Introduction

Physical activity is strongly recommended for individuals with type 1 diabetes as regular exercise is associated with greater life expectancy and a lower frequency of diabetic complications in this population (1). Higher levels of physical activity are associated with improved physical fitness, lower insulin requirements, more favourable lipid profiles, decreased cardiovascular disease risk, improved endothelial function, delayed onset and/or progression of peripheral neuropathy and higher self-reported quality of life in people with type 1 diabetes (1). Despite this, most individuals with type 1 diabetes fail to achieve the recommended levels of physical activity (2). In addition to the usual barriers to exercise cited by the general population, such as lack of time and/or energy, or lack of convenient/affordable facilities, individuals with type 1 diabetes generally list fear of hypoglycemia as an important barrier (3). Although it is clear that aerobic exercise generally increases the risk of hypoglycemia in type 1 diabetes, a handful of recent acute exercise studies indicated that anaerobic forms of exercise (weight lifting, sprinting and so forth) may reduce this risk (4,5). In the present review article, we discuss the energy systems involved in these types of activities, and provide an overview of recent studies related to resistance exercise in type 1 diabetes. We also discuss the current exercise guidelines for individuals with type 1 diabetes, provide further recommendations with respect to resistance exercise and propose a direction for future research in the area.

Abstract

It is relatively well known that moderate-intensity aerobic exercise increases the risk of hypoglycemia in individuals with type 1 diabetes. Conversely, brief high-intensity (anaerobic) activity can cause post-exercise hyperglycemia. Recent evidence has indicated that including small amounts of anaerobic activity, either in the form of short sprints or as resistance exercise (weight lifting), during aerobic exercise sessions may decrease the drop in blood glucose levels associated with moderate-intensity aerobic exercise. This review discusses the recent developments in the area of exercise and type 1 diabetes, with a particular focus on the effects of resistance exercise. Practical exercise recommendations, as well as suggestions for the future direction of research in this area, are also provided.

Résumé

Il est relativement bien connu que l'exercice aérobique d'intensité modérée augmente le risque d'hypoglycémie chez les individus ayant le diabète de type 1. Inversement, une séance brève d'activité d'intensité élevée (exercice anaérobie) peut causer une hyperglycémie après exercice. Des données scientifiques récentes ont montré que le fait d'inclure un petit nombre d'activités anaérobies sous la forme de sprints courts ou d'exercices contre résistance (poids et haltères) durant les séances d'exercice aérobique peut réduire la chute de glycémie associée à l'exercice aérobique d'intensité modérée. Cette revue traite de récents développements dans le domaine de l'exercice et du diabète de type 1, et met l'accent sur les effets de l'exercice contre résistance. Les recommandations pratiques sur l'exercice ainsi que les suggestions concernant l'orientation future de la recherche dans ce domaine sont également fournies.

Keywords:
- blood glucose control
- diabetes
- hypoglycemia
- weight lifting

Mots clés :
- régulation de la glycémie
- diabète
- hypoglycémie
- poids et haltères

Research Resistance Exercise in Type 1 Diabetes

Jane E. Yardley PhD a,b, Ronald J. Sigal MD, MPH c, Bruce A. Perkins MD, MPH d, Michael C. Riddell PhD e, Glen P. Kenny PhD a,*

a Human and Environmental Physiology Research Unit, University of Ottawa, Ottawa, Ontario, Canada
b Manitoba Institute of Child Health, University of Manitoba, Winnipeg, Manitoba, Canada
c Departments of Medicine, Cardiac Sciences and Community Health Sciences, Faculties of Medicine and Kinesiology, University of Calgary, Calgary, Alberta, Canada
d Mount Sinai Hospital and Samuel Lunenfeld Research Institute, University of Toronto, Toronto, Ontario, Canada
e School of Kinesiology and Health Science, York University, Toronto, Ontario, Canada

Address for correspondence: Glen P. Kenny, PhD, Room 367, Montpetit Hall, Ottawa, Ontario K1N 6N5, Canada.
E-mail address: gkenny@uottawa.ca.

