Keystone Journal of Undergraduate Research 4(1):7-15. 2017

The Effect of Training Status on Resting Glucose Tolerance in a Collegiate Population

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ABSTRACT

The purpose of this study was to measure the differences in glycemic regulation during an oral glucose tolerance test (OGTT) administered to collegiate aerobic and anaerobic athletes and a sedentary population. Aerobically trained ($n = 6$), anaerobically trained ($n = 6$) and sedentary ($n = 6$) men and women voluntarily participated in the study. After completing a 12 h fast, 10 min incremental blood glucose (BG) measurements were recorded over 80 min following consumption of a ~300ml dextrose beverage (1.5g/kg of body mass). On a separate day, the YMCA Cycle Ergometer protocol was utilized to estimate maximal oxygen uptake (VO_2max). Body composition was measured via bioelectrical impedance analysis. The collected data indicated that aerobic athletes displayed a significantly smaller ($P<0.05$) area under the blood glucose curve when compared to anaerobic and sedentary groups. No significant differences for glycemic control were present between the anaerobic and sedentary groups. A significant positive correlation ($r = 0.75$) was shown between BMI and area under the glucose curve (AUGC) ($P<0.01$). A moderate, but non-significant negative correlation ($r = -0.463$) between estimated VO_2max and AUGC was observed. Aerobic athletes displayed a significantly more efficient glucose metabolism, and an aerobic-based training program with goals to improve BMI may serve most beneficial for individuals with Type 2 diabetes mellitus or pre-diabetic symptoms.

Keywords: aerobic; anaerobic; blood glucose; cycle ergometry; VO_2max

Introduction

Type 2 (T2) diabetes mellitus presently ranks as the seventh leading cause of death in the United States (*Facts about Diabetes*). The disease remains a growing epidemic within the United States mainly as a result of poor diet and lifestyle choices. The effortlessness and simplicity of a sedentary lifestyle, combined with poor diet have significantly contributed to an overwhelming 25.80 million T2 diabetics in the United States alone. With much greater importance, 79 million Americans are suffering from prediabetes, a state of higher than normal blood glucose levels leading to an increased risk of T2 diabetes mellitus (American Diabetes Association 2013). Although US mortalities in relation to T2 diabetes mellitus are fewer when compared to cardiovascular disease and stroke, respectively the first and fourth leading causes of death, the progression of prediabetes to full diabetes doubles an individual's risk of death and development of cardiovascular disease and stroke (Diabetes Public Health Resource 2014 and *Facts about Diabetes*).

The financial cost of treating the disease is vast for the United States economy, as The American Diabetes Association estimated that diagnosed diabetes had cost the United States $245 billion in 2012, a 41% increase since 2007 (American Diabetes Association 2013). Roughly 70% of this total was believed to be produced by direct medical costs such as inpatient care, pharmaceuticals, and health professional salaries, while the other 30% was suggested to be due to the loss of productivity in the workforce. The onset of the disease and the severity of its effects, both physically and financially, can be drastically reduced or completely avoided by simple lifestyle improvements such as developing a healthy eating and exercise program. Without any form of national intervention, it has been estimated that the population suffering from the disease will increase to one in three adult Americans by 2050 (2013).

