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Elizabeth A. Moxley

Tory Bugaieski

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Exercise Intensities as Factors of Metabolic Outcomes in Type 2 Diabetes: A Systematic Review

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Elizabeth Moxley, PhD, RN, BS[1] **and Tory Bugaieski, MS, RN**[2]

Abstract

Exercise is effective to prevent and treat type 2 diabetes, although currently underutilized. This review analyzes the metabolic response to exercise performance at various intensities in individuals with type 2 diabetes. These findings provide insight into the development of safe and efficacious exercise prescriptions and education. We conducted a systemic review of the literature to examine the association of various exercise protocols with metabolic outcomes in type 2 diabetes. Between 1984 and 2018, 29 studies were categorized per exercise mode and intensity levels according to the American College of Sports Medicine standards. The most consistent improvement was found in HbA1c following moderate- to high-intensity exercise—post-exercise fasting glucose improved to a lesser extent. Low-intensity exercise improved HOMA-IR (homeostasis model assessment for insulin resistance) levels. Glucose and HbA1c improved most following interval compared with continuous exercise, irrespective of intensity. A comparison of high-intensity exercise with moderate-intensity exercise demonstrated few differences in HbA1c, fasting glucose, fasting insulin, and HOMA-IR. Irrespective of exercise intensity, HbA1c improvements were observed, suggesting a delayed progression to diabetes-related complications. Initial low-intensity exercise, with increased quantities when feasible, will contribute to metabolic improvements. The variability in methodology and measurement contributed to inconsistent outcomes; additional research with larger samples sizes is warranted.

Keywords

type 2 diabetes mellitus, exercise, insulin resistance, insulin sensitivity, blood glucose, glycemic control

Introduction

Diabetes remains a global metabolic health problem. An estimated 30.3 million individuals, 12.2% of U.S. adults, are diagnosed with diabetes, with another 7.2 million cases unreported.[1] Exercise is associated with improved quality of life and essential to prevent the progression to prediabetes and type 2 diabetes (T2D),[2] although an estimated 31% to 37% of individuals with T2D exercise at quantities consistent with the current recommended guidelines.[3] Safe and effective exercise prescriptions are necessary but require a thorough understanding of the physiological mechanisms that result from exercise performed at various intensities in individuals with T2D.

Methods

We performed a systematic review of the literature to analyze the metabolic outcomes from various exercise intensities as defined by the American College of Sports Medicine (ACSM; Table 1).[4] Using the key words *type 2 diabetes mellitus, exercise, insulin resistance, insulin sensitivity, blood glucose* to search PubMed and CINAHL, subject headings of key words were utilized in each database when present. The articles reviewed were limited to randomized controlled trials and clinical studies performed in adult participants (age 18+ years), written in English between the period 1984 and 2018, and not primarily focused on a dietary intervention. The exclusion criteria involved articles not published prior to 1984, and those studies which were not randomized controlled trials or clinical studies evaluating low-, moderate-, and high-intensity exercise interventions in individuals with T2D. Articles involving individuals with a specific disease process other than T2D were also excluded, or participants younger than 18 years of age. Several developmental stages are involved in pediatric populations, with an incidence of T2D that varies by age, and different recommendations for exercise[4] in children and adolescents compared with adults. Few studies evaluating low-, moderate-, and high-intensity exercise have been conducted in pediatric participants with T2D. Ultimately, 29 articles met the inclusion criteria and

[1]Northern Illinois University, DeKalb, IL, USA
[2]DePaul University, Chicago, IL, USA

Corresponding Author:
Elizabeth Moxley, School of Nursing, Northern Illinois University, 1240 Normal Rd., DeKalb, IL 60115, USA.
Email: emoxley@niu.edu

Table 1. Measures of Exercise Intensity (American College of Sports Medicine).[4]

Absolute-METs		Relative	Relative	Relative	Relative	Relative
Intensity level	Rest: MET = 3.5 mL O_2	Percent of VO_{2max}	Percent of heart rate reserve	Percent of maximum heart rate	Rating of perceived exertion (Borg scale, 6-20)	Percent of one repetition maximum
1	Very light 1.5 METs	<37	<30	<57	<9	<30
2	Light 2-<3 METs	37-45	30-39	57-<63	9-11	30-49
3	Moderate 3-6.0 METs	46-63	40-59	64-<76	12-13	50-69
4	Vigorous 6.0-8.8 METs	64-90	60-89	77-<95	14-17	70-84
5	Near maximal-maximal ≥8.8 METs	≥91	≥90	≥96	≥18	≥85

Note. METs = metabolic equivalents.

were utilized in the evaluation. Additional sources were obtained through ancestry searches.

