



Baker IDI Research Online

<http://library.bakeridi.edu.au>

This is the postprint version of the work. It is the manuscript that was accepted by the journal following peer review. It does not include the publisher's layout and pagination.

"Minges KE, Magliano DJ, Owen N, Daly RM, Salmon J, Shaw JE, Zimmet PZ, Dunstan DW.
Associations of strength training with impaired glucose metabolism: the AusDiab study. Med Sci Sports Exerc. 2013 Feb;45(2):299-303."

<http://hdl.handle.net/11187/1541>

Associations of Strength Training with Impaired Glucose Metabolism: the AusDiab Study

Short title: Strength training activity and metabolic risk

KARL E. MINGES¹, DIANNA J. MAGLIANO^{1,2}, NEVILLE OWEN^{1,3}, ROBIN M. DALY⁴, JO
SALMON^{1,4}, JONATHAN E. SHAW^{1,2}, PAUL Z. ZIMMET^{1,2}, AND DAVID W.
DUNSTAN^{1,2,3,4,5}

¹ Baker IDI Heart and Diabetes Institute, Melbourne, Victoria, Australia

² Department of Epidemiology and Preventive Medicine, Monash University

³ The University of Queensland, School of Population Health, Cancer Prevention Research
Centre, Brisbane, Australia

⁴ School of Exercise and Nutrition Sciences, Deakin University, Melbourne, Australia;

⁵ Edith Cowan Health and Wellness Institute, Edith Cowan University, Joondalup, Australia

Correspondence to:

Assoc. Professor David Dunstan, Ph.D.

Baker IDI Heart and Diabetes Institute, Level 4 – Alfred Centre, 99 Commercial Road, Melbourne,
Victoria, Australia, 3004

Telephone: 61 3 8532 1873, Fax: 61 3 8532 1100

Email: David.Dunstan@bakeridi.edu.au

Disclosures

We have not received funding for this work from the NIH, Wellcome Trust, Howard Hughes Medical Institute, or the like.

Conflict of Interest

There is no conflict of interest to report for any author listed on this paper. Karl Minges: None; Dianna Magliano: None; Neville Owen: None; Robin Daly: None; Jo Salmon: None; Jonathan Shaw: None; Paul Zimmet: None; David Dunstan: None.

ABSTRACT

Purpose: To examine the association of strength training (ST) activity with impaired glucose metabolism (IGM) in Australian adults.

Methods: Based on an oral glucose tolerance test, IGM (which includes impaired fasting glycemia [IFG], impaired glucose tolerance [IGT], or newly-diagnosed type 2 diabetes), was assessed in 5,831 adults (mean age 56.0 ± 12.7 years) without clinically diagnosed diabetes who participated in the 2004-2005 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Meeting the current ST guideline was based on reporting ST at least 2 times per week (frequency), or 40 or more minutes per week in total (duration). Multiple logistic regression analyses examined associations of self-reported ST frequency and duration with IGM.

Results: After adjustment for known confounding factors and total moderate to vigorous intensity leisure-time exercise, the odds (OR) of IGM was 0.73 (95% CI 0.59 to 0.91, $P \leq 0.005$) in those who met the ST frequency guideline (≥ 2 times/week) and 0.69 (95% CI 0.55 to 0.87, $P \leq 0.01$) in those who met the ST duration guideline (≥ 40 minutes/week). Those who achieved both the recommended frequency and duration of ST had 24% lower odds of IGM. There was also evidence that a moderate frequency (1 time/week) and duration (10-39 minutes/week) of ST reduced the odds of IGM [OR frequency 0.53 (95% CI 0.51 to 0.81, $P \leq 0.01$); OR duration 0.72 (95% CI 0.52 to 1.00, $P \leq 0.05$)].

Conclusions: These findings support the importance of including ST activity, at a frequency of at least once per week, within exercise management recommendations for the maintenance of favorable metabolic health, particularly as it may contribute to the reduction in risk for developing type 2 diabetes mellitus.