The largest factor to regulating diabetes is glucose control, and several studies have shown that exercise can positively influence the functioning of glucose metabolism in individuals at risk for or diagnosed with T2 diabetes (Yavari et al. 2012). Consistent findings have led to a consensus that both anaerobic and aerobic methods of exercise can provide substantial benefits to individuals with diabetes by improving both their metabolic functioning and also their quality of life (Swartz et al. 2003; Dunstan et al. 2002; Snowling and Hopkins 2006; Yavari et al. 2012) . For example, a study involving 18 obese women who had a family history of T2 diabetes mellitus were shown to improve their glucose tolerance along with additional cardiovascular benefits with as little as four weeks of walking with a goal of 10,000 steps per day (Swartz et al. 2003). Other studies have revealed the positive benefit of pure anaerobic training on glycemic control. Dunstan et al. (2002) reported significant glycemic improvements from high intensity anaerobic training in previously sedentary diabetic individuals aged 60-80. Aerobic forms of exercise are known to benefit individuals with T2 diabetes through the enhancement of cardiovascular and metabolic functioning within the body as a whole, which has been shown to improve insulin sensitivity and transportation, while reducing the risk for additional cardiovascular ailments at the same time (Swartz et al. 2003; *Diabetes Public Health Resource 2014*). Anaerobic (or resistance) training is thought to improve the condition by increasing lean muscle mass and functionality within the body, which also works to improve the mobility and quality of life of those suffering from the disease (Dunstan et al. 2002). Both of the previously described studies have shown that performing an exercise regimen (aerobic or anaerobic) was successful in battling glucose intolerance even without the subjects demonstrating substantial weight loss.

Due to the benefits that arise from both forms of aerobic and anaerobic exercise, researchers have come to the consensus in their findings that an exercise program including both modalities provides the most significant improvements in glucose control in additive ways that surpass the benefits seen by either exercise style alone (Snowling and Hopkins 2006; Yavari et al. 2012). This information has become the basis for the current exercise recommendations for individuals with the disease. Although the data reveal the additive effects of performing both exercises, there currently remains uncertainty as to which of the two is responsible for the majority of the benefits that are obtained. A study involving 153 T2 diabetics found that the subjects who were asked to perform anaerobic exercises displayed a significantly greater reduction in fasting blood glucose levels when compared to subjects who were restricted to aerobic training, and therefore concluded that anaerobic training was the largest contributor to the additive effects seen in the combination group (Yavari et al. 2012). Moreover, a meta-analysis performed by Snowling and Hopkins (2006) found benefits in subjects performing aerobic exercises that could have contributed greatly to the overall improvements seen in the combination groups as those individuals performing anaerobic exercise produced unclear results. As research has shown that individuals who perform a combination of aerobic and anaerobic exercises provide the most significant improvements in glucose metabolism, research comparing the two exercise modalities alone has been limited.

Discovering which exercise style produces greater glycemic control would aid in the formation of exercise programs by determining whether aerobic or anaerobic training should be the core of the program. Therefore, the aim of this study was to examine whether an acquired aerobic or anaerobic training status could be associated with a greater glucose clearance efficiency by analyzing the difference in resting glucose clearance efficiency between collegiate aerobic and anaerobic athletes, as well as relatively similar sedentary individuals following an oral glucose tolerance test. The study was based on the hypothesis that training status would provide significant differences in aerobic capacity and resultant glucose clearance rates, and that individuals with an acquired aerobic training level would display greater efficiency in blood glucose clearance levels. A secondary purpose of the study was to examine traditional indicators of insulin resistance, such as BMI and body fat, and their correlation to AUGC. Further research in this area has the potential to aid individuals with T2 diabetes mellitus, physicians, personal trainers, and other respective health professionals in the formulation of an exercise program to prevent and reduce the effects of T2 diabetes.

METHODS

Subjects

Eighteen university students volunteered for this study including six (four males/ two females) aerobically trained athletes, six (two males/four females) anaerobically trained athletes, and six (two males /four females) sedentary individuals (Table 1). The aerobic and anaerobic classified volunteers participated in university athletics, and were training for their sport at least five days per week at the time of testing. Aerobic athletes included track and field cross-country runners (six students), and anaerobic athletes included football linebackers (two students) as well as track and field throwers (four students). Students classified as sedentary reported that they did not participate in any regular exercise activities outside of their activities of daily living. All subjects signed an informed consent and Physical Activity Readiness Questionnaire (PAR-Q) in order to obtain their permission for testing as well as to assess general health status. The Shippensburg University Committee on Research with Human Subjects approved this study.

