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ORIGINAL RESEARCH

The Therapeutic Effects of Mild to Moderate Intensity Aerobic Exercise on Glycemic Control in Patients with Type 2 Diabetes Mellitus: A Meta-Analysis of Randomized Trials

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ABSTRACT

Introduction: It has been recommended that physical activity be a part of treatment and management regimens of type 2 diabetes mellitus (T2DM), and research has shown that regular physical exercise facilitates glycemic control in these patients. In this analysis, our aim was to systematically show the therapeutic effects of mild to moderate intensity aerobic exercise on glycemic control in patients with T2DM.

Methods: From February to April 2021, we searched the https://www.clinicaltrials.gov, EMBASE, MEDLINE, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science and Google Scholar databases for trials that showed the effects of aerobic exercise on glycemic control in patients with T2DM. Glycated hemoglobin (HbA1c) was the endpoint in the analysis. The RevMan version 5.4 statistical program was used for statistical analysis, and the mean difference (MD) and 95% confidence intervals (CI) used to represent the data following analysis.

Results: Eighteen trials involving 972 participants with T2DM were included in this meta-analysis, of whom 523 were assigned to an exercise group and 449 were assigned to a control group. A comparison pre- versus post-aerobic exercise showed that aerobic exercise significantly improved glycemic control (HbA1c) (MD 0.35, 95% CI 0.23–0.48;

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$P = 0.00001$) in these patients with T2DM. A second comparison, T2DM participants in the experimental group post-exercise versus T2DM participants from the control group at the end of the follow-up, also showed that aerobic exercise significantly improved glycemic control (MD − 0.46, 95% CI − 0.69 to − 0.22; $P = 0.0001$). However, a comparison of HbA1c of T2DM participants in the control group at the beginning of the study compared to those at the end of follow-up did not show any significant improvement in glycemic control (MD 0.08, 95% CI − 0.05 to 0.21; $P = 0.21$).

Conclusion: The current analysis showed that mild to moderate intensity aerobic exercise significantly improved glycemic control in patients with T2DM. Patients with T2DM who regularly participated in aerobic exercise activities had a better control of their disease than those who were not on a regular aerobic exercise regimen. These results lead to the recommendation that at least mild to moderate intensity aerobic exercise should be included in the treatment and management regimens of patients with T2DM.

Keywords: Type 2 diabetes mellitus; Aerobic exercise; Glycemic control; Glycosylated hemoglobin

Key Summary Points

Why carry out this study?

Physical activity has been recommended in the treatment and management of type 2 diabetes mellitus (T2DM), and research has shown glycemic control can be achieved with regular physical exercise.

The aim of this analysis was to systematically demonstrate the therapeutic effects of mild to moderate aerobic exercise on glycemic control in patients with T2DM.

What was learned from the study?

Mild to moderate aerobic exercise significantly improved glycemic control in patients with T2DM.

Patients with T2DM who performed aerobic exercise regularly achieved better disease control than those who did not.

These results lead to the recommendation that mild to moderate exercise should be included in the treatment and management regimens of patients with T2DM

INTRODUCTION

The prevalence of type 2 diabetes mellitus (T2DM) is on the rise [1], and given the unhealthy kind of lifestyle that has been adopted by many people around the globe [2], a decline in the number of patients with T2DM is not expected. Globally, 425 million people are living with T2DM, and a further rise is inevitable in the coming years. Over the past three decades, the total number of people with T2DM has more than doubled worldwide, with the results that T2DM is now considered to be one of the most important challenges faced by the public health systems of all nations [3]. A recently developed population-level T2DM

mathematical model, fitted to six population-based survey data collected between 1990 and 2017, was used to characterize T2DM in Jordan [4]. This model showed that T2DM prevalence in Jordan was 14.0% in 1990, reached approximately 16.0% in 2020 and would reach 20.6% in 2050. The total predicted number of new cases of T2DM in Jordan was 12,313 in 1990, 36,941 in 2020 and 79,419 by 2050 [4]. The authors of another study recommended that lifestyle modifications, including weight loss, physical exercise, healthy diet and smoking cessation, should be implemented to prevent the risk of cardiovascular and other major complications in such patients [5]. Physical activity has been recommended in the treatment and management of T2DM [6], and research has shown that glycemic control can be achieved with regular physical exercise. The aim of analysis presented here was to systematically show the therapeutic effects of mild to moderate intensity aerobic exercise on glycemic control in patients with T2DM.

METHODS

Databases and Search Strategies

Between February and April 2021, we searched the https://www.clinicaltrials.gov, EMBASE, MEDLINE, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science and Google Scholar databases for trials showing the effects of aerobic exercise on glycemic control in patients with T2DM. The following keywords and phrases were used to search the databases for relevant articles: "diabetes mellitus and exercise," "diabetes mellitus and aerobic exercise," "diabetes mellitus and glycemic control and exercise," "diabetes mellitus and exercise intervention," "diabetes mellitus and physical exercise," "diabetes mellitus and exercise and HbA1c (glycated hemoglobin)," "physical exercise and HbA1c," "'physical activity and diabetes mellitus," "physical activity and HbA1c".

Inclusion and Exclusion Criteria

Studies were included if: (1) they were randomized trials showing the effect of aerobic exercise on glycemic control in patients with T2DM; (2) they involved an experimental (aerobic exercise) group and a control (non-exercise) group; and (3) HbA1c was reported as the endpoint.

Studies were excluded if: (1) they were non-randomized studies (i.e. observational studies, systematic reviews, meta-analyses, literature reviews and case studies, among others); (2) they included only high-intensity aerobic exercise; and (3) HbA1c was not reported.

Data Extraction and Quality Assessment

Eight reviewers independently extracted data from all trials that met the inclusion criteria. The extracted data included: first author's name; year of publication; time period of participants' enrollment; total number of participants with T2DM who were assigned to the aerobic exercise and the control groups, respectively; HbA1c at baseline, pre-exercise and post-exercise; the type of aerobic exercise intervention; the duration of the follow-up; the type of study; and the methodological features of the trials. Any disagreement regarding the data was discussed with the corresponding author who made the final decision.