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Exercise Types and Energy Systems

Aerobic exercise

The terms “anaerobic” and “aerobic” refer mainly to the metabolic energy sources that dominate the activity. Aerobic exercise, such as walking, cycling, jogging or swimming, typically involves the repeated and continuous movements of the same large muscle groups over an extended duration of time (minimum 10 minutes at a time) at a moderate intensity (~40% to 60% of an individual’s aerobic capacity [VO_{2peak}] (6). In individuals without diabetes, the first 5 to 10 minutes of aerobic exercise are fueled mostly by muscle glycogen. After this initial period, glucose and nonesterified fatty acids (NEFA) become the main source of fuel, as they are broken down in the presence of oxygen in the mitochondria of the muscle cells to produce energy in the form of ATP. As the duration of moderate aerobic exercise increases, so does reliance on NEFA and circulating glucose as the primary fuel sources (7). Throughout this time, release of insulin from pancreatic beta cells decreases and glucagon concentration increases. The balance of these 2 hormones ensures that fuels are released from storage to meet the increased energy demands of the exercising muscles. Glucose, stored mainly as glycogen in the liver, and NEFA, stored mainly in adipocytes, are released into circulation for uptake and use in the exercising muscles (8). As a result, blood glucose levels during exercise in people without type 1 diabetes remain essentially unchanged. Once exercise has stopped, glucose production and use both return to baseline levels, as do the levels of insulin and glucagon. Where pancreatic function is normal, hypoglycemia only occurs if exercise lasts for several hours without food intake, resulting in glycojen depletion and hepatic glucose production falling short of glucose use (9).

For individuals with type 1 diabetes, autoimmune destruction of the insulin-producing beta cells of the pancreas eventually results in a complete or near-complete lack of endogenous insulin production. As such, circulating insulin levels during exercise depend on the timing and quantity of insulin introduced (either by injection or insulin pump infusion) into the individual’s system before exercise. Without careful planning and adjustments to insulin dosage before exercise, circulating insulin levels are often too high (hyperinsulinemia) or too low (hypoinsulinemia). Hyperinsulinemia stimulates glucose uptake by muscle, adipose and hepatic cells for storage and/or oxidation, and inhibits the release of glucose from the liver. Conversely, hypoinsulinemia increases hepatic glucose production and limits glucose uptake in the periphery. In most cases, aerobic exercise occurs while the participant with type 1 diabetes is in a hyperinsulinemic state, resulting from an inability to decrease circulating insulin levels at the start of exercise. This generally results in large decreases in blood glucose levels during the activity, resulting in hypoglycemia, unless sufficient quantities of carbohydrate are consumed before, during and after exercise. A summary of the response to aerobic exercise in individuals with and without type 1 diabetes can be found in Table 1.

Anaerobic exercise

When exercise is very intense (~85% of aerobic capacity) anaerobic metabolism, which breaks down glucose quickly in the absence of oxygen to produce adenosine triphosphate and lactate, supplies most of the energy. Under these conditions, the roles of insulin and glucagon are diminished (10). High intensity causes substantially increased levels of catecholamines (epinephrine and norepinephrine), which have an overriding influence on glucose release by the liver (11). Under the influence of the catecholamines, hepatic glucose production can increase 5- to 10-fold, often exceeding the rate of use and resulting in an increase in blood glucose concentration (11,12). This may cause hyperglycemia when the activity ends because glucose use returns to baseline faster than glucose production (11,12). In individuals without diabetes, the hyperglycemia stimulates normal mechanisms of glucose control, leading to the release of insulin to promote glucose storage and return blood glucose levels to normal. In one study of athletes without diabetes, exercising for 15 minutes at approximately 90% of their maximal aerobic capacity (an intensity level associated with elevated catecholamines and increased lactate production), circulating insulin levels doubled at the end of exercise and remained elevated for approximately 40 minutes (13). Thus, it would appear that insulin requirements increase at the end of intense aerobic/anaerobic exercise to help re-establish glucose homeostasis.