Definitions of Physical Activity, Exercise, and Training

When considering exercise prescription and implementation, it is necessary to understand the terms commonly used to describe energy expenditure. Common terms include physical activity, exercise, and training. A distinction exists between physical activity and exercise, where physical activity is considered skeletal muscle movement resulting in energy expenditure and exercise is a subcategory of physical activity to improve fitness.[5] Exercise training is associated with long-term physical activity and often used as preventive medicine, by a prescription. Exercise training is aerobic in nature[6] requiring continuous movement of large muscle groups typically from walking, cycling, jogging, or swimming.[2,5] Whereas, anaerobic exercise is typically performed at higher intensities for a shorter duration.

Exercise Dose Components and Classification

Exercise dose recommendations are established by ACSM[4] and include frequency, intensity, time, type, total volume, and progression, that is, the FITT-VP principle. The FITT-VP principle allows customization of exercise programs based on the abilities and exercise goals of the individual. Within the FITT-VP principle, *frequency* involves the number of exercise sessions in a specific time period; *intensity* refers to exertion during exercise and is a reflection of energy expenditure; *time* is the duration of each exercise session; *type* refers to the mode or method of exercise; *volume* of exercise refers to the product of frequency, intensity, and time; *progression* considers the increase in a component of frequency, intensity, or time over the course of an exercise program.[4,7]

For purpose of analysis, we categorized each type of exercise according to absolute measures of intensity consistent with ACSM (Table 1)[4]: Category 1 corresponds with very light exercise; Category 2, light exercise; Category 3, moderate exercise; Category 4, vigorous exercise; and Category 5, near-maximal to maximal exercise. The ACSM and the American Diabetes Association[8] recommend 150 minutes of moderate-intensity activity or 75 minutes of vigorous-intensity activity each week.

Light or very light exercise intensity. Very light or light-intensity exercise is consistent with an exertion level of 1.5 to 3.0 metabolic equivalents (METs).[4] Typical examples of such activities in METs include slow walking (<3.0), preparing food or playing musical instruments (2.0-2.5), power boating (2.5), or playing cards (1.5).

Moderate-intensity exercise (MIE). MIE is typically aerobic in nature and involves continuous activity performed for a longer duration.[4] Moderate-intensity activities include brisk walking, dancing, gardening, housework and domestic chores, and walking domestic animals.[9] Terms commonly associated with MIE include moderate-intensity continuous training (MICT), moderate-intensity continuous exercise (MICE).

High-intensity and near-maximal exercise. High-intensity exercise requires a higher oxygen consumption (80%-90% VO_{2peak} or >90% of HR_{max}) and acute physiological response, and is therefore typically performed in short bursts.[10,11] High-intensity exercise has been described using the terminology high-intensity interval training (HIIT), although a variety of nomenclature exists. Due to the vigorous nature of HIIT, brief intervals of intense exercise (5-8 minutes) are interspersed with periods of low activity or rest.[10] For example, a workout performed at 80% to 95% estimated HR_{max} interspersed with an exercise recovery period at 40% to 50% estimated HR_{max}.[11]

HIIT exercise modalities include running, jogging, cycle ergometry, elliptical, treadmill.

An additional variation of HIIT is high-intensity aerobic training (HIAT)[12] performed at 85% to 95% of HR_{max}.[13] Similar to HIIT, reduced-exertion high-intensity interval training (REHIT) is considered a more time-efficient and less strenuous alternative to HIIT and is used in two studies.[14,15] The REHIT protocol involved either a 10-minute session/week of cycling at 25W, interspersed with one or two Wingate-type cycle sprints of progressive duration (10-20 seconds) against a constant torque of 0.65N m × kg/lean mass,[14] or 10-minute exercise sessions consisting of low-intensity cycling (60W) in one (first session), or two (other session) brief "all-out" sprints at 10, 15, or 20 seconds depending on the week.[15] REHIT has been found to improve glucose tolerance and aerobic capacity at the same time.

The highest intensity exercise sessions, however, are sprints—sprint interval exercise (SIE) or sprint interval training (SIT). SIE involves the maximum achievable intensity at extremely low-volume exercise, 2 × 20-second intervals at or "all out bursts,"[16] whereas SIT is intense exercise for 1 minute within a 10-minute time commitment.[17-19]

Resistance training. Resistance exercise involves strength training using free weights, weight machines, or resistance bands,[2] and performed at two high-intensity protocols—high-intensity resistance training (HIRT) or high-intensity progressive resistance training (PRT).

