The Response of Blood Lactate and Glucose in Type I Diabetes to a Single Bout of Supramaximal Exercise With and Without Carbohydrate Ingestion

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Abstract

This randomized double-blind, placebo-controlled, crossover study closely examined the effects of carbohydrate supplementation before and throughout supramaximal exercise on blood glucose and blood lactate levels in active males between 18 and 35 years old with or without type 1 diabetes. 7 healthy males between 18 and 35 years old with IDDM (26.4±3.6 years) and 12 healthy males (29.2±3.1 years) between 18 and 35 years old without IDDM were asked to complete a baseline VO2max session, 2 self-report food and insulin logs, and two intervention sessions. Intervention sessions consisted of a 12 hour fast prior to testing, a 60 second Wingate test on a cycle ergometer, and a 5-minute lactate accumulation phase. 30 minutes of active recovery cycling was completed followed by 30 minutes of seated passive recovery. During each intervention session participants either consumed 12oz placebo drink (Crystal Light) or 12oz 6% carbohydrate drink (Dextrose and Crystal Light). Throughout all sessions blood glucose levels, blood lactate levels, heart rate, and blood pressure measurements were taken. MANOVA and Post Hoc analysis were used to calculate any significant correlations. Post Hoc analysis of the Carbohydrate supplement demonstrated a significant response to blood glucose levels in the IDDM group compared the non-IDDM group with a p-value of .00 in which the carbohydrate supplement in conjunction with the supramaximal exercise lead to an elevated blood glucose level in the IDDM group (173.56 mg/dL±8.9) compared to the non-IDDM group (100.17 mg/dL±6.9). The IDDM group also had a significantly higher blood lactate post wingate test of 13.17 mmol/L compared to the non-IDDM group of 10.51 mmol/L with a p-value=.035. The finding suggests it is safe for healthy individuals with IDDM to participate in supramaximal exercise; however, this group should closely monitor blood glucose levels prior to this type of exercise to design a carbohydrate supplementation plan that is best suited to their needs.
Chapter I: Introduction

Insulin Dependent Diabetes Mellitus (IDDM) is a disease that can cause severe complications without the proper management of glucose levels. These complications can range from macro and microvascular disease to coma and death. Physical activity plays a key role in the management of glucose for people who have IDDM. The American College of Sports Medicine (ACSM) deems exercise to be safe for people with type 1 diabetes and the exercise prescription is the same as it is for non-IDDM individuals (American College of Sports Medicine, 2010). Although physical activity is safe for people with IDDM, precautions must be taken to manage the acute effects that exercise can have on individuals with IDDM. Hypoglycemia and Hyperglycemia are two common events that type 1 diabetics must be aware of when participating in exercise. Blood glucose monitoring before, during, and after exercise is extremely important for type 1 diabetics to help them to prevent these two events from occurring.

There is a population of highly physically active individuals that suffer from IDDM and this population not only needs to manage their glucose but they must be able to perform at high levels. Two common ways of controlling glucose during exercise is through carbohydrate consumption and insulin dosage modification. People with type 1 diabetes must rely on insulin therapy and are unable to reduce circulating insulin at the onset of exercise. This usually results in hypoglycemia and becomes the biggest challenge at the onset of exercise. This study focuses on the effects of carbohydrate consumption on supramaximal exercise and the response of blood lactate and blood glucose levels in active non-IDDM and IDDM participants. Current research gives broad guidelines as to the timing of consumption and the amount of carbohydrates these athletes should consume to prevent hypoglycemia prior to, during, and post-exercise. There is also a lack of research that examines the effects of carbohydrate ingestion on blood lactate
clearance. Prior research agrees as to the amount of carbohydrate that should be consumed but the timing of when to consume is a broad range from every 10 minutes to every 60 minutes. This range is not specific enough to allow IDDM athletes to achieve the goals of hypoglycemia prevention and improved athletic performance. Athletes with diabetes should not exercise when blood glucose is $> 250 \text{ mg/dL}$ or $< 100 \text{ mg/dL}$ and ketosis is present. If glucose is $> 300 \text{ mg/dL}$, it is probably inadvisable to exercise even without ketosis (American College of Sports Science, 2010). This study will examine the effects of carbohydrate consumption before and during supramaximal exercise on blood glucose levels and blood lactate levels. This is an area of research that is lacking and there is a great need for it given that in the United States of America alone there are 1.29 million people living with type 1 diabetes (American Diabetes Associate, 2011; Center for Disease Control, 2011). Having a better understanding of the effects of carbohydrate consumption before and during supramaximal exercise on blood glucose and blood lactate levels in physically active non-IDDM and IDDM participants will have important implications for individuals living with this disease.

**Statement of the Problem**

There are few randomized trials that focus on physically active IDDM subjects for managing blood glucose during supramaximal exercise. This study examined the response of consuming a 6% carbohydrate sports drink on blood glucose and blood lactate levels throughout supramaximal exercise for non-IDDM and IDDM subjects. The main research question in this study is if consuming a 6% carbohydrate sports drink prior to and during supramaximal exercise and active recovery will effect blood lactate and blood glucose levels. There are a few other questions that will be examined as well which include: if there is a difference between IDDM and non-IDDM subjects with regard to lactate accumulation, if the carbohydrate drink leads to
improvements in lactate recovery in both or either group, does the supplement and interval of administration have any complications that increase or decrease the risk of hypo and/or hyperglycemia, if there are any complications to supramaximal exercise in each group with and without the glucose supplement. We examined these questions while answering the main question regarding the response of blood lactate and blood glucose levels to the ingestion of the 6% carbohydrate drink in non-IDDM and IDDM subjects.

**Scope of the Study**

This double blind randomized study assessed 19 male subjects between 18 and 35 years old who engage in physical activity 3 or more times per week with an HbA1c ≤ 8.5%. Subjects were recruited through the Northeastern University campus and local groups associated with diabetes research such as the Joslin Diabetes Center in Boston, MA. All data were collected using the protocols approved in the signed informed consent and following the guidelines approved by the Northeastern University IRB.

Fitness capacity was assessed using a cycle ergometer VO$_2$ max test following a ramp protocol. This test allowed us to determine the active recovery zones for each participant’s intervention sessions along with their current fitness level.

Blood glucose and blood lactate were tested using a One Touch Ultra Glucose Meter and a Nova Biomedical Lactate Meter. Both of these units allowed for the researchers to monitor blood glucose and blood lactate levels to ensure the safety of the participants and for data collections. Anthropometric measurements such as height, weight, and BMI along with other basic physiological tests such as heart rate and blood pressure were taken throughout the testing sessions.
Diet and nutrition information was gathered using self-report food logs that participants were asked to fill out prior to testing sessions. This allowed us to determine if differences in diet are attributed to our results. Self-report Insulin logs were also administered to examine the possible differences in treatment and performance.

Limitations

As with any study there are some limitations that must be explained. The population of physically active people with type 1 diabetes is specialized and therefore may result in a study sample size that is small. Type 1 diabetes is also a variable disease and can affect everyone differently. It is this small sample size and variability in IDDM participants that are some of the major limitations. This means that a small variation in the data collected by one participant can have a large effect on the results. In order to minimize possible confounding variables, participants will be used as their own controls with a wash-out period of at least 3 days.

Another possible limitation of this study is that of the state of the glucose control of participants entering the study. A person with poor glucose control, determined by hbA1c, may react differently than a person with good glucose control. It is for this reason that this study will set inclusion criteria to a specific HbA1c range of less than 8.5% in order to participate. All testing was done in the morning after a 12 hour fast to better control the glucose levels of all subjects. These limitations were taken into account in the study protocol and have been minimized as best as possible thus making the conclusions of this study valid and reliable.

Hypothesis

For the purposes of this study the following hypothesis have been set:
1.) Pre-training ingestion of a 6% carbohydrate drink and frequent ingestion during and after supramaximal intensity exercise will increase glucose levels throughout exercise and will significantly decrease lactate clearance in IDDM subjects.

2.) There will be a positive correlation between the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between non-IDDM and IDDM subjects.

3.) There will be no difference in response to the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between non-IDDM subjects.

4.) There will be no difference in response to the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between IDDM subjects.

5.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between non-IDDM and IDDM subjects.

6.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between non-IDDM subjects.

7.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between IDDM subjects.

**Definition of Terms**

**IDDM**-Insulin Dependent Diabetes Mellitus or type 1 diabetes-a chronic disease in which the body does not produce insulin. The treatment for this disorder is exogenous insulin.

**HbA1c**-Glycated Hemoglobin-this is a measure of the average plasma glucose concentration over the past 120 days. For this study, a controlled HbA1c level will be defined as anything under 7.0%
**Hypoglycemia** - This is a condition that occurs when blood glucose is too low. For this study, hypoglycemia will be considered to be a blood glucose $\leq 70$ mg/dL based on American College of Sports Medicine guidelines (2010).

**Hyperglycemia** - This is a condition that happens when blood glucose is considered to be too high. This will be defined as a blood glucose level $\geq 250$ mg/dL based on American college of Sports Medicine guidelines (2010).

**Supramaximal Exercise** - This is a level of exercise that requires energy from anaerobic metabolism. Based on prior research, this will be defined as 120% of VO$_2$max of each subject for this study (Dantas-De-Lucas et al., 2003).
Chapter II: Literature Review

Diabetes mellitus, also known as type 1 diabetes or insulin-dependent diabetes mellitus (IDDM), is a chronic disease in which the body does not produce insulin. Type 1 diabetes occurs when the body’s immune system attacks its insulin producing beta cells in the pancreas (American Associate of Diabetes Educators, 2011). The only treatment for type 1 diabetics is exogenous insulin therapy. However, type 1 diabetes is a manageable disease with proper diet, exercise, and insulin treatments. Over the past twenty years many studies focusing on exercise and glucose control have been conducted among non-diabetic individuals along with type 1 and 2 diabetic populations. The major burden of type 1 diabetics is managing blood glucose levels throughout and after exercise in an effort to reduce the incidence of hypo- and hyperglycemic events. The purpose of this chapter is to examine prior works on the blood glucose and blood lactate responses to different forms of physical activity in type 1 diabetic populations.

Background

Many benefits exist for people with IDDM to participate in exercise programs which include improving blood glucose management, increasing insulin sensitivity, lowering blood pressure, improving lipid profiles, and lowering weight and reducing the risk of complications associated with IDDM. The American Diabetes Association (ADA) and American College of Sports Medicine (ACSM) encourage type 1 diabetics to participate regularly in aerobic and resistance activity (American College of Sports Medicine, 2010; American Diabetes Association, 2004). Although exercise is encouraged for people with IDDM, there is a common barrier to exercise for this population, the fear of hypoglycemia during and after exercise (Brazeau et al., 2008). Although this fear of hypoglycemia is the main barrier (Brazeau et al. 2008), there were three additional barriers that were also considered significant. The three other barriers to
exercise in IDDM subjects are work schedules, loss of control over diabetes, and low fitness levels. The ADA encourages all people with type 1 diabetes to exercise regularly; however, this population must take extra precautions compared to non-diabetic individuals (American College of Sports Medicine, 2010; American Diabetes Association, 2004). Exercise helps type 1 diabetics prevent heart disease, high blood pressure, and obesity while helping to manage blood glucose levels (ADA, 2011). The most important goal, in managing diabetes, is to keep blood glucose levels as close to normal as possible without causing hypoglycemia (Jimenez et al., 2007). Hyperglycemia can occur from high intensity exercise at 70% of peak VO2 or higher. High intensity exercise leads to increased catecholamine levels, free fatty acids, and ketone bodies which all increase blood glucose levels. This is seen more commonly in athletes because these high levels of intensity are not commonly seen during prolonged periods of time during normal physical activity and exercise. If fasting blood glucose is greater than or equal to 250 mg/dL before exercise and ketones are present, then exercise is contraindicated. If no ketones are present the person can exercise but should proceed with caution (Jimenez et al., 2007). This is a particularly important consideration for this study because the focus is on active males with IDDM and many athletes go into exercise with higher blood glucose levels than 250mg/dL to prevent incidence of hypoglycemia. This prior research helped in this study’s protocol design that was safe for type 1 diabetic participants.

