in an underwater treadmill allows for a person to obtain VO_2 measures similar to those seen in land-based treadmill activities, while also experiencing decreased GRF's (Alkurdi et al., 2010). As a result, the need for an aquatic treadmill walking program for adults with type 2 diabetes is justified.

CHAPTER III

UNDERWATER TREADMILL TRAINING, GLYCEMIC CONTROL, AND HEALTH-RELATED FITNESS IN ADULTS WITH TYPE 2 DIABETES

Introduction

Type 2 diabetes is a chronic disease that can lead to decreased insulin sensitivity and a reduced ability to maintain glucose control. A common diagnostic measure of diabetes is glycosylated hemoglobin (HbA1c), which reflects mean blood glucose levels over a 1- to 3-month period (Bennett, Guo, & Dharmage, 2007; Marcus et al., 2008). In adults, an HbA1c value lower than 5.7% is considered normal, whereas levels between 5.7% to 6.49% indicate prediabetes, and a value of 6.5% or higher is reflective of diabetes (Gebel, 2013). A strong correlation exists among HbA1c levels, microvascular complications, reduced glycemic control, glycation of proteins, and complications associated with type 2 diabetes (Kharroubi, Darwish, Al-Halaweh, & Khammash, 2014).

Given the health benefits of endurance exercise in reducing body weight and body fat, normalizing blood lipid profiles, and improving whole-body insulin sensitivity, lifestyle intervention programs for persons with type 2 diabetes typically incorporate aerobic training (Praet & van Loon, 2007). Factors such as muscle weakness and diminished exercise tolerance, however, can lessen participation in and adherence to aerobic activities among individuals with type 2 diabetes (Sayer et al., 2005). Interventions featuring resistance exercise have also been shown to lower HbA1c, enhance insulin sensitivity, and increase skeletal muscle mass, thereby improving glucose-disposal capacity (American College of Sports Medicine [ACSM], 2014; Dunstan et al., 2002) and enabling activities of daily living to be accomplished with less relative physical strain (Praet & van Loon, 2007). While compelling evidence exists for persons with type 2 diabetes to regularly engage in cardiorespiratory and musculoskeletal exercise, participation in a comprehensive, therapeutically-based regimen consisting of moderate-to vigorous-intensity aerobic and resistance-based activities can be difficult to sustain (Marcus et al., 2008; Praet & van Loon, 2007). Performing these commonly prescribed exercise programs could potentially lead to overuse injuries, especially among individuals who are relatively sedentary, overweight, display low exercise capacity, or experience musculoskeletal pain while engaging in traditional forms of aerobic exercise and strength training (Marcus et al., 2008). Hence, a need exists to develop and test new strategies to optimize health-producing benefits of physical activity which integrate endurance and resistance training, while enhancing program compliance and minimizing health complications (Praet & van Loon, 2007).

An innovative exercise program which has remained largely unexamined, but holds great promise in improving the metabolic health, aerobic fitness, and physical function of persons with type 2 diabetes, is underwater treadmill training (UTT). The use of a treadmill submerged in a self-contained tank allows for the precise control of walking speed, water depth, and water temperature, a trio of variables which can markedly influence aerobic and strength training responses. The partial support supplied by the buoyant effect of water also creates a more comfortable and realistic unloading of body weight than that provided by typical harness unweighting systems and can serve as an effective alternative to land-based walking programs in adults who display mobility and balance problems and lower-limb joint and muscle weakness (Bocalini, Serra, Murad, & Levy, 2008). Other advantages of walking on an underwater treadmill include generation of muscle activity and gait patterns similar to those recorded during land walking, enhanced cardiovascular function due to the hydrostatic pressure of water, and increased leg strength caused by overcoming water resistance and turbulence (Giaquinto, Ciotola, & Margutti, 2007).

Against this backdrop, we conducted an exploratory study to quantify the effects of UTT on glycemic control and selected components of health-related fitness in middle-aged men and women with type 2 diabetes. Specifically, it was hypothesized that an 8-week program of UTT would result in better control of blood glucose levels and improvements in body composition, cardiorespiratory function, and leg strength.

Methodology

Participants. Adults (2 males, 5 females; mean age = 55.3 ± 7.7 years) with type 2 diabetes volunteered to participate in this study. Participant characteristics are displayed in Table 1. Inclusion criteria for participants included confirmation of diabetes (fasting plasma glucose value of $\geq$ 126 mg/dl or current use of diabetes medications) and medical clearance from a personal physician (Castaneda et al., 2002). Eligible participants also refrained from participation in aerobic or resistance training during the 6-month period preceding UTT. Exclusion criteria included occurrence of a myocardial infarction within six months before the start of the investigation, recent changes in oral hypoglycemic medication use, and the presence of additional chronic medical conditions (e.g. respiratory disease, heart failure, renal disease, hepatic disease, myopathies, and

Table 1

Participant Characteristics

Variable	*M* (*SD*)
Mean age (years)	55.3 (7.7)
Sex (female/male)	5/2
Height (m)	1.7 (0.1)
Body mass (kg)	88.2 (14.3)
Length of diabetes diagnosis (years)	5.7 (3.1)
Number of current smokers	0
Percentage taking diabetes medications	57.0 (4)

neuropathies) that could hinder full participation in UTT. Written informed consent was obtained from all study participants prior to data collection.

Instrumentation and outcome measures.

Glycemic control. The primary measure for glycemic control was HbA1c, a measure of average blood glucose over the previous 1- to 3-month period (Marcus et al., 2008). A 10-ml venous blood sample was drawn from a forearm vein and analyzed for HbA1c using turbidimetric immunoinhibition. Diabetic medication levels for each participant were recorded by his or her primary physician and rechecked for maintenance following cessation of UTT.

Anthropometric measures. Body mass (without shoes) was measured to the nearest 0.1 kg using a Seca 869 flat digital scale (Hanover, MD) and height was determined to the nearest 0.25 cm using a Seca 217 stadiometer (Hanover, MD). A trained laboratory technician measured skinfold thickness (in duplicate) at seven upper- and lower-body with a Harpenden skinfold caliper (Model 136, West Sussex, UK). Using population-specific equations (Allison et al., 2011), average thicknesses at each anatomical location were used to calculate body fat percentage (%BF) and lean body mass. Duplicate measures of waist circumference (WC), taken as the circumference around the body at the narrowest distance between the last rib and the anterior superior iliac spine, were also obtained using a Gulick tape measure and averaged to derive mean WC. To mitigate the potential influence of nutritional influences on body composition, participants were reminded on a weekly basis to maintain their current dietary patterns.

Cardiorespiratory function. Following 5 minutes of seated rest in a quiet, dark room, resting heart rate (RHR) was determined from palpation of the radial pulse for

30 seconds and doubling the number of recorded beats (Allison et al., 2011). Duplicate measures of RHR were obtained within a 5-minute period and averaged to derive mean RHR. The rationale for measuring RHR was based on data showing that RHR is lower following endurance training in previously sedentary individuals (Carter & Blaber, 2003).

Maximal aerobic power ($VO_{2\ max}$) was estimated using a single-stage, land-based walking treadmill protocol (Ebbeling, Ward, Puleo, Widrick, & Rippe, 1991). Participants wore a Polar heart rate monitor and watch (Model FT1, Lake Success, NY) during testing. The test began with participants walking at 2 mph and 0% grade and speed was increased gradually until a heart rate of 50% to 70% of estimated maximal heart rate (220 – age) was attained. After completing this 4-min warm-up stage, treadmill grade was increased to 5% and walking speed was maintained for an additional 4 minutes. Heart rate was recorded at the end of the 8^{th} minute of exercise (including the warm-up stage) and used, along with sex, age, and treadmill speed, to predict $VO_{2\ max}$ (Ebbeling et al., 1991)

Leg strength. Concentric peak torque of the dominant leg quadriceps and hamstrings at $30°\cdot sec^{-1}$, $60°\cdot sec^{-1}$, and $90°\cdot sec^{-1}$ was assessed using a Biodex System III dynamometer (Biodex Medical Systems, Shirley, NY). The dominant leg was identified as the leg chosen to kick a ball (Zakas, 2006) and this trio of contraction velocities was chosen to reflect a range of overground walking speeds (Lanshammar & Ribom, 2011). Participants were seated in an upright position and adjustable straps were placed around the upper body and the dominant thigh to isolate the quadriceps and hamstrings and limit the amount of muscle activation in the muscle groups not being evaluated. The main fulcrum of the lever arm of the dynamometer was positioned at the lateral aspect of the knee joint axis.

Range of motion for strength testing was measured from a start position of the knee joint bent at 90° through full extension (0° flexion) and back to 90° of knee flexion. Standardized verbal encouragement was provided to each participant during testing and a total of three accommodation trials preceded quadriceps and hamstrings testing at each contraction velocity. Following the accommodation phase, participants performed three maximum voluntary efforts at each contraction velocity, with 30 seconds of rest between trials. For each muscle group and velocity condition, the highest torque measure across trials was taken as the peak torque value. Leg strength was expressed as peak torque (ft-lbs), which is considered a representative indicator of both knee flexion and extension strength (Blain et al., 2001).

Procedures.

Preparation. A week before participating in the study, participants completed the informed consent approved by the University Institutional Review Board (see Appendix A) and participated in all baseline outcome measurement testing that were listed above.

Treadmill accommodation. Prior to UTT, participants completed two pre-training accommodation walking sessions spaced 2 days apart. The treadmill accommodation sessions occurred in a therapy pool, which contained an underwater treadmill (Ferno, Wilmington, OH) and a control panel from which the treadmill was operated, a water reservoir with a water filtration system, a variable-speed motor, and two large Plexiglas windows which enabled participants to be visually monitored (see Figure 1). Water height was set at 10 cm below the xiphoid process (Alkurdi, Paul, Sadowski, & Dolny, 2010) and maintained during training. For both treadmill accommodation sessions, a Polar heart rate monitor was worn and heart rate was recorded before the session and following the first minute of walking. During each session, participants walked for 5 minutes at a speed that elicited 20% of HRR [HRR = ((age-adjusted maximal heart rate - RHR) x % intensity desired) + RHR].