The powerful effects of epinephrine and norepinephrine on glucose production are also present in individuals with type 1 diabetes. Brief (10 to 15 minutes), very high intensity exercise causes an increase in glucose production during exercise. After the cessation of exercise, glucose production does not diminish as quickly as glucose use, resulting in post-exercise hyperglycemia (14,15). In individuals with type 1 diabetes, because there is no endogenous insulin secretion, hyperglycemia can persist for several hours after exercise unless a correction bolus of insulin is administered (16). When applied in short bursts, however, anaerobic activity in the form of short (4 to 10 seconds) sprints can be used to attenuate decreases in blood glucose concentration during moderate aerobic exercise (4). Such sprints reduce hypoglycemia owing to decreased glucose disposal rather than increased glucose production (17). Studies differ regarding whether or not exercise sessions involving intermittent high-intensity intervals lead to a greater risk of nocturnal hypoglycemia, resulting from muscle and liver glycogen stores being replenished for up to 12 hours after exercise (18–20). A summary of the response to anaerobic exercise in individuals with and without type 1 diabetes can be found in Table 2.

Resistance exercise

Resistance exercise also relies mostly on anaerobic sources of fuel, and, as such, elicits very similar hormonal and metabolic responses to that of anaerobic exercise, such as high-intensity running or cycling (21,22). The design of each training protocol and the resulting hormonal responses depend on the goals of the

### Table 1

Responses to aerobic exercise in individuals with and without type 1 diabetes

<table>
<thead>
<tr>
<th>Exercise response</th>
<th>No diabetes</th>
<th>Type 1 diabetes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in glucose uptake</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Initial blood glucose response</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Insulin response</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Glucagon response</td>
<td>↑</td>
<td>↑ or ↔</td>
</tr>
<tr>
<td>Catecholamine response</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Hepatic glucose production</td>
<td>↑↑</td>
<td>↑</td>
</tr>
<tr>
<td>Resulting blood glucose levels</td>
<td>↔ (euglycemia)</td>
<td>↓ ↓ (hypoglycemia)</td>
</tr>
</tbody>
</table>

### Table 2

Response to anaerobic exercise in individuals with and without type 1 diabetes

<table>
<thead>
<tr>
<th>Exercise response</th>
<th>No diabetes</th>
<th>Type 1 diabetes</th>
</tr>
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<tbody>
<tr>
<td>Change in glucose uptake</td>
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<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Insulin response (exercise)</td>
<td>↓ or ↔</td>
<td>↔</td>
</tr>
<tr>
<td>Glucagon response (exercise)</td>
<td>↑</td>
<td>↑ or ↔</td>
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<tr>
<td>Hepatic glucose production</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Insulin response (post-exercise)</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Resulting blood glucose levels</td>
<td>↔ (euglycemia)</td>
<td>↓ ↓ (hypoglycemia)</td>
</tr>
</tbody>
</table>
individual performing them. The speed of the movement, along with the amount of weight lifted (as a percentage of the person's maximum lifting ability), the number of repetitions (times the weight is lifted), the number of sets of each exercise as well as the rest interval between the sets affect the body's response to the activity (22,23).

During moderate-intensity resistance exercise in individuals without diabetes, insulin and glucagon responses are the main regulators of blood glucose levels. More intense resistance exercise (faster or heavier lifts) will result in a greater release of catecholamines (24). Hepatic glucose production increases in proportion to the concentration of catecholamines present, increasing blood glucose levels (sometimes to the point of hyperglycemia) when glucose supply exceeds demand (24,25). Within an hour of completing a resistance exercise session, the balance of insulin and glucagon restores blood glucose levels to baseline in individuals without diabetes.

Very few studies to date have examined the acute effects of resistance exercise in individuals with type 1 diabetes. Two recent publications have indicated that, similar to other forms of anaerobic activity, resistance exercise causes less of a decrease in blood glucose levels during exercise and a more stable blood glucose profile immediately after exercise, without increasing the risk of nocturnal hypoglycemia (5,26). These studies are discussed in more detail later along with resistance exercise recommendations for individuals with type 1 diabetes, after an overview of the health benefits of resistance training and its impact on longer-term blood glucose control in individuals with type 1 diabetes.