Key Words: RESISTANCE TRAINING, MUSCLE STRENGTHENING ACTIVITY,
PHYSICAL ACTIVITY, IMPAIRED GLUCOSE TOLERANCE, PREDIABETES,
POPULATION-BASED

BACKGROUND

Paragraph 1 Diabetes is a significant health problem worldwide and its prevalence is on the rise. Globally, it was estimated that there were 285 million adults living with diabetes in 2010 (26). In Australia, a national survey of diabetes in 2000 reported that 7.4% of the population had diabetes, and an additional 16.4% had precursors to diabetes (impaired fasting glycemia [IFG] or impaired glucose tolerance [IGT]) (15). In the USA, the prevalence of diabetes in 2006 was 7.7%, and another 29.5% had IFG or IGT (12). Those with IFG or IGT are not only at increased risk of developing type 2 diabetes, but also have an elevated risk of cardiovascular complications and associated mortality (5).

Paragraph 2 Strength training (ST) is known to lead to improved glycemic control for those with or at risk of developing type 2 diabetes (13, 25, 29). Furthermore, ST assists in maintaining functional capacity and is beneficial in the prevention and management of sarcopenia, osteoporosis, blood pressure, cardiovascular risk, musculoskeletal disorders and injuries, and reduces susceptibility to falls (1, 6, 11, 28). The American College of Sports Medicine (ACSM), American Diabetes Association (ADA) and the American Heart Association (AHA) identify ST exercise as an integral component of a daily leisure-time exercise routine for healthy adults (6, 11, 18, 24). These guidelines recommend that ST be undertaken at least twice per week by those with and without diabetes. Whilst there are no explicit recommendations relating to ST duration, the AHA states that a 20-minute period should be adequate to perform one set of 8 to 10 different resistance exercises (6). In the context of the recommended frequency (≥ 2 times/week), this would be expected to yield a minimum of 40 or more minutes of strength training per week.

Despite the consensus of these leading public health organizations, there is a lack of evidence to describe how the guidelines interact at the population-level, specifically when characterizing the association of ST and IGM. Indeed, one other population-based study has identified muscle-strengthening activity to be associated beneficially with insulin sensitivity; but this study considered a different metabolic endpoint, did not stratify the study sample by the recommended guidelines, and only the associations with ST frequency were reported (10).

Paragraph 3 We examined the associations of achieving the current guideline relating to ST activity (both frequency and duration) with IGM, in a large national population-based sample of Australian adults without clinically diagnosed diabetes.

RESEARCH DESIGN AND METHODS

Paragraph 4 Details of the Australian Diabetes, Obesity and Lifestyle (AusDiab) study methods have been described in greater detail elsewhere (14, 23). In brief, the AusDiab study is a national, longitudinal survey designed to examine the prevalence of diabetes and obesity across Australia. The stratified, clustered, population-based study sample was drawn from 42 randomly selected Census Collector Districts across Australia. The study was approved by the Baker IDI Heart and Diabetes Institute Ethics Committee, and written informed consent was obtained from all participants. The baseline 1999/2000 survey included 11,247 adults (5049 men) aged ≥ 25 years who represented 55.3% of those completing the initial household interview. In 2004/2005, 6,400 adults attended the follow-up survey (response rate 58%), with the primary aim of estimating the incidence of diabetes. The present analyses use data from the follow-up survey

where ST measures were first implemented. Weight, height, hip and waist circumference were measured as previously described (7, 14). A fasting blood sample was taken, and a 75 gram oral glucose tolerance test (OGTT) was performed. We excluded those who had health conditions that may affect physical activity habits, including those with clinically diagnosed type 2 diabetes ($n = 544$) or an unclassified diabetes status. We also excluded those with implausibly high values or with no leisure-time exercise data provided ($n = 25$); the remaining 5,831 participants were included in these analyses.