Exercise intervention. Participants completed three UTT sessions per week on alternate days for a total of 8 weeks. Each training session featured three walking bouts separated by at least 5 minutes of seated rest on a flotation device inside the underwater treadmill unit. Water temperature was maintained between 29 ºC and 30ºC (Bocalini et al., 2008) and exercise heart rate was monitored at the beginning, middle, and conclusion of each exercise bout using a Polar heart rate monitor. Baseline levels of exercise intensity and duration and the systematic progression of these training variables were established based on previous research involving water-based exercise (Jones, Meredith-Jones, & Legge, 2009; Stevens & Morgan, 2010) and exercise guidelines published by the ACSM (2014).

During UTT, walking speed and duration were increased in a structured and gradual manner (see Table 2) and participants were asked to maintain their usual levels of home- and community-based physical activity. Weekly check lists were also completed by participants to record physician visits, acute illnesses, and hypoglycemic events that occurred during the study (Castaneda et al., 2002).

Figure 1. Participant walking during an underwater-treadmill session.

Table 2

Weekly Exercise Progression for Underwater Treadmill Training

Variable	W1	W2	W3	W4	W5	W6	W7	W8
Intensity (HRR)	40-50	40-50	40-50	50-60	50-60	50-70	50-70	50-70
Duration (trials x min)	3x10	3x12	3x14	3x14	3x16	3x16	3x18	3x20

Note. W = week; HRR = [((age-adjusted maximal heart rate – resting heart rate) x % intensity desired) + resting heart rate].

Statistical analyses. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 19.0. Paired *t* tests were used to compare pre- and post-UTT values for HbA1c, body mass, %BF, WC, RHR, estimated $VO_{2\ max}$, and hamstring and quadriceps peak torque. Statistical significance was established at $p \leq .05$.

Results

Compliance with the underwater treadmill training program was 100%, with all participants completing 24 (8 wks x 3 $d \cdot wk^{-1}$) UTT sessions. In addition, no exercise-related injuries were reported. A single hypoglycemic event occurred after UTT and was treated immediately by having the participant ingest a high-sugar beverage. No hypoglycemic events were recorded at home or in transit from the exercise laboratory.

An average reduction in HbA1c from 6.7% to 6.0 % was observed following UTT ($p < .001$). A total of 6 of the 7 participants reported no change in diabetic medication levels, and the remaining participant reduced medication usage during the study. Relative to anthropometric measures, mean body mass (3.4 kg, $p = < .001$), %BF (3.6 %, $p = .001$), and WC (8 cm, $p = .001$) were reduced after UTT, but lean body mass was not significantly altered following training (see Table 3).

A mean decrease in RHR of 7 beats per minute (bpm) occurred after UTT ($p = .002$) and estimated $VO_{2\ max}$ increased by an average of 2.6 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p < .001$). With respect to leg strength, an average increase of 5.5 ft-lbs ($p = .027$) and 7.0 ft-lbs ($p = .05$) were observed in quadriceps peak torque measured at $30° \cdot sec^{-1}$ and $60° \cdot sec^{-1}$, respectively, and a trend ($p = .07$) towards greater peak torque of the quadriceps at

Table 3

Changes in Primary Outcome Variables Following Underwater Treadmill Training

Variable	Pre UTT	Post UTT
Glycemic control		
HbA1c (%)	6.7 ± 2.0	6.0 ± 2.0*
Anthropometric measures		
Body mass (kg)	88.2 ± 14.0	84.7 ± 4.2*
Body fat (%)	28.3 ± 6.6	24.7 ± 5.5*
Waist circumference (cm)	105.0 ± 13.1	97.0 ± 10.5*
Cardiovascular function		
Resting heart rate (bpm)	83 ± 14	75 ± 13*
Estimated $VO_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	28.8 ± 3.9	31.0 ± 4.0*
Leg strength (ft-lbs)		
Hamstrings peak torque @ $30° \cdot sec^{-1}$	42.7 ± 12.3	53.2 ± 17.0*
Hamstrings peak torque @ $60° \cdot sec^{-1}$	35.9 ± 10.4	47.7 ± 12.0*
Hamstrings peak torque @ $90° \cdot sec^{-1}$	32.2 ± 10.2	42.1 ± 11.4*
Quadriceps peak torque @ $30° \cdot sec^{-1}$	71.4 ± 23.1	76.9 ± 20.2*
Quadriceps peak torque @ $60° \cdot sec^{-1}$	60.0 ± 21.0	67.0 ± 15.2*
Quadriceps peak torque @ $90° \cdot sec^{-1}$	48.1 ± 19.3	56.4 ± 13.3

Note. Values are mean ± standard deviation; UTT = underwater treadmill training; * = $p \leq .05$ from pre-training values.

90°·sec^{-1} (8.3 ft-lbs) was noted. In addition, mean post-training gains in peak hamstring torque at 30°·sec^{-1} (10.4 ft-lbs; p = .007), 60°·sec^{-1} (11.8 ft-lbs; p = .002), and 90°·sec^{-1} (9.9 ft-lbs; p = .01) were registered after UTT (see Table 3).

Discussion

The focus of this exploratory study was to quantify the impact of UTT on various health and fitness variables that are particularly relevant for adults with type 2 diabetes. Taken together, our findings indicate that for this clinical population, an aquatic treadmill walking program featuring systematic and gradual increases in walking speed and duration resulted in overall improvements in glycemic control, body composition, aerobic fitness, and peak leg torque. Positive changes in each dependent variable were also exhibited by all study participants, thus highlighting the coherent nature between group and individual responses to UTT.

Despite the crucial role of regular physical activity in the optimal management of diabetes, more than 36% of persons with type 2 diabetes do not engage in regular physical activity and an additional 38% report less than recommended levels of physical activity (American Association of Diabetes Educators, 2012). We speculate that the perfect adherence rate observed during UTT was related to the use of light and moderate exercise intensities and the incremental rise in total exercise volume (i.e., intensity x duration). Support for this assertion can be found in data revealing high levels of exercise adherence and enjoyment in overweight individuals exercising below vigorous levels (Lind & Ekkekakis, 2005).

No exercise-related injuries were experienced by participants during the 168 training UTT sessions (24 training sessions x 7 participants) and the single hypoglycemic event which did occur was resolved in a timely and satisfactory manner. In comparison, other studies of land-based treadmill walking and resistance training involving adults with type 2 diabetes have reported a higher number of hypoglycemic events (Castaneda et al., 2002). As previously noted, it is reasonable to suggest that the combination of less-intense workloads and gradual increases in walking duration contributed to the near-absence of negative clinical events in our group of sedentary and relatively unfit participants. It is also possible that the concurrent performance of light-to-moderate aerobic- and resistance-based walking exercise in a weight-supported environment may have led to a reduced incidence of injuries and hypoglycemic episodes compared to studies of persons with type 2 diabetes featuring longer and more-intense exercise programs and separate, land-based aerobic and resistance training sessions (Sigal et al., 2007).

Participants in our investigation exhibited a modest degree of initial glycemic control, as demonstrated by a mean HbA1c level of 6.7%. The 0.7% decrease in HbA1c after 8 weeks of UTT is consistent with data showing reductions of 0.55% and 0.59% in HbA1c following 16 weeks of combined aerobic and resistance training performed on land, respectively (Marcus et al., 2008; Tan, Li, & Wang, 2012). Likewise, our findings concur with meta-analyses performed by Umpierre et al. (2011) and Snowling and Hopkins (2006) revealing mean decreases in HbA1c of 0.67% and 0.80%, respectively, when adults with type 2 diabetes performed structured land-based aerobic exercise, resistance exercise, or a combination of both training modes for at least 12 weeks.

Expressed as a function of study duration, the magnitude of improvement in HbA1c levels following UTT was more than two times that reported in earlier investigations of middle-aged and older adults with type 2 diabetes who participated in both land-based endurance and resistance training programs (Alkurdi et al., 2010; Jones et al., 2009). Proposed mechanisms underlying the beneficial combined aerobic and resistance training on glycemic control include improved insulin action (Castaneda et al., 2002), enhanced glucose uptake due to up-regulation of mitochondrial proteins (Menshikova et al., 2006), increased glucose-4 transporter protein content and glycogen synthase activity leading to conversion of plasma glucose into glycogen (Christ-Roberts et al., 2003), and an elevation in metabolic rate and glucose uptake resulting from an increase in contractile proteins (Eriksson et al., 1997).

While few data are available concerning the effects of aquatic walking programs in adults with type 2 diabetes, results from our study are in agreement with findings of Jones et al. (2009), showing that water-based exercise incorporating deep water running and resistance exercise is effective in improving glucose and insulin response in overweight women with impaired glucose tolerance. Interestingly, the positive changes in glycemic control observed in our participants were independent of diabetic medication use, which either remained unchanged or decreased during the study, and the degree of reduction in HbA1c (0.7%) was comparable to that reported following long-term diabetic pharmacological interventions (Allison, et al., 2011) in persons with type 2 diabetes (0.6 – 0.8%). From a clinical perspective, findings from the current project suggest that engaging in UTT may reduce the need for oral hypoglycemic agents in persons with type

2 diabetes and provide health benefits for individuals who are not fully compliant in taking diabetic medications.

Body mass, %BF, and WC were lower after the UTT program. The average reduction in body mass of 3.5 kg is generally consistent with recommended weekly weight-loss standards for adults (0.5 - 0.9 $kg \cdot wk^{-1}$) established by the ACSM (2014). The decrease in body mass noted in our investigation may have been associated with the elevated aerobic demand of walking in an aquatic environment compared to walking on land. Related to this point, it has been shown that walking on a submerged treadmill results in a significantly higher aerobic demand compared to walking on a land-based treadmill (Alkurdi et al., 2010). The degree of body mass loss recorded among our participants, which was markedly greater than the mean decrease of 0.7 kg observed in middle-aged obese adults who performed 12 weeks of underwater treadmill walking, may reflect the interactive effect of walking speed and water height on overall exercise intensity (Greene et al., 2009). In this regard, a higher water height has been shown to result in greater buoyancy and a decreased level of energy expenditure compared to walking on land at the same speed (Alkurdi et al., 2010; Gleim & Nicholas, 1989). In the current project, water height was set at 10 cm below the xiphoid process based on data indicating that walking on an underwater treadmill at a water height 10 cm below the xiphoid process resulted in higher aerobic demand and heart rate values compared to walking at a water height at or 10 cm above the xiphoid process (Alkurdi et al., 2010).