Procedures

Following completion of the informed consent and PAR-Q, subject height and weight were measured. A handheld Omron HBF-306 body fat analyzer (Omron Healthcare Inc., Bannockburn, Illinois) was used to quantify body fat through bioelectrical impedance analysis. All subjects completed the YMCA submaximal cycle ergometer test using the Monark Ergomedic 828E (Monark, Vansbro Sweden) in order to estimate VO_2max, while a fasted, resting blood glucose assessment was performed on a separate morning using the Contour blood glucose meter (Bayer, Leverkusen, Germany). All assessments, detailed below, were completed between 0700 and 1100 hours EST for all subjects.

Oral glucose tolerance test (OGTT). Upon arriving at the Shippensburg University Exercise Science laboratory, subjects confirmed a 12 h overnight fast. After confirming the fast, a beverage was prepared using 100% pure corn dextrose dosed 1.5g·kg^{-1} of body mass in ~300mL of bottled natural spring water (Foodhold U.S.A., Landover, Maryland). For larger subjects, due to the concentrated nature of the beverage, additional water was supplied to elicit a solution concentration of approximately 30% carbohydrate. Before consuming the beverage, a baseline blood glucose measurement was obtained via fingertip sampling with an Ascensia Microlet lancing device (Bayer, Inc., Leverkusen, Germany) after sanitizing the desired sample location with alcohol prep pads. A Contour blood glucose meter and a Contour blood glucose strip were used to analyze blood glucose. Once a baseline blood glucose measurement was acquired, the subject was instructed to consume the prepared beverage as quickly as possible to initiate the OGTT. The same sampling and blood glucose analysis procedures were reproduced every 10 min following consumption of the prepared beverage for a total of 80 min. All subjects remained seated for the entire duration of the OGTT. Area under the blood glucose curve (AUGC), measured in arbitrary units (a.u.) was determined using the midpoint formula:

Area = [(BG measure 1 + BG measure 2)/2] x 10

Where "10" represents the time (min) between each sample point. Each of eight midpoint derivations was summed to derive the overall AUGC for each study participant.

Table 1. Descriptive characteristics (mean±S.D)

Training Status	Mass (kg)	Height (m)	BMI (kg.m^{-2})	Body fat (%)
Aerobic	61.16±9.9	1.71±0.1	20.72±1.2*	12.48±6.0*
Anaerobic	79.39±20.9	1.71±0.1	26.57±3.2	20.97±3.3
Sedentary	76.36±22.8	1.73±0.1	24.93±4.2	21.78±5.3

* Different from both groups ($p<0.05$)

YMCA Cycle Ergometer test. Upon arrival to the laboratory, a Polar heart rate transmitter strap (Polar, Kempele Finland) was fitted around each subject's chest and heart rate was measured via telemetry. Seat height of the Monark cycle ergometer was adjusted to the height of the greater trochanter of each individual subject before mounting the cycle ergometer. Each subject was informed to perform one full slow motion cycle in order to ensure that slight knee flexion was maintained at the bottom of the revolution. Before initiation of the YMCA Cycle Ergometer protocol, resting heart rate and blood pressure were obtained using the Polar heart rate monitor and the Omron automated blood pressure cuff (Omron Healthcare Inc., Bannockburn, Illinois), respectively, after completing a 3 min motionless rest period in the exercise position. Following resting measurements, each subject was instructed to perform a desired pedal cadence of 50 revolutions per minute (rpm) without resistance for a total of 2 min as a warm-up. Immediately after completing the 2 min warm-up, the YMCA Cycle Ergometer protocol was performed as described by Pescatello et al. (2014). Heart rate was recorded every second and third minute of each of the four stages. Blood pressure was recorded between the last 30 seconds of the first stage to ensure there was an appropriate response to an increased workload. Following completion of the third minute of the fourth Stage, each subject entered a 2 min recovery phase equal to the first stage workload. Recovery blood pressure and heart rate were obtained immediately following completion of the 2 min recovery.