Paragraph 5 Impaired glucose metabolism was defined as having either impaired fasting glucose (IFG) (FPG 6.1–6.9 mmol/l and 2-hr PG < 7.8 mmol/l); impaired glucose tolerance (IGT) (FPG < 7.0 mmol/l and 2-hr PG 7.8–11.1 mmol/l); or undiagnosed diabetes mellitus (FPG ≥ 7.0 mmol/l and/or 2-hr PG ≥ 11.1 mmol/l) (31). Participants who reported ≥ 2.5 hours of leisure-time exercise per week were classified as meeting the public health guidelines for physical activity (2).

Paragraph 6 Strength training activity was assessed using questions adapted from the Behavioral Risk Factor Surveillance System Survey (9). Strength training frequency was determined by asking participants to report separately for the last week, “*How many times have you done any activities designed to increase muscle strength or tone, such as lifting weights, pull-ups, push-ups, or sit-ups?*” In a separate question, ST duration was evaluated by asking, “*What do you estimate was the total time that you spent in these activities in the last week?*”

Paragraph 7 In accordance with the 2010 ACSM/ADA and the AHA physical activity guidelines (6, 11), we categorized self-reported ST frequency into three groups: those meeting the recommended guidelines (≥ 2 times/week); those reporting a ST frequency of one time per week; and those who did not participate in ST exercise (< 1 times/week). Additionally, we categorized self-reported ST duration into three groups: < 10 ; $10 - 39$; ≥ 40 minutes/week. To reduce possible inconsistencies with self-reported frequency and duration, we further stratified the analyses by those participants who fulfilled both ST elements (frequency, duration) (≥ 2 times per week and ≥ 40 minutes per week) versus those who did not.

Paragraph 8 Analyses used Stata version 11.0 (STATA, College Station, TX, USA), employing multiple logistic regression models adjusting for potential confounding factors. Model A adjusted for age and gender. Model B included model A plus education (never attended/primary/some education or high school/university graduate), family history of diabetes (parents/siblings), and smoking (current/former/non-smoker). Model C included model B plus total leisure-time exercise (those meeting the public health physical activity guidelines of ≥ 2.5 h/week versus those who did not). Model D included model C plus waist circumference. Waist circumference is a widely used indirect measure of central adiposity that has previously been shown to be an independent predictor of mortality risk (32). Furthermore, waist circumference is considered to be a better predictor of diabetes than body mass index (BMI) in the AusDiab sample (23). There were no significant interactions between age or gender and ST frequency/duration ($P > 0.05$), thus the analyses were not stratified by age or gender.

RESULTS

Paragraph 9 The mean ($\pm$ SD) age of the participants (2622 men and 3209 women) was 56.0 ($\pm$ 12.7) years. In this sample, 1,055 participants (18.1%) were identified as having IGM. Of those, 28.1% had IFG, 53.5% had IGT and 18.5% had undiagnosed type 2 diabetes. The proportion of the sample reporting participation in $ST \geq 2$ times per week was similar to the proportion reporting duration of $ST \geq 40$ minutes per week in men (16.5% and 14.1% respectively) and in women (14.8% and 13.9% respectively). Furthermore, 11.8% of all of the participants met both frequency and duration guidelines. A total of 5.0% and 6.1% of all participants reported undertaking ST once a week or for a duration of 10-39 minutes per week respectively. Of those with IGM, 11.6% achieved the frequency guideline of ≥ 2 times in the previous week and 9.5% achieved ≥ 40 minutes of ST in the previous week, compared to 16.4% and 15.0% of those without IGM respectively.

Paragraph 10 The odds ratios (95% CI) for having IGM in those meeting the guidelines for ST frequency and/or duration are shown in the Table. Those who undertook ST once per week or achieved the recommended frequency of ≥ 2 times/week had a 52% and 33% lower odds of having IGM (model A). Similarly, those who participated in 10-39 minutes per week or the recommended duration of ≥ 40 minutes/week of ST had a 34% and 37% lower odds of having IGM (model A). When educational attainment, family history of diabetes, smoking and leisure-time exercise were included in the models, the beneficial influence of ST frequency and duration remained, with the exception of ST duration of 10-39 minutes per week (model C). However, after adjusting for waist circumference, only the associations of moderate frequency (1 time/week) (OR = 0.58 [95% CI 0.38, 0.90], $P = 0.016$) and high duration (≥ 40 minutes/week) remained statistically significant (OR = 0.78 [95% CI 0.61, 0.99], $P = 0.038$).