The Health Benefits of Resistance Training

Recent decades have seen the transition of resistance exercise as a form of training primarily performed for competition weight lifting and body building, to a training tool for fitness, strength and balance in most sports and a prescription for healthy living in the general population. With the aging of the population, a great deal of emphasis has been placed on the role of resistance training in the maintenance of muscle mass, strength and metabolic health (27), along with improved physical functioning and longer-lasting independence among elderly individuals (28). The therapeutic and prophylactic properties of resistance exercise training also have been recognized: studies have shown that this type of training can augment resting energy expenditure (29), increase bone mineral density (30), improve body composition by increasing lean muscle mass and decreasing fat mass (31), reduce the risk of type 2 diabetes through improvements in insulin sensitivity (32), lower resting blood pressure (33), ameliorate blood lipid profiles (34) and generally improve cardiovascular health (31,33). In addition, resistance training has been associated with mental health benefits including improvements in self-rated quality of life (35), cognition (36) and self-esteem (37). Overall, resistance training offers a multitude of benefits for individuals of all ages and all fitness levels.

Resistance Training and Blood Glucose Control Type 1 Diabetes

Although individuals with type 1 diabetes will experience all of the same health benefits of resistance training as people without diabetes, it remains to be shown conclusively whether or not resistance exercise has a positive effect on blood glucose control, as measured by glycated hemoglobin (A1C) in this population. Some studies found that resistance exercise, either on its own or combined with aerobic activity, reduced A1C (38–41), whereas others did not find any positive effects on blood glucose control (42,43). These studies generally have involved small sample sizes and often lacked a nonexercising control group with type 1 diabetes.

Among these studies, there are only 2 that have been published examining the chronic effect of resistance exercise training by itself on blood glucose control in type 1 diabetes (38,39); Durak et al (38) randomized 8 subjects in a crossover design into 2 groups: 1 group performed a 10-week resistance training program before taking a 6-week break, and the second group spent 6 weeks without exercise before performing the 10-week resistance training program (n=4 per group). The training consisted of 3 sessions weekly (approximately an hour each) of weight-lifting exercises. After 6 weeks without training, the mean A1C was 6.9%±1.4%, whereas post-training it was measured at 5.8%±0.9% (p<0.05) (38). Additional benefits of the exercise included decreases in serum cholesterol and self-monitored blood glucose levels.

In a separate study, Ramalho et al (39) randomized 16 previously sedentary participants with type 1 diabetes to either 12 weeks of aerobic exercise 3 times per week, or 12 weeks of resistance exercise 3 times weekly. Although the decrease in A1C levels found in the resistance training group was not statistically significant (from 8.2%±2.9% to 7.6%±1.6%), aerobic training produced a significant increase in A1C (from 8.7%±1.6% to 9.8%±1.8%; p<0.05) (39). It is possible that those individuals performing aerobic exercise had a greater tendency to compensate with excessive carbohydrate intake to avoid hypoglycemia both during and after exercise; however, these data were not reported by Ramalho et al (39). All participants in the study were following a regimen of multiple daily insulin injections (as opposed to an insulin pump), which also has been associated with worse post-exercise blood glucose outcomes after aerobic exercise (44). Overall, both training programs reduced mean waist circumference, insulin dosage and self-monitored blood glucose; however, these changes were only statistically significant in the aerobic exercise group.