The ADA suggests that type 1 diabetics follow the same standards of physical activity set forth by the Surgeon General’s Report on Physical Activity and Health which states that individuals should participate in 30 minutes of moderate physical activity most days of the week (American Diabetes Association, 2004). Type 1 diabetics are different because they must find an insulin therapy and nutritional regime that best suits this active lifestyle while reducing the risks
of hypoglycemia and hyperglycemia. All types of exercise are appropriate for type 1 diabetics including aerobic endurance activities and resistance activities. Resistance training is also considered to be safe and effective for type 1 diabetics (Ehrman et al., 2009). It is perfectly safe for people with IDDM to participate in sports and be collegiate and elite level athletes based on the information provided by the ADA and ACSM.

Since type 1 diabetes does carry some risks while performing exercise, the ACSM has provided some noteworthy precautions for the exercise prescription in this population that are supported by other studies. The time of day that a type 1 diabetic participates in exercise is extremely important. Exercise should not be performed at peak insulin level as this will increase the risk of hypoglycemia (Bussau et al., 2011.; Ehrman et al., 2009.; ACSM, 2010). If exercising in the late evening, type 1 diabetics should consume carbohydrates to reduce the incidence of nocturnal hypoglycemia. While exercising the individual should be aware of the symptoms associated with hypoglycemia which include shakiness, weakness, abnormal sweating, anxiety, and tingling of the mouth and fingers. Blood glucose monitoring should be done before and following exercise and medications should be adjusted so that blood glucose is at least 120 mg/dL (Tansey et al., 2006). Hyperglycemia with and without ketosis is also a risk for type 1 diabetes during exercise. Symptoms of this include polyuria, fatigue, increased thirst, and acetone breath. People who have hyperglycemia without ketosis can exercise but should not participate in any high-intensity activities. Type 1 diabetics with complications such as autonomic neuropathy and retinopathy should avoid vigorous-intensity aerobic exercise and resistance exercise should be avoided (ACSM, 2010). An effective exercise program for the type 1 diabetic should be that of a non-diabetic individual; however, blood glucose should be
monitored closely and insulin dosage and carbohydrate consumption should be adjusted to help prevent hypo- and hyperglycemia from occurring during and post exercise.

Much of the information provided by the ADA and ACSM is based on prior works in this field of exercise and IDDM. The results of these studies have helped provide organizations with vital information to safely and effectively design training programs and testing protocols specifically for people with IDDM. These studies have also provided information of the risks of exercise on type 1 diabetes and the preventative measures for type 1 diabetics to take during exercise. These works are essential in designing future studies that specifically target the population of athletes with IDDM rather than the general population of type 1 diabetics. It also allows future researchers to understand that high intensity exercise is safe for testing procedures for subjects with IDDM.

**Hypoglycemia and Hyperglycemia in IDDM**

Type 1 diabetics carry around the added complications of hypoglycemia during and after exercise. Most research on the acute effects of exercise for type 1 diabetics revolves around hypoglycemia and blood glucose control. Much of the current research focuses on the acute effects of exercise on blood glucose concentrations along with the hormones that may affect hypoglycemia. The major conclusion for these studies is that prolonged, low to moderate intensity exercise causes a rapid drop in blood glucose concentration and blunts the counterregulatory hormonal effects of exercise on blood glucose. This increases the risk of hypoglycemia post exercise. This provides the important rationale in the design of this study regarding the timing of administration of carbohydrates to prevent hypoglycemia. Throughout this study there was an emphasis on blood glucose monitoring to prevent any ill effects to subjects. The ACSM guidelines for exercise for people with IDDM were followed to prevent
hypo and hyperglycemia as well as injuries. These precautions included: not having IDDM subjects exercise with a blood glucose level less than 70 mg/dL; not having IDDM subjects exercise during hours of peak insulin action; not exercising until pre-exercise blood glucose is over 100 mg/dL; having subjects avoid injecting insulin into the exercising limbs; postponing exercise in IDDM subjects with a blood glucose greater than 250 mg/dL with ketosis; avoiding vigorous exercise with IDDM subjects who have retinopathy and taking extra precautions to take care of the feet if peripheral neuropathy is present (American College of Sports Medicine, 2010). The current study is novel because no prior studies have investigated the effects of carbohydrate administration during and post-exercise supramaximal exercise specifically for active males with IDDM. The ADA suggests that carbohydrate administration is up to the needs of the person, a major aim for this study is to find the blood glucose response to carbohydrate administration for high intensity activity.

Physical activity provides an important method of preventing many complications associated with IDDM and controlling glucose levels; however, the number one barrier to the participation in exercise in type 1 diabetics is the fear of having a hypo- or hyperglycemic event (Brazeau et al., 2008). This is one reason why researchers have been examining the frequency of glycemic events during and post exercise. The studies reviewed in this chapter use different mechanisms to try to help people with IDDM keep blood glucose under control during and immediately after a single bout of exercise. These mechanisms include reducing insulin dosages prior to exercise, mixing up the timing of carbohydrate ingestion and using high intensity sprints to oppose the fall in blood glucose after moderate intensity exercise. Based on much of the research on IDDM and exercise, the ADA and ACSM has devised a set of guidelines for exercise...
prescription for type 1 diabetics that includes these carbohydrate consumption and insulin administration recommendations.

Type 1 diabetics are able to participate in physical activity and sports like other healthy individuals. Exercise has been proven to benefit people with type 1 diabetes (Tansey et al., 2006). The major difference for type 1 diabetics is that there is the potential for dangerous effects of acute exercise such as hypo- or hyperglycemia. The incidence of hypoglycemia during and post exercise tends to be higher than that of hyperglycemic incidents. Tansey et al. examined the acute effects of aerobic exercise on blood glucose levels in 50 adolescents with type 1 diabetes. This was a randomized trial in which subjects did one 75-minute moderate intensity walking session in the late afternoon on one day. Then one to four weeks later the subject came back and did no exercise to serve as the control. The subjects followed their normal insulin treatments for both days. Blood samples were taken every 15 minutes, immediately after finishing the exercise, and then 30 minutes after the end of the test. Glucose levels were taken every 15 minutes of the test. Tansey et al. demonstrated results that included rapid reduction in glucose concentrations within the first 15 minutes of exercise and extended until 45 minutes after the test ended. Subjects were also observed to have an increase in growth hormone and norepinephrine but not significant changes in plasma cortisol and glucagon. 15 of the 50 subjects experienced a hypoglycemic event. The major outcome that is relevant for this study is that the blood glucose drops rapidly which can lead to hypoglycemia in prolonged exercise. In order for type 1 diabetics to prevent hypoglycemic events during and after aerobic exercise bouts, the blood glucose levels should be at least 120mg/dL to help reduce the risk of this acute effect of exercise (Tansey et al., 2006). This result supports the ACSM’s 2010
guidelines for exercise prescription for safe blood glucose levels prior to exercise for type 1 diabetes mellitus patients.

Aerobic exercise that is performed at moderate intensity is known to increase the risk of hypoglycemia in type 1 diabetics during and after exercise due to the rapid decrease in plasma glucose (Bussau et al, 2011; Tansey et al, 2006). Since many sports and activities that people do for exercise include both aerobic and anaerobic components, blood glucose monitoring is extremely important in keeping type 1 diabetics safe. Blood glucose monitoring and control is the most effective way of preventing a hypoglycemic event during and after a single bout of exercise. Aerobic exercise is proven to lower blood glucose concentrations. Conversely, high intensity exercise has been shown to increase blood glucose and studies are being conducted to see if this is an effective way of preventing hypoglycemia during and after exercise (Bussau et al., 2011). Bussau et al. studied the effect of 10 second sprints as a method of opposing a drop in glycemia from moderate intensity exercise instead of resting post exercise. Bussau et al. had 7 IDDM patients ride a cycle ergometer at 40% of peak VO₂, for 20 minutes. After the 20 minutes, the subjects were asked to either rest or complete a single 10 second sprint. The acute effects of this exercise bout found a rapid and significant decrease in blood glucose during the 20 minute moderate intensity aerobic exercise, which is a similar result to that of Tansey et al. The sprint group was able to oppose a further drop in blood glucose for the next 120 minutes, while the control group that rested after the 20 minute aerobic exercise continued to see a drop in glucose (Bussau et al., 2011). The 10 second sprint group saw epinephrine and norepinephrine reach maximum levels after the 10 second sprint as well as increased levels of growth hormone and cortisol. These hormones counteract the drop in blood glucose and the 10 second sprint was able to increase these hormones to near maximal levels. This is why there was a reduction in the
depletion of glucose after moderate intensity exercise. Bussau et al. concluded that in healthy type 1 diabetics without complications, a 10 second sprint should be performed after moderate intensity exercise just before resting in order to oppose an exercise-mediated fall in glycemia (Bussau et al., 2011). This result demonstrated the acute effect of exercise on the hormones of type 1 diabetics as well as helping to support the conclusion that moderate-intensity exercise rapidly decreases blood glucose levels in type 1 diabetics. This result also helps future researchers to use a new mechanism for preventing exercise induced hypoglycemia. Sprinting in conjunction with carbohydrate consumption during exercise may be extremely effective in the management of glucose concentrations during and post exercise.

Sandoval et al. (Sandoval et al., 2006) examined if exercise caused blunted autonomic and metabolic responses to hypoglycemia in type 1 diabetics. In order to test this idea Sandoval et al. examined the acute effects of morning exercise or moderate hypoglycemia on autonomic, neuroendocrine, and metabolic responses during afternoon hypoglycemia in type 1 diabetics. Subjects were placed in one of four groups: hyperinsulinemic euglycemic clamp group, hyperinsulinemic hypoglycemic clamp, control group and the exercise group. The control group sat in a chair and the exercise group used an upright cycle ergometer pedaling at 60 to 70 rpms for 90 minutes. Insulin was infused into both the control group and exercise group throughout the test and plasma glucose was measured every five minutes. The exercise group experienced an increased heart rate and systolic blood pressure due to the morning hypoglycemia. Norepinephrine and cortisol levels were increased during the last 30 minutes of exercise. The lactate increase was significantly higher in the exercise group than the control group who had morning hypoglycemia. In the afternoon, the insulin and plasma glucose levels were similar among the four groups. Epinephrine was lower in the exercise group compared to the control
group. Norepinephrine, growth hormone, cortisol, and glucagon were all at similar levels in the four groups. Heart rate seemed to increase significantly in all hypoglycemic subjects but SBP, DBP, and MAP did not change in any of the groups in the afternoon. The key finding in this study was that acute exercise blunted epinephrine response and based on this, Sandoval et al. concluded that morning exercise is a major risk factor for hypoglycemia in type 1 diabetics.

There are counter-regulatory deficits that occur within hours of morning exercise or hypoglycemia and they can last for up to 24 hours, causing exercise induced hypoglycemia (Sandoval et al., 2011). It is this acute exercise effect that provides support for the strict adherence to blood glucose monitoring and insulin adjustments after exercise in type 1 diabetics to help reduce the risk of exercise induced hypoglycemia. This result is similar to the acute effects of antecedent hypoglycemia on counter-regulatory response to exercise in type 1 diabetics that were researched by Galasetti et al. This study followed a similar procedure to that of Sandoval et al. except Galasetti et al. had patients stay overnight to see if a more severe hypoglycemia blunted counter-regulatory responses during next day moderate prolonged exercise. 22 type 1 diabetic patients rode an upright cycle ergometer at 60 to 70 rpms for 90 minutes at approximately 50% of peak VO2 which is the same as in the Sandoval et al. study. Galasetti et al. found that the group that had euglycemia had an increase in glucagon production while the hypoglycemic groups saw a reduction that depended on the depth of the hypoglycemia. The catecholamine production was also greatly reduced based on the depth of hypoglycemia in subjects. Galasetti et al. stretched out the acute effects seen in Sandoval et al. over a two day period and were able to conclude that there is a dose-response relationship between the depth of antecedent hypoglycemia and the severity of counter regulatory failure during future exercise. This has a large implication for active type 1 diabetics. Many high-school and collegiate athletes
practice at least once a day up to two times a day most days of the week. Galasetti et al. explained that hypoglycemia from one day can carry over to the next which is a point of concern for athletes. These studies demonstrate that morning exercise will cause hypoglycemia in afternoon exercise. For the type 1 diabetic athlete, this means insulin management and carbohydrate consumption must be strictly monitored and adhered. Finding the most effective timing and combination of insulin administration and carbohydrate intake before, during, and post exercise is one key to success in keeping these athletes safe and while having no negative impacts on performance.