[INSERT TABLE 1 ABOUT HERE]

DISCUSSION

Paragraph 11 In this population-based study of Australian adults, achieving the current the ACSM/ADA and AHA recommended guideline of two or more times of ST per week or 40 minutes or more of ST weekly was associated with a reduced risk of having IGM. There were no additional benefits for those who achieved both the ST frequency and duration guidelines. The study also demonstrated that undertaking ST once a week or training for 10-39 minutes weekly was associated with a significantly reduced risk for IGM relative to those who undertook ST < 10 min per week even after controlling for age, gender, educational attainment, family history of diabetes, smoking, and leisure-time exercise. This suggests that ST undertaken at least once weekly may provide benefit in terms of minimizing the risk of developing diabetes, although this will need to be confirmed in experimental intervention studies.

Paragraph 12 Only one other population-based study has evaluated the associations of muscle-strengthening activities, or strength training, and glucose tolerance. In a sample of 4,504 U.S. adults involved in the 1999-2004 National Health and Nutrition Examination Survey (NHANES), the associations of muscle-strengthening activities with insulin sensitivity, fasting insulin and fasting glucose were examined (10). After adjustment for major confounders including, age, leisure-time non-muscle-strengthening activities, race/ethnicity, BMI, smoking status, alcohol consumption, and daily total caloric intake, muscle-strengthening activities levels

were positively associated with insulin sensitivity and fasting insulin, but not fasting glucose. Statistically significant associations were generally observed for the group participating in ST three or more times per week compared to the referent group (<1 muscle-strengthening activities per week). Our findings provide additional evidence to indicate that ST activity is inversely associated with the presence of IGM in adults and that this favorable association is present even with a modest frequency of strength training activities – as little as once per week.

Paragraph 13 Clinical trials show strength training, particularly high-intensity progressive strength training, improves insulin sensitivity, glycemic control and blood glucose control in those with type 2 diabetes (8, 15, 17, 21, 27), largely as a result of gains in muscle mass. Furthermore, previous studies have demonstrated significant reductions in central obesity (waist circumference) following ST in individuals with or at risk of type 2 diabetes (4, 20, 30). In our previous randomized controlled trial of older adults with type 2 diabetes, we reported that the combination of a modest weight loss diet with high-intensity ST led to a 6.9 cm decrease in waist circumference compared to baseline measurements, which coincided with a significant 0.8 percentage point net reduction in glycated hemoglobin (HbA1c) relative to the controls (13). It is plausible that through improving insulin sensitivity, ST may be an important contributor to diabetes risk reduction and potentially could be given stronger endorsement as an integral component of a daily exercise program for both healthy individuals and those who are at risk of developing prediabetes or diabetes (16, 29).

Paragraph 14 Whilst the numerous health benefits of ST are now well-established (30), our findings indicate that the prevalence of ST in the community is low, with only 20.5% of the

study sample participating in ST one or more times per week. These findings are comparable with other studies that have assessed the prevalence of ST within populations. For example, a study in regional Australia reported that 13.7% of participants completed one or more sessions of ST in the previous week (19), while a 2004 study in the USA established a national prevalence of 21.9% among men and 17.5% among women participating in ST two or more times per week (22). The lowest participation rates are evident in the older adults (3, 22), with 7% of Australian adults age 55 or greater participating in ST activities (19). Importantly, older adults are a population group whom would be expected to derive the greatest benefits from ST. It is well documented that advancing age coincides with substantial losses in muscle mass and strength, which invariably impacts on physical function and well-being (30).