HIRT. Dynamic exercise such as concentric and eccentric contractions with a goal of 75% to 85% of the current 1RM is considered HIRT.[20]

High-intensity PRT. High-intensity PRT uses a PRT protocol designed to progressively increase intensity with periodic weeks of reduced intensity with the purpose of minimizing risk of injury and overtraining, such as the use of pneumatic resistance training machines.[21]

Metabolic outcome measurements. Several metabolic outcomes were included in the outcomes of the studies that were evaluated in this review, although the metabolic measures explored in this review were limited due to the number of years of the studies and include fasting glucose, HbA1c, homeostasis model assessment for insulin resistance (HOMA-IR), and fasting insulin. In addition, the measures of glucose control form the basis of the American Diabetes Association's Classification of Diabetes.[8]

Results

Demographics

Study participants were primarily female, between 27.5 ± 4.3 and 68 ± 9 years of age (n = 1,453, 93% female, M_{age} = 55 years). Of the 29 total studies, three studies enrolled only males, four enrolled only females, and one study did not report gender. Age-specific studies were excluded from this review, and participants older than 65 years of age were excluded from enrollment in one study. As T2D increases in incidence only minimally after age 65 years, this age offers a reasonable age limit for enrollment.

Outcomes According to Intensity or Type

The outcomes of various combination of exercise intensities across experimental groups are analyzed and compared in Table 2. Exercise was either supervised or unsupervised, with mode of exercise in the studies involving walking, running, uphill walking, elliptical use, bicycle ergometer, or weights, either individually or in combination. Of note is the variability in methodology used in the measurements of the studies (Table 2). The metabolic outcomes most commonly reported in the results included fasting glucose (n = 20), HbA1c (n = 19), HOMA-IR (n = 12), and fasting insulin (n = 8; Table 2).

High intensity. Eleven studies analyzed the effects of high-intensity interventions without comparing with a lower intensity intervention (categories for each intensity in Table 1). Nine studies included a Category 4 (high-intensity) intervention, of which four compared a high-intensity intervention with a no-exercise control group. Three studies included Category 5 (sprint intensity) intervention. One study compared low-volume exercise with high-volume doses performed at a high intensity.[28] The interventions in all but four studies lasted for an extended period of time (12 or more weeks): two studies[26,29] consisted of only six training sessions over the course of 2 weeks, one study lasted 5 weeks,[24] and one[27] involved a duration of 7 weeks.

The average number of participants in high-intensity studies was 23, ranging from eight to 62, and between 30 and 70 years of age. Seven studies included both male and female participants; two studies enrolled only females;[28,32] one study included only males;[24] and one study did not report gender.[26]

Postintervention fasting glucose, HbA1c, fasting insulin, and HOMA-IR values and their significances were reported as indicated in Table 2. Fasting glucose and HbA1c were most frequently reported; six (of 16) studies demonstrated a significant decrease in postintervention glucose levels,[22,24,25,30,32,36] and HbA1c significantly decreased in 12 studies.[12,20,22,23,28,30,32-35,38] No significance in HOMA-IR (five significant of 14 reports) or fasting insulin (three of nine) was observed following high-intensity exercise in the majority of outcomes.

High intensity versus moderate intensity. Twelve studies compared high-intensity (Category 4 or 5) exercise with intermediate/moderate intensity (Category 3); four included a no-exercise control group. In eight of the 12 studies, the intervention lasted at least 12 weeks, four had a shorter

Table 2. ACSM[4] Exercise Categorization of Current Literature According to Intensity.