Statistical Analysis. Data were analyzed using SPSS v. 23 (SPSS Inc., Chicago, IL). One way ANOVA was applied to test for group differences for dependent variables; including AUGC, estimated VO_2max, and subject demographics such as BMI and body fat. Repeated measures ANOVA was used to examine time x treatment interactions for BG response during the OGTT. Correlational analyses were run for variables including VO_2max vs. AUGC, BMI vs. AUGC and body fat vs. AUGC.

RESULTS

Statistical analysis showed that aerobic athletes (8786.67 a.u.) had a significantly lower AUGC when compared to the anaerobic (10937.50 a.u.) and sedentary groups (10630.83 a.u.) (P= 0.01, P= 0.03, respectively); however, no significant differences were discovered between the anaerobic and sedentary groups (P= 0.88) (Figures 1 and 2). Aerobic individuals also appeared to show a trend of a lower fasting BG (75.83 mg/dl) when compared to anaerobic (89.33 mg/dl) and sedentary individuals (86.00 mg/dl), although it was not statistically significant within this sample size; -15.11% and -11.82%, (P= 0.13, P= 0.29) respectively. The YMCA Cycle Ergometer protocol produced mean VO_2max (ml/kg/min) estimations of 49.40, 38.24, and 31.31 for the aerobic, anaerobic, and sedentary groups, respectively. Significant differences were noted between the aerobic and both anaerobic and sedentary groups (P= 0.01, P= 0.00), while the difference in VO_2max between the anaerobic and sedentary groups was not significant (P= 0.21). There were no significant differences in maximal watts powered by the aerobic (256.67 W), anaerobic (234.61 W), and sedentary (179.17 W) groups (P=0.13), although the sedentary group powered 35.56% less watts than the aerobic group, and 26.80% less watts than the anaerobic group. There were significant differences in BMI and BF between the groups, with the aerobic group falling significantly lower on these measures than the other groups. On average, BMI was 22.04% lower in the aerobic group compared to the anaerobic group (P = 0.02). BF was 40.46% lower in the aerobic group vs. the anaerobic group (P = 0.03) and 42.69% lower than the sedentary group (P = 0.02) (Table 1).

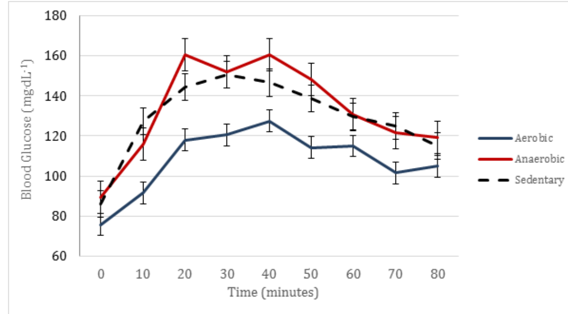

Figure 1. Mean blood glucose curves for aerobic, anaerobic, and sedentary training statuses during an 80 min. oral glucose tolerance test.

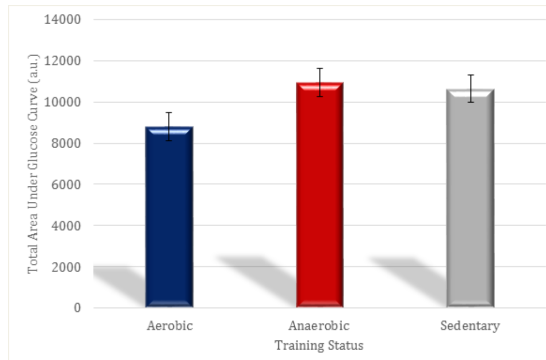

Figure 2. Mean area under the glucose curves for aerobic, anaerobic, and sedentary training statuses over the course of an 80 min. oral glucose tolerance test. Aerobic athletes had a significantly lower area under the glucose curve when compared to the anaerobic and sedentary groups (p= 0.011, p= 0.028, respectively).