Paragraph 15 Although our study has several strengths, including the large sample size, objective measurement of glucose tolerance, and observation of the role of habitual resistance exercise at the population-level, limitations do exist. The cross-sectional nature of our study limits our ability to make causal inferences about the association of ST and IGM, and thereby emphasizes the importance for prospective studies to assess the ST and IGM relationship longitudinally. The nature of the ST question used and the inherent biases of a self-report measure may have misrepresented the actual ST frequency and duration values. Furthermore, we lacked information about the intensity of ST, which might have resulted in an underestimate of the observed relationship. Also, the relatively small number of individuals reporting a moderate frequency ($n = 290$, 5.0% of the sample) and duration ($n = 357$, 6.1% of the sample) of ST may over-estimate the magnitude of the associations of ST with IGM. Nevertheless, since high-intensity ST can lead to favourable changes in glucose metabolism in those with or at risk of type

2 diabetes (8, 13), it is plausible that performing ST only once a week, specifically high-intensity ST, may produce benefits typically consistent with more frequent, but less intense, ST regimens.

Paragraph 16 In conclusion, our findings indicate that ST, even for a frequency of one time per week, may have favorable effects on metabolic health and thereby could contribute to reducing the risk of developing type 2 diabetes. In addition, these findings provide further evidence that diabetes prevention strategies should give greater emphasis to approaches that incorporate ST, consistent with existing physical activity guidelines for healthy adults and those with type 2 diabetes.

ACKNOWLEDGEMENTS

Karl Minges was supported by a U.S. Fulbright Postgraduate Scholarship administered by the Australian-American Fulbright Commission. Neville Owen was supported by a Queensland Health Core Research Infrastructure grant and by NHMRC Program Grant funding (#301200). Robin Daly was supported by an NHMRC Career Development Award (ID 425849). Jo Salmon was supported by a National Heart Foundation and sanofi-aventis Career Development Award. Jonathan Shaw was supported by an NHMRC Research Fellowship. David W. Dunstan was supported by an Australian Research Council Future Fellowship.

The AusDiab study, coordinated by the Baker IDI Heart and Diabetes Institute, gratefully acknowledges the generous support given by the NHMRC (grant no. 233200); the Australian Government Department of Health and Ageing; Abbott Australasia; Alphapharm; AstraZeneca; Aventis Pharma; Bristol-Myers Squibb; City Health Centre, Diabetes Service, Canberra; Department of Health and Community Services, Northern Territory; Department of Health and Human services, Tasmania; the Department of Health, New South Wales; the Department of Health, Western Australia; the Department of Health, South Australia; the Department of Human

Services, Victoria; Diabetes Australia; Diabetes Australia Northern Territory; Eli Lilly Australia; Estate of the Late Edward Wilson; GlaxoSmithKline; the Jack Brockhoff Foundation; Janssen-Cilag; Kidney Health Australia; Marian & FH Flack Trust; Menzies Research Institute; Merck Sharp & Dohme; Novartis Pharmaceuticals; Novo Nordisk Pharmaceuticals; Pfizer; Pratt Foundation; Queensland Health; Roche Diagnostics Australia; Royal Prince Alfred Hospital, Sydney; Sanofi Synthelabo; and the Victorian Government's Operational Infrastructure Support Program.

The authors would like to thank Genevieve Healy, Ph.D. for her comments on a prior version of this manuscript. Also, we are enormously grateful to Shirley Murray (AusDiab project manager), and Sue Fournel (administration) for their invaluable contribution to the study. We also thank Theresa Whalen, Annaliese Bonney (AusDiab field coordinators 2004-2005), and especially the participants for volunteering their time to be involved in the study.

The results of the present study do not constitute endorsement by American College of Sports Medicine.