The studies (40–43) involving combined aerobic and resistance training also were small in number and generally had small sample sizes (n=8–13, except for one study (43) in which n=73). In addition, the lack of concurrent nonexercise control groups with diabetes in some of the studies complicates interpretation of the outcomes. In an early study, Peterson et al (40) measured a significant decrease in A1C level (from 10.3% to 7.6%), a decrease in blood pressure, heart rate and mean body fat and improvements in nerve conduction in 10 young adults with type 1 diabetes. The 8-month training program consisted of a 5-minute warm-up, 15 minutes of cycling and 15 minutes of resistance exercise, in addition to monthly medical examinations, strict glucose monitoring instructions and weekly group meetings. Without a concurrent control group, it is difficult to know whether improvements in blood glucose control can be attributed to the exercise program or simply to the improvements in patient blood glucose monitoring and other aspects of self-care. Similarly, although a study by Mosher et al (41) found improved strength and cardiorespiratory endurance, increased lean body mass and significant improvements in A1C levels (from 7.72%±1.26% to 6.76%±1.07%) in 10 adolescents with type 1 diabetes after 12 weeks of circuit training (45 minutes of combined endurance and strength activities three times weekly), it too lacked a non-exercising control group with type 1 diabetes.

Two recent studies involved adolescents with type 1 diabetes who performed both aerobic and resistance training and included nonexercise control groups (42,43). A small (n=8 per group) study by D’Hooge et al (42) found that a combination of supervised aerobic (30 minutes) and strength (30 minutes) training performed twice weekly improved muscular strength and endurance and decreased insulin dosage, but had no significant effect on body composition or A1C levels in children with type 1 diabetes. However, study participants had low compliance rates (mean...
attendence, 63%) and did not have their diet monitored during the study, both of which could have affected the outcome negatively. A larger study by Salem et al (43) in Egyptian children and adolescents with type 1 diabetes involved a combination of aerobic exercise (cycling/treadmill at 65% to 85% of their target heart rate for 30 minutes including warm-up and cool-down), anaerobic exercise (1 to 2 minutes at >85% of their maximal heart rate) and resistance exercise (~20 minutes of lower body exercises involving sets of 10 repetitions at between 50% and 100% of the individual’s 10-repetition maximum) and looked more closely at the importance of exercise frequency. Of the 2 exercise groups, one group performed the exercise protocol once per week (n=75), whereas the other group exercised 3 times per week (n=73). In addition, a non-exercise control group with type 1 diabetes (n=48) was included. The published outcomes, however, must be viewed with caution as it seems that the 24% of participants who did not adhere to the required protocol were not included in an intention-to-treat analysis, thereby increasing the likelihood of false positives. The rate of attrition for each group in the study also was not explicitly stated. Of the individuals analyzed, the control group showed a nonsignificant increase in A1C levels (from 8.3%±2.1% to 8.9%±1.4%) whereas both exercise groups experienced significant decreases. Greater improvements were found in the group performing exercise more frequently (from 8.9%±1.6% to 7.8%±1% [p=0.03] vs. 8.9%±1.4% to 8.1%±1.1% [p=0.01]). Similarly, improvements in weight, body mass index, waist circumference, lipid profiles and insulin dosage were found in both exercise groups, with greater improvements being associated with higher exercise volume (43). The outcomes for the lipid profiles should be viewed with caution, however, as the more frequently exercising group had higher low-density lipoprotein (p=0.01) and total triglyceride levels (p=0.001) at baseline.

**Acute Effects of Resistance Exercise on Blood Glucose Levels in Patients With Type 1 Diabetes**

Until very recently, there were no studies examining the acute effects of resistance exercise on blood glucose levels in patients with type 1 diabetes. A recent study by our group (26) examined the acute glycemic effects of a resistance exercise protocol consisting of 3 sets of 8 repetitions, of 7 different exercises at the individual’s predetermined 8 repetition maximum (8 RM), in comparison to aerobic exercise (45 minutes of treadmill running at 60% of their predetermined peak aerobic capacity [V_{O2peak}] and no exercise (sitting upright for 45 minutes) in physically fit individuals with moderate to good control of their type 1 diabetes (A1C levels=7.1%±1.1%). Participants wore continuous glucose monitoring devices for 24 hours before the testing session, during the exercise session and for 24 hours after exercise. They also consumed the same foods (self-selected) for 3 straight days (the day before, the day of and the day after testing) at the same time of day for all 3 testing sessions and matched their insulin intake for each day of monitoring as closely as possible.