Much of the prior work with IDDM and exercise has focused on the acute effects of exercise on hypo- or hyperglycemia. Rather than focusing on nutrition and ways to prevent these events, researchers have examined what causes these events to happen and if there is a mechanism that causes them to happen more frequently. These works have helped give future researchers a better understanding as to what mechanisms are involved in hypo- and hyperglycemic events. This knowledge now gives researchers the ability to look at specific interventions to help prevent these events such as through the use of reduced insulin dosages or carbohydrate supplementation. These studies lack the investigation into sports performance as well and this is where future research should set its sights.

**Carbohydrate Consumption Timing**

Prior research mainly focused on glycemic control during exercise through insulin, but there is another mechanism for control and that is through carbohydrate ingestion. Many of the guidelines for glucose ingestion prior to and during exercise set forth by the ACSM are based on prior studies of carbohydrate ingestion in non-diabetic individuals. The studies that have focused on this topic have found that there is no significant difference on how the body oxidizes
carbohydrates in IDDM subjects and non-diabetic subjects (Riddell et al., 2000). The current research on carbohydrate ingestion and exercise performance is focused mainly on non-diabetic individuals: however, based on ACSM recommendations and other prior works, carbohydrate ingestion and its effects on blood lactate levels can be generalized to the type 1 diabetic population.

One area that has been examined is the effect of carbohydrate ingestion on muscle glycogen during exercise. Robitaille et al. studied the substrate source utilization during moderate intensity exercise with glucose ingestion in Type 1 diabetic patients. This study compared eight healthy subjects with eight type 1 diabetics throughout 60 minutes of cycle ergometer exercise. Three hours prior to exercise all subjects ate a meal consisting of 80g of carbohydrates and then they were given 30g of carbohydrate 15 minutes before the exercise test. Robitaille et al. found that there were no significant differences in the amount of exogenous carbohydrates oxidized during the exercise by both groups. The type 1 diabetics oxidized 5.2g/30 minutes while the non-diabetic subjects oxidized 6.3g/30 minutes. The major difference between these two groups was that the IDDM subjects had significantly lower oxidation of plasma glucose and liver glucose while the muscle glycogen was significantly higher when compared to the healthy subjects (Robitaille et al., 2007). When glucose is ingested before or during exercise, IDDM subjects rely more on muscle glycogen and less on plasma glucose oxidation than non-diabetic control subjects (Robitaille et al., 2007). The results from this study are supported by Krzentowski et al. and Riddell et al., which conclude that type 1 diabetics who receive insulin have very similar fuel selection and oxidation of exogenous glucose as their non-diabetic counterparts (Robitaille et al., 2007). IDDM subjects appear to rely more on muscle glycogen and less on plasma glucose oxidation than non-diabetic individuals when glucose is
ingested. These results support the need for carbohydrate ingestion on improving athletic performance of type 1 diabetics while preventing hypo- and hyperglycemia.

The study by Robitaille et al. supports the idea that carbohydrate ingestion before and during exercise can improve exercise performance. One mechanism for fatigue is the depletion of muscle glycogen. According to Robitaille et al. people with IDDM have higher muscle glycogen oxidation during moderate intensity aerobic exercise. The carbohydrate ingestion during exercise has been shown to reduce the muscle glycogen utilization by up to 28% which means that it takes longer for a person to fatigue during exercise (Karelis et al., 2010). Even though muscle glycogen utilization is higher in people with IDDM, the use of carbohydrates helps to delay the onset of fatigue leading to improved performances. Ramires et al. (1997) examined the effects of oral glucose ingestion prior to exercise until exhaustion in health and IDDM subjects. Subjects in this study were given 1g/kg of glucose 30 minutes prior to exercise at 55 to 60% of VO2max until exhaustion. The results of this study saw that pre-exercise glucose administration increased endurance capacity in well controlled IDDM subjects whose blood glucose levels decrease during exercise (Ramires et al., 1997). A study by Tsintzas et al. demonstrated that ingesting 50g of carbohydrates during 60 minutes of exercise at 70% of VO2 maximum, subjects were able to spare 28% of glycogen and increase blood glucose levels (Karelis et al., 2010). The implications of this result for people with IDDM is that ingestion of carbohydrates will help to spare muscle glycogen as well as reduce the risk of hypoglycemia during this type of endurance exercise.

There is some research regarding the timing of carbohydrate consumption during exercise. Prior research demonstrates mixed results as to whether timing of carbohydrate consumption can improve athletic performance. Krzentowski et al. examined whether the timing
of exogenous glucose ingested during exercise affects exogenous glucose disposal. In this study, 9 subjects participated in four hours of running on a treadmill at 45% of VO2 max. All subjects were given 100g of glucose given orally. One group was given this glucose 120 minutes into the exercise test and the other group received this oral glucose 15 minutes after the onset of exercise. Krzentowski et al. found that there was no statistical difference in glucose oxidation between the two groups. The main conclusion for this study was that glucose oxidation during moderate intensity aerobic exercise will be similar and timing of carbohydrate ingestion does not matter.

A recent position by the International Society of Sports Nutrition explains that exercise intensity and work output decrease as glycogen levels are depleted. By eating a high carbohydrate diet, 8-10g/kg/d, athletes are able to improve performance by increasing glycogen stores 1 to 3 days prior to exercise and improve blood glucose maintenance during exercise (Kerksick et al., 2008). Although some studies have found that carbohydrate ingestion during exercise does not improve performance the ISSN takes a different stance based on recent research. An Australian study had eight cyclists do two trials of cycling at 70% of VO2 maximum until volitional fatigue. One group was given an 8% carbohydrate solution before and every 15 minutes of exercise while the other group got a placebo. The group that had the carbohydrate drink cycled for 30% longer than the placebo group (McConnell et al, 1999; Kerksick et al., 2008). The ISSN demonstrates through a review of several studies that ingestion of carbohydrates during endurance exercise is a suitable method to sustain blood glucose levels, spare glycogen, and improve performance. The recommendation on the timing of carbohydrate supplementation during exercise to maintain muscle glycogen and blood glucose is approximately 30 to 60g of carbohydrate per hour for exercise lasting 60 minutes or more (Kerksick et al., 2008). The administration of this glucose can be through drinking 8 oz. to 16
oz. of a 6% to 8% carbohydrate solution every 10 to 15 minutes. Carbohydrate ingestion will also help to increase muscle glycogen stores, offset damage to muscles, and improve training adaptations to acute and long term periods of resistance training (Kerksick et al., 2008). Based on the current research, it appears that timing of exogenous glucose is important to improving performance. Research examining the timing of glucose ingestion for people with IDDM is lacking. The ADA and ACSM have exercise precautions with regard to blood glucose monitoring and levels that agrees with this ISSN position on nutrient timing.

McKewen et al. examined the effects of differing carbohydrate diets on glycemic control, muscle glycogen, and exercise performance in type 1 diabetics. Seven patients with IDDM were randomly assigned into a high carbohydrate diet of 60% of energy intake from carbohydrates and 25% from fat and a normal mixed diet which was 50% of energy from carbohydrates and 35% from fat. Maximal aerobic capacity tests were done on a cycle ergometer or treadmill and glucose was monitored with a glucose meter. Subjects alternated 5 minute intervals on the bike between 70% and 50% of their maximal aerobic power for fifty minutes and then they did a 15 minute time trial. Mean blood glucose was 10% higher in the high carbohydrate diet, hbA1c was unchanged by the diet, and insulin dosage was 14% higher in the high carbohydrate diet group. There was no statistical significance in exercise performance between the two groups. This study concluded that a 10% increase in carbohydrate intake for 3 weeks is associated with a deterioration of glycemic control, increased insulin requirements, and a decrease in resting muscle glycogen levels (McKewen et al., 1999).

In a more recent paper, Hornsby and Chetlin examined how to manage competitive athletes with diabetes and they address the carbohydrate issue. The ACSM, the American Dietetic Association, and Dietitians of Canada recommend that competitive athletes should
consume between 6 to 10 g/kg of carbohydrates per day (Hornsby & Chetlin, 2005). Hornsby and Chetlin believe that the best strategy for type 1 diabetic athletes to manage the disease is through trial and error. Before exercise, it is recommended that total insulin dose should be reduced by 20-50% and it should be administered at least 60 minutes before the start of activity (Hornsby & Chetlin, 2005). After the athlete is in a routine, carbohydrate supplementation can be used during exercise to prevent hypoglycemia and improve performance. De Feo et al. recommends that carbohydrate intake be about 15-60g and can come from a 5-10% carbohydrate drink. The timing of this intake should match the time that glucose tends to drop but this is different for everyone. It is for this reason that Hornsby and Chetlin believe the best management plan is through trial and error. The ADA also agrees with Hornsby and Chetlin that IDDM athletes should ingest carbohydrates as they need based on blood glucose monitoring. De Feo et al. offer a different recommendation that 15-60g of carbohydrate should be ingested every 30 minutes of moderate or higher intensity exercise. There are no clearly defined recommendations for carbohydrate use to prevent hypoglycemia during exercise. The major method suggested by the studies above along with the associations that specialize on people with IDDM is that it all depends on the exercise modality and the needs of the individual.

MacKnight et al. (MacKnight et al., 2009) focused on explaining the daily management of athletes with diabetes. The main emphasis of this paper was to examine the use of nutrition and insulin to improve the performance of type 1 diabetics. The stance taken in this paper also supports the carbohydrate ingestion suggestions made by the ACSM and ISSN. MacKnight et al. recommends that daily carbohydrate consumption for an athlete with IDDM is approximately 6 to 10g/kg body weight per day in order to maintain blood glucose levels during and after exercise and to replace glycogen stores. This is roughly 60% of the daily caloric intake from
Carbohydrates. Prior to exercise, a meal of 250g to 300g of carbohydrates should be consumed between 3 and 6 hours before exercise. During prolonged exercise more than 45 minutes 15g of carbohydrate should be consumed every 30 to 60 minutes of activity to start (MacKnight et al., 2009). If exercise is greater than 60 minutes a liquid carbohydrate solution is recommended. Type 1 diabetics should also consider reducing short-acting insulin by 30-50% prior to exercise to help reduce the risk of hypoglycemia. MacKnight et al. (2009) believe that by following these guidelines for carbohydrate consumption and insulin reduction, the athlete with IDDM will be able to prevent hypoglycemia and improve athletic performance by maintaining proper blood glucose as well as muscle glycogen stores during and post-exercise.

**Supramaximal Lactate Testing**

Supramaximal exercise testing to examine peak lactate levels is not a new practice. One common method for supramaximal exercise testing is the Wingate test. The Wingate test is the most popular anaerobic non-invasive exercise test (Ucok et al., 2005). The Wingate test is used to assess the glycolytic contribution of exercise along with peak anaerobic power and capacity (Weinstein et al., 1998). The Wingate test is considered to be a supramaximal test that provides valid and reliable results for peak lactate levels, heart rate, and plasma volume (Weinstein et al., 1998). Ucok et al. (2005) supports the findings by Weinstein et al., (1998) in the validity and reliability of the Wingate test. Ucok et al. (2005) also explains that the reason for its popularity is that it is non-invasive and can be used on most populations including but not limited to: children, elderly, disabled patients, and patients with chronic diseases.