REFERENCES

1. American College of Sports Medicine. Progression models in resistance training for healthy adults. *Med & Sci Sports & Exerc.* 2009;41(3):687-708.
2. Armstrong T, Bauman A, Davies J. *Physical activity patterns of Australian adults: results of the 1999 National Physical Activity Survey*. Canberra, Australia: Australian Institute of Health and Welfare, 2000. p. 13.
3. Australian Bureau of Statistics. Participation in sports and physical recreation. 4177.0 c (Ed.) Canberra, 2007, p 48.
4. Banz WJ, Maher MA, Thompson WG, et al. Effects of resistance versus aerobic training on coronary artery disease risk factors. *Exp Biol Med.* 2003;228(4):434-40.
5. Barr ELM, Zimmet PZ, Welborn TA, et al. Risk of cardiovascular and all-cause mortality in individuals with diabetes mellitus, impaired fasting glucose, and impaired glucose tolerance: The Australian Diabetes, Obesity, and Lifestyle Study (AusDiab). *Circulation.* 2007;116(2):151-57.
6. Braith RW, Stewart KJ. Resistance exercise training: its role in the prevention of cardiovascular disease. *Circulation.* 2006;113(22):2642-50.
7. Cameron AJ, Welborn TA, Zimmet PZ, et al. Overweight and obesity in Australia: the 1999-2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Med J Aust.* 2003;178(9):427-32.
8. Castaneda C, Layne JE, Munoz-Orians L, et al. A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. *Diabetes Care.* 2002;25(12):2335-41.
9. Centers for Disease Control and Prevention (CDC). *Behavioral Risk Factor Surveillance System Survey Questionnaire*. Atlanta, Georgia: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention; 2000.p. 12-14.
10. Cheng YJ, Gregg EW, De Rekeneire N, et al. Muscle-strengthening activity and its association with insulin sensitivity. *Diabetes Care.* 2007;30(9):2264-70.
11. Colberg SR, Sigal RJ, Fernhall B, et al. Exercise and type 2 diabetes: the American College of Sports Medicine and the American Diabetes Association: joint position statement executive summary. *Diabetes Care.* 2010;33(12):2692-96.
12. Cowie CC, Rust KF, Ford ES, et al. Full accounting of diabetes and pre-diabetes in the U.S. Population in 1988–1994 and 2005–2006. *Diabetes Care.* 2009;32(2):287-94.
13. Dunstan DW, Daly RM, Owen N, et al. High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care.* 2002;25(10):1729-36.
14. Dunstan DW, Zimmet PZ, Welborn TA, et al. The Australian Diabetes, Obesity and Lifestyle Study (AusDiab)-methods and response rates. *Diabetes Res Clin Pract.* 2002;57(2):119-29.
15. Dunstan DW, Zimmet PZ, Welborn TA, et al. The rising prevalence of diabetes and impaired glucose tolerance. *Diabetes Care.* 2002;25(5):829-34.
16. Eriksson J, Tuominen J, Valle T, et al. Aerobic endurance exercise or circuit-type resistance training for individuals with impaired glucose tolerance? *Horm Metab Res.* 1998;30(1):37-41.