	Intervention ACSM rating(s)	Fasting glucose	HbA1c	HOMA-IR	Fasting insulin
High intensity					
Alvarez et al[22]	4	↓	↓	NR	NR
Cassidy et al[23]	4	NS(–)	↓(%)	NS(↑)	NS(–)
Castaneda et al[21]	4	NS(↓)	↓	NR	NR
Dunstan et al[20]	5	NS(↓)	↓	NR	NS(↑)
Eriksen et al[24]	4	↓ (3 × 10)	NS(↓)	NR	NS(↑CON, ↓INT)
Fex et al[25]	4	↓	NS(↓)	NR	NR
Little et al[26]	4	NR	NR	NR	NR
Morton et al[27]	4	NS(↓)	NS(–)	NR	NR
Revdal et al[16]	5	NS(↓)	NS(↓)	NS(↓)	NR
	4	NS(↓)	NS(↓)	NS(↓)	NR
Segerström et al[28]	4	NR	↓ (high volume)	NR	NR
Shaban et al[29]	5	NS(↑)	NS(↓)	NS(↓)	NS(↓)
High vs. moderate intensity					
Balducci et al[30]	4	↓	↓+	↑	↓
	3	↓	↓	↑	↓
Braun et al[31]	4	NS(↑)	NR	NR	NS(↓)
	3	NS(↑+)	NR	NR	NS(↓)
Da Silva et al[32]	4	↓	↓	NR	NR
	3	↓	↓	NR	NR
Hollekim-Strand et al[33]	4	NR	↓	NS(–)	NR
	Moderate	NR	↓	NS(↓)	NR
Li et al[34]	4	NS(↓17-24 h post, ↑15 days post)	↓	↓ (16-24 h post)	↓(16-24 h post)
	3	NS(↓)	↓	↓(16-24 h post)	↓(16-24 h post)
Pandey et al[35]	4	NR	↓+	NR	NR
	3	NR	↓	NR	NR
Ruffino et al[14]	5	NS(↓)	NR	NS(↓)	NS(↑)
	3	NS(↓)	NR	NS(↑)	NS(↑)
Støa et al[12]	4	NR	↓+	NS(↑)	NR
	3	NR	↓	NS(↓)	NR
Taylor, Fletcher, Mathis, and Cade (2014)[73]	4	NR	NR	NR	NR
	3	NR	NR	NR	NR
Terada et al[36]	5	↓	NR	NR	NR
	3	NS (↓)	NR	NR	NR
Terada et al[37]	5	NR	NR	NR	NR
	3	NR	NR	NR	NR
Yang et al[38]	4	NS (↓)	↓	NR	NR
	3	↓	↓	NR	NR
Moderate/low intensity					
Hazley et al[39]	3	NS(–)	NS(↓)	NR	NR
Honkola et al[40]	Moderate	NR	NS(↓)	NR	NR
Madsen et al[41]	3	↓ (T2D)	↓ (T2D)	↓ (T2D)	NR
Mitranun et al[42a]	3	↓	↓ (INT)	↓	NR
Motahari-Tabari et al[43]	2	NS (↓)	NR	↓	↓
Usui et al[44]	3	NR	NR	NR	NR

Note. ↓indicates significant decrease in the intervention group and ↑ significant increase in intervention group. NS indicates no significance found and NR indicates the result value was not reported for that study. NS(↓) indicates result was not significant but demonstrated a downward trend. NS(↑) indicates result was not significant but demonstrated an upward trend. NS(-) indicates result was not significant and demonstrated no change due to intervention. ACSM = American College of Sports Medicine; HOMA-IR = homeostasis model assessment for insulin resistance; T2D = type 2 diabetes.
[+]Indicates a result was more significant in one group than the other.

Table 3. Comparison of Glucose Outcomes in Continuous Versus Interval Exercise Intervention.

Study	Time	Fasting glucose	HbA1c	HOMA-IR	Fasting insulin
Interval versus continuous					
Eriksen et al[24]	Continuous	NS(↑)	NS(↓)	NR	NS(↑)
	Interval	↓	NS(↓+)	NR	NS(↓)
Mitranun et al[42]	Continuous	↓	NS(↓)	↓	NR
	Interval	↓	↓	↓	NR
Pandey et al[35]	Continuous	NR	↓	NR	NR
	Interval	NR	↓+	NR	NR
Terada et al[36]	Continuous	NS	NR	NR	NR
	Interval	↓	NR	NR	NR
Terada et al[37]	Continuous	NR	NR	NR	NR
	Interval	NR	NR	NR	NR

Note. ↓indicates significant decrease in the intervention group and ↑ significant increase in intervention group; NS indicates no significance found and NR indicates the result value was not reported for that study. NS(↓) indicates result was not significant but demonstrated a downward trend. NS(↑) indicates result was not significant but demonstrated an upward trend. HOMA-IR = homeostasis model assessment for insulin resistance.
+ Indicates a result was more significant in one group than the other.

duration including studies lasting 8 weeks[14] and 6 weeks.[32] One study utilized four 60-minute interventions of a different intensity or fasting state, and one control,[36] and another included a 2-day intervention with two sessions per day.[31]