In the present investigation, body fat levels also decreased by nearly 4% after UTT. This reduction in overall fat percentage is larger than that noted in previous studies in which body fat was decreased by 1.0% in adults with type 2 diabetes who completed a

12-week endurance walking program (Marcus et al., 2008) or 22 weeks of combined aerobic and resistance training (Sigal et al., 2007) and is greater than the 1.5% decrease in body fat reported in obese patients with type 2 diabetes who underwent an intense 12-week insulin therapy program (Shah et al., 2011). The improvement in body fat level seen following UTT was also larger than the average decrease of 1.3 %BF in middle-aged obese men and women who performed 12 weeks of walking on underwater- or land-based treadmills at similar levels of exercise volume and intensity (Greene et al., 2009). The change in body fat percentage observed in our study does not appear to be associated with the elevated body mass index (BMI) of our participants (BMI = 32.3 $kg/m^2 \pm 6.0$), as other intervention-based projects of adults with type 2 diabetes with similar BMI values have produced smaller decreases in relative body fat (Dunstan et al., 2002; Jones et al., 2009; Sigal et al., 2007). As mentioned earlier, it seems reasonable to imply that the marked reduction in %BF following UTT may be linked to the higher caloric expenditure associated with upper- and lower-body limb movement in water compared to walking on land (Alkurdi et al., 2010).

Following UTT, waist circumference was decreased by 8 cm, a reduction which is greater than changes noted in other long-term, land-based exercise studies (1.5 – 3 cm) conducted with middle-aged and older adults incorporating land-based aerobic and resistance training (Alkurdi et al., 2010; Sigal et al., 2007). Findings from previous research suggest that reductions in subcutaneous and visceral fat produced by aquatic training may be partially responsible for the decrease in WC measured in the current project (Jones et al., 2009).

Low aerobic fitness has been associated with heightened metabolic risk and an increased likelihood of cardiovascular disease (Jurca et al., 2005). While a direct evaluation of aerobic fitness is typically preferred, assessment of indirect measures of aerobic function, such as RHR and estimated $VO_{2\ max}$, eliminates the need to exercise to volitional exhaustion, while providing a reasonably accurate estimation of cardiovascular risk and aerobic function in sedentary and overweight middle-aged adults (Jones et al., 2009; Jurca et al., 2005).

The RHR of our participants was nearly 10% lower (8 bpm) following UTT. In contrast, a non-significant decrease in RHR of 1 bpm was recorded in both postmenopausal women with type 2 diabetes who engaged in circuit resistance training for 12 weeks and older adults with type 2 diabetes who completed a 16-week resistance exercise training program (Castaneda et al., 2002; Kang et al., 2009). The extensive amount of cardiovascular exercise performed by participants during UTT, coupled with their relatively sedentary lifestyle, may partially account for the observed decrease in RHR measured in the present study.

The post-UTT increase in estimated $VO_{2\ max}$ (~ 8% or 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$) is consistent with relative gains in aerobic fitness in middle-aged and older adults with type 2 diabetes after 4 weeks of supervised land-based resistance and aerobic exercise (6.3%; Hordern et al., 2008) and 6 months of combined aerobic and resistance training (7.5%; Tan et al., 2012). The degree of improvement in cardiorespiratory fitness noted in our study was also similar to the 8.6% increase in $VO_{2\ max}$ following 16 weeks of a circuit resistance training program which employed gradual increments in intensity and duration and met current exercise guidelines for adults with type 2 diabetes (Kang et al., 2009).

The increase in aerobic fitness in the current study was also similar to the average gain of 3.6 ml·kg^{-1}·min^{-1} seen in middle-aged obese adults who completed 3 months of underwater- or land-based treadmill walking (Greene et al., 2009). While the overall increase in estimated maximal aerobic power fell within the standard error of estimate range for predicting $VO_{2\,max}$ using a single-stage treadmill test (Ebbeling et al., 1991), all study participants exhibited an increase in predicted $VO_{2\,max}$, lending credence to the notion that the improvement in aerobic fitness could be reasonably attributed to UTT.

The systematic rise in overall training volume in the current study enabled our participants to increase locomotor energy demands and improve estimated maximal aerobic power without experiencing the levels of pain and discomfort which sometimes accompany land-based walking in older adults (Poyhonen et al., 2002). From a practical standpoint, a training-induced increase in $VO_{2\,max}$ would also translate into reduced cardiovascular and metabolic strain and a diminished level of fatigue during physical activities requiring extended periods of walking (Boule, Haddad, Kenny, Wells, & Sigal, 2001).

Previous work has shown that adults with type 2 diabetes exhibit impaired mobility and 30% to 50% lower maximal leg strength values compared to healthy persons of similar age (Boule et al., 2001). Results from our investigation demonstrated that hamstring peak torque at slow (25%), moderate (19%), and fast (31%) velocities and quadriceps peak torque at slow (8%) and moderate (12%) velocities were greater after UTT. These findings align with recent data indicating higher leg muscle strength values in elderly patients with type 2 diabetes following an integrated aerobic and resistance training program (Tan et al., 2012) and middle-aged adults with type 2 diabetes who engaged in resistance training (Larose et al., 2010). Because lean body mass was not significantly increased in our participants following 8 weeks of UTT, the increase in peak muscle torque may have been due to reduced leg muscle coactivation, which would increase net force production by agonist muscles (Hakkinen et al., 1998), or greater motor unit recruitment (Hakkinen et al., 1998; Poyhonen et al., 2002).

While this exploratory project featured an innovative exercise therapy for adults with type 2 diabetes, the absence of a matched control group hampered our ability to firmly establish the health and functional benefits of underwater treadmill training in our sample. Given the scarcity of published data regarding this unique water-based walking program, additional studies featuring appropriate control groups and larger sample sizes are needed to confirm the effectiveness of UTT in adults with type 2 diabetes and refine training protocols. The assessment of dietary intake would also be useful in interpreting changes in body composition following UTT. In addition, completion of an extended period of UTT might yield larger improvements in glycemic control, as the average lifespan of a red blood cell can be as long as 120 days (Shima et al., 2012).

In conclusion, results from our preliminary study have demonstrated significant improvements in glycemic control, body composition, cardiorespiratory function, and leg strength in middle-aged adults with type 2 diabetes following 8 weeks of underwater treadmill training. Given the commercial availability of portable underwater treadmills which are simple to use and similar in cost to quality land-based treadmills, our initial findings provide support for implementing UTT as a means of enhancing glycemic control and health-related fitness in adults with type 2 diabetes and easing the transition to land-based walking programs in this population.

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APPENDICES

APPENDIX A

IRB Letter of Approval

MIDDLE TENNESSEE STATE UNIVERSITY

July 28, 2011

Ryan T. Conners
Department of Health and Human Performance

rtc2m@mtmail.mtsu.edu , jcaputo@mtsu.edu

Protocol Title: "Effects of an Underwater Treadmill Walking Program on Adults with Type 2 Diabetes"

Protocol Number: **12-010**

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 Category 4.

Approval is granted for one (1) year from the date of this letter for 10 participants.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance (c/o Emily Born, Box 134) before they begin to work on the project.** Any change to the protocol must be submitted to the IRB before implementing this change.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Your study expires **July 28, 2012**.

Also, all research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Emily Born

Emily Born
Research Compliance Officer
Middle Tennessee State University
eborn@mtsu.edu

CHAPTER IV

UNDERWATER TREADMILL WALKING PROGRAM, GLYCEMIC AND METABOLIC CONTROL, CALORIC EXPENDITURE, AND HEALTH-RELATED FITNESS IN ADULTS WITH TYPE 2 DIABETES

Introduction

Diabetes is characterized as hyperglycemia caused by deficiencies in insulin secretion and/or insulin action (Snowling & Hopkins, 2006). The use of exercise as a therapeutic modality for type 2 diabetes has been shown to improve overall glycemic control with increased insulin sensitivity and decreased glycosylated hemoglobin (HbA1c). Current exercise recommendations (American Association of Diabetes Educators [AADE], 2012) for adults with type 2 diabetes include performing aerobic and resistance exercise with the combination leading to increased glycemic control compared to performing either modality alone (Cuff et al., 2003; Marcus et al., 2008; Sigal et al., 2007; Wallace, Mills, & Browning, 1997). However, many adults with type 2 diabetes are overweight and/or obese and may have limited mobility from osteoarthritis or other joint problems that discourage an active lifestyle and limit the ability to meet current exercise guidelines (Jones, Meredith-Jones, & Legge, 2009). Aquatic exercise is a promising exercise modality that may assist adults with type 2 diabetes in overcoming barriers to an active lifestyle.

Water exercise provides a unique medium that combines the benefits of aerobic and resistance exercise. Specifically, walking on an underwater treadmill poses a cardiovascular challenge while also providing resistance as the limbs are moved against the resistance of the water. In the aquatic environment, individuals can be physically active while also reducing the vertical ground reactions forces on the joints (Alkurdi, Paul, Sadowski, & Dolny, 2010). Intensity can be altered by changing the speed of the belt and lowering or raising the water height. Further, caloric expenditure values are similar to dry-land walking (Hall, Macdonald, Maddison, & O'Hare, 1998). Increasing caloric expenditure is an important component in the treatment of type 2 diabetes (Tuomilehto et al., 2001). Caloric expenditure helps combat the macrovascular and obesity-related complications (Partanen et al., 1995; Uusitupa, Siitonen, Aro, & Pyörälä, 1985) and has also been linked to increased glycemic control (Frederico et al., 2007).