Since all studies included in this analysis were randomized trials, the methodological quality was assessed following the recommendations of the Cochrane Collaboration [7], with a grade given to each trial as follows: grade 'A' indicated a low risk of bias; grade 'B' indicated a moderate risk of bias; and grade 'C' indicated a high risk of bias.

Statistical Analysis

The statistical analysis was carried out using the RevMan software version 5.4. Since continuous data, including means and standard deviations, were reported in the original studies, the mean difference (MD) with the respective 95% confidence interval (CI) was used to represent the

results following analysis. Heterogeneity was assessed by the Q statistic test whereby a P value ≤ 0.05 was considered to be statistically significant. Any P value > 0.05 was considered to indicate non-insignificance. Heterogeneity was also assessed by the I^2 statistic test, whereby a lower I^2 value denoted a lower heterogeneity. A fixed statistical effect model was used if $I^2 < 50\%$, and a random statistical effect model was used if $I^2 > 50\%$.

A sensitivity analysis was also carried out by an exclusion method, and each trial was excluded one by one and a new analysis was carried out each time to observe for any significant change in result.

Compliance with Ethical Guidelines

This article is based on previously conducted studies and does not contain any new studies with human or animal participants performed by any of the authors.

RESULTS

Search Outcomes

The Preferred Reporting Items in Systematic Reviews and Meta-Analyses (PRISMA) reporting guideline was followed [8]. Our search of the above-mentioned databases resulted in the identification of 24,836 publications. After a careful assessment of the titles and abstracts, 24,410 publications were excluded since they were irrelevant to the topic under evaluation, leaving 426 full-text articles to be assessed for eligibility. Ultimately, only 18 trials [9–26] were selected for inclusion in this analysis, with the other 408 studies excluded for the following reasons:

- Non-randomized studies ($n = 26$);
- Systematic reviews, meta-analyses, literature reviews, case studies ($n = 68$);
- Did not report the endpoint (HbA1c) which was under consideration ($n = 14$);
- A control group was absent ($n = 21$);
- Non-aerobic exercises or very intense training ($n = 48$);
- Duplicated studies ($n = 231$).

The flow diagram of study inclusion is shown in Fig. 1.

Endpoints, Follow-Up and Type of Interventions

The endpoints, duration of the follow-up and the type of aerobic exercise intervention performed by the participants are shown in Table 1. Based on the data in Table 1, we considered a mean follow-up time period ranging from 8 to 104 weeks. HbA1c (%) was considered to be the endpoint.

HBA1c was assessed in patients with T2DM as: HbA1c in those assigned to the aerobic exercise group (pre-exercise vs. post-exercise); HbA1c in the post-exercise group versus the control group at the end of the study; and HbA1c in the control group at the start/baseline versus HbA1c at the end of the follow-up in the control group.

General and Baseline Features of the Trials

The general features of the trials are listed in Table 1. Eighteen trials involving 972 participants with T2DM were included in this meta-analysis, of whom 523 were assigned to an exercise group and 449 were assigned to a control group. The time period of patients' enrollment ranged from 1999 to 2018.

The baseline features of the participants are listed in Table 2. The mean age of the participants ranged from 47.2 to 70.2 years. Four studies reported only female patients, gender was not mentioned in four studies and in the remaining ten studies, the mean percentage of male participants varied from 31.8 to 60.0% (Table 2. The mean body mass index also varied from 25.0 to 36.7 kg/m^2. Mean HbA1c at baseline varied from 46.0 to 79.0 mmol/mol.

Main Result of this Analysis

Comparison of groups pre- versus post-aerobic exercise showed that mild to moderate intensity aerobic exercise significantly improved