The number of participants in the studies varied greatly, ranging from eight to 303 individuals (average = 52) with an average age between ~35 and 70 years. Ten studies included male and female participants; one study enrolled only female participants;[31] and one study involved only males.[14]

Postintervention fasting glucose, HbA1c, fasting insulin, and HOMA-IR values and their significances were reported as indicated in Table 2. Twenty-three moderate- versus high-intensity comparison points were reported across all studies for fasting glucose, HbA1c, HOMA-IR, and fasting insulin, while only five pairings provided differing results between high and moderate intensities. The postintervention results by intensity in the remaining studies were increased or decreased, although nonsignificant. Three studies comparing high and moderate intensities found significant decreases in fasting glucose from high intensity[30,32,36] while three[30,32,38] reported a significant decrease following moderate intensity. For HbA1c, three studies observed a significantly greater decrease following high-intensity exercise versus MIE.[12,30,35]

Moderate and low intensities. Six studies included a moderate or lower (Category 3) exercise intensity; five included a nonexercise control group. One study matched healthy controls with individuals with T2D to participate in the exercise intervention.[41] The study duration was highly variable in this category: two lasted at least 12 weeks,[40,42] one involved a single exercise session,[44] and the remainder lasted 8 weeks.

On average, 30 participants were enrolled, ranging from 12 to 53 per study, with an average age between ~20 and 70 years. Four studies included males and females; one study included only females;[43] and one study included only males.[44]

Postintervention fasting glucose, HbA1c, fasting insulin, and HOMA-IR values and their significances were reported as indicated in Table 2. Two studies[41,42] reported decreases in fasting glucose, HbA1c, and HOMA-IR, while one study[43] reported significant decreases in HOMA-IR and fasting insulin levels.

Interval/continuous exercise. Five studies evaluated the effect of interval versus continuous exercise. Postintervention fasting glucose, HbA1c, fasting insulin, and HOMA-IR values and their significances were reported as indicated in Table 3. One study reported a significant decrease in HOMA-IR for both continuous and interval groups, but no significant difference between groups.[35] One study reported a more significant decrease in HbA1c for individuals using interval training over continuous training, while another study found a significant decrease in HbA1c for the interval group alone.[42] Two studies[24,36] reported significant decreases in fasting glucose for interval participants alone, while one study[42] found both interval and continuous groups to demonstrate a significant decrease.

Resistance training. Six studies utilized resistance training as either an exercise intervention or component of their primary intervention. Postintervention fasting glucose, HbA1c, fasting insulin, and HOMA-IR values and their significances were reported as indicated in Table 4. Three studies reported decreased HbA1c from moderate to sprint intensity resistance training,[21,30,38] and HbA1c and fasting glucose trended down across all resistance training intensities.

Discussion

The most important finding in our evaluation of these studies is the consistent diminishing effect on HbA1c and, to a lesser extent, fasting glucose levels following an acute bout

Table 4. Glucose Outcomes in Resistance Training Exercise Interventions and Their Corresponding ACSM Intensity Categorizations.

Study	Intervention ACSM rating(s)	Fasting glucose	HbA1c	HOMA-IR	Fasting insulin
Resistance training					
Balducci et al[30]	4	↓	↓+	↑	↓
	3	↓	↓	↑	↓
Castaneda et al[21]	4	NS(↓)	↓	NR	NR
Dunstan et al[20]	5	NS(↓)	↓	NR	NS(↑)
Hazley et al[39]	3	NS(-)	NS(↓)	NR	NR
Honkola et al[40]	Moderate	NR	NS(↓)	NR	NR
Yang et al[38]	4	NS (↓)	↓	NR	NR
	3	↓	↓	NR	NR

Note. ↓ indicates significant decrease in the intervention group and ↑ significant increase in intervention group; NS indicates no significance found and NR indicates the result value was not reported for that study. NS(↓) indicates result was not significant but demonstrated a downward trend. NS(↑) indicates result was not significant but demonstrated an upward trend. NS(-) indicates result was not significant and demonstrated no change due to intervention. ACSM = American College of Sports Medicine; HOMA-IR = homeostasis model assessment for insulin resistance.
+Indicates a result was more significant in one group than the other.

of high-intensity exercise. Nearly all variables of glucose control improved in nearly all the studies, in spite mode or intensity of exercise, although significant improvements were found in HbA1c following high-intensity exercise in 14 of the 21 studies that included a high-intensity intervention. Fasting glucose improved significantly in nine of the 20 studies that included a high-intensity intervention. Variables of insulin or insulin regulation were measured less frequently, with outcomes of lesser significance.