With an estimated 25.8 million diabetics in the United States (Center for Disease Control and Prevention [CDCP], 2011), and this number continuing to escalate in collaboration with obesity rates and sedentary behavior in adults (Snowling & Hopkins, 2006), it is important to investigate new opportunities to minimize the impact of this diagnosis. Therefore, the purpose of this study was to evaluate the effects of an underwater treadmill training (UTT) program versus a control treatment on glycemic and metabolic control, body composition, aerobic capacity, caloric expenditure, and leg strength in adults with type 2 diabetes. We hypothesized that a 12 week underwater treadmill walking program would result in decreased HbA1c, fasting plasma glucose (FPG), low-density lipoproteins levels, total cholesterol, and triglyceride levels. Furthermore, it was hypothesized that participation in the training program would result in increased free-living caloric expenditure and high-density lipoprotein levels, and improved health-related fitness.

Methodology

Participants. A sample of 26 adults (10 males, 16 females; mean age = 58.3 ± 4.5 years) with physician-diagnosed type 2 diabetes volunteered to participate in this study. The inclusion criteria for the participants included diagnosed diabetes for a minimum of 2 years and medical clearance to participate in an exercise program from their personal physician (Marcus et al., 2008). Eligible participants were sedentary, which was defined as no involvement in regular aerobic (exercising 2 or more times a week for 20 minutes or longer) or resistance exercise (any form of resistance training) in the 6-month period preceding the study (Sigal et al., 2007). Participants were ruled ineligible for the study if they had a myocardial infarction within 6 months of the investigation, the presence of additional unstable chronic medical conditions (e.g., respiratory disease, heart failure, renal disease, or hepatic disease), changes in oral hypoglycemic medication use within the past 6 months, or the presence of diabetic-related myopathies or neuropathies that would prevent full completion of the exercise program (Castaneda et al., 2002; Sigal et al., 2007).

Instrumentation and outcome measures.

Glycemic and metabolic control. Plasma glycosylated hemoglobin (HbA1c) was the primary outcome measure, which represents average blood glucose concentration over a 1- to 3-month period (Bennett, Guo, & Dharmage, 2007). Serum cholesterol and triglyceride (TG) levels were used as the main metabolic control outcome measures. A 10-ml venous blood sample was drawn from a forearm vein and collected by a licensed nurse at the University Health Services Center. All blood analyses were completed at Quest Diagnostics laboratory (Murfreesboro, TN). Glycosylated hemoglobin was determined using immunoturbidimetry (Roche COBAS Integra 800, Mannheim, Germany, 1.5 – 3.0% CV). FPG (1.6 – 2.5% CV), high-density lipoprotein (HDL; 2.8 – 3.9% CV), low density lipoprotein (LDL; calculated, no CV), and TG levels (1.3 – 2.1% CV) were analyzed using spectrophotometry (Beckman Coulter AU5400, Brea, CA).

Anthropometric and body composition measurements. Duplicate measures of body mass (without shoes) were taken on a Seca 869 flat digital scale (Hanover, MD) to the nearest 0.1 kg and averaged to determine mean body mass. The average height of each participant (without shoes) was derived by averaging duplicate values (to the nearest 0.25 cm) obtained using a Seca 217 stadiometer (Hanover, MD). Body mass index (BMI) was ascertained from body mass and height as kilograms per meter squared. The skinfold thicknesses at seven sites (abdomen, pectoral, suprailiac, mid-axillary, subscapular, quadriceps, and triceps) were evaluated by way of a Harpenden skinfold caliper (Model 136, West Sussex, UK). Duplicate measurements were taken (within 1 mm error range) and averaged to calculate an average skinfold thickness for each of the seven sites. All measures were performed on the right side of the body by a trained technician. Using population- and sex-specific equations (Allison et al., 2011), average thicknesses at each of the seven locations were used to calculate body fat percentage and the percentage of lean body mass. Duplicate measures of waist circumference, taken as the narrowest point between the iliac crest and the xiphoid process (American College of

Sports Medicine, 2014), were obtained in centimeters using a Gulick tape measure and averaged to derive mean waist circumference.

Resting cardiovascular and fitness measures. Resting blood pressure (RBP) and resting heart rate (RHR) were used as aerobic fitness measures as they are useful and straightforward biomarkers of the status of the cardiovascular system and blood circulation (Nagaya, Yoshida, Takahashi, & Kawai, 2010). Following 10 minutes of seated rest in a quiet, dark room (Allison et al., 2011), RHR was determined from palpation of the radial pulse for 30 seconds and doubling the number of recorded beats (Allison et al., 2011). The two measures of RHR were obtained within a 5-minute period and then averaged to derive a mean RHR value. Resting systolic blood pressure (SBP) and resting diastolic blood pressure (DBP) were taken in millimeters of mercury at the brachial artery by the primary investigator using the same adult sphygmomanometer and stethoscope (Nagaya et al., 2010).

The 6 minute walk for distance (6MWFD) was used as a measure of functional capacity. The 6MWFD is an endurance walking test that reflects the ability of a person to perform a variety of daily-life activities (Latiri et al., 2012). This test was chosen based upon its reliability, effectiveness, easy application, and safety amongst diseased populations (Enright & Sherrill, 1998; Sciurba & Slivka, 1998). In the test, participants were asked to walk for 6 minutes around a pre-measured oval course on an indoor collegiate track. Each participant was instructed to cover as much distance as possible. All of the participants were given standardized encouragement throughout the testing procedure. At the conclusion of the test, total walking distance was recorded to the nearest foot using a calibrated measuring wheel and converted into meters traveled.

Leg strength. Concentric peak torque of the dominant leg quadriceps and hamstrings at 30°·sec^{-1} and 60°·sec^{-1} were assessed using a Biodex System III dynamometer (Biodex Medical Systems, Shirley, NY). All tests were windowed and cushion filtered. The dominant leg was identified as the leg chosen to kick a ball that was placed directly in front of the participant (Hoffman, Schrader, Applegate, & Koceja, 1998; Jacobs, Uhl, Seeley, Sterling, & Goodrich, 2005) and the contraction velocities were chosen to reflect the range of walking speeds used by adults (Lanshammar & Ribom, 2011). Participants were seated in an upright position and the adjustable straps were placed around the upper body and the dominant thigh to isolate the quadriceps and hamstrings muscles. The straps were also utilized to limit the amount of muscle activation in the muscle groups that were not being evaluated. The fulcrum of the lever arm of the dynamometer was situated at the lateral aspect of the knee joint axis.

The range of motion for the leg strength tests were measured from a start position with the knee joint bent at 90° through full extension (0° flexion) and back to the starting position of 90° of knee flexion. Consistent verbal encouragement was delivered to each participant during the testing process and three accommodation trials preceded quadriceps and hamstrings testing at each of the two contraction velocities. After completing the accommodation phase, participants performed the three maximum voluntary bouts in a randomized order at both of the contraction velocities, with a total of 30 seconds of rest between trials. The highest peak torque measure across the trials for each muscle group and individual velocity were recorded. The leg strength measure was expressed as peak torque (ft-lbs), because it is considered to be a representative indicator of strength for both knee flexion and extension (Blain et al., 2001).

Caloric expenditure. Caloric expenditure over a 7 day period was determined using a SenseWear™ Armband (SWA; Pittsburgh, PA), which is a physical activity monitoring device that also includes software that determines daily caloric expenditure (Barry et al., 2011). Participants wore the SWA for 7 day periods prior to participation in the study, at week 12, and at week 25 of the study. The SWA was initialized for each participant based upon age, height, mass, and sex. The SWA was placed on the upper-left arm at the midpoint between the olecranon process and the acromion process (Johannsen et al., 2010). Participants were instructed to wear the device 24 hours a day and only take off the device when showering or performing activities in the water. During the time the armband was worn by the participant's, they did not receive any feedback from the device (Barry et al., 2011). The weekly caloric expenditure was then divided by seven to give a daily average caloric expenditure (DACE).

Dietary intake. Participants were asked to continue with their current diet throughout the duration of the study (Cuff et al., 2003). Participants completed a 3 day food log (see Appendix A) prior to the start of the study, as well as at 12 weeks, and 24 weeks. Total caloric intake, as well as the percentage of carbohydrates, protein, and fat consumed as a percentage of the total amount of energy intake, was assessed for each participant over the 3 day period (Castaneda et al., 2002). The food log consisted of questions about the type of food items that were consumed, what serving size was consumed, and the way in which the food was prepared. Prior to each participant receiving the 3 day food log, he or she had a meeting with the lead researcher to discuss serving sizes and the proper manner to complete the food log. Nutritional intake was analyzed using FoodWorks (version 13 software; Long Valley, NJ).

Procedures.

Preparation. Participants in the study were recruited via flyers and word of mouth from the local Middle Tennessee area, following approval of the study by the University Institutional Review Board (see Appendix B). Interested participants were made aware of the procedures and the purposes of the study. Furthermore, each participant was required to obtain clearance from his or her physician prior to participating in the study. Once cleared by their physician, all participants completed the informed consent form and a current medication log (see Appendix C). The participants then had a pre-UTT blood draw by a licensed nurse at the University Health Services Office. After completion of the blood analyses to determine glycemic and metabolic control, participants returned to the laboratory to have baseline testing performed for anthropometric measures and leg strength. Participants returned to the laboratory setting 24-48 hours later to perform testing for resting cardiovascular measures, cardiovascular fitness, and body composition. At the conclusion of this session, the participants were given a tutorial on how to properly fill out the 3 day food log as well as given the directions on how to wear the SWA for 7 days. Throughout the study, all participants were asked to maintain their current medication usage and not begin any regimented exercise programs.

A 26 week, single center, randomized cross-over design study was used. Following baseline measurements, participants were randomly allocated into group number 1(training/control) or into group number 2(control/training) and were stratified by sex. At the conclusion of the first 12 weeks, all baseline measures were reassessed and participants were then reassigned to the opposite group. At the end of the 25th week, all previously measured outcomes were reassessed within 1 week of the conclusion of the study. Table 4 depicts the sequencing that participants underwent throughout the duration of the study.