Four of the six correlations produced between the variables were statistically significant, while body fat to BMI (r = 0.45) and VO_2max to AUGC (r = -0.46) (Figure 3) were not statistically significant (P= 0.06, P= 0.05, respectively) The strongest correlation with AUGC was shown to be BMI (r = 0.75, P = <0.01) (Figure 4), while body fat produced a moderate correlation (r = 0.67, P = 0.00). Lesser statistical significance was shown with VO_2max correlations when compared to similar AUGC correlations. VO_2max vs. both body fat and BMI exhibited moderate correlations (r = -0.65, P = 0.00; r = -0.49, P = 0.04, respectively). Aerobic and anaerobic groups revealed weak correlations between AUGC and total glucose consumed while the sedentary group showed a strong correlation between these measures (Figure 5).

DISCUSSION

As anticipated, aerobically trained college athletes were found to possess the highest estimated aerobic power relative to the anaerobically trained and sedentary groups. The aerobic athletes were also shown to have the greatest efficiency in regulating blood glucose in response to an OGTT in which the glycemic load was provided relative to body mass. With a collegiate-aged population, we originally hypothesized that the most significant correlating factor between training status and glucose clearance efficiency would be the individual's estimated aerobic power; however, our data revealed that BMI had the strongest association ($r = 0.75$) with OGTT AUGC, when tested in the resting state. Body fat percentage was also strongly associated with AUGC ($r = 0.67$). Evidence of a positive correlation between BMI and glycemic control has also been reported by Narayan et al. (2007), who used U.S. census data to determine the characteristics that would project the largest lifetime risk for developing diabetes. Their analysis, based on diabetic prevalence and incidence rates as stated in the 2004 United States census, revealed that the lifetime diabetes risk for an 18 year old increased from 7.60% to 70.30% between underweight and very obese males, and increased from 12.20 % to 74.40% in females (Narayan et al. 2007). While BMI and body fat percentage displayed the strongest significant correlations to AUGC in the present study, a notable positive trend was also observed with VO_2max (Figure 3). From this trend it can be inferred that individuals who have obtained a higher VO_2max may more commonly experience improved glycemic control. Whether this association is a result of the primary type of training can be debated. For example, both moderate intensity aerobic and interval type bouts of exercise have been shown to improve blood glucose regulation upon exercise cessation in Nordic skiing vs. a non-exercise control condition (Braun 2014). Brestoff et al., 2009 found that endurance exercise elicited a ~10% smaller glucose AUC relative to sprint interval work following exercise, though these areas were not statistically different. Thus, it is possible that some of the training effect seen in the present study could be due to recent, acute exercise. Acute exercise is known to enhance glucose uptake by muscle tissue and this effect may persevere for up to 24 hours (Lehnen et al. 2012). While we sought to limit exercise activity among the trained subjects, it is possible that residual effects of exercise could have positively impacted blood glucose regulation during the resting OGTT.

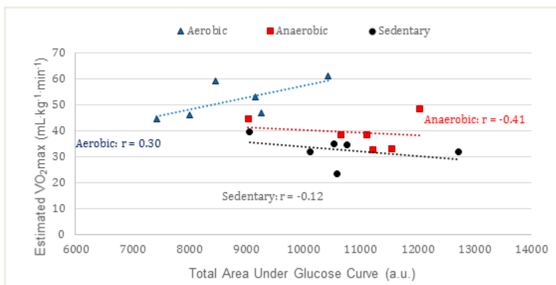

Figure 3. Correlation of estimated VO2max to the area under the glucose curve. The linear regression of all three groups combined produced a Pearson's r of -0.46.

BMI, body fat percentage, and AUGC all provide insight into general health and physical activity of an individual; therefore, objectives in an exercise program based on improving them may help to reduce the risk of diabetes. However, while a high VO_2max does appear to be an indicator of an efficient glucose regulatory system, a direct or cause and effect relationship between the two variables is not likely based with our statistical analysis. A more likely explanation would describe a high VO_2max in most circumstances as an indicator of good health and thus efficient blood glucose regulation (Ebeling et al. 1993; Houmard et al.1993), while significant BMI and body fat percentage alterations would directly influence glucose tolerance efficiency. An epidemiologic study conducted by Colditz et al. (1990) discovered that increases in BMI and body fat across all ranges (below average-above average) correlated to an increased risk of insulin resistance and T2 diabetes mellitus.