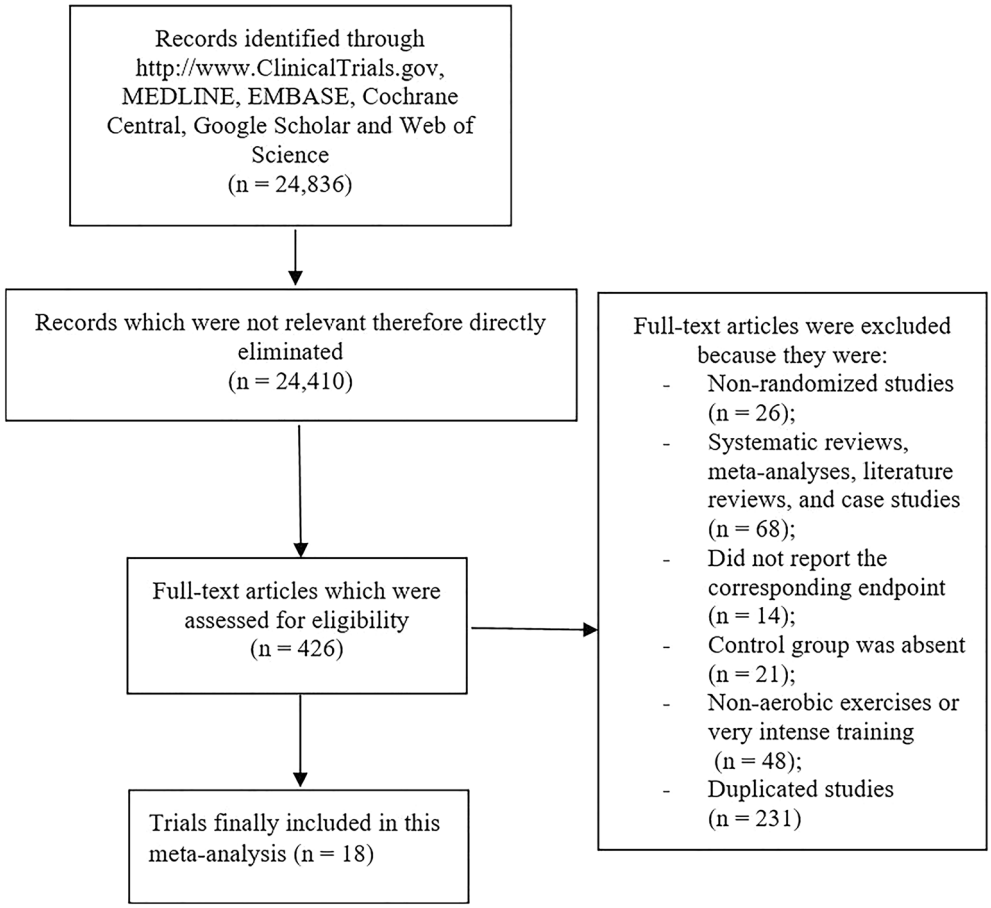


Fig. 1 Study selection flow diagram

glycemic control (HbA1c) (MD 0.35, 95% CI 0.23–0.48; $P = 0.00001$) in these patients with T2DM, as shown in Fig. 2a, b.

A second comparison was betweenh T2DM participants post exercise (HbA1c at the end of the study) versus the control group (HbA1c at the end of follow-up). This analysis showed that aerobic exercise significantly improved glycemic control (MD − 0.46, 95% CI − 0.69 to − 0.22; $P = 0.0001$]) in these patients with T2DM, as shown in Fig. 3a, b.

However, when a comparison of HbA1c was carried out in participants within the control group at the beginning of the study vs. at the end of the follow-up (only on participants who were not assigned to aerobic exercise), our analysis did not show any significant improvement in glycemic control (MD 0.08, 95% CI − 0.05 to 0.21; $P = 0.21$), as shown in Fig. 4a, b.

The study of Loreto et al. [19] had a follow-up period of 104 weeks; all other studies included in this analysis had a shorter follow-up time period. Therefore, we carried out an analysis that excluded this study and found that there were no significant changes in the results when compared to the results obtained with all studies included. We then performed an analysis excluding the study of Loreto et al. [19] in which we compared pre- and post-aerobic exercise; the results still showed that mild to moderate intensity aerobic exercise significantly improved glycemic control (MD 0.48, 95% CI 0.28–0.67; $P = 0.00001$). When T2DM participants were compared post-exercise versus the control group, the results remained the same (MD − 0.52, 95% CI − 0.76 to − 0.27; $P = 0.0001$). Finally, a comparison of the control group at the beginning of the intervention versus the end of the follow-up also did not

Table 1 General features of the studies

First author of study and year of publication [reference]	Type of study	No. T2DM participants in the experimental group (*n*)	No. T2DM participants in the control group (*n*)	Participants' enrollment period	Duration of follow-up (weeks)	Exercise intervention[a]	Bias risk score[b]	Endpoint
Abdelbasset 2020 [9]	RCT	15	16	2017–2018	8	Moderate intensity AE	B	HbA1c
Arora 2009 [10]	RCT	10	10	2007	8	Walking training AE	B	HbA1c
Belli 2011 [11]	RCT	8	9	–	12	Walking training AE	B	HbA1c
Church 2010 [12]	RCT	72	41	2007–2009	36	Moderate intensity AE	B	HbA1c
Dixit 2017 [13]	RCT	40	47	2009–2012	8	Moderate intensity AE	B	HbA1c
Fiebert 2003 [14]	RCT	40	35	2002	12	Walking training AE	B	HbA1c
Gram 2010 [15]	RCT	22	22	–	16	Nordic walking AE	B	HbA1c
Han 2010 [16]	RCT	15	16	2008	12	Moderate intensity walking AE	B	HbA1c
Koo 2010 [17]	RCT	13	18	–	12	Moderate intensity AE	B	HbA1c
Kurban 2011 [18]	RCT	30	30	–	12	Chronic regular AE	B	HbA1c
Loreto 2005 [19]	RCT	58	28	1999–2000	104	Voluntary AE	B	HbA1c
Negri 2010 [20]	RCT	21	20	–	16	Walking training AE	B	HbA1c

Table 1 continued

First author of study and year of publication [reference]	Type of study	No. T2DM participants in the experimental group (*n*)	No. T2DM participants in the control group (*n*)	Participants' enrollment period	Duration of follow-up (weeks)	Exercise intervention[a]	Bias risk score[b]	Endpoint
Rooijen 2004 [21]	RCT	80	77	2002	12	Moderate intensity AE	B	HbA1c
Shenoy 2010 [22]	RCT	20	20	–	8	Walking training AE	B	HbA1c
Sung 2012 [23]	RCT	22	18	–	12	Walking training AE	B	HbA1c
Zhang 2017 [24]	RCT	17	15	–	12	Walking and simple aerobic bicycle training	B	HbA1c
Akbarinia 2018 [25]	Quasi-experimental controlled trial	12	12	–	8	Aerobic training	B	HbA1c
Mitranum 2013 [26]	RCT	28	15	–	12	Aerobic training	B	HbA1c

AE Aerobic exercise, *HbA1c* glycated hemoglobin, *RCT* randomized controlled trials, *T2DM* type 2 diabetes mellitus