Underwater treadmill training group. A day prior to UTT, participants completed an accommodation session. The accommodation session occurred in the underwater treadmill (Ferno, Wilmington, OH) that features a self-contained therapy pool, a control panel from which the treadmill was operated, a water reservoir with a water filtration system, a variable-speed motor, and two large Plexiglas windows which enabled participants to be monitored visually (see Figure 2). The height of the water was set at 10cm below the xiphoid process and was maintained at this height for the duration of the study (Alkurdi et al., 2010). The accommodation session consisted of 5 minutes at a speed that elicited 20% of heart rate reserve (HRR) [HRR = ((220 – participant's age - resting heart rate) x % intensity desired) + resting heart rate]. The participants in the study completed three UTT sessions per week on alternate days for a total of 12 weeks. An individual training session consisted of 3 walking bouts separated by at least 5 minutes of rest on a flotation device that was placed inside of the underwater treadmill unit. During the study, the water temperature was kept at a neutral temperature between 29ºC and 31ºC (Bocalini, Serra, Murad, & Levy, 2008).

Table 4

Participant Sequencing for the Cross-Over Design

	Time				
Group	Baseline (Time 1)	W 1-12	W 13 (Time 2)	W 14-25	W 26 (Time 3)
1 = training/control	PRT	UTT	PST	C*	FUT
2 = control/training	PRT	C	PST	UTT	FUT

Note. W = week; PRT = pre-test; UTT = underwater treadmill training; C = control; C* = control/free-living; PST = post-test; FUT = follow-up test.

Figure 2. Participant performing a UTT walking bout

During UTT, the chosen levels of exercise intensity, duration, and the progression that were employed were based upon previous aquatic-based exercise programs (Jones et al., 2009; Stevens & Morgan, 2010) and exercise guidelines published by the ACSM (2014). Table 5 depicts the training progression employed. Once a week, the participants were verbally asked about any recent physician visits, acute illnesses, and hypoglycemic events that occurred so they could be documented (Castaneda et al., 2002).

Control group. When the participants were in the control group they were asked to maintain their current dietary and physical activity habits. Weekly emails and phone calls were made to the participants to ensure adherence.

Statistical analyses. Statistical analyses were performed using the International Business Machines Corporation Statistical Package for Social Sciences (SPSS) version 19.0. Descriptive statistics, were expressed as means ± standard deviations. The hypotheses were evaluated in terms of effect sizes as well as statistical significance. Table 1 depicts the sequence that participants followed for the randomized cross-over design. Repeated measures analyses of variance (RM ANOVA) were used to determine if HbA1c and caloric expenditure were different following both the UTT and the control periods. A familywise alpha of .05 was used for these analyses.

RM ANOVAs (α = .0125) were also used to determine if the metabolic control factors (HDL, LDL, TG, and TG/HDL), resting cardiovascular and fitness measures (RHR, RSBP, RDBP, and 6MWFD), and leg strength values (quadriceps/hamstrings peak torque at $30°\cdot sec^{-1}$ and $60°\cdot sec^{-1}$) changed throughout the cross-over design. Additionally, RM ANOVAs (α = .0167) were used to determine if anthropometric and body composition (BM, BF%, and WC) values changed throughout the design.

Table 5

The Walking Durations and Intensities Utilized During the UTT

Variable	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Intensity (% HRR)	40-50	40-50	40-50	50-60	50-60	50-60	50-60	50-60	50-60	50-70	50-70	50-70
Duration (min)	10	10	12	12	14	14	16	16	18	18	20	20
Total Time (min)	30	30	36	36	42	42	48	48	54	54	60	60

Note. W = Week; % HRR = percent of heart rate reserve. Each session included three exercise bouts.

Due to the fact that a cross-over design was utilized, specific contrast comparisons were used to determine changes that occurred in outcome measures between the subgroups in the study. For each dependent variable, the following analyses were conducted:

1. A one-way RM ANOVA was used to compare all treatment scores (i.e., Group 1 = Time 2, Group 2 = Time 3) to all control scores (i.e., Group 1 = Time 1, Group 2 = Time 2). This test evaluates the effect of the intervention but assumes that no carry-over effect is present following the control condition.
2. A one-way ANOVA was used to compare the group 1 and group 2 scores for change from baseline values (i.e., Time 2 – Time 1). This test evaluates the effect of the intervention and has no risk of a carry-over effect.

Results

A total of 26 participants took part in the study and all descriptive statistics appear in Table 6. Participant adherence to the training protocol was 100%, with all participants completing 36 (12 wks x 3 $d \cdot wk^{-1}$) UTT sessions and no UTT-related injuries were reported during the duration of the study. Furthermore, no hypoglycemic events occurred prior to UTT, during the walking sessions, or following the training sessions. The one-way RM ANOVAs and one-way ANOVAs yielded similar conclusions about intervention effectiveness for almost all analyses. For brevity, only the results of the one-way RM ANOVAs are presented unless the two procedures yielded different results.

Glycemic and metabolic control. HbA1c was the primary outcome measure. The means and standard deviations are presented in Table 7. The HbA1c values were higher for the control period (M = 7.58, SD = 1.16) than for the UTT

Table 6

Participant Baseline Characteristics *(N = 26)*

Variable	*n*	*M* ± *SD*
Mean age (years)		58.3 ± 4.5
Sex (female/male)	16/10	
Height (m)		1.8 ± 0.2
Body mass (kg)		91.2 ± 9.6
Time since diabetes diagnosis (years)		7.1 ± 4.6
Number of current smokers	3	
Percent taking diabetes medication		70.4 ± 4.0

Table 7

Changes in Primary Outcome Variables for the Group 1 and Group 2 Sequences

Variable	Group 1 Control (Time 1)	Group 1 Treatment (Time 2)	Group 2 Control (Time 2)	Group 2 Treatment (Time 3)
Glycemic control				
HbA1c (%)	7.90 ± 1.17	7.23 ± .94	7.27 ± 1.10	6.75 ± .89
Metabolic control				
HDL (mg/dl)	43.38 ± 8.67	49.54 ± 10.0	55.77 ± 30.19	65.85 ± 28.04
LDL (mg/dl)	133.15 ± 99.12	126.00 ± 90.93	104.54 ± 87.85	97.23 ± 84.23
TG (mg/dl)	215.15 ± 161.56	203.54 ±147. 95	164.38 ± 138.92	154.62 ± 135.64
TG/HDL	5.69 ± 5.74	4.62 ± 4.38	4.08 ± 4.32	2.89 ± 2.89
A.P. measures				
Body mass (kg)	102.6 ± 12.2	100.0 ± 12.2	96.4 ± 16.5	92.2 ± 15.8
Body fat (%)	29.6 ± 4.5	27.2 ± 4.5	31.62 ± 6.0	28.7 ± 6.0
W.C. (cm)	115.5 ± 10.2	111.4 ± 9.6	105.7 ± 9.3	102.2 ± 9.4
C.V. measures				
RHR (bpm)	82 ± 8	74 ± 7	83 ± 8	69 ± 10
RDBP (mm Hg)	81 ± 9	75 ± 7	82 ± 9	75 ± 7
RSBP (mm Hg)	129 ± 7	121 ± 6	129 ± 9	121 ± 7
6 MWFD (m)	508 ± 107	604 ± 96	477 ± 106	579 ± 140

Table 7

	Group 1		Group 2	
Variable	Control (Time 1)	Treatment (Time 2)	Control (Time 2)	Treatment (Time 3)
Leg Strength (ft-lbs)				
Hams. p.t. @ 30°·sec^{-1}	87.4 ± 37.0	94.0 ± 36.5	73.3 ± 37.7	81.6 ± 39.7
Hams. p.t. @ 60°·sec^{-1}	64.4 ± 28.9	72.4 ± 23.5	53.4 ± 27.2	58.2 ± 27.8
Quads. p.t. @ 30°·sec^{-1}	85.4 ± 33.1	88.9 ± 33.2	70.1 ± 32.6	78.5 ± 36.7
Quads. p.t. @ 60°·sec^{-1}	60.5 ± 24.4	68.3 ± 20.2	51.7 ± 23.4	57.2 ± 25.0
Caloric expenditure				
DACE (cal.)	2686 ± 374	2963 ± 21	2460 ± 524	2827 ± 607

Note. Values are mean ± standard deviation; HDL = high-density lipoproteins; LDL = low-density lipoproteins; TG = triglycerides; HDL/TG = high-density lipoproteins divided by triglycerides; A.P. = anthropometric; W.C. = waist circumference; C.V. = cardiovascular; RHR = resting heart rate; RDP = resting diastolic blood pressure; RSP = resting systolic blood pressure; 6 MWFD = 6-minute walk for distance; hams. p.t. = hamstring peak torque; quads. p.t. = quadriceps peak torque; DACE = daily average caloric expenditure.

condition (*M* = 6.99, *SD* = 0.93), *F* (1, 25) = 76.05, *p* < .001, η_P^2 = .75. The HDL values were lower for the control period (*M* = 49.58, *SD* = 22.66) than for the UTT condition (*M* = 57.69, *SD* = 22.24), *F* (1, 25) = 38.97, *p* < .001, η_P^2 = .61. The LDL values were significantly higher for the control group (*M* = 121.85, *SD* = 92.91) compared to the UTT condition (*M* = 114.61, *SD* = 87.69), *F* (1, 25) = 3.66, *p* = .010, η_P^2 = .61. The RM ANOVA indicated the TG values were significantly lower following UTT (*M* = 179.08, *SD* = 141.28) compared to the control period (*M* = 189.77, *SD* = 149.87), *F* (1, 25) = 7.49, *p* = .011, η_P^2 = .23.

The one-way ANOVA, however, indicated the change in TG values from baseline for group 1 (*M* = 179.08, *SD* = 27.71) and for group 2 participants (*M* = 189.77 *SD* = 29.39) were not significantly different, *F* (1, 25) = 2.25, *p* = .147, η_P^2 = .09. Finally, the TG/HDL ratio values were significantly lower following UTT (*M* = 3.76, *SD* = 3.74) compared to the control period (*M* = 4.88, *SD* = 5.04), *F* (1, 25) = 12.43, *p* = .002, η_P^2 = .33.