Although the Wingate test is proven effective in finding peak lactate levels there are many variables that go along with this test. For this study there are a couple of variables that are of more concern and than others. One major variable is the timing of the supramaximal portion
of the test. The Wingate test procedure that is commonly used is five seconds of unloaded pedaling on a cycle ergometer as fast as possible and then the load is applied instantly and the participant continues to pedal as fast as possible for thirty seconds. The question has become whether thirty seconds is an adequate time for physically active people or if it should be closer to sixty seconds. This question has been answered by the protocols of previous studies using a Wingate Test. There are several studies that have done a 30 second Wingate test with healthy, highly trained subjects. Burgomaster et al. (2006) used a 30 second Wingate test to see the effects of short-term sprint training on skeletal muscle carbohydrate metabolism during exercise and time trial performance in healthy, active subjects. The 30 second Wingate test provided the study with enough data to find reliable peak and mean power outputs for each participant. Another study by Popadic et al. (2009) examined the maximal anaerobic power in elite athletes from different sports. In order to test the peak, mean, and explosive power, a 30 second Wingate test was used. The subjects in this study were 18 to 27 year old elite athletes, which gives more evidence that 30 seconds is enough time to reach peak power levels for a highly trained population. Jacobs et al. (1983) examined the lactate in skeletal muscle after 10 and 30 second bouts of supramaximal exercise. The 30 second bout of supramaximal exercise was enough to produce an expected lactate response in both males and females. Nugent et al. (1997) looked into the exercise responses in patients with IDDM. In this study healthy and type 1 diabetic subjects did incremental cycle ergometer exercise. Lactate levels were taken throughout and there was no significant difference between the healthy and IDDM subjects. Blood glucose levels were taken and the IDDM subjects saw a higher level than healthy subjects throughout the exercise. This is important for this study since supramaximal exercise will be done. It is important that this study monitors glucose closely to ensure that IDDM subjects do not increase
glucose to a range considered unsafe, which is greater than 250 mg/dL according to the ACSM (American College of Sports Medicine, 2010). Rapid and large amounts of blood lactate occur during maximal exercise that lasts between 60 and 180 seconds (McArdle et al., 2010). For the purposes of this study the 60 second Wingate test is a valid and reliable way to test anaerobic exercise capacity in highly active non-IDDM and IDDM subjects, specifically focusing on peak lactate accumulation.

Another variable that must be considered by reviewing prior research is that of the load that should be applied to the mechanically braked cycle ergometer during the Wingate test. The proper load is necessary in order to obtain accurate results for peak power, mean power, and peak lactate. Lactate accumulation is directly related to exercise intensity (Rieu et al., 1998). If the proper load is not applied, then the results from the Wingate test will not give an expected response and may be less than expected. The load applied to the cycle ergometer will depend on the fitness level of the participants and there is no set guideline for what this load should be. Ucok et al. (2005) came to the conclusion that the Wingate test is a valid and reliable anaerobic test. This study looked at the best way to sign a load that would produce the best results. They examined the difference between using a load based on body weight or lean body mass. The conclusion that they came to was that a load of 100 to 110 g/kg lean body mass was a more effective load to produce accurate results (Ucok et al., 2005). On the other hand, Dotan and Bar-Or (1983) believed that using a load of 51.4 to 52.3 g/kg body weight is a better load for producing enough resistance to get accurate peak power, mean power, and lactate measurements. The study closest to this study in terms of subjects, is that of Bradley and Bell (1992). In this study, the subjects used were female athletes between 19 and 28 years old. This study also used body weight instead of lean body mass to figure out the proper load. The conclusion was that a
load of 105 g/kg body weight is the optimum load for female athletes; however, they also suggest a load of between 90 to 120 g/kg body weight of adult athletes (Bradley and Bell, 1992). Based on the previous research a load of 5% of the subject’s body weight will be used for this study. This load has been selected because the Wingate test for this study will be 60 seconds rather than 30 seconds to allow for more lactate to build up. Since subjects are not necessarily athletes, but are physically active, this falls well within the suggested range of load for adult athletes and will produce valid and reliable results for peak power, mean power, and blood lactate levels.

**Active Recovery Intensity**

The final variable of concern for this study is the best intensity for active recovery to elicit faster lactate clearance. Once again this will vary based on the fitness level of participants. Based on prior and current research, using a percentage of VO\(_2\) max is a better measure for active recovery than heart rate (Dodd et al., 1984; Dupont et al., (2004); Fukuba et al., 1999; Gmada et al., 2005; Martin et al., 1998; Signorile et al, 1993). For non-IDDM and IDDM subjects who are highly active, blood lactate levels are important to improve recovery time and reduce muscle fatigue. IDDM subjects have to be especially carefully because active recovery occurs in a VO\(_2\) range in which blood glucose is known to drop rapidly. Active recovery promotes lactate clearance by increasing the metabolic rate and systemic blood flow which accelerates lactate metabolism through oxidation and gluconeogenesis (Martin et al., 1998). For this study it is important to find exercise intensities at which the non-diabetic and type 1 diabetic subjects can ride a cycle ergometer at safely while reducing lactate as quickly as possible. Few studies have examined supramaximal exercise recovery intensities in type 1 diabetics. In prior and current research there are some conflicting conclusions regarding the best intensities for active recovery.
to optimize lactate clearance. Martin et al. (1998) found that in elite cyclists between 21 and 34 years old, optimal active recovery for accelerating lactate clearance following maximal exercise is 40% of VO2 max. Dupont et al. (2004) came to the same conclusion as Martin et al. (1998) that 40% is the optimal active recovery intensity for blood lactate clearance. Monederno and Donne (2000) showed that 50% of VO2 max is an intensity best for active recovery. Dodd et al. (1984) who looked at trained and untrained males after a 50 second Wingate test and found that a combination of 35% and 65% of VO2max is the most effective active recovery intensity. Gmada et al. (2005) also examined trained and untrained 18 to 22 year old subjects and agreed that a combination of lower and higher intensities of active recovery is most effective for lactate clearance. There is conflicting conclusions over what the best intensity of active recovery is for lactate clearance. Gmada et al. (2005) explained that optimal active recovery intensity for lactate clearance is dependent on the fitness level of the subjects. The subjects for this study are active and as a result the protocol will be using a higher intensity for active recovery. Based on the prior and current research an active recovery between 50% of 60% of VO2 max is the optimal range for lactate clearance for the subjects in this study.

**Summary**

Over the past five years there has been a shift in research from carbohydrate consumption and nutrition in people with IDDM to a focus on managing exercise and insulin to prevent hypo and hyperglycemic responses. One reason for this shift may be that there is enough support from prior works to say that the current dietary recommendations are as good as they will get and no more research is needed on the topic. Many studies conducted over the past 20 years have supported the hypothesis that carbohydrate consumption prior to and during exercise can improve exercise performance by maintaining blood glucose levels and reducing the fall in
muscle glycogen (Karelis et al., 2010; Kerksick et al., 2008; Robitaille et al., 2007). Not only does carbohydrate consumption improve performance but it also helps to reduce the risk of hypoglycemia during and after exercise. There are many benefits to using carbohydrate consumption to improve performance in the general population as well as the type 1 diabetic population. The major drawback from all the prior research is that it focuses on untrained healthy individuals with IDDM. This leaves out the entire population of healthy and active people with IDDM. These people are trained and have adaptations to training that are not seen in the general population of IDDM patients.

Another limitation to the current research on the topic of carbohydrate consumption in people with IDDM is that the studies demonstrate a wide range of times that are considered optimal for carbohydrate consumption along with a large range of carbohydrate dosage. The range of carbohydrate consumption recommended by the ISSN and ACSM range from 20-60g of carbohydrate every 10 to 60 minutes of exercise (ACSM, 2010; De Feo et al., 2006; Kerksick et al., 2008). This range is extremely large and really does not give an optimal timing or dose of carbohydrate that active people with IDDM can actually use to prevent hypoglycemia during high and moderate intensity aerobic endurance activity. A major aim of this study is to examine the effects of carbohydrate supplementation on blood glucose and blood lactate levels during and after supramaximal intensity exercise. Based on the prior research and the lack of focus on physically active people with IDDM, there is a need for this study in helping to improve the safety and recovery of people with IDDM who participate in supramaximal activity through carbohydrate consumption before and during the supramaximal exercise bout and active recovery.
Chapter III: Procedures

This chapter will explain the procedures and methodologies used for this study. The protocol was designed based on conclusions and limitations from prior research. The procedure also takes into account all the safety precautions necessary for type 1 diabetics during exercise based on ACSM guidelines. A procedure was established to test the main hypothesis as well as keep all participants safe. This protocol was approved by the Northeastern University Institutional Review Board.

Subjects

The study population targeted diagnosed type 1 diabetic males on insulin therapy who participated in physical activity at least 3 times per week with an HbA1c less than 8.5% and between the ages of 18 and 35 years old. This population was selected because physically active type 1 diabetics tend to have good glucose control and will benefit most from this type of study. Males were selected in order to limit complications that may arise due to possible gender differences in blood sugar control and response to exercise. The subjects were recruited to test the following hypotheses: 1) There is no difference in blood lactate accumulation between the diabetic group and the non-diabetic groups following the supramaximal exercise; 2) There is no difference in blood lactate levels between the diabetic and non-diabetic group; 3) There is no difference in blood lactate levels and blood glucose levels from the frequent ingestion of carbohydrate drink following supramaximal exercise. Twelve non-IDDM individuals and seven IDDM were recruited for this study.

The inclusion criteria for this study are the participant must: be male, be between the ages of 18 and 35, have been diagnosed with type 1 diabetes and on insulin therapy, participate in moderate to vigorous physical activity at least 2~3 days a week, and have an HbA1c less than or
equal to 8.5%. The exclusion criteria for this study are the participant: has an HbA1c greater than 8.5%, is under 18 or over 35 years old, uses any ergogenic aids such as steroids or testosterone, has any metabolic diseases other than the diagnosed Type 1 diabetes, and has any complications or disabilities that do not allow them to do moderate to vigorous intensity aerobic. The complications that would cause a subject to be excluded include cardiovascular diseases, peripheral neuropathy, autonomic neuropathy, coronary artery disease, peripheral vascular disease, retinopathy, and nephropathy. These criteria are designed to ensure patient safety but also to allow us to best test the hypothesis and reducing confounding variables.

In order to recruit these participants, coaches and athletes from local collegiate athletic teams in the Boston area were contacted. Fliers were posted and distributed at local gyms explaining the study and the need for physically active type 1 diabetics as well as non-IDDM individuals. Fliers were posted throughout the Northeastern University campus in an effort to find possible participants. Listings were posted on Craigslist.com to find potential participants as well. E-mails were sent to student athletes explaining this study. Our target sample size was 20 to 24 participants.

**Study Location**

All testing occurred at the Human Performance and Exercise Science Laboratory located on the fifth floor, room 520, of the Behrakis Health Center at Northeastern University. This lab is fully equipped with treadmills, cycle ergometers, strength training equipment, and metabolic carts. The laboratory has all necessary equipment for blood lactate and blood glucose analysis as well as other basic exercise physiology testing needs. There is AED and first aid equipment located in the lab for easy access in the case of an emergency.
Methods

Prescreening

People interested in this cross-over study with repeated measurements, were assigned to a non-IDDM group and an IDDM group. Both groups went through the same procedure. The non-IDDM group contained 12 people while the IDDM group contained 7 type 1 diabetics.

Entry and Familiarization,

Prior to the testing sessions, all subjects had a prescreening phone interview with the researchers to see if they were qualified for the study. Accepted subjects then met with the researchers at the Northeastern Human Performance and Exercise Science Laboratory to go over the informed consent, to ask questions, to find out what was expected of them, to go through baseline testing, and to be familiarized with the Wingate exercise test protocol and the active recovery protocol. Researchers made sure that all subjects understood what was expected of them and they had a chance to make sure all of their questions were answered.

Baseline Testing

During the baseline testing session prior to the intervention sessions, measurements were taken including anthropometric measures which included height, weight, BMI, and body composition. Physiological measurements were also taken including resting heart rate, peak exercise heart rate, resting blood pressure, peak blood pressure, and blood glucose before exercise as well as at peak exercise. A VO$_2$ max test was done to determine the proper exercise zones for each testing session. A major element to the placebo and carbohydrate testing session was an active recovery portion in which a heart rate associated with 50% and 70% of the participant’s VO$_2$ max was needed. The VO$_2$ max test done during the baseline testing session
allowed researchers to extrapolate the heart rate zones necessary for each participant to complete the supramaximal and active recovery portion of the placebo and carbohydrate testing sessions.