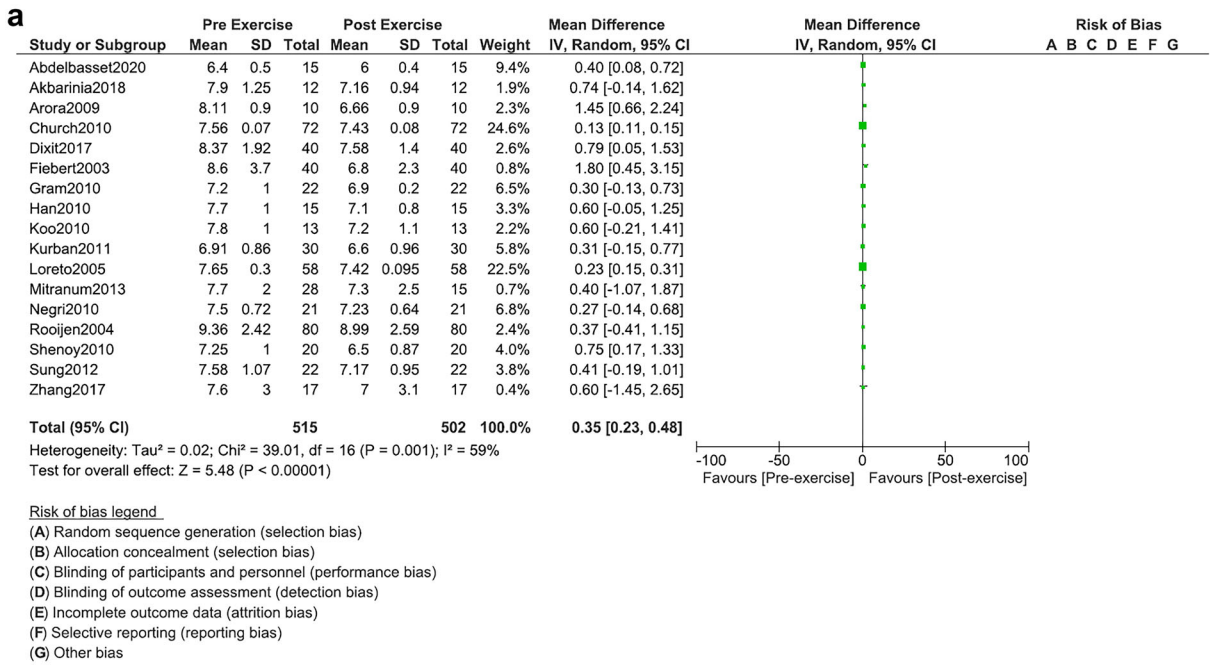
[a] Walking training is considered to be mild or low-impact aerobic exercise

[b] Methodological quality was assessed according to Cochrane Collaboration recommendations [7], where 'A' indicates a low risk of bias, 'B' indicates a moderate risk of bias and 'C' indicates a high risk of bias.

Table 2 Baseline characteristics of the participants with T2DM in the 18 studies analyzed

First author of study and year of publication [reference]	Age (years) Exp/Cont	Males (%) Exp/Cont	BMI (kg/m^2) Exp/Cont	HbA1c (%) Exp/Cont	HbA1c (mmol/mol)
Abdelbasset 2020 [9]	54.9/55.2	53.3/56.2	36.7/35.9	6.40/6.70	46.0/50.0
Arora 2009 [10]	52.2/58.4	60.0/60.0	26.2/25.0	8.11/7.77	65.0/61.0
Belli 2011 [11]	53.4/55.9	0.00/0.00	32.2/29.9	7.20/7.20	55.0/55.0
Church 2010 [12]	53.7/58.6	37.5/31.7	34.6/34.8	7.60/7.90	60.0/63.0
Dixit 2017 [13]	54.4/59.4	57.5, 63.8	–	8.37/8.02	68.0/64.0
Fiebert 2003 [14]	60.0/57.0	17.5, 22.5	30.1/29.0	8.60/8.60	70.0/70.0
Gram 2010 [15]	62.0/61.0	45.4, 59.1	31.4/32.8	7.20/7.80	55.0/62.0
Han 2010 [16]	55.7/57.8	–	27.1/27.4	7.70/7.30	61.0/56.0
Koo 2010 [17]	59.0/57.0	0.00/0.00	25.5/28.5	7.80/7.50	62.0/58.0
Kurban 2011 [18]	53.8/53.6	56.7, 40.0	30.9/30.2	6.91/6.80	52.0/51.0
Loreto 2005 [19]	–	–	29.0/29.5	7.65/7.30	60.0/56.0
Negri 2010 [20]	65.7/65.7	–	29.2/29.5	7.50/7.39	58.0/57.0
Rooijen 2004 [21]	54.0/55.0	0.00/0.00	31.7/33.7	9.36/9.25	79.0/78.0
Shenoy 2010 [22]	–	–	27.6/26.3	7.25/7.55	56.0/59.0
Sung 2012 [23]	70.2/70.1	31.8/38.9	–	7.58/7.62	59.0/60.0
Zhang 2017 [24]	47.2/46.9	41.2, 53.3	27.6/27.9	7.60/7.60	60.0/60.0
Akbarinia 2018 [25]	61.9/61.9	0.00/0.00	30.9/30.1	7.90/7.12	63.0/54.0
Mitranum 2013 [26]	61.5/60.9	35.7/33.3	29.5/29.7	7.70/7.80	61.0/62.0

BMI Body mass index, *Cont* control group, *Exp* experimental group



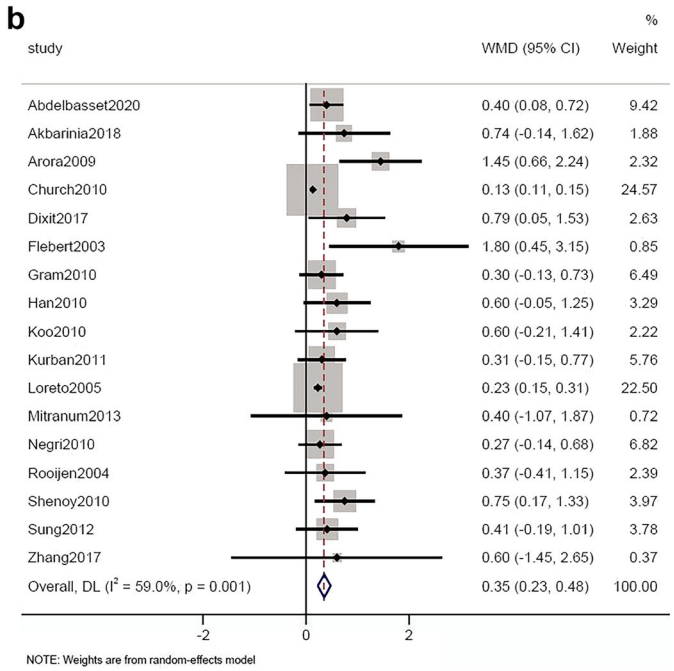


Fig. 2 **a** Glycemic control (HbA1c) in patients pre-exercise versus post-exercise intervention. **b** HbA1c pre-exercise versus post-exercise intervention (Stata statistical software; StataCorp, TX, USA). *CI* Confidence interval, *SD* standard deviation, *WMD* Weighted mean difference

show any significant improvement in HbA1c (MD 0.11, 95% CI − 0.07 to 0.28; $P = 0.23$).