Anthropometric and body composition measurements. The BM values were higher for the control period (*M* = 99.9, *SD* = 14.46) then for the UTT condition (*M* = 95.79, *SD* = 14.41), *F* [1, 25] = 104.36, *p* < .001, η_P^2 = .81. Similarly, the BF% scores were significantly lower following the UTT condition (*M* = 27.96, *SD* = 5.25) compared to the control period (*M* = 30.67, *SD* = 5.30), *F* [1, 25] = 172.83, *p* < .001, η_P^2 = .88. The RM ANOVA also indicated that WC values were higher for the control period (*M* = 110.62, *SD* = 10.80) than for the UTT condition (*M* = 106.80, *SD* = 10.41), *F* [1, 25] = 67.27, *p* < .001, η_P^2 = .73.

Resting cardiovascular and fitness measures. Resting systolic blood pressure, RDBP, RHR, and the 6MWFD were the outcome variables that were investigated in the study. The RSBP (*F* [1, 25] = 39.70, $p < .001$, $\eta_P^2 = .61$), RDBP (*F* [1, 25] = 47.30, $p < .001$, $\eta_P^2 = .65$), and RHR (*F* [1, 25] = 27.22, $p < .001$, $\eta_P^2 = .52$) values were lower for the UTT period (RSBP *M* = 121.38, *SD* = 6.34, RDBP *M* = 74.92, *SD* = 7.03, RHR *M* = 71.35, *SD* = 8.99) than for the control period (RSBP *M* = 128.92, *SD* = 7.66, RDBP *M* = 81.31, *SD* = 8.43, RHR *M* = 79.42, *SD* = 10.19). The 6MWFD scores were higher for the UTT period (*M* = 591.31, *SD* = 118.48) than for the control period (*M* = 493.08, *SD* = 105.70), *F* (1, 25) = 48.59, $p = .001$, $\eta_P^2 = .66$.

Leg strength. The outcome measures for leg strength were determined from the concentric isokinetic peak torques of the quadriceps and hamstring muscle groups at $30°\cdot sec^{-1}$ and $60°\cdot sec^{-1}$. The leg strength values at the hamstrings at $30°\cdot sec^{-1}$ were higher for the UTT period (*M* = 87.78, *SD* = 37.85) than for the control condition (*M* = 82.79, *SD* = 37.28), *F* (1, 25) = 24.46, $p < .001$, $\eta_P^2 = .50$. Similarly, the leg strength values at the hamstring at $60°\cdot sec^{-1}$ were higher for the UTT period (*M* = 65.27, *SD* = 26.27) than for the control condition (*M* = 62.44, *SD* = 26.15), *F* (1, 25) = 17.58, $p < .001$, $\eta_P^2 = .41$. The leg strength values at the quadriceps at $30°\cdot sec^{-1}$ (*F* [1, 25] = 8.56, $p = .007$, $\eta_P^2 = .26$) and at $60°\cdot sec^{-1}$ (*F* [1, 25] = 25.69, $p < .001$, $\eta_P^2 = .51$) were higher for the UTT period ($30°\cdot sec^{-1}$ *M* = 83.69, *SD* = 34.68, $60°\cdot sec^{-1}$ *M* = 62.77, *SD* = 23.00) than for the control condition ($30°\cdot sec^{-1}$ *M* = 79.51, *SD* = 32.84, $60°\cdot sec^{-1}$ *M* = 58.57, *SD* = 22.52).

Caloric expenditure. The DACE values were lower for the control period (M = 2572.84, SD = 460.59) than for the UTT condition (M = 2895.16, SD = 537.34), F (1, 25) = 17.20, $p < .001$, $\eta_P^2 = .41$.

Discussion

The focus of this study was to quantify the health and fitness outcomes of a 12-week UTT program for adults with type 2 diabetes. Performing simultaneous aerobic and resistance training by walking in an aquatic environment resulted in improvements in glycemic control, metabolic control, anthropometric values, cardiovascular endurance, caloric expenditure, and leg strength. All of the participants demonstrated positive changes, in the absence of any untoward events, thus confirming the findings of a previous exploratory study by Conners, Morgan, Fuller, and Caputo (2014) on the safety and efficacy of UTT in this population.

Along with pharmacological treatment and dietary modification, exercise is one of the main strategies recommended by the ACSM and the ADA in treating type 2 diabetes (American Diabetes Educator, 2012; Colberg et al., 2010). In patients with type 2 diabetes, microvascular and macrovascular complications can make it difficult to perform physical activity (PA) and therefore, even more of a challenge to meet the ACSM and ADA PA guidelines. As a result, more than 36% of adults with type 2 diabetes do not engage in regular PA (Lee, Yoo, & So, 2015).

Our data highlights the potential use of aquatic exercise in increasing PA levels in adults with type 2 diabetes. Throughout the duration of the study, which consisted of a total of 936 walking sessions (26 participants x 12 weeks of UTT x 3 sessions a week), there were no exercise-related injuries or diabetic complications, and there was an adherence rate of 100%. This is in contrast to a greater number of exercise-related injuries and diabetic complications reported in studies of traditional treadmill- and resistance-based exercise interventions in adults with type 2 diabetes (Castaneda et al., 2002; Yavari, Najafipoor, Aliasgarzadeh, Niafar, & Mobasseri, 2012). For example, 71 of the 188 exercise group participants experienced a hypoglycemic event in the Sigal et al. (2007) study, when performing separate bouts of aerobic and resistance exercise or a combination of the two. Walking in an underwater treadmill is a safe-exercise medium for adults with type 2 diabetes. The shorter duration of the exercise bouts in the current study attributed to the combined aerobic and resistance nature of UTT may explain our absence of hypoglycemic events. Further, adherence may have been fostered because walking in an aquatic environment decreases forces acting on the joints and allows a more gradual increase in walking intensity.

Glycosylated hemoglobin, an indicator of long-term glycemic control, was one of the primary study outcomes. Participation in 12 weeks of UTT resulted in an average decrease in HbA1c of 0.80% to a mean sample value below 7.0%. The overall average reduction represents a potential decrease in long-term complications from diabetes upwards of 76% (Shenoy, Arova, & Jaspal, 2009). Our improvement in HbA1c is comparable to the limited pool of data on aquatic fitness programs in adults with type 2 diabetes. Cugusi et al. (2015) showed a mean reduction in HbA1c of 0.51%, following 12 weeks of aquatic exercise, which consisted of swimming and circuit training using both body weight and resistance equipment, in middle-aged men with type 2 diabetes. It was also similar to the HbA1c reduction of 0.70% that was seen following aquatic exercise in middle-aged patients with heart failure and type 2 diabetes by Asa, Maria, Katharina, and Bert (2012). Their aquatic training program consisted of 45-minute sessions of muscle training performed at low to moderate intensities in neck high water, three days a week.

The present reduction in Hba1c is superior to the 0.57% reduction found following 16 weeks of a combination of aerobic and resistance training performed on land in studies performed by Marcus et al. (2008) and Tan, Li, and Wang (2012). The findings in our study are similar to the findings of meta-analyses performed by Snowling and Hopkins (2006) and Kelly and Kelly (2007), which revealed an average decrease in HbA1c of 0.80% when performing structured land-based aerobic training or a combination of resistance and aerobic exercise programs a minimum of 12 weeks in duration. Through UTT, adults with type 2 diabetes are able to see reductions in HbA1c that are consistent with land-based interventions, but experienced in a shorter duration.

The improvement in HbA1c in the current study was higher in magnitude than the reduction of 0.70% following the eight week UTT intervention conducted by Conners et al. (2014). The explanation for the greater reduction is likely due to the longer duration of the current study and based upon the average life-span of a red blood cell of 90-120 days. The glycation of red blood cells occur over time, and is an indicator of the average glucose values over the life span of the cells. Thus, the longer duration study illustrated greater changes in HbA1c because new red blood cells were being produced in a lower blood glucose medium. Other potential mechanisms linked to the improvement in HbA1c from UTT include upregulation of mitochondrial proteins (Menshikova et al., 2006), increased glycogen synthase activity (Christ-Roberts et al., 2003), and increased glucose-4 transporter protein content (Christ-Roberts et al., 2004). It is also hypothesized that the improvements in HbA1c could be a result of increased contractile protein content (Christ-Roberts et al., 2004), higher basal metabolic rate and greater absolute glucose uptake (Eriksson et al., 1997). The improvement in long-term glycemic control could also be from an increased amount of mitochondrial proteins and an improvement in capillary to muscle fiber ratio (Halseth, Bracy, & Wasserman, 2001), and a reduction in regional visceral and intermuscular fat stores, which can directly influence insulin sensitivity (Wei et al., 2008).

A reduction in HbA1c of 0.80% is at the upper range of the decrease (0.60% to 0.80%) typically seen from participation in long-term drug or insulin therapy and diet programs (Marcus et al., 2008). This indicates that an UTT walking program for adults with type 2 diabetes is comparable to an oral hypoglycemic agent in reducing HbA1c, without a modification in diet. The positive changes in HbA1c in our participants occurred independently of any alterations in diabetes medication and dietary intake. With the use of 3-day food logs, it was confirmed that there were no changes in the percentages of macronutrients that were consumed by participants throughout the study. This result suggests that the changes seen in glycemic control and other health-related factors were due to the UTT and not modifications in other treatment variables.