A CosMed metabolic cart connected to a PC was used for administering the VO2\textsubscript{max} exercise test. The VO2\textsubscript{max} test was done on a Monark Peak Bike Ergomedic 894E following a ramp protocol. This test included an EKG to get an accurate heart rate measurement during this test. Prior to the VO2 max test, blood glucose readings were taken to ensure that the glucose of the type 1 diabetic subjects was below 250 mg/dL and above 100 mg/dL (American College of Sports Medicine, 2010). If glucose was too low, then 20g to 30 g of carbohydrate was given to the person and the test continued. If the blood glucose was too high, then insulin was administered or the test was postponed until the glucose was at a safe level for exercise. All subjects were asked to ride on the cycle ergometer until volitional exhaustion. The protocol for this VO2 max test had subjects pedal at a cadence of 60-80 rpms and start at 1.5kp. Every 2 minutes the resistance increased by .5 kp. The subject continued pedaling until volitional exhaustion. If the subject made it past stage 5, then the stage time increased from 2 minutes to 3 minutes. The test was stopped when the subject could no longer continue or requests to stop. The ACSM guidelines for exercise testing were used to determine when it was absolutely necessary for a test to be terminated. The information from this allowed researchers to find the proper exercise zones for the exercise testing sessions.

Prior to this baseline testing, subjects were asked about their insulin dosages on days of physical activity and they were asked to complete a nutrition recall survey. Blood glucose was monitored to ensure that no hypo- or hyperglycemic events occurred during the VO2 max testing session. The heart rate zones associated with 50% and 70% of VO2\textsubscript{max} were extrapolated based on the data from the cycle ergometer VO2 max testing session. In order to test the blood
glucose a OneTouch Ultra Blood Glucose Meter made by LifeScan with OneTouch Ultra Blue Glucose Test strips was used.

*Food and Insulin Reports*

Prior to the intervention testing days, subjects were asked to keep a food log for 48 hours prior to the both testing sessions. This food log tracked the macronutrient intake prior to the test. It also asked what time the food was consumed. The IDDM subjects were asked to record insulin dosages and the times in which the insulin was administered. Subjects were also asked to avoid exercise the day of the testing and to not smoke or ingest caffeine. Subjects were required to do a 12 hour fast to better control for blood glucose levels. All IDDM subjects were advised to continue insulin treatment as they normally do before exercise. When the subjects arrived for their testing sessions, researchers collected the food and insulin logs from the subjects.

*Placebo and Carbohydrate Intervention Sessions*

The non-IDDM group and the IDDM group both went through the same protocols. All subjects were required to do two testing sessions that will last up to 3.5 hours in total. There was a minimum of a 3 day washout period between the two sessions. On the days of the testing sessions, subjects arrived in the morning after a 12 hour fast and a blood glucose measurement was taken. The morning was selected as the time for all tests because it was easier to control glucose in the morning after a fast. If the subject had a blood glucose less than or equal to 100 mg/dL, then they were asked to consume 20g-30g of the carbohydrate through the 6% carbohydrate sports drink (Dextrose and Crystal Light) (American College of Sports Medicine, 2010). In order to reduce the risk of hypoglycemia, researchers made every effort not to exercise subjects during peak insulin action. If the patient had a blood glucose level of 250 mg/dL
without ketosis, then the test continued; however, if ketosis was present then the test was postponed to another day.

*Wingate/Supramaximal Exercise Session Protocol*

Subjects were asked to complete a 1 minute Wingate protocol on a Monark Cycle ergometer followed by 5 minutes of passive rest to allow for peak lactate accumulation. After the peak lactate accumulation stage the subjects then did 30 minutes of active recovery cycle ergometer riding. After the 30 minutes of active recovery cycling, the subject was then asked to sit in a chair for 30 minutes of passive rest.

When the subject arrived, a set of resting measurements was taken including blood pressure, heart rate, blood lactate, and blood glucose. The resistance for the Wingate test was calculated. The resistance used for this test was set to 5% of the subject’s body weight. All testing was done using a Monark Peak Bike Ergomedic 894E cycle ergometer. The subjects were asked to do a 5 minute unloaded warm up on the Monark cycle ergometer. At the start of the Wingate test, subjects were instructed to pedal as fast as possible for 5 seconds with no load applied to the cycle ergometer. Immediately after the 5 seconds of unloaded pedaling, the load of 5% of the subject’s body weight was applied to the cycle ergometer and the subject was instructed to pedal as hard and as fast as they possibly could for 60 seconds. After this supramaximal 60 second exercise bout, blood lactate, blood glucose, heart rate, and blood pressure were taken. The subjects then remained seated on the bike without moving for 5 minutes to allow the blood lactate to accumulate and reach peak levels. After the 5 minute lactate accumulation period, blood lactate, blood glucose, heart rate, and blood pressure measurements were taken. The subject then continued pedaling for active recovery for 30 minutes. The first 15 minutes of active recovery were done at 70% of VO₂ max and the second
15 minutes was done at 50% of VO₂ max. Blood glucose, blood lactate, blood pressure, and heart rate measurements were taken every 10 minutes during this 30 minute active recovery. After the active recovery segment the subjects then rested in a chair for 30 minutes for passive recovery. Blood pressure, blood glucose, blood lactate, and heart rate were taken one last time after the 30 minutes of passive recovery. Subjects were then sent home and completed a self report blood glucose levels at 2, 6, 12, and 24 hours after the testing session. This protocol was followed for both the carbohydrate drink testing session and the placebo testing session separated by a minimum of a 3 day washout period.

Supplementation Protocol

This study was a double blind randomized study in which the subject received the placebo drink during one intervention session and the carbohydrate sport drink for the other intervention session. The placebo drink consisted of fruit punch Crystal Light powder mixed with water. This formula has zero calories and zero carbohydrates. During any testing session, if there was a risk of a hypoglycemic event based on blood glucose readings a 6% carbohydrate drink was given to avoid any incidents. The carbohydrate drink was fruit punch Crystal Light powder mixed with dextrose powder to make a 6% carbohydrate drink. The main carbohydrate in the drink was dextrose. The timing and amount of the placebo or 6% carbohydrate drink was the same, 4 oz every 15 minutes. This amount of the 6% carbohydrate drink is equivalent to the same carbohydrate content as 4 oz. of fruit juice. The placebo or carbohydrate drink was given 15 minutes prior to the Wingate test. However; if there was a possibility of hypoglycemia on the placebo testing session, then the 6% carbohydrate drink was given before 15 minutes for the safety of the subjects. If this occurred, then researchers monitored the timing of the administration of the carbohydrate drink. Blood glucose and blood lactate were tested when the
subject arrived, then immediately after the 5-minute peak lactate accumulation segment, and then every 10 minutes during active recovery as well as 30 minutes into passive recovery. 4oz of the placebo or carbohydrate sports drink was then given every 15 minutes of exercise during the intervention exercise testing sessions. 4oz of the carbohydrate drink is equivalent to 45g of carbohydrate for an hour of exercise which is a recommended dosage by the ACSM (American College of Sports Medicine, 2010). Once the test was complete, subjects completed a self reported follow up of their blood glucose at 2 hours, 6 hours, 12 hours, and 24 hours after the testing sessions. The goal was to keep blood glucose between 100 to 250mg/dL before, during, and after exercise.

**Blood testing**

Throughout the testing sessions, blood glucose and blood lactate measurements were taken. Blood glucose measurements were taken with a OneTouch Ultra Blood Glucose Monitor made by LifeScan using OneTouch Ultra Blue Blood Glucose Test Strips. These samples were collected from the finger tips via lancing device. In order to test blood lactate, a Nova Biomedical Lactate Plus lactate analyzer was used. In order to reduce the amount of times that a test subject was lanced for blood, researchers used every effort to take blood from the same finger that was used for the blood glucose tests. Blood glucose and blood lactate levels were taken when the subject arrived, immediately after the 1 minute Wingate test, after the 5 minute peak lactate accumulation segment, every 10 minutes during active recovery, and 30 minutes into passive recovery.
Safety precautions

Subject safety throughout all baseline testing and exercise testing was a major concern. The American College of Sports Medicine guidelines for exercise testing were followed to ensure subject safety. Researchers ensured that there were no contraindications to exercise testing in any subject through the pre-screening interview. Blood glucose levels were also tested prior to exercise to make sure that the levels were safe for exercise. If the subject had a blood glucose level less than or equal to 100 mg/dL, then they were asked to consume 20-30g of carbohydrate through the 6% carbohydrate drink (American College of Sports Medicine, 2010). The timing of the test also ensured that subjects did not exercise at peak insulin action to reduce the chance of hypoglycemia. If the patient had a blood glucose level of 250 mg/dL without ketosis, then the test proceeded; however, if ketosis was present then the test was postponed to another day. If at any point during the testing, a subject began to become hypo or hyperglycemic then the test was stopped immediately and the proper care was taken to keep the subject safe.

All exercise sessions had a researcher present who was CPR, First Aid, and AED certified. The testing location also had a full first aid kit and an easily accessible AED in case of emergency.
All of these safety precautions were taken in order to ensure subject safety throughout all sessions in which the subjects were exercising.

**Statistical Analysis**

IBM SPSS 19 and Microsoft Excel were used for all data analysis calculations. The main method of comparing and analyzing the test results from each testing session was multivariate analysis of variance. From this data conclusions could be made regarding the response of blood lactate levels and blood glucose levels due to the consumption of a 6% carbohydrate drink before and during supramaximal and active recovery exercise on IDDM and non-IDDM subjects.
Chapter IV: Results and Discussion

The purpose of this study was to determine the effects of carbohydrate supplementation on blood glucose and blood lactate when administered prior to, during, and post supramaximal exercise. The specific aims of the study were to test the hypotheses that there is a difference in response of blood glucose and lactate between IDDM and non-IDDM subjects and carbohydrate supplementation throughout supramaximal exercise will induce a different response than a placebo. The aim of this chapter is to first present the results and analysis of the baseline and intervention sessions explained in depth in chapter III. The chapter will then go in to an interpretation and discussion of the results to explain the conclusions and implications of this study. This chapter will make clear the importance of this research to the Type 1 diabetic community. All measurements were analyzed using IBM SPSS Statistics 19.