A sensitivity analysis was carried out using the RevMan software program in which each trial was excluded one by one, in turn, in the data input section and a new analysis was carried out each time to be compared with the final result. Again, consistent results were obtained

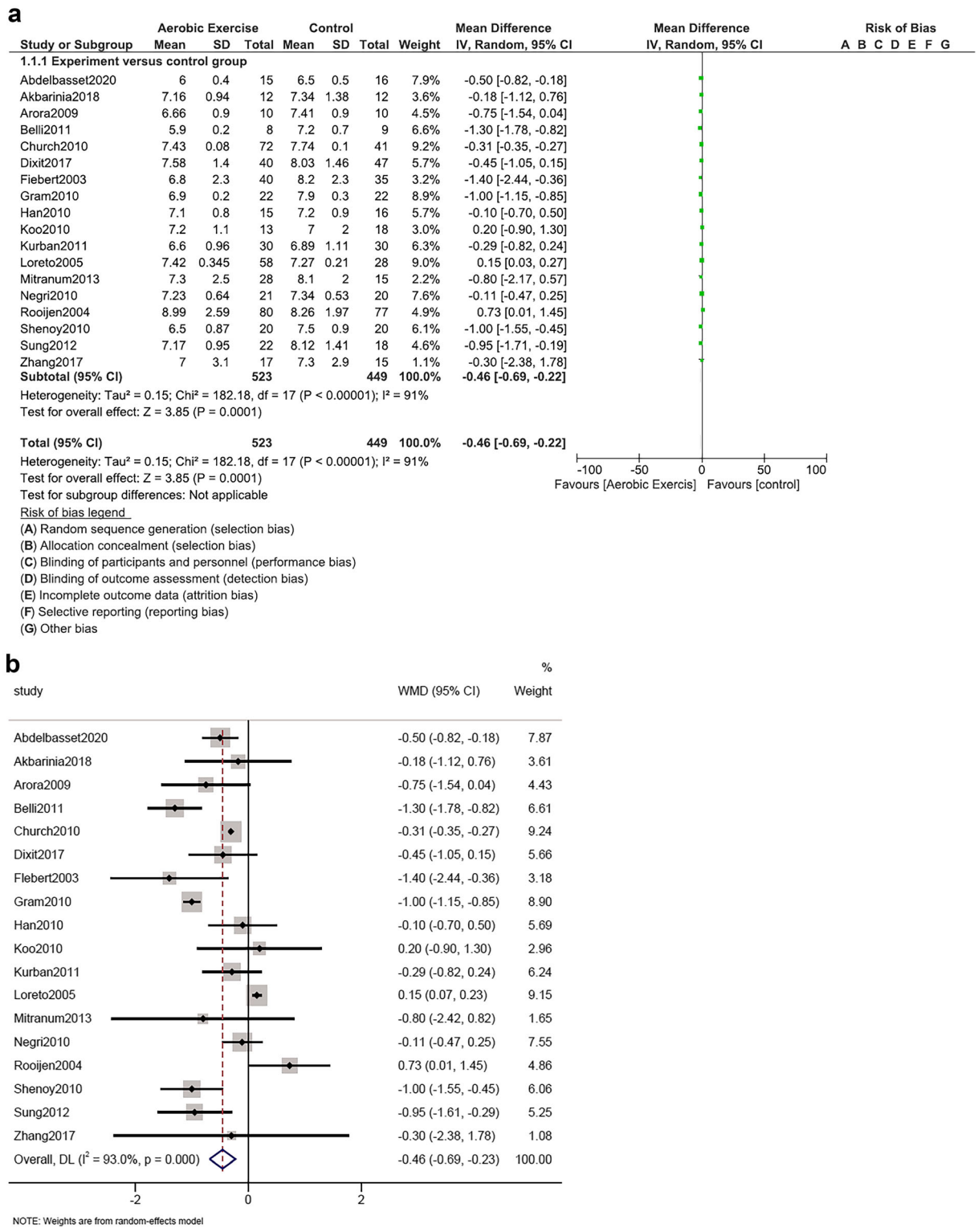


Fig. 3 **a** HbA1c in the exercise intervention vs. control group. **b** HbA1c in the exercise intervention vs. the control group (STATA)