T2D is a complex heterogeneous disorder. The Centers for Disease Control and Prevention (CDC)[1] estimates ~30.2 million U.S. adults currently have T2D, the majority of whom are males between 45 and 64 years of age, consistent with our findings with respect to age and gender distributions. Exercise is beneficial to prevent and treat T2D and improve metabolic outcomes,[2] although a consensus is lacking regarding an effective exercise prescription for T2D. Further complicating matters is the lack of randomized studies demonstrating consistency of metabolic outcomes.

Trends in Literature Methodology

A high degree of variability existed in our studies, such as variation in methods of measurement, sample sizes, mode and exercise regime, and consistency between reported exercise intensity with that of established guidelines.[4] One notable feature in the outcomes was the diversity of results across the 29 articles; more than 50 outcome measurements were reported, none of which were consistent for all studies. Those most reported included fasting glucose, HbA1c (mmol/L, %, or both), fasting insulin, and HOMA-IR. Consequently, it is difficult to ascertain the significance of the outcomes due to a lack of reliability among experiments in variables other than these four categories (and even among those four).

Another notable trend is the diversity in categorization of intensity as low, moderate, and high. Several studies verbally categorized groups as low intensity, however, considering the same group qualified as moderate intensity according to ACSM definitions.[30,32,34,38,39,44] This variation and lack of delineation in the categorization of exercise groups resulted in difficulty in comparisons among groups.

High-Intensity Exercise

Nearly twice as many studies observed a significant improvement in HbA1c as those that did not; fasting glucose results demonstrated less overall significance, as studies reporting no significant change in fasting glucose amounted to nearly twice the number of those with significant results. The consistent improvement observed in fasting glucose and HbA1c levels from high-intensity exercise suggests a consistent diminishing effect occurs in HbA1c and, to a lesser extent, fasting glucose. More research is necessary before a definitive causal relationship can be conferred.

No significance in HOMA-IR (five significant of 14 reports) or fasting insulin (three of nine) was observed following high-intensity exercise in the majority of outcomes. The outcomes for HOMA-IR and fasting insulin reported by Balducci et al[30] and Li et al[34] following high-intensity exercise were variable and, considering the number of studies analyzed, additional investigations are warranted to substantiate the magnitude of these findings.

High-intensity exercise versus MIE. Few differences were found when comparing high-intensity with moderate-intensity group pairings. These differences were most apparent in HbA1c. Of the 23 moderate-intensity versus high-intensity comparison points reported, only five pairings provided differing results between high and moderate intensities. Two provided opposing significant results for high-intensity versus low-intensity decreases in fasting glucose[36,38]; however, three studies similarly reported a greater decrease in HbA1c for individuals involved in a higher intensity workout. Thus, while high intensity may not provide more significant short-term benefits when compared with moderate-intensity activity, it may facilitate greater decreases in chronic glucose levels when performed regularly.

Moderate- and low-intensity exercise. HbA1c demonstrated the most significant change after moderate-intensity interventions, followed by fasting glucose levels. Interestingly, no articles directly compared moderate-intensity with low-intensity outcomes, as was frequently done between moderate- and high-intensity exercise. Many of the studies that did include a "low-intensity" exercise intervention were inaccurately categorized as thus (per ACSM[4]), and thus did not serve as low-intensity points of comparison for this review.

HOMA-IR and fasting insulin levels were significantly reduced following low-intensity exercise; although fasting glucose levels trended downward, significance was not observed.[43] The verbal categorization of "low-intensity" groups in several of the studies suggests it is a priority to identify glycemic outcomes consistent with this particular exercise intensity. Further research involving low-intensity interventions is necessary to substantiate the outcomes of Motahari-Tabari et al[43] and more thoroughly understand the implications of low-intensity interventions within the proper intensity parameters.

Interval versus continuous exercise. Interval may be associated with a higher intensity, whereas continuous with a moderate intensity as was found in three (of five) studies with interval versus continuous interventions in this review.[35-37] Physiologically, this is a reasonable method of implementing interval and continuous exercise, given the difficulty in sustaining higher intensities for longer durations. The lack of intensity restriction for each type, and implementation of interval versus continuous studies in this fashion, makes it difficult to ascertain whether glycemic changes are due to intensity or mode of exercise. Two studies isolated intensity; Eriksen et al[24] used high intensity for both interval and continuous groups, and Mitranun et al[42] used moderate intensity. Overall, interval exercise more effectively lowered fasting glucose and HbA1c levels than continuous interventions, in spite of accounting for intensity.

