# The Effect of Exercise on Quality of Life in Type 2 Diabetes: A Systematic Review and Meta-analysis



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**ABSTRACT**

SABAG, A., C. R. CHANG, M. E. FRANCOIS, S. E. KEATING, J. S. COOMBES, N. A. JOHNSON, M. PASTOR-VALERO, and J. P. REY LOPEZ. The Effect of Exercise on Quality of Life in Type 2 Diabetes: A Systematic Review and Meta-analysis. Med. Sci. Sports Exerc., Vol. 55, No. 8, pp. 1353–1365, 2023. **Background:** Exercise is a proven therapy for managing cardiometabolic risk factors in type 2 diabetes (T2D). However, its effects on patient-reported outcome measures such as quality of life (QoL) in people with T2D remain unclear. Consequently, the primary aim of this study was to determine the effect of regular exercise on QoL in adults with T2D. A secondary aim was to determine the effect of different exercise modalities on QoL. The third aim was to determine whether improvements in QoL were associated with improvements in gly'cated hemoglobin (A1C). **Methods:** Relevant databases were searched to May 2022. Eligible studies included randomized trials involving ≥2 wk of aerobic and/or resistance exercise and assessed QoL using a purpose-specific tool. Mean differences and 95% confidence intervals (CI) were calculated as standardized mean difference (SMD) or weighted mean difference. A regression analysis was undertaken to examine the interaction between change in QoL with change in A1C. **Results:** Of the 12,642 studies retrieved, 29 were included involving 2354 participants. Exercise improved QoL when compared with control (SMD, 0.384; 95% CI, 0.257 to 0.512; $P < 0.001$). Aerobic exercise, alone (SMD, 0.475; 95% CI, 0.295 to 0.655; $P < 0.001$) or in combination with resistance training (SMD, 0.363; 95% CI, 0.179 to 0.548; $P < 0.001$) improved QoL, whereas resistance training alone did not. Physical components of health-related QoL (HRQoL) improved with all exercise modalities, but mental components of HRQoL remained unchanged. Exercise improved A1C (mean difference, −0.509%; 95% CI, −0.806% to −0.212%; $P = 0.001$), and this change was associated with improvements in HRQoL ($\beta = -0.305$, SE = 0.140, $Z = -2.18$, $P = 0.030$). **Conclusions:** These results provide robust evidence that regular aerobic exercise alone or in combination with resistance training is effective for improving QoL in adults with T2D. Such improvements seem to be mediated by improvements in physical components of HRQoL and are associated with improved blood glucose control. Further studies should be undertaken to determine the relative importance of exercise duration, intensity, and frequency on patient-reported outcomes such as QoL. **Key Words:** QUALITY OF LIFE, TYPE 2 DIABETES, EXERCISE

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Routine clinical management of type 2 diabetes (T2D) centers on improving blood glucose control, often measured as glycated hemoglobin (A1C), by improving cardiometabolic risk factors via long-term lifestyle and/or pharmacological intervention (1). Importantly, individuals with T2D may report feeling frustrated and overwhelmed by treatment goals and self-management practices, particularly those with more severe comorbidities (2). As such, patient-reported outcome measures, such as quality of life (QoL) assessments, are often implemented to determine the impact of healthcare interventions on functioning (physical, social, and work-related) and well-being in research and clinical practice settings (3).

The World Health Organization's definition of QoL is a broad-ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships, and their relationship to salient features of their environment (4). In the context of T2D, self-care activities, including diet modification and regular exercise, have been identified as key strategies for improving health-related QoL (HRQoL) (5). A previous systematic review highlighted that self-care practices can significantly improve QoL in adults with type 1 diabetes or T2D (6). Although the aforementioned study categorized physical activity as a self-care practice, the analyses involved interventions where physical activity promotion was combined with other practices such as dietary counseling and other self-care practices. As such, isolation of the effect of exercise on QoL was not possible. Furthermore, although most assessments often measure both physical and mental components of HRQoL, the relative importance of each component in the context of T2D management may vary. For example, previous findings suggest that higher physical component scores rather than mental component scores may be more beneficial for reducing the risk of mortality in T2D (7). As such, it is important to determine the impact of exercise on both physical and mental components of HRQoL in addition to overall QoL.