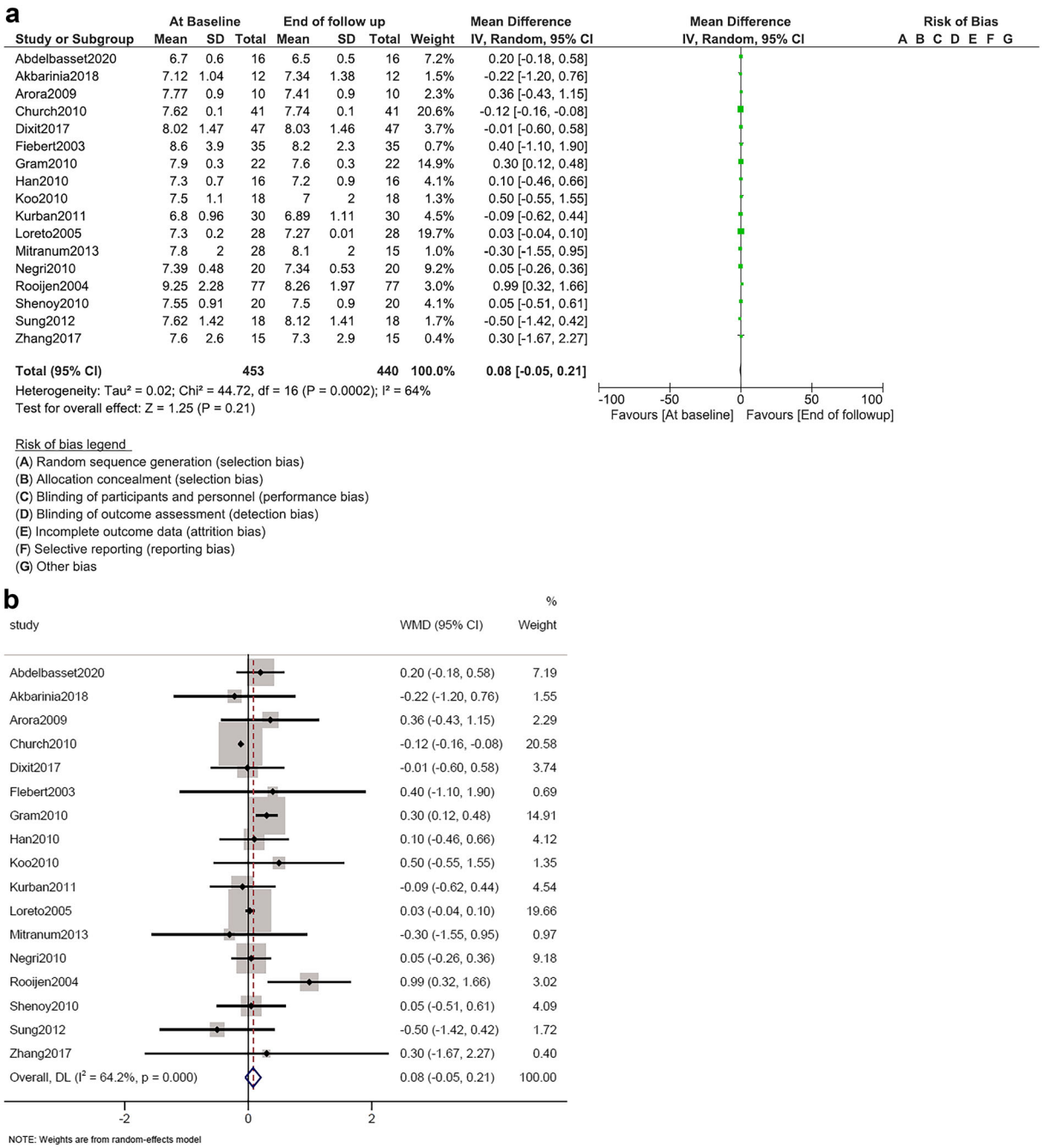


Fig. 4 **a** HbA1c in the control group at baseline versus at the end of the study intervention. **b** HbA1c in the control group at baseline versus at the end of the study intervention (STATA)

throughout. The results for the sensitivity analysis were not significantly different from the main results.

Publication bias is shown in Fig. 5.

DISCUSSION

Our results demonstrate that a significantly improved glycemic control was achieved by patients with T2DM who were assigned to a

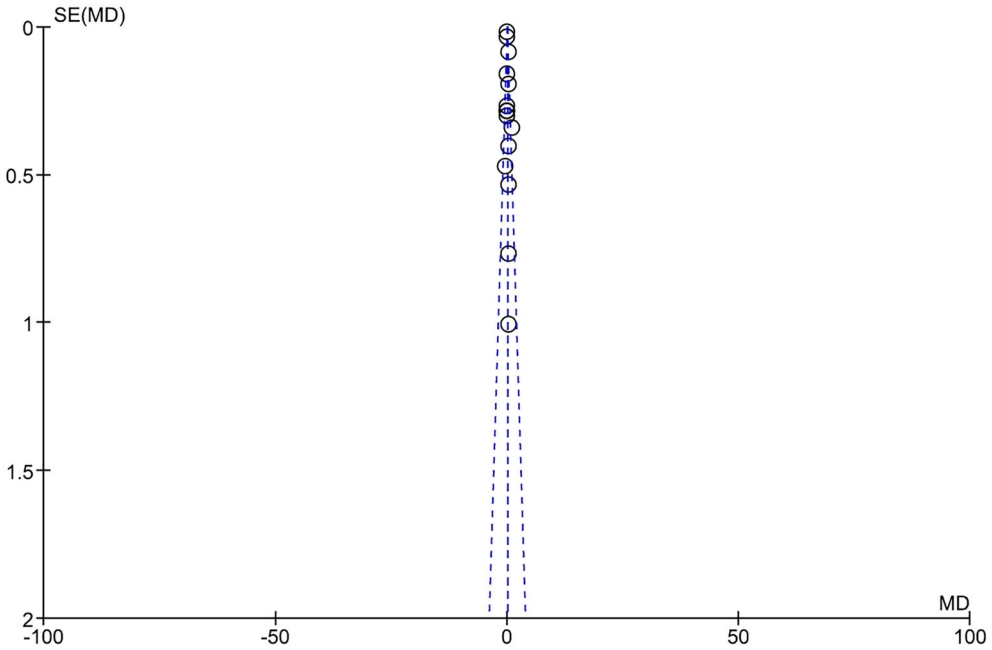


Fig. 5 Funnel plot showing publication bias

mild to moderate intensity aerobic exercise group in comparison to the control group. Different categories of comparisons were made: pre- versus post-exercise in the interventional group; the exercise group versus the control group at the end of the follow-up period; and participants in the control group at the beginning (baseline) versus at the end of the follow-up time period.