17. Gordon BA, Benson AC, Bird SR, Fraser SF. Resistance training improves metabolic health in type 2 diabetes: a systematic review. *Diabetes Res Clin Pract.* 2009;83(2):157-75.
18. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation.* 2007;116(9):1081-93.
19. Humphries B, Duncan MJ, Mummery WK. Prevalence and correlates of resistance training in a regional Australian population. *Br J Sports Med.* 2010;44(9):653-6.
20. Ibanez J, Izquierdo M, Arguelles I, et al. Twice-weekly progressive resistance training decreases abdominal fat and improves insulin sensitivity in older men with type 2 diabetes. *Diabetes Care.* 2005;28(3):662-67.
21. Ivy JL. Role of exercise training in the prevention and treatment of insulin resistance and non-insulin-dependent diabetes mellitus. *Sports Med.* 1997;24(5):321-36.
22. Kruger J, Carlson S, Kohl H. Trends in strength training--United States, 1998-2004. *MMWR Morb Mortal Wkly Rep.* 2006;55(28):769-72.
23. Magliano DJ, Barr ELM, Zimmet PZ, et al. Glucose indices, health behaviors, and incidence of diabetes in Australia. *Diabetes Care.* 2008;31(2):267-72.
24. Nelson NE, Rejeski WJ, Blair SN, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Med & Sci Sports & Exerc.* 2007;39(8):1435-45.
25. Seguin R, Nelson ME. The benefits of strength training for older adults. *Am J Prev Med.* 2003;25(3):141-49.
26. Shaw JE, Sicree RA, Zimmet PZ. Global estimates of the prevalence of diabetes for 2010 and 2030. *Diabetes Res Clin Pract.* 2010;87(1):4-14.
27. Sigal RJ, Kenny GP, Boulé NG, et al. Effects of aerobic training, resistance training, or both on glycemic control in type 2 diabetes. *Ann Intern Med.* 2007;147(6):357-69.
28. Sigal RJ, Kenny GP, Wasserman DH, Castaneda-Sceppa C. Physical activity/exercise and type 2 diabetes. *Diabetes Care.* 2004;27(10):2518-39.
29. Strasser B, Siebert U, Schobersberger W. Resistance training in the treatment of the metabolic syndrome: a systematic review and meta-analysis of the effect of resistance training on metabolic clustering in patients with abnormal glucose metabolism. *Sports Med.* 2010;40(5):397-415.
30. Winett R, Carpinelli R. Potential health-related benefits of resistance training. *Prev Med.* 2001;33(5):503-13.
31. World Health Organization. *Definition, Diagnosis and Classification of Diabetes Mellitus and Its Complications.* Geneva: World Health Organization; 1999. p. 59.
32. Zhang C, Rexrode KM, van Dam RM, Li TY, Hu FB. Abdominal obesity and the risk of all-cause, cardiovascular, and cancer mortality: sixteen years of follow-up in US women. *Circulation.* 2008;117(13):1658-67.

Table: Odds ratios (ORs) for the presence of impaired glucose metabolism according to achieving the recommended strength training frequency, duration, and both frequency and duration

		Models			
		A	B	C	D
n (%)					
Frequency, sessions per week					
0	4,634 (79.5)	1.00	1.00	1.00	1.00
1	290 (5.0)	0.48 (0.32, 0.73)‡	0.51 (0.33, 0.77)†	0.53 (0.34, 0.81)†	0.58 (0.38, 0.90)*
≥ 2	907 (15.5)	0.67 (0.54, 0.82)‡	0.71 (0.58, 0.87)‡	0.73 (0.59, 0.91)†	0.82 (0.66, 1.02)
Duration, minutes per week					
0 – 9	4,659 (79.9)	1.00	1.00	1.00	1.00
10 – 39	357 (6.1)	0.66 (0.48, 0.90)†	0.70 (0.51, 0.97)*	0.72 (0.52, 1.00)*	0.80 (0.57, 1.13)
≥ 40	815 (14.0)	0.63 (0.50, 0.79)‡	0.66 (0.53, 0.84)‡	0.69 (0.55, 0.87)†	0.78 (0.61, 0.99)*
Frequency ≥ 2 times per week and duration ≥ 40 minutes per week.					
No	5,143 (88.2)	1.00	1.00	1.00	1.00
Yes	688 (11.8)	0.70 (0.55, 0.88)†	0.73 (0.57, 0.93)*	0.76 (0.60, 0.98)*	0.85 (0.66, 1.09)

Notes: Data are presented as odds ratios (95% CI) * $p \leq 0.05$; † $p \leq 0.01$; ‡ $p \leq 0.001$. Strength training frequency (times per week) and duration (minutes per week) coefficients are based on self-report data using the timeframe of the previous 7 days. **Model A:** adjusted for age and gender only. **Model B:** adjusted for model A plus education (never attended/primary/some education or high school/university graduate), family history of diabetes (parents/siblings), and smoking (current/former/non-smoker). **Model C:** adjusted for model B plus total leisure-time physical activity (those meeting the public health physical activity guidelines of ≥ 2.5 h/week versus those who did not). **Model D:** adjusted for model C plus waist circumference (cm).