Resistance training. Similar to interval and continuous exercise, resistance training was implemented at various intensities in the studies in this review. Results were mixed in the outcomes of two studies comparing high- and moderate-intensity resistance training; both intensities trended down and it was unclear which demonstrated more significance on glycemic control.[30,38] Small, beneficial outcomes in HbA1c were observed from moderate-intensity, medium- to high-volume resistance training compared with controls.[40]

Resistance exercise in T2D has only been studied for the past three decades[45,46] and the extent to which resistance exercise may improve glucose tolerance is an area of ongoing investigation. Early studies found insulin action was enhanced for 18 hours post-exercise in T2D.[45] Resistance exercise utilizes upper and lower body muscular activity, integrating whole body glucose concentration.[45] Resistance training has demonstrated adaptations in skeletal muscle and adipose tissue that are irrespective of weight loss[47] as well as improvements in insulin resistance and glycemic control.[2]

Physiological Implications

Mechanism of exercise in the context of T2D. Improvements in glucose tolerance depend on baseline glucose levels prior to exercise, and β cell viability. The studies included in this review found minimal improvement in post-exercise glucose levels in several studies following exercise performed at various intensities. Exercise training has been found to demonstrate improved glucose control, although the outcomes are not consistent and often transient, especially without weight loss (Coopman as cited in[48]). Theoretically, prolonged exercise training improves both fasting and postprandial glucose levels[49]; this may be linked to augmented translocation of GLUT4 transporters to the plasma membrane, thus improving glucose uptake.[50]

Although it is known that acute exercise performed at moderate to high intensities improves post-exercise glucose levels, the magnitude of effect from training as well as precise dose response remains unclear.[51,52] Muscle glucose uptake has been found to increase from training by fivefold and remain elevated for 2 hours through insulin-independent mechanisms and 4 hours through insulin-dependent mechanisms after prolonged exercise,[53] linked with muscle glycogen repletion.[54]

HbA1c levels. It should be noted that given the brief time frame of the exercise interventions of the studies included in this review, the accuracy of HbA1c in terms of altered metabolic function should be considered given the life span of HbA1c. HbA1c significantly improved in the majority of our findings, irrespective of exercise intensity. HbA1c has been shown to decrease from either longer duration of training[55] or increased exercise intensity.[56] Solomon et al[57] found significantly reduced HbA1c levels in individuals with T2D following combined aerobic and resistance training. Yoga[58] and tai chi also improved HbA1c,[59] although the magnitude of HbA1c effect on cardiovascular fitness has been demonstrated in few studies.[57,60-62] The benefits of HbA1c in delaying microvascular complications[40] are pronounced, resulting from only a 0.5% improvement in HbA1c levels.

MIE (60%-65% VO_{2max}) involving multiple short-term bouts over a 4- to 5-minute duration improved HbA1c and fasting glucose compared with a time-controlled group, exercising at the beginning and end of a 4- to 5-week period for 30 minutes.[24] Short-term exercise (<6 weeks) contributed to improvements in HbA1c,[63] in addition to mixed-intensity interval versus continuous training[64] and has been theorized to be due to volume rather than intensity.[28]

Insulin sensitivity and resistance in acute exercise outcomes. Insulin resistance is generally considered to be the initial defect in the development of T2D contributing to significant hyperglycemia. We found lower intensity interventions were most effective to improve HOMA-IR. There are a number of proposed reasons as to why acute exercise may improve insulin sensitivity. Original investigations determined acute aerobic exercise improved glucose tolerance by decreasing insulin resistance in the peripheral tissues and improving defective insulin-stimulated glycogen metabolism in skeletal muscles.[65,66] A single bout of high-intensity aerobic exercise sufficiently depleted glycogen stores, increasing glucose disposal for up to 18 hours after acute, high-intensity (to exhaustion) exercise performed to exhaustion.[67] Decreased glycogen stores enhanced nonoxidative glucose disposal, contributing to increased peripheral glucose utilization, improving insulin sensitivity post-exercise.[65,67-69] Increased glucose utilization resulted in lower fasting glucose following exercise, decreased endogenous glucose production, a primary reason for the lowered glucose levels following exercise,[67] and insulin-stimulated rates of glucose oxidation have been found to decrease post-exercise,[67] although the effect from a single bout of acute exercise on postprandial glucose controls is considered far less consistent than exercise training.[66,68]