The results of our analysis involved a high level of heterogeneity due to several confounding factors. Information bias, which results in systematic differences in the manner data on exposure or outcomes are obtained from the different study groups, associated with incorrect estimations and errors or small variations in the measurement of HbA1c, and the different kinds of aerobic exercises with different intensities in each specific study, considered to be misclassification, may have had an influence on the final results. Selection bias, consisting of sampling bias in the original studies and during data extraction for the present current meta-analysis, might also have contributed to the high heterogeneity in our current analysis. Interaction of other factors, such as comorbidities (e.g. obesity, smoking status, dyslipidemia) might also have contributed to this high level of heterogeneity.

In support of the results of this analysis, in a study performed by Shakil-Ur-Rehman et al., a supervised structured aerobic exercise training program in patients with T2DM showed that aerobic exercise was significantly effective in improving blood sugar control compared to a non-exercise control group, with this improvement seen in both male and female participants [27]. Furthermore, a secondary analysis of a randomized controlled trial demonstrating physical activity and glycemic control in Chinese patients with T2DM also supported the results of this current analysis, with a significant improvement in HbA1c achieved by those patients who were assigned to an exercise intervention group [28].

In another recent systematic review and meta-analysis by Shah et al. [29], which aimed to show the therapeutic effects of exercise and general physical activity on glycemic control in patients with T2DM, the authors reported that exercise played a major role in optimizing glycemic control and improving quality of life, waist circumference and body mass index in their patients with T2DM, leading them to

recommend physical activity in the daily life of such patients. Their meta-analysis was focused on general physical activity, including aerobic as well as intense anaerobic exercises, and was also based on the assessment of the effect of exercise on other parameters [29]. Our current analysis is differs from that of Shah et al. [29] in that it is strictly limited to the effects of mild to moderate intensity aerobic exercise and its specific impact on glycemic control only. Many patients with T2DM have other co-morbidities, such as obesity and health complications, including cardiovascular diseases, which do not allow them to carry out intense exercises or which restrict their ability to carry out intense physical activities. Therefore, we believe that mild to moderate intensity aerobic exercise might be more appropriate in these patients. A systematic review and the joint AMD/SID/SISMES evidence-based practical guideline based on walking for subjects with T2DM [30] recommend at least low-impact aerobic exercise. and the authors stated that there is sufficient evidence to show walking or low-impact aerobic exercise to be beneficial.

Research has shown that walking is the major activity of choice in patients with T2DM [29]. While our analysis showed mild to moderate intensity aerobic exercise had a positive effect on glycemic control, such exercises could also promote weight loss and maintenance. Moderate intensity physical activity at least 30 min per day should be effective and could result in favorable long-term cardiovascular adaptations in patients with T2DM.

Apart from glycemic control, in another study [31, 32] examining the effects of aerobic exercise on abdominal fat, thigh muscle mass and muscle strength in diabetic subjects, moderate intensity aerobic exercise on a daily basis was found to be effective in reducing abdominal fat mass and other benefits. These results indicate that aerobic exercise in patients with T2DM result in a better control of their overall health status. In addition, aerobic training could improve platelet functions in patients with T2DM, thereby preventing platelet hyperreactivity [25].

Limitations

This study has a number of limitations. First, the total number of patients with T2DM were limited in comparison to the number included in other meta-analyses, which could have had an impact on the final outcome. Second, the follow-up time period was not similar in all studies, which may also have affected the results of this analysis. Third, any oral hypoglycemic agents or insulin used for the control of blood sugar, as well as for diet control, were not taken into account in the present analysis; co-morbidities were also ignored. Fourth, apart from walking, few studies included other forms of exercise, such as cycling; however, all of these different types of aerobic exercises could not be separately assessed because the number of studies reporting certain exercises were limited and there would not be sufficient numbers of patients for comparison, thus leading to inconclusive outcomes. Furthermore, a moderate risk of heterogeneity was observed, which could have been due to several confounding factors.

CONCLUSION

The present analysis showed that mild to moderate intensity aerobic exercise significantly improved glycemic control in patients with T2DM. Patients with T2DM who participated in regular aerobic exercise programs had a better control of their disease than those who were not on a regular aerobic exercise regimen. These results lead to the recommendation that at least mild to moderate intensity aerobic exercise should be included in the treatment and management of patients with T2DM.

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Authors' Contributions. SG, JT, GY, ZL, ZC, LY, FZ, YH and ZT were responsible for the conception and design of the study, acquisition, analysis and interpretation of the data, drafting of the initial manuscript and critical revision for important intellectual content. All authors approved the final manuscript as it is.

Disclosures. Siyao Gao, Jialing Tang, Guozhong Yi, Zhong Li, Zhenyin Chen, Ling Yu, Feng Zheng, Yajing Hu and Zhangui Tang declare that they have no competing interests.

Compliance with Ethical Guidelines. This meta-analysis is based on previously conducted studies and does not contain any new study with human participants or animals performed by any of the authors.

Data Availability. All data generated or analyzed during this study are included in this published article. References of the original papers involving the data source which have been used in this paper have been listed in the main text of this current manuscript. All data are publicly available in electronic databases.

REFERENCES

1. Lovic D, Piperidou A, Zografou I, et al. The growing epidemic of diabetes mellitus. Curr Vasc Pharmacol. 2020;18(2):104–9.
2. Moon S. Unhealthy lifestyle behaviors in Korean People with metabolic syndrome. J Community Health Nurs. 2017;34(2):69–79.
3. Chen L, Magliano DJ, Zimmet PZ. The worldwide epidemiology of type 2 diabetes mellitus—present and future perspectives. Nat Rev Endocrinol. 2011;8(4):228–36.
4. Awad SF, Huangfu P, Dargham SR, et al. Characterizing the type 2 diabetes mellitus epidemic in Jordan up to 2050. Sci Rep. 2020;10(1):21001.
5. Afroz A, Ali L, Karim MN, et al. Glycaemic control for people with type 2 diabetes mellitus in Bangladesh—an urgent need for optimization of management plan. Sci Rep. 2019;9(1):10248.
6. Lumb A. Diabetes and exercise. Clin Med (Lond). 2014;14(6):673–6.
7. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928.
8. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ. 2009;339:b2700.
9. Abdelbasset WK, Tantawy SA, Kamel DM, et al. Effects of high-intensity interval and moderate-intensity continuous aerobic exercise on diabetic obese patients with nonalcoholic fatty liver disease: a comparative randomized controlled trial. Medicine (Baltimore). 2020;99(10):e19471.
10. Arora E, Shenoy S, Sandhu JS. Effects of resistance training on metabolic profile of adults with type 2 diabetes. Indian J Med Res. 2009;129(5):515–9.
11. Belli T, Ribeiro LFP, Ackermann MA, Baldissera V, Gobatto CA, da Silva RG. Effects of 12-week

overground walking training at ventilatory threshold velocity in type 2 diabetic women. Diabetes Res Clin Pract. 2011;93(3):337–43.