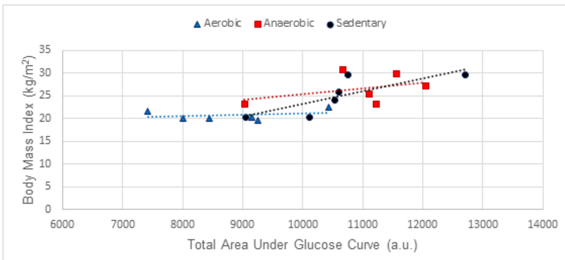

Figure 4. Correlation of body mass index to the area under the glucose curve. The linear regression of all three groups combined produced a Pearson's r of 0.75.

Based on the data presented, the utmost importance of individuals with T2 or prediabetes should be to attain healthy BMI and body fat values, while a greater VO_2 max should be considered as a secondary goal solely for overall health benefits rather than for the purpose of more efficient glucose regulation. However, the importance of aerobic exercise should not be set aside. It appears that developing an exercise program centered around aerobic modalities would be the most beneficial for these at risk or diseased individuals, as athletes with this classification of training status had significantly lower BMI and body fat values when compared to anaerobic and sedentary groups. This recommendation is also supported by Yavari et al. (2012), who reported significant benefits in glucose metabolism after performing an aerobic exercise regime.

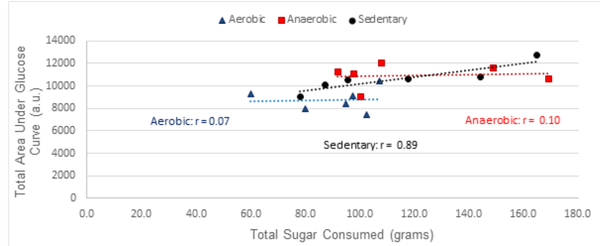

Figure 5. Correlation of area under the glucose curve to total sugar consumed (grams). The linear regression of all three groups combined produced a Pearson's r of 0.58.

There were limitations in this study that could be accounted for in future investigations to produce stronger results and develop a deeper understanding between the mechanisms of VO_2, BMI, body fat, and glucose clearance efficiency. For example, the distribution of males and females across groups was not matched. This could have had an impact on BMI and body fat levels, as there are differences in the recommended values between sexes. While subjects reported to the lab following an overnight fast, the previous day's food intake was not controlled. It would have also been of benefit to either control the prior day's exercise activity or to omit exercise for the preceding 36 hours. In addition, the study was designed to deliver glucose based on body mass using a fixed volume solution. Due to the wide range of body masses, drink concentration was not optimally controlled. In the future it may be better to supply the subjects with a fixed concentration rather than volume; however, with larger volumes gastric emptying and total glucose uptake could vary.

Although statistically insignificant (likely due to sample size), it appears that in a sedentary population, glucose concentration was associated with AUGC, but this trend was not seen in aerobic and anaerobic populations (Figure 5). The role of training mode in glycemic control should be studied further to verify observations made based on this study. Likewise, imposing a controlled exercise protocol preceding OGTT administration in a sedentary group could be of value in effort to characterize the effects of acute exercise on glucose regulation. This is especially relevant as exercise can be a vital component in the prevention and treatment of T2 diabetes mellitus. In conclusion, it appears that training status may possibly influence glycemic control in response to an OGTT during the resting state. However, the strongest associations with OGTT response were found to be body composition factors. Certainly, training will have great influence over variables such as BMI and body fat. So, it seems reasonable that these associations are a function of training status. Surprisingly, estimated aerobic power was not significantly associated with OGTT AUGC. A larger sample size may affect this outcome. Finally, it is recommended that those with compromised glucose regulatory mechanisms adopt aerobic and/or anaerobic exercise, as both seem to positively influence glucose regulation.