Plasma glucose levels decreased rapidly during aerobic exercise, resulting in significantly lower levels than the no-exercise condition within 10 minutes of exercise. Decreases during resistance exercise were more gradual and of a smaller magnitude (Figure 1), with differences being significant only after 45 minutes of resistance exercise when compared with the no-exercise session. During exercise, 2 of 12 participants needed carbohydrate supplementation (glucose tablets) because of low blood glucose levels in the no-exercise trial, 9 of 12 in the aerobic exercise trial and 3 of 12 for the resistance exercise session (26). After exercise, blood glucose levels remained unchanged in the 1-hour recovery period after the resistance exercise and no-exercise sessions, whereas a significant increase in blood glucose levels was observed after the aerobic exercise session. Less late (3 to 6 hours) post-exercise hyperglycemia (as measured by continuous glucose monitoring) also was found after resistance exercise than after aerobic exercise, with blood glucose trends after resistance exercise mirroring those from the no-exercise control session (Figure 2) (26).

**Combining aerobic and resistance exercise**

Many individuals who perform both resistance and aerobic exercise regularly tend to combine them into a single session. In individuals with type 1 diabetes, recent studies by us indicated that including resistance exercise alongside aerobic exercise affects blood glucose levels differently than performing aerobic exercise alone. Specifically, performing resistance exercise (3 sets of 8 repetitions of 7 different exercises at the participants’ 8 RM, session duration of approximately 45 minutes) before aerobic exercise (45 minutes at 60% V_{O2peak}) may attenuate the decreases in blood glucose concentration associated with moderate aerobic activity (Figure 3). In one of our studies, the participants’ plasma glucose levels decreased during aerobic exercise (Figure 2). In another study, the participants’ plasma glucose levels decreased during resistance exercise (Figure 1). The solid line represents the aerobic exercise session and the dashed line represents the resistance exercise session. The line represents the period of time when glucose was significantly higher after aerobic exercise as compared with resistance exercise (p<0.05) [n=11 [control], n=10 [aerobic] and n=12 [resistance]]. Copyright 2012 American Diabetes Association. From Diabetes Care, Vol. 36, 2013;537-542. Modified by permission of The American Diabetes Association.
concentration decreased significantly over the course of the exercise session when aerobic exercise was performed alone (from 9.2±3.4 to 5.8±2.0 mmol/L, p=0.001). When the participants performed resistance exercise before the same aerobic exercise protocol on a separate occasion, changes in plasma glucose concentration were much smaller (from 9.2±4.0 to 6.9±3.1 mmol/L, p=0.04). The decreases in blood glucose levels during the aerobic exercise session may have been even more pronounced had fast-acting glucose supplements (Dex 4; AMG Medical, Montreal, Canada) not been provided: participants were given 16 g of glucose in tablet form when blood glucose levels decreased to less than 4.5 mmol/L during the exercise session. More participants required carbohydrate supplementation during the session that involved aerobic exercise on its own (9 of 12 as compared with 5 of 12 when resistance exercise preceded the running), despite the greater energy demands associated with the combined exercise session. Performing the resistance exercise in addition to the aerobic activity also did not increase the risk of nocturnal hypoglycemia: the frequency of low blood glucose levels, average lowest blood glucose concentration and area under the curve were similar for both exercise sessions (unpublished data).

When aerobic and resistance exercise are combined into a single exercise session, the order in which the exercises are performed also affects blood glucose levels in individuals with type 1 diabetes (5). When regularly active individuals with type 1 diabetes (n=12) performed aerobic exercise (45 minutes of running at 60% \( \dot{V}O_{2\text{peak}} \)) before resistance exercise (3 sets of 8 repetitions with heavy resistance may be associated with a steeper decrease in blood glucose levels owing to the more aerobic nature of the activity. Likewise, training protocols involving short sets (i.e. 3 to 5 repetitions) with heavy resistance may be associated with a higher epinephrine response (22) and, therefore, a greater likelihood of high blood glucose levels. The fitness level of the individual performing resistance exercise also could impact acute blood glucose responses as highly trained individuals are known to have higher epinephrine secretion, and consequently greater increases in blood glucose levels, in response to exercise than untrained individuals (46).