Improvement in metabolic control was documented with an increase in HDL (+8.11 mg/dl) and reductions LDL (-6.24 mg/dl), TG (-10.69 mg/dl), and HDL/TG (-1.12 mg/dl). The improvement in HDL values is contrary to the non-significant changes seen in the aquatic exercise studies performed by Cugusi et al. (2015) and Asa et al. (2012). The discrepancy may be due to the shorter eight weeks of training in the study by Asa et al. (2012) and due to the larger decrease in BM (4.11 kg) seen in our study, compared to the decrease in BM (2.28 kg) in the study by Cugusi et al. (2015). The improvements in HDL could also be due to the fact that exercise is involved in increasing the production and action of several enzymes that function to enhance the reverse cholesterol transport system (Durstine & Haskell, 1994). The current increase in HDL, along with reduction in BM, were similar to other studies involving adults with type 2 diabetes that performed land-based aerobic exercise, resistance exercise, or a combination of both (Hayashino, Jackson, Fukumori, Nakamura, & Fukuhara, 2012; Kelley & Kelley, 2007).

The improvements in LDL, TG, and HDL/TG are similar to those of Asa et al. (2012), Balducci et al. (2007), Cugusi et al. (2015), and Takeshima et al. (2002). The study by Takeshima et al. (2002) involved 15 elderly women that completed 12 weeks of aquatic walking, dancing, and resistance exercise in an aquatic setting. The reductions in LDL are also similar to reductions that have been found in studies involving land-based combinations of aerobic and resistance training (Kelly & Kelly, 2007; Sunyer et al., 2007) in those with type 2 diabetes. The decrease in TG, likely associated with the concurrent decrease in BM among the participants, is important because it is an indicator of a decreased risk of macrovascular complications (Arora, Shenoy, & Sandhu, 2009) and cardiovascular risk (Balducci, Leonetti, Di Mario, & Fallucca, 2004; Cuff et al., 2003). The improvement in HDL/TG ratio of 23% is similar to the improvements in other aquatic exercise studies that showed an average decrease of 17% (Cugusi et al., 2015; Delevatti, Marson, & Kruel, 2015) and is important because it is represents a decreased risk for cardiovascular disease and other metabolic abnormalities (Gaziano, Hennekens, O.Donell, Breslow, & Buring, 1997; Jeppsen, Hein, Suadicani, & Gyntelberg, 1997; Salazar et al., 2013; Scott et al., 2009). An improvement in this ratio is also reflective of improvements in insulin action and insulin resistance (DeFronzo, 2009; Laws & Reaven, 1992; McLaughlin et al., 2003; McLaughlin et al., 2005). Therefore, it is speculated that an UTT program can be as advantageous as a traditional land-based treadmill program in improving overall metabolic control in adults with type 2 diabetes.

Body mass, %BF, and WC were all significantly lower compared to control values following participation in the training program. Body mass was reduced by an average of 4.11 kg across the 12 weeks and is consistent with the ACSM weight loss standard per week for adults (ACSM, 2014). This reduction is higher than the mean decrease of approximately 3.00 kg observed in the middle-aged men with type 2 diabetes that completed the 12 week aquatic exercise program in the Cugusi et al. (2015) investigation. The higher reduction in BM in the current sample is likely associated with the lower water height (10 cm below the xiphoid process as opposed to at the xiphoid process) and the higher exercise intensity of the training program (50 to 70% of HRR as opposed to 50 to 70% of $VO_{2\ max}$ at baseline). The present reduction in BM was also higher than the reduction (3.31 kg) following 12 weeks of a combination of 15 minutes of aerobic exercise on a land-based treadmill and 15 minutes of resistance exercise (two sets of leg press, leg curls, leg extensions, bench press, and seated deltoid rows) performed in the study by Ho, Radavelli-Bagatini, Dhaliwal, Hills, and Pal (2012).

One mechanism linked to the decrease in BM is the increase in daily physical activity performed by the participants while not in the laboratory. Our data indicated the amount of DACE increased by 13%. This increase in energy expenditure is similar to the increase found by Cugusi et al. (2015), who also found an increase in energy expenditure throughout the day due to an increase in the amount of daily physical activity being performed. The increase in DACE is likely attributable to being more active on a daily basis while performing activities of daily living since no participants began a structured training program outside of the study. Therefore, performing UTT lead to an overall increase in the amount of daily physical activity, which would lead to a decrease in the amount of cardiovascular risk and mortality rate in high-risk populations, such as adults with type 2 diabetes (Cugusi et al., 2015; McAuley, Myers, Abella, Tan, & Froelicher, 2007).

Our participants also had a significant reduction in BF% of 2.7%. This decrease coincides with an average decrease of 1.0% to 3.0% found in research studies using a combination of separate aerobic and resistance exercise in adults with type 2 diabetes (Cuff et al., 2003, Maiorana, O'Driscoll, Goodman, Taylor, & Green, 2002; Marcus et al., 2008). Similar reductions in BF% were also seen in a study involving 16 weeks of shallow-water, circuit training in overweight, postmenopausal women (Volaklis, Spassis, & Tokmakidis, 2006), and a study that incorporated an eight month aquatic aerobics program performed in shallow water with 38 middle-aged, women who were obese (Gappmaier, Lake, Nelson, & Fisher, 2006). The improvement in BF% in our participants is higher than land-based exercise training performed in adults with type 2 diabetes (Marcus et al., 2008; Sigal et al., 2007) and to a reduction of 1.5% that was reported following 12 weeks of an insulin-therapy intervention in middle-aged adults (Shah et al., 2011). It is important to note that the caloric expenditure associated with the concurrent aerobic and resistance work performed by moving the upper and the lower limbs against water resistance during UTT is higher than walking at similar speeds on dry land (Alkurdi et al., 2010). This increased caloric expenditure, coupled with the stable dietary consumption of the current participants, likely contributed to the larger decrease in BF%. This is a promising outcome given that BF% is highly positively correlated with all-cause and cardiovascular mortality (Lahmann, Lissner, Gullberg, & Berglund, 2002; Romero-Corral et al., 2010) and the development of glucose intolerance (Rodriguez, Catalan, Gomez-Ambrosi, & Fruhbeck, 2007; Wahrenberg et al., 2005).

Along with the improvement in BF%, we documented an average reduction in WC of 5.8 cm, illustrating a decrease in risk of diseases associated with abdominal fat patterning. This reduction in WC is similar to a mean reduction of 5 cm reported by Jones, Mererdith-Jones, and Legge (2009) following 12 weeks of deep-water circuit training in older, overweight women and a reduction of approximately 6.0 cm observed in middle-aged men following 12 weeks of an aquatic-based exercise program (Cugusi et al., 2015). The reduction in WC may be a reflection of a decrease in centrally distributed visceral and/or subcutaneous fat mass. A reduction in visceral fat is important because the amount of visceral fat in the abdominal region is directly linked to insulin sensitivity and can play a direct role in influencing intramyoclellular fat storage on insulin receptor function within muscle tissue. Therefore, exercise in an underwater treadmill can help with the reduction of central adiposity and may help improve insulin receptor sensitivity in adults with type 2 diabetes (Marcus et al., 2008).

A low level of aerobic fitness in adult men and women is an independent risk factor of all-cause mortality and cardiovascular disease risk, and has been associated with an elevated metabolic risk (Blair & Brodney, 1999; Blair et al., 1989; Jurca et al., 2005). In this study, RHR, RDBP, RSBP, and 6MWFD were used as indirect indicators of improved cardiovascular fitness and cardiovascular performance amongst our participants

(Jones et al., 2009; Jurca et al., 2005). Resting heart rate was 8 bpm lower (10% reduction) after training. This change is in line with the results of Bocalini, Serra, Murad, and Levy (2008), who also showed a 10% reduction in RHR in healthy, sedentary, older women following participation in 12 weeks of water-based exercise (45 minutes/day of races, arm and leg movements, and water-resistance exercises).

Resting diastolic blood pressure was reduced by an average of 6 mm Hg and RSBP was reduced by an average of 8 mm Hg, which is consistent with a 5-7 mm Hg reduction seen in adults who are hypertensive following an aerobic training program (Johnson et al., 2014). The reduction in resting blood pressure is promising due to the fact that hypertension is present in more than 60% of people with type 2 diabetes (Ezzati & Lopez, 2003; Grossman, Messerli, & Goldbourt, 2000; Stewart, 2004) and the risk of vascular complications is 66 % to 100 % higher in a person that has both hypertension and type 2 diabetes, compared to an individual that has just one of the aforementioned conditions (Grossman et al., 2000; Hayashino et al., 2012; Mourad & Le Jeune, 2008).

The 6MWFD test has been shown to be valid in identifying mobility performance and function in adults and the distance traveled during the test has been shown to be lower in adults with type 2 diabetes compared to adults without the metabolic condition (Gibbons, Fruchter, Sloan, & Levy, 2001, Marcus et al., 2008). The improvement in walking distance was higher than the average 70 m improvement that was reported by Asa et al. (2012). It is speculated that the greater increase in walking distance is based upon the longer duration of our training study, which would allow for more central and peripheral adaptations (Asa et al., 2012). Increases in walking capacity could allow adults with type 2 diabetes to engage in and sustain exercise or work for longer period of time and improve overall health (Meredith-Jones, Waters, Legge, & Jones, 2011; Takeshima et al., 2002). The increased performance in the 6MWFD was also higher compared to the reported average increase of 46 meters in the Marcus et al. (2008) investigation. A lower baseline walking performance (M = 493.1 m) amongst the participants in our study, as compared to the study by Marcus et al. (2008) (M = 554.5 m), could explain the greater changes following the combination of aerobic and resistance exercise performed with UTT. While not directly assessed, it is suspected that the increased cardiovascular fitness and decrease in BM, from participation in UTT, resulted in the improvements in walking capacity.