Baseline analysis

Descriptive statistics were calculated for body mass index, age, height, weight, resting heart rate, maximum heart rate, VO₂ max, and resting blood glucose using the mean (M) and standard deviation (SD). One-way analysis of variance (ANOVA) was used to analyze and determine if there were any baseline differences among the non-IDDM and IDDM groups in this study. No significant differences were seen for height, weight, BMI, Age, max heart rate, and VO₂ max. There were differences between the IDDM and non-IDDM groups in resting heart rate and resting blood glucose. These differences were expected based on the characteristics of IDDM (Nugent et al., 1997; Veves et al., 1997) Summaries of these values are listed in Table 1.
Table 1 Subject Demographics

<table>
<thead>
<tr>
<th>Physical Characteristics</th>
<th>Non-IDDM</th>
<th>IDDM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.9</td>
<td>34.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>92.5</td>
<td>35.9</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>25.1</td>
<td>3.8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>29.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Resting Heart Rate</td>
<td>67.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Max Heart Rate</td>
<td>181.3</td>
<td>13.2</td>
</tr>
<tr>
<td>VO2 Max</td>
<td>49.3</td>
<td>10.7</td>
</tr>
<tr>
<td>Resting Blood Glucose</td>
<td>97.8</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Nutritional analysis

Table 2 shows the nutritional intake (total calories, carbohydrate, protein, and fat) for the 48 hours prior to the placebo and carbohydrate supplement intervention sessions. A univariate ANOVA was analyzed to determine if there were any differences in the macronutrient consumption between the carbohydrate and placebo intervention sessions. There were no statistically significant differences in the macronutrient intake: within the IDDM group’s placebo and carbohydrate sessions, within the non-IDDM group’s placebo and carbohydrate sessions, and between the combination of the two groups macronutrient intake placebo and carbohydrate sessions. The diet within the groups having no statistically significant differences eliminates the risk of nutrition being a confounding variable. Each individual is their own control and because of the lack of differences between the placebo and carbohydrate group nutrition, this serves as a strong control for this study.
Table 2 Nutritional Intake Variables

<table>
<thead>
<tr>
<th>Group</th>
<th>Nutritional Variable</th>
<th>Placebo</th>
<th>CHO</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDDM</td>
<td>Calories (kcal)</td>
<td>3577.4±665.8</td>
<td>4493.54±1200.2</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Protein (g)</td>
<td>201.9±49.5</td>
<td>248.6±91.2</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Carbohydrate (g)</td>
<td>316.3±77</td>
<td>387.0±62.1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Fat (g)</td>
<td>159.45±32.14</td>
<td>185.1±50.8</td>
<td>0.28</td>
</tr>
<tr>
<td>Non-IDDM</td>
<td>Calories (kcal)</td>
<td>4887.5±1387.7</td>
<td>3865.9±1368.8</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Protein (g)</td>
<td>218.8±31.3</td>
<td>187.2±48.1</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Carbohydrate (g)</td>
<td>539.4±215</td>
<td>455.8±266.9</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Fat (g)</td>
<td>191.9±81.3</td>
<td>148.3±41.4</td>
<td>0.41</td>
</tr>
<tr>
<td>Combined</td>
<td>Calories (kcal)</td>
<td>4404.8±1321.46</td>
<td>4097.2.8±1312.2</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Protein (g)</td>
<td>212.6±38.5</td>
<td>209.8±71.5</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Carbohydrate (g)</td>
<td>457.21±206.02</td>
<td>430.5±214.5</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Fat (g)</td>
<td>180±68.2</td>
<td>161.9±47.4</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Carbohydrate Supplement Session Analysis

A bivariate Pearson Product correlation analysis for all the independent variables was conducted to determine if any correlations existed between the dependent variables. The analysis revealed significant correlations (p<0.05) between: DM condition and lactate post Wingate which demonstrated that the IDDM group had an elevated lactate post Wingate compared to the non-IDDM group; DM condition also had higher resting blood glucose, blood lactate peak, blood glucose post Wingate and blood lactate resting levels than the non-IDDM group.

A multivariate analysis of variance (MANOVA) was used to analyze all variables from the intervention sessions. The MANOVAs were calculated to determine if there were any main effects for DM condition groups and the carbohydrate supplement and placebo sessions. The MANOVAS revealed statistically significant differences for DM condition, Drink, and the interaction of the two effects. Table 3 summarizes the MANOVA results.
Separate univariate ANOVAs were run on each dependent variable as follow up tests to the MANOVA. The ANOVAs revealed that there were significant differences ($p < .05$) between the IDDM and non-IDDM groups for the blood lactate post Wingate test. There were also significant differences between the two groups for peak blood lactate. The IDDM group and non-IDDM group also demonstrated significant differences for the resting blood glucose, blood glucose post Wingate, peak blood glucose, and passive recovery blood glucose. There were significant differences between the placebo session and carbohydrate supplement session for passive recovery blood glucose. There was no statistical significance with any of the dependent variables for the interaction of the Drink and DMcondition. Table 4 summarizes the results of the univariate ANOVA analysis.

### Table 4 Univariate ANOVA of Dependent Variables

<table>
<thead>
<tr>
<th>Effect</th>
<th>Dependent Variable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMcondition</td>
<td>Blood Glucose Passive Recovery</td>
<td>0.00</td>
</tr>
<tr>
<td>Drink</td>
<td>Blood Glucose Passive Recovery</td>
<td>0.02</td>
</tr>
<tr>
<td>DMcondition Drink Interaction</td>
<td>Blood Glucose Passive Recovery</td>
<td>0.00</td>
</tr>
<tr>
<td>DMcondition</td>
<td>Lactate Post Wingate</td>
<td>0.04</td>
</tr>
<tr>
<td>DMcondition</td>
<td>Resting Blood Glucose</td>
<td>0.00</td>
</tr>
<tr>
<td>DMcondition</td>
<td>Blood Glucose Post Wingate</td>
<td>0.00</td>
</tr>
<tr>
<td>DMcondition</td>
<td>Blood Glucose Peak</td>
<td>0.00</td>
</tr>
</tbody>
</table>

As a follow up to the univariate ANOVAs, LSD post hoc tests were used to examine if there are any overall effects of the main effect on the dependent variables. The results of the post hoc tests revealed that there were no statistically significant differences of the effect of the Drink. The DMcondition had statistically significant effects on blood lactate post Wingate test,
resting blood glucose, post Wingate blood glucose, peak blood glucose and passive recovery blood glucose. Table 5 summarizes the results of the post hoc tests.

Table 5 Post Hoc Test Results

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Group (I)</th>
<th>Group (J)</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactate Post Wingate</td>
<td>NON-IDDM CHO</td>
<td>IDDM CHO</td>
<td>-3.59</td>
<td>1.66</td>
<td>0.045</td>
</tr>
<tr>
<td>Blood Glucose Rest</td>
<td>NON-IDDM Placebo</td>
<td>IDDM Placebo</td>
<td>-64.35</td>
<td>12.06</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>NON-IDDM CHO</td>
<td>IDDM CHO</td>
<td>-30.66</td>
<td>12.79</td>
<td>0.028</td>
</tr>
<tr>
<td>Blood Glucose Post Wingate</td>
<td>NON-IDDM Placebo</td>
<td>IDDM Placebo</td>
<td>-65.64</td>
<td>11.64</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>NON-IDDM CHO</td>
<td>IDDM CHO</td>
<td>-47.41</td>
<td>16.29</td>
<td>0.010</td>
</tr>
<tr>
<td>Blood Glucose Peak</td>
<td>NON-IDDM Placebo</td>
<td>IDDM Placebo</td>
<td>-61.35</td>
<td>8.84</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>NON-IDDM CHO</td>
<td>IDDM CHO</td>
<td>-70.75</td>
<td>14.3</td>
<td>0.000</td>
</tr>
<tr>
<td>Blood Glucose Passive Recovery</td>
<td>NON-IDDM CHO</td>
<td>IDDM CHO</td>
<td>-76.5</td>
<td>17.63</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Upon further analysis of the blood lactate levels at each phase of the exercise testing sessions, it is clear that carbohydrate supplementation throughout supramaximal exercise does not significantly impact lactate clearance. It is interesting that the IDDM group started these exercise sessions with similar blood lactate levels but upon supramaximal exercise this group sees significantly elevated blood lactate levels compared to the non-IDDM group at the same stage. The non-IDDM group appears to elevate their blood lactate levels at peak lactate accumulation to a level that shows no statistical difference between the groups. Blood lactate levels in IDDM subjects elevate faster than that of non-IDDM subjects; however, more research is needed to draw any conclusions. Both groups also end the sessions at similar lactate levels which indicates that blood lactate clearance between the two groups is similar with and without carbohydrate supplementation. Figure 2 shows the blood lactate level progression throughout both supramaximal testing sessions for the IDDM and non-IDDM groups.
Blood glucose levels are significantly different at all stages of both the carbohydrate and placebo exercise sessions between the IDDM and non-IDDM groups. The blood glucose levels of the IDDM group are significantly higher at all points of the testing sessions. The supramaximal exercise without carbohydrate supplementation appears to keep blood glucose levels at a stable level compared to the carbohydrate supplementation sessions; however, the carbohydrate session did not significantly increase blood glucose levels in the IDDM group. The difference between both groups can clearly be seen in figure 3 which shows the progression of blood glucose levels in both groups during the placebo and carbohydrate exercise sessions.
Figure 3. Data above represents change in blood glucose across the two groups for the Placebo and CHO sessions. There were 4 significant points (BGRest, BGPost, BGPeak, and BGPassiveRec) for each group. At all time points during the Placebo and CHO sessions, the IDDM group’s blood glucose levels were significantly higher compared to both sessions of the non-IDDM group’s (p<0.05). There was one significant difference within the non-IDDM group’s BGPassiveRec. The non-IDDM’s CHO BGPassiveRec (I) was significantly higher for the non-IDDM’s CHO session compared to the placebo session (p<0.05). No significant differences were found within either group’s blood glucose levels for the Placebo or CHO sessions (p>0.05).

**Discussion**

The primary purpose of this study was to describe the effects of the consumption of a 6% carbohydrate supplement on blood lactate and blood glucose throughout and after supramaximal exercise and active recovery. The results of this study demonstrate that consuming a 6% carbohydrate supplement throughout supramaximal exercise and active recovery does not lead to improved lactate clearance in both IDDM and non-IDDM subjects but it did lead to a difference in response to blood glucose levels in IDDM subjects. These results agree with previous studies examining the effects of blood glucose and blood lactate with regard to high intensity exercise. This section will explain the results from this study and it will then discuss the mechanisms to better explain the results seen. Recommendations can be made based on this information as to how to IDDM subjects can safely train at high intensities while controlling their risks for hyperglycemia.
**Blood Glucose**

The data from previous studies have shown that high-intensity exercise without carbohydrate supplementation leads to increased blood glucose levels for people with IDDM (Bussau et al., 2011; Guelfi et al., 2005; Yardley et al., 2012). Bussau et al. found that IDDM subjects who performed 10 seconds of sprinting after 20 minutes of aerobic activity were able to prevent blood glucose levels from dropping compared to subjects who rested after aerobic activity. These subjects also saw a rise in catecholamines. These hormones counteract the drop in blood glucose and the 10 second sprint was able to increase these hormones to near maximal levels. This same effect was seen in Dube et al. (2012) in which intermittent high intensity exercise in IDDM subjects lead to an increase in norepinephrine and helped to prevent exercise-induced hypoglycemia. Although the current study did not collect data on catecholamines, the patterns seen in the blood glucose of the IDDM group are in line with the results from these prior studies.

The current research demonstrated a significant difference between the IDDM and non-IDDM groups with regard to blood glucose at all stages of testing as well as a significant difference between the placebo and carbohydrate supplementation sessions. These results lead to the conclusion that blood glucose levels in people with IDDM do not normalize with carbohydrate supplementation during supramaximal exercise. Due to the novelty of this research these results have yet to be seen in other studies. Based on the prior research with regard to high intensity exercise without carbohydrate supplementation this conclusion can be made. Prior studies have seen that high intensity exercise leads to increased blood glucose levels (Bussau et al., 2011; Guelfi et al., 2005; Nugent et al., 1997; Yardley et al., 2012). This information can be applied to the current study in that the IDDM subjects saw a significant increase in blood glucose
between the placebo session and carbohydrate supplement session while doing supramaximal exercise.

There was also a significant increase in blood glucose between the IDDM and non-IDDM groups. Had the blood glucose normalized in the IDDM group, the result would have demonstrated no significant difference between the IDDM and non-IDDM subjects in the carbohydrate supplement session. This was not the result that was seen in the current study. The IDDM group in the current study had a blood glucose that was significantly higher than that seen in the non-IDDM group for the carbohydrate supplementation session. The non-IDDM group had a mean passive recovery blood glucose of $112.33\pm19.14$ mg/dL while the IDDM group had a passive recovery blood glucose of $188.83\pm58.52$ mg/dL. Yardley et al. (2012) found that although blood glucose did drop with aerobic exercise following anaerobic exercise, the drop in glucose levels in the IDDM group did not bring the subjects back to normal levels much like the results of the current study. Ramires et al. (1997) found a similar result as this study with regard to carbohydrate supplementation during exercise. Rameries et al. found that at all stages of the carbohydrate testing session, the glycemia of the IDDM group was higher compared to that of the placebo session and the blood lactate for the IDDM group for both sessions was significantly greater than that of the non-IDDM control group. This directly agrees with the results of the current study in which IDDM blood glucose levels for the carbohydrate intervention session were significantly higher for the passive recovery stage of the carbohydrate supplementation session and they were also significantly greater than all stages of both sessions compared to the non-IDDM group.