When combining aerobic and resistance activities within a single exercise session, it is advisable to perform resistance exercise before aerobic exercise if a low blood glucose level during exercise is a concern. It should be noted that these recommendations are based on studies involving relatively young individuals with type 1 diabetes, and that the effects of resistance exercise in older adults with type 1 diabetes remain to be examined. With age-related decreases in muscle mass (47), the glucose-lowering effect of exercise may be attenuated in older individuals. In
addition, it is probable that hormonal responses to resistance exercise will be less pronounced (48), which could decrease the glucose stabilizing effect of resistance exercise in older individuals with type 1 diabetes. As with beginning any type of exercise program, individuals with type 1 diabetes should check their blood glucose levels frequently and be prepared to make adjustments during exercise and in the 12 to 24 hours after activity. In addition, it is highly recommended that individuals with type 1 diabetes undergo screening for diabetic retinopathy with a dilated retinal examination or retinal photographs before starting a resistance training program, if one was not performed in the previous year. Pre-proliferative or proliferative retinopathy, if present, should be treated and stabilized before starting a resistance exercise program.

Perspective

There is still a great deal to learn about the effects of resistance exercise on acute blood glucose responses in individuals with type 1 diabetes, and the effects of different frequencies, intensities and durations of resistance exercise to prescribe. The only type of protocol that has been examined in this population to date is a relatively high-intensity protocol consisting of 3 sets of 8 repetitions at the maximum weight that can be lifted 8 times. Blood glucose responses for moderate-intensity programs aimed at increasing muscular endurance (i.e. consisting of 3 or more sets of 15 or more repetitions) still need to be quantified. An examination of shorter weight lifting sets consisting of 3 to 5 repetitions in which much heavier loads are lifted and longer rest periods are provided between sets (designed for maximizing strength and muscle hypertrophy) also is warranted. Finally, a study examining the effects of alternating resistance and aerobic exercises for short periods of time (i.e. circuit training, as is often performed in fitness boot camps) would be beneficial.

To be able to generalize the results of these studies, there are several factors that must be examined more closely. The responses of several exercise-related hormones (cortisol, growth hormone, catecholamines and so forth) vary depending on the age (24), sex (24,49) and fitness level (11) of the individual, thereby warranting studies of these various subgroups. There is also recent evidence to indicate that blood glucose responses to exercise might be different depending on whether the individual is using an insulin pump or multiple daily injections for their insulin delivery (44), the reasons for which need to be explored in greater detail.

Considering the technology that is currently available (i.e. continuous glucose monitoring systems), we now have the potential to extend the window of observation associated with these exercise sessions to include data for the overnight period, and even for a few days after exercise, without requiring subjects to remain in a laboratory. The effects of exercise on blood glucose homeostasis may extend well beyond the 12-hour period in individuals with type 1 diabetes, although the myriad of factors that influence blood glucose levels make examining the prolonged effects of exercise on glucose control challenging. Continuous glucose monitoring systems have been identified as a useful and accurate (50) tool for monitoring blood glucose trends during exercise, recovery and overnight post-exercise. The ability to observe overnight trends will allow a closer examination of the lasting effects of a daytime exercise session, as well as providing the ability to compare with the nights where no daytime exercise has been performed. In theory, this eventually may enable us to provide better recommendations for exercise in terms of the type, duration and intensity of exercise, and to refine algorithms for adjustment of insulin and carbohydrate intake for individuals with type 1 diabetes. Although being vigilant about blood glucose levels will always be necessary when performing resistance exercise, this type of activity has numerous benefits and should be recommended as an important activity for health and well-being in individuals with type 1 diabetes.

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Author Contributions

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