Implications for Home Health Care

One key component to client implementation of a home exercise regimen is an explicit exercise prescription from a health care professional. The American Diabetes Association[2] advocates for participation in moderate- to vigorous-intensity aerobic exercise, including interval exercises for younger and more fit individuals. This review supports these recommendations given the increased benefits associated with HbA1c deductions during consistent exercise at these intensities, but highlights the need for more consistent intensity measurement parameters during exercise performance to ensure the proper intensity is achieved. Although not all measurements utilized in the clinical studies included in this review are practical for home use (i.e., MET and percent VO_2max), it is important that those measurements which are possible to use at home (percent of heart rate reserve, percent of maximum heart rate, rating of perceived exertion, and percent of one repetition maximum) are calculated ahead of time with the help of a health care professional to ensure appropriate exercise performance at home and maximize glycemic benefits. Determining an exercise prescription to yield metabolic improvements is difficult given the heterogeneity of T2D. Safe exercise ranges are consistent with heart rate reserve ranges between 40% and 70%.[70,71] This range of intensity is consistent with the majority of studies included in this review.

It is also important to acknowledge that these intensity recommendations may not be possible for all individuals to perform on a regular basis, especially those individuals with certain diabetic-related complications. In addition to the benefits associated with moderate- to high-intensity exercise, this review has demonstrated the potential for glycemic benefits at every intensity level. Exercise prescriptions may be started at lower intensities, with some glycemic improvements, and gradually increased by shifting any one component of FITT to meet current recommendations of moderate- to high-intensity exercise.[2] Individuals at risk for or currently living with diabetic foot ulcers or diabetic-related complications should consult with their primary care provider prior to initiating exercise at a low intensity. All individuals should be monitored when new exercise begins, and with any increase in intensity or other change to their exercise regimen. In addition, individuals should demonstrate adequate glycemic control prior to initiating exercise, in accordance with recommendations by their primary care provider. Based on changes in glucose control, the provider may recommend an adjusted decrease in insulin, cessation of insulin use altogether, and potentially decrease dosages of oral antihyperglycemic medications along with increased monitoring of glucose control, especially if accompanied by weight loss.

Limitations

Certain limitations existed in the outcomes of this systematic review. The study participants were mainly female; however, according to the CDC,[72] males are more likely to be diagnosed with T2D than females (12.7 million vs. 11.7, respectively); thus, the findings are not representative of the population.

Due to the lack of consistent methodology and measurement for intensity categorization among the studies, including the absence of a direct comparison between moderate- and low-intensity exercise, it was difficult to determine the validity of results and subsequently establish an accurate consensus for exercise recommendations. Studies lacked consistency in categorization of exercise intensity (i.e., high, moderate, low intensities), sample sizes, and duration and type of exercise, with variability in measures reported for metabolic outcomes. These limitations resulted in an inability to determine exercise recommendations with clarity, limiting the generalizability of findings to individuals with T2D and suggesting the need for additional studies with similar hypotheses.

Future Research

A notable feature in our findings was the diversity of result measurements utilized across all 29 reports. More than 50 different measurements are reported, many appear inconsistently, contributing to difficulty in determining the validity of results. Future treatment priorities involve clarifying the intensity and magnitude of exercise for individuals with *T2D* to mitigate metabolic complications.

A priority need to continued investigation is a systematic approach to categorizing exercise intensity, that is, high, moderate, low. In addition, a consistent comparative approach to investigations such as randomized controlled trials with larger sample sizes and longer treatment durations to more adequately determine dose-response relationships between exercise and improved metabolic outcomes is needed. Perhaps most important for individuals with diabetes, however, is the most simple—motivating individuals to change their lifestyle.

Conclusion

It is well established that physical activity is associated with improved quality of life, although not until the last few decades has acute exercise and exercise training for persons with T2D been extensively investigated. Due to variation of methodology, measurement, and exercise classification, a specific recommended dose of exercise for individuals with T2D to improve metabolic outcomes is not known. Any exercise, if safe for the individual, is considered beneficial, although several acute exercise sessions that are performed at least a moderate to high intensity are preferable than longer, infrequent sessions. Regardless, any type of safe exercise intervention will be beneficial in a setting of T2D.

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ORCID iD

Elizabeth Moxley https://orcid.org/0000-0002-0929-4717

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