The major mechanism that would explain this phenomenon is the rise in catecholamine levels associated with high intensity exercise (Bussau et al., 2011; Guelfi et al., 2005; Mitchell et
al., 1988; Yardley et al., 2012). High intensity exercise leads to elevated glucose production because of the increased levels of epinephrine in the blood flow. This elevation in epinephrine and norepinephrine can be anywhere between 3 and 14 times resting levels depending on the duration of the maximal exercise and these hormones are known to enhance glycogenolysis throughout exercise and recovery (Ramires et al. 1997; Yardley et al., 2012). The increase in catecholamine also leads to an increase in growth hormone following anaerobic activity which will also inhibit the glucose uptake caused by insulin leading to an increase of glucose in the blood (Guelfi et al., 2005). By supplementing this mechanism with a 6% carbohydrate drink, the blood glucose increase is even greater due to this addition of carbohydrate. Even with the active and passive recovery the blood glucose will not naturally normalize in IDDM subjects back to fasting levels. Another mechanism that leads to the increase of blood glucose in high intensity exercise is an effect of increased lactate build up. The build-up of lactate caused by high intensity exercise inhibits insulin’s role on glucose uptake in skeletal muscle and it enhances glucose production through hepatic gluconeogenesis (Guelfi et al., 2005; Harmer et al., 2007).

Based on these mechanisms and the results from the current study, carbohydrate supplementation before, during, and after supramaximal exercise followed by active and passive recovery does not lead to blood glucose normalization and in fact can lead to hyperglycemia in people with IDDM depending on the state in which they begin the high intensity exercise.

**Blood Lactate**

A major aim of this study was to examine the impact of carbohydrate supplementation on blood lactate clearance in IDDM subjects after supramaximal exercise. The post hoc analysis of the lactate levels for the Drink main effect shows that there are no significant differences seen between the placebo and carbohydrate supplementation sessions. The post hoc analysis shows
that the IDDM group has a significantly higher blood lactate level post Wingate test compared to the non-IDDM group. The IDDM group had a mean blood lactate 13.176 ±1.002 mmol/L compared to the non-IDDM group with a mean blood lactate of 10.517±.771 mmol/L. There are not many studies examining the impact of carbohydrate supplementation on blood lactate in people with IDDM but this finding is comparable to the study done by Ramires et al. (1997) in which 21 IDDM subjects and 23 non-IDDM subjects were asked to drink a carbohydrate supplement and then use a cycle ergometer until exhaustion. Ramires et al. found that the IDDM group’s lactate levels did not decrease at exhaustion and they were significantly higher than those in the non-IDDM group. Our results regarding no significant effects of carbohydrate on blood lactate levels is the same as that of Ramires et al. (1997). Rameris et al. (1997) found that glucose administration did not significantly change lactate levels in either the IDDM patients or the normal controls.

There are conflicting results regarding lactate levels between IDDM and non-IDDM subjects. Harmer et al. (2007) had 8 IDDM subjects and 7 non-IDDM subjects do 4 30second maximal effort cycle ergometer sprints and found that there was no significant difference between the IDDM and control group’s lactate levels after the maximal effort cycling bouts. Nugent et al. 1997 had 8 IDDM subjects and 8 non-IDDM control subjects participate in progressive incremental bicycle exercise test and higher blood lactate levels in IDDM subjects but not at a significant level (Nugent et al., 1997). Although the IDDM’s blood lactate levels seen in Nugent et al.’s study were not statistically higher than the non-IDDM group it still was higher which is a similar result seen in the current research. Based on the prior research and this study, there is no universal finding as to whether people with IDDM have higher blood lactate levels than non-IDDM subjects. This may be due to the different exercise modalities that were
employed in these studies. More research is needed using similar protocols and exercise modalities to determine if there truly is a difference in blood lactate levels between these two groups. This study has found that carbohydrate supplementation does not have a significant influence on blood lactate clearance in IDDM subjects.

The mechanism that leads to increase blood lactate during anaerobic exercise is that of anaerobic glycogenolysis. Jacobs et al.’s (1983) study examined this mechanism and concluded that glycolysis begins to occur within the first 10s of supramaximal exercise and it increases with increases in intensity which is a finding also confirmed by Rieu et al. (1998). One possible explanation regarding the significant difference in blood lactate post Wingate test between IDDM and non-IDDM groups is that the Wingate test was 60 seconds long compared to the 10seconds and 30seconds used in prior tests (Jacobs et al., 1983; Harmer et al.,2007). This extended duration of a supramaximal test and the use of muscle glycogen as an energy source in IDDMs may lead to the higher post Wingate test blood lactate level. The lack of decreasing lactate levels in the IDDM subjects as exercise continued to exhaustion suggests that muscle glycogen represents an important energy supply for exercising muscle during all exercise periods (Ramires et al, 1997).

**Limitations**

Most of the possible confounding variables are eliminated in this study because all subjects act as their own controls based on the cross over design of this study. There are a few limitations that must be discussed. The first major limitation is the sample size. This study only looks at 7 IDDM subjects and as a result this may be too small for conclusions to apply to the entire male IDDM population. Another possible limitation to the study was the self-report nutrition form. This may lead to an over or underestimation of the food consumption based on
how participants respond to researchers analyzing their diets. There is the chance of participants accidentally leaving out foods or drinks that they may have consumed. The likelihood of this happening to all participants is low and the analysis shows no differences within the groups between the two sessions. Therefore, each person served as a strong control for himself due to the elimination of this possible confounding factor. This study was unable to observe changes at the skeletal muscle and blood circulation level and therefore it is difficult to determine the impact that diet leading up to this type of testing has on blood glucose and blood lactate levels. Even though there are a few small differences in the diet, the main macronutrient that affects blood glucose is carbohydrate (Kerksick et al., 2008). There were no significant differences in carbohydrate intake between either of the groups for either exercise session. Although there were small differences in diet, the macronutrients affected should not have a major influence on the blood lactate and blood glucose levels measured in this study. One last limitation of this study is that it was conducted only on males, so the conclusions of this study and the recommendations set forth cannot be generalized to the entire IDDM population.

**Suggestions to IDDM Performing High-intensity exercise**

In summary, the data presented demonstrates that the use of carbohydrate supplementation during high intensity exercise followed by aerobic active recovery leads to an elevated blood glucose level in IDDM subjects with no significant drop in blood lactate levels. This type of exercise is similar to those who participate in sports with high intensity exercise followed by aerobic active recovery and passive recovery such as track and field, competitive swimming, hockey, basketball, and soccer. Based on the findings of this research it is suggested that participants in these types of sports with type 1 diabetes pay particularly close attention to their blood glucose levels throughout their activity. The findings of this study show that during
supramaximal exercise, blood glucose levels increase significantly with high intensity exercise combined with a 6% carbohydrate supplement. It is recommended that IDDM athletes be educated on the effects of supramaximal exercise on blood glucose. This population should understand that their blood glucose will rise significantly with supramaximal exercise alone and the use of carbohydrate supplementation will lead to an increased risk of hyperglycemia, which can be just as dangerous as hypoglycemia and it can lead to ketoacidosis. Athletes with type 1 diabetes who participate in high intensity exercise followed by aerobic active recovery will see that the active recovery is effective in clearing blood lactate levels however it is not significantly faster while using carbohydrate supplementation. The active recovery aerobic exercise will help to reduce the blood glucose levels; however, it is not a rapid drop and therefore supplementing with a 6% carbohydrate drink will cause blood glucose levels to rise instead of fall. It is recommended that athletes with IDDM who participate in sports that require supramaximal activity followed by active recovery exercise pay particularly close attention to their blood glucose levels prior to this type of exercise. This will allow individuals to plan out the amount of carbohydrate supplement needed to prevent bouts of hyperglycemia during this exercise.

Based on the findings of this research it is perfectly safe for males between 18 and 35 years old with type 1 diabetes as long as they monitor their blood glucose levels closely prior to and immediately after bouts of supramaximal intensity exercise and consume a 6% carbohydrate drink based on their blood glucose levels. The present findings of this research are novel in that this appears to be the first investigation to examine the acute effects of carbohydrate supplementation on blood glucose and blood lactate levels in males with IDDM during bouts of supramaximal intensity exercise, aerobic active recovery, followed by passive recovery.
Supramaximal intensity exercise with carbohydrate supplementation leads to significant increases in blood glucose level in type 1 diabetic males and therefore this population should pay particular attention to their blood glucose levels during these types of activities to create a carbohydrate supplementation plan that balances their caloric needs while preventing hyperglycemia. People with IDDM who participate in these types of high intensity sports, will have to devise an optimized carbohydrate supplementation plan through trial and error while paying close attention to blood glucose levels to prevent hyperglycemia.
Chapter V: Conclusions

Summary

This randomized double-blind cross over study closely examined the effects of carbohydrate supplementation before and throughout supramaximal exercise on blood glucose and blood lactate levels in active males between 18 and 35 years old who have type 1 diabetes. 7 healthy males between 18 and 35 years old with IDDM and 12 healthy males between 18 and 35 years old without IDDM were asked to complete a baseline VO2max session, 2 self-report food and insulin logs, and two intervention sessions. Both sessions had all participants complete a 12 hour fast and then a 60 second Wingate test on a cycle ergometer followed by a 5-minute lactate accumulation phase. After this all participants underwent 30 minutes of active recovery cycling with 15 minutes at 70% of VO2max and 15 minutes at 50% of VO2max. Then participants went through 30 minutes of seated passive recovery. In one session participants were asked to drink 4 Oz. of a 6% carbohydrate supplement (Dextrose and Crystal Light) 15 minutes prior to the Wingate Test, 15 minutes into active recovery, and immediately after active recovery. In the other session 4 Oz. of a placebo (Crystal Light) was given at the same time intervals.

Throughout both testing sessions blood glucose levels, blood lactate levels, heart rate, and blood pressure measurements were taken to monitor the physiological responses to the supramaximal exercise and supplementation. MANOVA and Post Hoc analyses showed that the carbohydrate supplement did not lead to any significant differences in blood lactate responses to the supramaximal exercise between the IDDM and non-IDDM subjects. There was a significant response to blood glucose levels in the IDDM group compared the non-IDDM group in which the carbohydrate supplement in conjunction with the supramaximal exercise lead to an elevated blood glucose level in the IDDM group compared to the non-IDDM group. Based on the data
collected from this study, active 18 to 35 year old males with IDDM should take precaution when participating in activities that require supramaximal exercise. Although carbohydrate supplementation may be needed to prevent hypoglycemia, precautions should be taken when adding in carbohydrate supplementation to supramaximal exercise as this leads to significant increases in blood glucose levels in people with IDDM. This population should closely monitor blood glucose levels prior to this type of exercise to design a plan that is best suited to their needs.

**Conclusions**

Based on the data from this study, the following conclusions have been set for each of the following hypotheses:

1.) Pre-training ingestion of a 6% carbohydrate drink and frequent ingestion during and after supramaximal intensity exercise will increase glucose levels throughout exercise and will significantly increase lactate clearance in IDDM subjects. Based on the data, the hypothesis that blood glucose levels will increase significantly with carbohydrate supplementation and supramaximal exercise is failed to be rejected. Based on the data the hypothesis that that the carbohydrate supplement will increase lactate clearance in IDDM subjects is rejected.

2.) There will be a positive correlation between the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between non-IDDM and IDDM subjects. Based on the results from the MANOVA and post hoc analysis this research hypothesis is failed to be rejected.
3.) There will be no difference in response to the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between non-IDDM subjects. This research hypothesis has failed to be rejected.

4.) There will be no difference in response to the consumption of a 6% carbohydrate drink on blood lactate levels and blood glucose levels between IDDM subjects. This hypothesis has failed to be rejected.

5.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between non-IDDM and IDDM subjects. This research hypothesis has been rejected. There is a significant difference in blood glucose levels between the two groups.

6.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between non-IDDM subjects. This hypothesis has failed to be rejected.

7.) There will be no difference in lactate levels and blood glucose levels in response to the placebo between IDDM subjects. This hypothesis has failed to be rejected.