LITERATURE CITED

American Diabetes Association. 2013. *Fast Facts: Data and Statistics about Diabetes.* Retrieved March 2, 2014, from http://professional.diabetes.org/admin/UserFiles/0%20-%20Sean/FastFacts%20March%202013.pdf

Braun, W. 2014. Glycemic control and hunger during recovery from high and moderate intensity nordic skiing in well-trained skiers. *Journal of Sports Medicine and Physical Fitness* (EPUB ahead of print).

Brestoff, J.R., B.Clippinger, T. Spinella, S.P. von Duvillard, B. Nindl, and P.J. Arciero. 2009. An acute bout of endurance exercise but not sprint interval exercise enhances insulin sensitivity. *Applied Physiology, Nutrition, and Metab*olism: 34: 25-32.

Diabetes Public Health Resource. 2014. Retrieved March 8, 2014, from: *http://www.cdc.gov/diabetes/consumer/research.htm*

Colditz G.A., W.C. Willett, M.J. Stampfer, and J.E. Manson. 1990. Weight as a risk factor for clinical diabetes in women. *American Journal of Epidemiology* 132:501–513.

Dunstan, D.W., R.M. Daly, N. Owen, D. Jolley, M. De Courten, J. Shaw, and P. Zimmet. 2002. High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care* 25(10): 1729-1736.

Ebeling, P., R. Bourey, L.C. Groop, J. Henriksson, V.A. Koivisto, L. Koranyi, M. Mueckler, A. Sovijarvi, J.A. Tuominen. 1993. Mechanism of Enhanced Insulin Sensitivity in Athletes: Increased Blood Flow, Muscle Glucose Transport Protein (GLUT-4) Concentration, and Glycogen Synthase Activity. *The American Society for Clinical Investigation* 92: 1623-1631.

Houmard, J.A., R.K. Bruner, G.L. Dohm, P.L. Dolan, R.G. Israel, N. Leggett Frazier, M.R. McCammon, M.H. S hinebarger. 1993. Exercise training increases GLUT-4 protein concentration in previously sedentary middle-aged men. *American Journal of Physiology - Endocrinology and Metabolism* 264(6): 896-901.

Lehnen, A.M., K. DeAngelis, M.M. Markoski, and B. D'Agord Schaan. 2012. Changes in the GLUT4 expression by acute exercise,

exercise training and detraining in experimental models. *J Diabetes Metab* 2012; S10:002. doi.10.4172/2155-6156.S10-002

Narayan, K., J. Boyle, T. Thompson, E. Gregg, and D. Williamson. 2007. Effect of BMI on lifetime risk for diabetes in the U.S. *Diabetes Care* 30(6): 1562-1566.

Pescatello, L.S., R. Arena, D. Reibe, and P. Thompson. 2014. *ACSM's Guidelines for Testing and Prescription. (9th ed.).* Lippincott Williams & Wilkins, Baltimore, MD

Snowling, N. and W. Hopkins. 2006. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetes. *Diabetes Care* 14(11): 2518-2527.

Swartz, A.M., S.J. Strath, D.R. Bassett, J.B. Moore, B.A. Redwine, M. Groer, and D.L Thompson. 2003. Increasing daily walking improves glucose tolerance in overweight women. *Preventative Medicine* 37(4)*: 356-362.*

The facts about diabetes: a leading cause of death in the U.S. n.d. Retrieved March 3, 2014, from: http://ndep.nih.gov/diabetes-facts/

Yavari, A., F. Najafipoor, A. Aliasgarzadeh, M. Niafar, and M. Mobasseri. 2012. Effect of aerobic exercise, resistance training or combined training on glycemic control and cardiovascular risk factors in patients with type 2 diabetes. *Biology of Sport* 29(2): 135-143.