Previous studies have shown that adults with type 2 diabetes have significantly more muscle weakness, specifically in the lower body, as opposed to adults that do not have type 2 diabetes (Andersen, Nielsen, Mogensen, & Jakobsen, 1996; Andersen, Poulsen, Mogensen, & Jakobsen, 1996; Park et al., 2006). This muscle weakness leads to impaired mobility, increased fall risk, and physical disability (De Rekeneire et al., 2003; Gregg et al., 2000; Gregg et al., 2002; Miller, Lui, Perry, Kaiser, & Morley, 1999; Ryerson et al., 2003; Von Korff et al., 2005). Our results included a 9% increase in hamstring peak torque and an 8% increase in quadriceps peak torque at $30°\cdot sec^{-1}$, following UTT. There was also an 11% increase in hamstring peak torque at $60°\cdot sec^{-1}$ and a 12% increase in quadriceps peak torque at $60°\cdot sec^{-1}$. These findings align with recent data showing higher leg strength in middle-aged adults following an eight week underwater treadmill walking program (Conners et al., 2014) and several other studies that found significant increases in leg strength after traditional resistance training in adults with type 2 diabetes (Castaneda et al., 2002; Dunstan et al., 2002; Ibanez et al., 2005; Larose et al., 2010). The finding that the increases in leg strength from UTT are similar to those seen in land-based studies is beneficial to adults with type 2 diabetes because performing exercise in water is safer and involves less stress on the joints. Adults with type 2 diabetes are at a higher level of risk for musculoskeletal injuries and being able to achieve increases in lower body strength will make it safer to perform exercise in a population of adults who, on average, have diminished exercise tolerance and poor lower extremity function (Brooks et al., 2007; Melton et al., 2008).

Our increases in leg strength are also similar to the increases in knee extension by 8% and knee flexion by 13% in studies involving older and overweight women, respectively, completing aquatic exercise interventions (Jones et al., 2009; Takeshima et al., 2002). The increase in leg strength is associated with moving the limbs against the resistance provided by the water. Water is 800 times denser than air and provides upwards of 4 to 42 times greater resistance to movement (Meredith-Jones et al., 2011; Tsourlou, Benik, Dipla, Zafeiridis, & Kellis, 2006). These results indicate that the use of an UTT program could be helpful in delaying limited mobility, which has been shown to affect independence and quality of life in adults with type 2 diabetes (Van Schie, Vermigli, Carrington, & Boulton, 2004). It is also speculated that the benefits of performing this form of aquatic exercise include adaptions to skeletal muscle that allow an increased glucose metabolic rate for individuals with type 2 diabetes (Albright et al., 2000).

The findings of this study support the concept of using an aquatic based walking program in an underwater treadmill as an exercise modality for the treatment of type 2 diabetes in adults. A possible limitation of this study is the current accessibility and application of self-contained aquatic treadmills in a community setting. However, there has been an increase in commercial availability of self-contained and portable units. Future research incorporating multiple water temperatures and water heights is needed in an effort to better generalize these data to alternative settings. Overall, our results indicate that performing UTT can significantly improve glycemic control, metabolic control, body composition, cardiovascular health, leg strength, and DACE in adults with type 2 diabetes. It may also have an additional benefit of decreasing the number of hypoglycemic events in adults with type 2 diabetes that wish to gain the benefits of both aerobic and resistance exercise.

CHAPTER IV REFERENCES

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APPENDICES

APPENDIX A

Three Day Food Record

A three day food record is designed to get an accurate description of your typical daily diet. Because this food record will be used to help you record your diet, try not to change your usual eating patterns for these 3 days. Please try to be as accurate as possible by recording all of the foods and beverages you eat and drink. Include the exact amount of food eaten and important variations (ex. skim, 2%, reduced fat, sugar-free, etc). If the food is prepared at home or in a restaurant, please include a description of the preparation techniques (ex. grilled vs. fried). If available, please put the brand or the product name that you consumed. If you ate at a location other than your home, you can include the restaurant or location name in this section as well. Remember, the more information you can provide, the better we will be able to accurately determine the amount of nutrients and calories consumed. If you have any questions, at any time, please feel free to call me at (315) 382-5186 or email at Ryan.Conners@mtsu.edu.

In order to get an accurate representation of your diet, record your food intake for 2 weekdays and 1 weekend day (ex. Monday, Thursday, & Saturday).

<u>*Example Log:*</u>

Time	*Food & Beverage Description*	*Serving Size*	*How was it Prepared/*	*Brand*
7:15 am	Blueberry bagel	1	Toasted	
	Margarine	2 tablespoons		
	100% orange juice	6 ounces		
12:30 pm	Grilled chicken	3 ounces		ChickFil-A
	Romaine lettuce	1 cup		

	Spinach leaves	1 cup		
	Baby carrots	½ cup		
	Bacon bits	2 tablespoons		
	Kraft Italian dressing	2 tablespoons		
	Ritz crackers	4		
	Water	16 ounces		
6:00 pm	Pizza Hut hand-tossed pepperoni pizza	3 slices		Pizza Hut
	Diet Coke	16 ounces		
9:15 pm	Chocolate chip cookies – 4" diameter	4		Subway

Time	*Food & Beverage Description*	*Serving Size*	*How was it Prepared*	*Brand*

APPENDIX B

IRB Letter of Approval

MIDDLE TENNESSEE STATE UNIVERSITY

9/7/2014

Investigator(s): Ryan Conners, Dr. Jennifer Caputo
Department: HHP
Investigator(s) Email: Ryan.Conners@mtsu.edu, Jenn.Caputo@mtsu.edu

Protocol Title: "**EFFECTS OF AN UNDERWATER TREADMILL WALKING PROGRAM ON GLYCEMIC AND METABOLIC CONTROL, CALORIC EXPENDITURE, AND HEALTH-RELATED FITNESS IN ADULTS WITH TYPE 2 DIABETES** "

Protocol Number: 15-039

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for 40 participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will not be able to use any data and/or collect any data. Your study expires **9/7/2015**.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. **If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.**

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

Kellie Hilker

APPENDIX C

Medication Log

MEDICATION LOG			
Participant Name:		Date of Initial Diagnosis of Type 2 Diabetes (xx/xx/xxxx)	
DATE	MEDICATION		
Start / Stop	Name	Dosage	Amount Taking

CHAPTER V

OVERALL CONCLUSIONS

The prevalence of type 2 diabetes continues to increase on both national and international levels. This global health problem continues to result in increased mortality rates and is estimated to effect over 300 million people worldwide by the year 2025 (Polikandrioti & Doloutsidou, 2009). Type 2 diabetes is commonly associated with being overweight or obese and having a sedentary lifestyle (Helmrich, Ragland, Leung, & Paffenbarger, 1991). Dietary interventions, prescription medication, and exercise are the cornerstone treatments in the fight against type 2 diabetes.

The improvements in glucose control, RHR, resting blood pressure values, and health-related fitness in adults with type 2 diabetes from exercise are well-documented (Eriksson & Lindgarde, 1991; Helmrich et al., 1991). Specifically, it is known that performing both aerobic and resistance exercise is superior to performing one of these modes in isolation with regards to improving glycemic control, metabolic control, and body composition (Sigal et al., 2007). Despite these benefits, exercise remains an underutilized management tool in treating and preventing type 2 diabetes. Both the ACSM and the ADA recommend that adults with type 2 diabetes perform at least 150 minutes of exercise per week (Colberg et al., 2010). Due to the comorbidities and complications associated with the disease, adults with type 2 diabetes often find that meeting these guidelines is difficult to achieve (Delevatti, Marson, & Kruel, 2015).

The comorbidities associated with type 2 diabetes make land-based exercise particularly more problematic. A potential solution to this problem is performing exercise in an aquatic environment where one can achieve both aerobic and resistance training benefits concurrently. This combination leads to a shorter overall exercise session that could potentially lead to a decreased risk of a hypoglycemic event. Furthermore, the aquatic environment exploits the benefits of buoyancy which include reduced ground reaction forces (Delevatti et al., 2015), decreased musculoskeletal injury risk, and lower risk of falls in sedentary adults with type 2 diabetes (Batista et al., 2008; Gaida, Cook, & Bass, 2008). Hence, the main objectives of this dissertation were to investigate the effectiveness of an UTT program in adults with type 2 diabetes on glycemic control, metabolic control, cardiovascular health, and other aspects of health-related fitness.

The purpose of the first study was to determine the outcomes of an UTT program in improving glycemic control and health-related fitness in adults with type 2 diabetes. It was hypothesized that participation in the eight week program with no change in diet would lower HbA1c and body composition, improve cardiovascular measures, and increase leg strength. All measurements were taken at baseline and one week after the conclusion of the UTT program. As hypothesized, there were significant reductions in HbA1c, BM, BF%, RHR, and WC. In addition, there were increases in aerobic capacity, hamstring strength, and quadriceps strength. This initial investigation demonstrated the safety and efficacy of UTT in adults with type 2 diabetes.

The purpose of the second study was to improve on the first study by incorporating a larger sample size, a control group, and more health and metabolic variables. It was hypothesized that the longer duration of the second study (12 weeks) would result in greater improvements in glycemic control. It was also hypothesized that metabolic control would improve as a result of participation in the walking program, as would the cardiovascular risk profile of the participants. Lastly, it was hypothesized that cardiovascular measures (RHR and resting blood pressure values), anthropometric values (BM, BF%, and WC), leg strength, and caloric expenditure would improve as a result of the intervention.

A total of 26 participants were randomized into either an UTT group or a control group and a randomized cross-over design was utilized. The underwater treadmill group completed three days of walking per week at low to moderate levels of intensity. The participants in the control group maintained their current exercise and dietary habits. All measurements were assessed at baseline, week 13, and week 26. All 26 participants completed the study. There were significant reductions in HbA1c and improvements in HDL, LDL, TG, and HDL/TG following training. There were also reductions in BM, BF %, and WC. Resting heart rate, RDBP, and RSBP were lower. Lastly, there were increases in 6MWFD, hamstring peak torque, and quadriceps peak torque.

Both studies confirmed that performing a submaximal UTT program is effective in the treatment and management of type 2 diabetes in adults. Due to the high adherence rate and only one hypoglycemic event, UTT is a safe exercise medium for adults with this metabolic disorder. Taken together, these findings highlight the value of using an aquatic based exercise setting to improve glycemic control. The results of this dissertation are also in support of the need for local fitness facilities to use aquatic treadmills as an effective exercise medium for their clients with type 2 diabetes. Future research needs to be performed in regards to the effectiveness of pool walking programs as opposed to self-contained underwater treadmills. This would help to make aquatic exercise more feasible and available for a larger population.

DISSERTATION REFERENCES

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