**Future directions for research**

Although this study has confirmed theories seen in previous research, there are other topics regarding the effects of a carbohydrate supplement on blood glucose and blood lactate levels during and after supramaximal exercise that must be examined further. This research only examined the effects of carbohydrate supplementation and supramaximal intensity exercise in males between 18 and 35 years old. Future research should turn its focus to females between the same ages along with all individuals of any age suffering from type 1 diabetes. An interesting area for future research is to also examine the hormonal response of this type of exercise with and without carbohydrate supplementation on females with type 1 diabetes. Another possible
and important question to answer is finding the proper timing of carbohydrate supplementation during these this type of exercise to promote optimal performance while decreasing the risk of hypoglycemia and hyperglycemia. This field has many opportunities for future research however the main limitation is the small pool of people suffering from type 1 diabetes.
APPENDIX

Northeastern

Notification of IRB Action

Date: February 2, 2012
IRB #: 12-0-109

Principal Investigator(s): Rui Li
Craig Lewin

Department: Health Sciences
Northeastern University

Address: 520 Behrakis

Title of Project: The Response of Blood Lactate and Glucose in Type I
Diabetes to a Single Bout of Supramaximal Exercise
With and Without Carbohydrate Ingestion

Participating Sites: N/A

Informed Consent: One (1) signed consent

DHHS Review Category: Expedited #2, #4, #7

Monitoring Interval: 12 months

Approval Expiration Date: FEBRUARY 1, 2013

Investigator’s Responsibilities:

1. Informed consent form bearing the IRB approval stamp must be used when recruiting
participants into the study.

2. The investigator must notify IRB immediately of unexpected adverse reactions, or new
information that may alter our perception of the benefits-risk ratio.

3. Study procedures and files are subject to audit any time.

4. Any modifications of the protocol or the informed consent as the study progresses must be
reviewed and approved by this committee prior to being instituted.

5. Continuing Review Approval for the proposal should be requested at least one month prior to
the expiration date above.

6. This approval applies to the protection of human subjects only. It does not apply to any other
university approvals that may be necessary.

C. Randall Colvin, Ph.D., Chair
Northeastern University Institutional Review Board

Nan G. Regina, Director
Human Subject Research Protection

Northeastern University FWA #: 4630
Principal Investigator: Rui Li, PhD; Student Researcher: Craig Lewin, MS candidate

Research Title: The Response of Blood Lactate and Glucose in Type 1 Diabetes to a Single Bout of Supramaximal Exercise With and Without Carbohydrate Ingestion

Informed Consent and Health Information Use and Disclosure Authorization
We are inviting you to take part in a research study. This form will tell you about the study, but the researchers will explain it to you first. You may ask this person any questions that you have. When you are ready to make a decision, you may tell the researcher if you want to participate or not. You do not have to participate if you do not want to. If you decide to participate, the researcher will ask you to sign this statement and will give you a copy to keep.

Why am I being asked to take part in this research study?
We are asking you to be a part of this study because you are a physically active and 18-35 year old male who weighs over 110lbs. You are otherwise healthy, with or without controlled type 1 diabetes that is willing to do moderate to vigorous physical activity while having your blood lactate and glucose tested and consume a placebo and 6% carbohydrate beverage.

Why is this research study being done and for what purpose will my health information be used and disclosed?
You are invited to participate in a research study that will investigate the responses of blood lactate and glucose, in healthy and type 1 diabetic individuals, to supramaximal exercise with and without carbohydrate consumption. Currently there is a need for studies that can help to shed light on how insulin dependent diabetes mellitus (IDDM) respond to supramaximal exercise and what the effect of a carbohydrate supplement has on blood lactate and blood glucose. The data collected during this study will be used to help us determine the effects of supramaximal exercise on blood lactate and glucose with and without carbohydrate supplementation. All data collected will be de-identified so that all your information will remain anonymous and confidential.

The data may be used in a scientific presentation or publication of the study results but your identity will not be revealed.

Who will be using and disclosing information about me?
Dr. Rui Li (Primary Investigator) and her graduate student investigator Craig Lewin will use and disclose your health information pursuant to this authorization.

What will I be asked to do?
If you decide to take part in this study, we will ask you to:

- Attend a baseline testing session. During this session we will be taking your height, weight, body mass index, resting heart rate, resting blood pressure, blood glucose test, and a VO₂ max test. During the VO₂ max test we will also record your peak exercise heart rate, peak
exercise blood pressure, and peakVO₂. The VO₂ max test will be done on a Monark cycle ergometer. You will be asked to pedal at a cadence of 60 rpms and start at 40 watts. Every 2 minutes the wattage will increase by 25 Watts. You will continue pedaling until you can no longer go on.

• Schedule two appointments for exercise testing that are separated by 5 to 7 days.

• Record your food consumption and insulin use for the two days prior to your exercise testing sessions. This will be done on forms given to you by the researchers after your baseline testing session.

• Attend 2 exercise test sessions. The protocol that you will be asked to do will be the same for both sessions. You will be taking between 5 to 7 days between each testing session. One testing session will be a control in which you will receive a placebo and the other will be an intervention session in which you will be given a 6% carbohydrate drink. Neither you nor the researchers will know which session will be the control or the intervention session. The protocol for the days is as follows:

1. Arrive and have the researcher do blood glucose, blood lactate, heart rate, and blood pressure measurements at rest.
2. Consume 4oz of the placebo or carbohydrate 15 minutes prior to exercise.
3. Do a 5-minute warm up on the stationary bicycle with no resistance.
4. Do a Wingate test in which you will be asked to pedal as hard and as fast as possible for 60 seconds with a resistance equal to 5% of your body weight.
5. Sit on the stationary bike for 5 minutes and then have your blood glucose, blood lactate, heart rate, and blood pressure measurements taken.
6. Do 15 minutes of active recovery pedaling at 70% of VO₂ max then do 15 more minutes of active recovery pedaling at 50% of VO₂ max.
7. Every 10 minutes during the 30 minute active recovery pedaling a blood glucose, blood lactate, heart rate, and blood pressure will be taken.
8. Every 15 minutes starting after the Wingate 60 second test and the 5 minutes lactate accumulation phase, you will be asked to drink 4oz of the placebo or carbohydrate drink.
9. After the 30 minute active recovery session you will be asked to sit in a chair relaxed for 30 minutes of passive recovery.
10. After the 30 minutes of passive recovery we will do one last blood glucose, blood lactate, heart rate, and blood pressure measurement.
11. You will then be asked to self report your blood glucose levels at 2, 6, 12, and 24 hours after your exercise test.
12. Come back and repeat the procedure 5 to 7 days later at your second exercise testing session.
Where will this take place and how much of my time will it take?
This research will be conducted at Northeastern University Human Performance & Exercise Science Laboratory in the Behrakis Health Science building. The baseline session, the control exercise session, and the intervention exercise session will all take approximately 90 minutes each. All three sessions combined will take no longer than 5 hours.

Will there be any risk or discomfort to me?
The risks associated with this study may include dizziness, light-headedness, fainting, difficulty in breathing, and hypo or hyperglycemia. All of these risks are minimal and precautions will be taken so that these outcomes do not occur. Medical attention will be provided by the researchers should an emergency occur. Each researcher is CPR/AED certified as well as proficient in advanced first aid. An Emergency Action Plan will be implemented if the situation is deemed necessary.

There are no risks for the finger prick for blood lactate and blood glucose measurements other than the possibility of slight discomfort. Only minimal blood equal to roughly 25 microliters will be drawn for each stick. Lactate test strips and blood glucose test strips are one-time use only and will promptly be discarded. Sterile gauze will be used to wipe the blood drops off and each site will be covered with a sterile band-aid following completion of testing.

If you decide to participate in the Dual X-ray absorptiometry (DXA) scan as part of your compensation there are some risks associated with this. DXA is an enhanced form of x-ray technology. An x-ray (radiograph) is a painless medical test that helps physicians diagnose and treat medical conditions. The effective radiation dose from this procedure is about the same as the average person receives from background radiation in one day. It is a painless procedure but radiation is present; however, the amount of radiation present produces minimal risks.

It is important to remember that you are free to withdraw from this study at any time. Furthermore, you are also free to decline to answer any of the questions that will be asked as part of the initial experiment setup or end of study interview if a question makes you feel uncomfortable.

You may ask questions at any time and you may ask to see examples of collected data, to better understand how your data will be used and protected.

Will I benefit by being in this research?
There are no immediate benefits for you other than a better understanding of how your body responds to exercise and an explanation of your current functional capacity and body composition. The data from this study will further research on highly active IDDM subjects. It
will help to offer suggestions on how to improve recovery of IDDM populations from very intense physical activity and how to maintain blood glucose while doing so.

**What health information will be used and disclosed?**
Your health information related to this study may be used or disclosed in connection with this research study, including, but not limited to your measured body height, weight, gender, age, BMI, blood glucose levels, blood lactate levels, peak VO\(_2\), peak power, mean power, heart rates, and blood pressures.

**Who will see the information about me?**
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Your responses and data will be referenced by an ID number in order to protect your identity. A study enrollment log will be kept that will include participants’ unique identification numbers, names, telephone numbers and enrollment data. This log will be stored in a locked cabinet in the investigators’ office and will be destroyed 1 year after the completion of the study.

When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity. Your name will not in any way be associated your data. Once your data is made anonymous, it may be shared with other researchers for future studies. These data may be used in a scientific presentation or publication of the study results but your identity will not be revealed.

**Note:** Some person or organizations that receive your health information pursuant to this authorization may not be covered by the Health Insurance Portability and Accountability Act or other privacy laws.

**What will happen if I suffer any harm from this research?**
In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the Northeastern University Health and Counseling Services, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. Northeastern University does not provide any other form of compensation for injury. Moreover, neither the offer to provide medical assistance nor the actual provision of medical services shall be construed as an admission of negligence or acceptance of liability. No special arrangements will be made for compensation or for payment for treatment solely because of my participation in this research.

**Can I stop my participation in this study?**
Your participation in this research is completely voluntary. You do not have to participate if you do not want to. Even if you begin the study, you may quit at any time. If you do not participate or if you decide to quit, you will not lose any rights, benefits, or services that you would otherwise have [as a student, employee, etc.].

Who can I contact if I have questions or problems?
If you have any questions or concerns about the research, please feel free to contact:

Rui Li, PhD
Primary Investigator
617-373-2526, r.li@neu.edu

Who can I contact about my rights as a participant?
If you have any questions about your rights as a participant, you may contact Nan C. Regina, Director, Human Subject Research Protection, 960 Renaissance Park, Northeastern University Boston, MA 02115 tel. 617-373-7570, email: irb@neu.edu. You may call anonymously if you wish.

Can I access the health information collected about me and request corrections where necessary?
You will have the right to review and request amendment of your health records. However, access to your private health information may be delayed until the end of the study. To request access to your private health information you must contact Dr. Rui Li (Primary Investigator) directly.

Will I be paid for my participation?
We highly appreciate you take time understanding our study and decide to participate. Your participation will make great contribution to the research and expansion of the knowledge in exercise science. For your participation we will be offering you the invaluable results of your exercise tests including the VO2 max test, blood glucose tests, and blood lactate tests. You will also be given a consultation session that explains these results and how to use them to reach their fitness goals. You will also be offered the chance to have a Dual X-ray absorptiometry (DXA) scan to obtain an accurate body composition and bone density reading*. An explanation of the results will also be explained during this consultation.

*There are some minimal risks associated with a DXA scan due to the radiation involved. The amount of radiation is no more than the background radiation that you encounter during a normal day.

Will it cost me anything to participate?
You may incur some costs including travel to Northeastern University and parking.

When will this authorization end?
This authorization will be indefinite.
I agree to take part in this research and authorize the use and disclosure of my health information consistent with provisions above.

Signature of person agreeing to take part ____________________________ Date ______________

Printed name of person above ____________________________

Signature of person who explained the study to the participant above and obtained consent ____________________________ Date ______________

Printed name of person above ____________________________
References


43. Popadic Gacesa, J. Z., Barak, O. F., & Grujic, N. G. (2009). Maximal anaerobic power test in athletes of different sport disciplines. [Research Support, Non-U.S. Gov't]. *Journal of*