12. Church TS, Blair SN, Cocreham S, et al. Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized controlled trial. JAMA. 2010;304(20):2253–62.

13. Dixit S, Maiya A, Shastry BA. Effect of moderate-intensity aerobic exercise on glycosylated haemoglobin among elderly patients with type 2 diabetes and peripheral neuropathy. Indian J Med Res. 2017;145(1):129–32.

14. Goldhaber-Fiebert JD, Goldhaber-Fiebert SN, Tristán ML, Nathan DM. Randomized controlled community-based nutrition and exercise intervention improves glycemia and cardiovascular risk factors in type 2 diabetic patients in rural Costa Rica. Diabetes Care. 2003;26(1):24–9.

15. Gram B, Christensen R, Christiansen C, Gram J. Effects of nordic walking and exercise in type 2 diabetes mellitus: a randomized controlled trial. Clin J Sport Med. 2010;20(5):355–61.

16. Ku YH, Han KA, Ahn H, et al. Resistance exercise did not alter intramuscular adipose tissue but reduced retinol-binding protein-4 concentration in individuals with type 2 diabetes mellitus. J Int Med Res May-Jun. 2010;38(3):782–91.

17. Koo BK, Han KA, Ahn HJ, Jung JY, Kim HC, Min KW. The effects of total energy expenditure from all levels of physical activity vs. physical activity energy expenditure from moderate-to-vigorous activity on visceral fat and insulin sensitivity in obese type 2 diabetic women. Diabet Med. 2010;27(9):1088–92.

18. Kurban S, Mehmetoglu I, Yerlikaya HF, Gönen S, Erdem S. Effect of chronic regular exercise on serum ischemia-modified albumin levels and oxidative stress in type 2 diabetes mellitus. Endocr Res. 2011;36(3):116–23.

19. Di Loreto C, Fanelli C, Lucidi P, et al. Make your diabetic patients walk: long-term impact of different amounts of physical activity on type 2 diabetes. Diabetes Care. 2005;28(6):1295–302.

20. Negri C, Bacchi E, Morgante S, et al. Supervised walking groups to increase physical activity in type 2 diabetic patients. Diabetes Care. 2010;33(11):2333–5.

21. van Rooijen AJ, Rheeder P, Eales CJ, Becker PJ. Effect of exercise versus relaxation on haemoglobin A1C in Black females with type 2 diabetes mellitus. QJM. 2004;97(6):343–51.

22. Shenoy S, Guglani R, Sandhu JS. Effectiveness of an aerobic walking program using heart rate monitor and pedometer on the parameters of diabetes control in Asian Indians with type 2 diabetes. Prim Care Diabetes. 2010;4(1):41–5.

23. Sung K, Bae S. Effects of a regular walking exercise program on behavioral and biochemical aspects in elderly people with type II diabetes. Nurs Health Sci. 2012;14(4):438–45.

24. Zhang L-Y, Liu T, Teng Y-Q, et al. Effect of a 12-week aerobic exercise training on serum fetuin-a and adipocytokine levels in type 2 diabetes. Exp Clin Endocrinol Diabetes. 2018;126(8):487–92.

25. Akbarinia A, Kargarfard M, Naderi M. Aerobic training improves platelet function in type 2 diabetic patients: role of microRNA-130a and GPIIb. Acta Diabetol. 2018;55(9):893–9.

26. Mitranun W, Deerochanawong C, Tanaka H, Suksom D. Continuous vs interval training on glycemic control and macro- and microvascular reactivity in type 2 diabetic patients. Scand J Med Sci Sports. 2014;24(2):e69-76.

27. Shakil-Ur-Rehman S, Karimi H, Gillani SA, Amjad I, Ahmad S, Yaseen A. Response to a supervised structured aerobic exercise training program in patients with type 2 diabetes mellitus—does gender make a difference? A randomized controlled clinical trial. J Natl Med Assoc. 2018;110(5):431–9.

28. Yao W-Y, Han M-G, De Vito G, et al. Physical activity and glycemic control status in chinese patients with type 2 diabetes: a secondary analysis of a randomized controlled trial. Int J Environ Res Public Health. 2021;18(8):4292.

29. Shah SZA, Karam JA, Zeb A, et al. Movement is improvement: the therapeutic effects of exercise and general physical activity on glycemic control in patients with type 2 diabetes mellitus: a systematic review and meta-analysis of randomized controlled trials. Diabetes Ther. 2021;12(3):707–32.

30. Moghetti P, Balducci S, Guidetti L, et al. Walking for subjects with type 2 diabetes: a systematic review and joint AMD/SID/SISMES evidence-based practical guideline. Nutr Metab Cardiovasc Dis. 2020;30(11):1882–98.

31. Ford ES, Herman WH. Leisure-time physical activity patterns in the U.S. diabetic population. Findings from the 1990 National Health Interview Survey-Health Promotion and Disease Prevention Supplement. Diabetes Care. 1990;1995(18):27–33.

32. Kwon HR, Min KW, Ahn HJ, et al. Effects of aerobic exercise on abdominal fat, thigh muscle mass and muscle strength in type 2 diabetic subject. Korean Diabetes J. 2010;34(1):23–31.