Exercise is conceptualized as planned and structured physical activity, which can be broadly subcategorized by modality into aerobic or resistance exercise. Both aerobic and resistance exercises play powerful and unique roles in the management of T2D by improving glucose control (8–10), ectopic fat (11,12), cardiovascular health (13,14), and physical function (15). Despite the relative effectiveness of each modality for improving cardiometabolic outcomes in T2D, their effects on QoL-related outcomes remain unclear. For example, a previous systematic review published in 2017 and involving 30 studies found that regular aerobic but not resistance exercise improved QoL in T2D (16). However, this systematic review had several limitations such as: the inclusion of nonrandomized studies, the inclusion of studies without a control group, and the omission of pooled effects via meta-analysis. As a result, the lack of strong evidence surrounding the effect of different types of exercise programs on QoL requires additional evidence synthesis through a comprehensive systematic review and meta-analysis. Consequently, the primary aims of this study were to evaluate the independent effects of different exercise modalities on QoL in adults with T2D and to assess whether improvements in QoL were associated with changes in A1C.

## METHODS

This systematic review was prospectively registered on the Prospero International Prospective Register of Systematic Reviews (CRD42021272546) and conforms to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (17).

**Search strategy.** An online literature search was performed by one reviewer (A. S.) in Web of Science, Embase (Ovid), Medline (Ovid), Scopus, and SportDiscus (EBSCO Host) from the earliest record to May 2022. Search terms included keywords and Medical Subject Headings to find literature surrounding exercise and T2D. Specifically, the database searches were conducted using the terms: (type 2 diabetes*.mp. OR diabetes.mp.) AND (quality of life.mp. OR health-related quality of life.mp.) AND (exercise.mp. OR muscle strengthening exercise.mp. OR plyometric exercise.mp. OR resistance training.mp. OR running.mp. OR swimming.mp. OR walking.mp. OR cycling.mp. OR aerobic exercise.mp. OR aerobic training.mp. OR endurance training.mp. OR endurance exercise.mp. OR strength training.mp.). Where possible, searches were limited to humans. All articles related to the search terms from each database were exported to a central database (Covidence systematic review software; Veritas Health Innovation, Melbourne, Australia; available at www.covidence.org) where studies were screened against the inclusion and exclusion criteria.

**Eligibility criteria.** Only randomized trials were included in the systematic review, whereas nonrandomized trials and cross-sectional studies were excluded. Studies were excluded if not published in the English language. Studies were also excluded if they were book sections, theses, film/broadcast, opinion articles, observational studies, reviews, and conference presentation abstracts.

**Participants.** Studies involving adult human participants (≥18 yr) with T2D were included. Studies involving participants with comorbidities not directly related to T2D, such as rapidly progressive diseases, were excluded.

**Intervention.** Exercise interventions involving regular aerobic exercise and/or resistance training lasting ≥2 wk were included. Studies involving mind–body exercise, exergaming, or Pilates were excluded.

**Comparator group.** Studies were included if they compared an exercise group with a nonexercise control group. Studies involving exercise with an additional intervention were included if both the exercise and comparator group undertook the same additional intervention (e.g., diet plus exercise vs diet alone).

**Outcome measures.** Studies were included if they assessed QoL using a novel, standardized, or adapted purpose-specific tool that was intended to specifically measure QoL (including HRQoL). Studies that did not measure QoL but measured depression, anxiety, or well-being were excluded.

**Selection of studies.** After eliminating duplicates, search results were screened by two independent researchers (A. S. and J. P. R.-L.) against the eligibility criteria, and studies that could not be eliminated by title or abstract were retrieved and assessed for eligibility. Disagreements were resolved by a third researcher (M. E. F.). Reference lists of included studies were manually searched for potentially eligible articles that were not identified in the database search. On occasions where the identified studies reported insufficient data, attempts were made to contact authors to acquire the required information, and if no response was received after the second attempt, the study was excluded.

**Data extraction.** Data from all eligible studies were independently extracted to relevant tables by two reviewers (A. S. and C. R. C.). Graphical data were extracted and converted into numerical format using appropriate software (Graph Data Extractor, Version 0.0.0.1., Dr. A. J. Matthews). Where applicable, data were converted to mean and SD using the RevMan calculator.

**Risk of bias assessment and certainty of evidence.** Studies were assessed for risk of bias independently by two reviewers (J. P. R.-L. and M. P.-V.) using the Cochrane Risk of Bias tool, which is structured into a fixed set of domains of bias including selection bias, performance bias, detection bias, attrition bias, reporting bias, and other bias (18). "Other" bias was judged by determining whether studies incorporated supervised or monitored exercise interventions and whether they reported exercise adherence. The studies are rated across domains on a scale of low, unclear, or high risk of bias. Scores obtained by reviewers were compared and disagreements resolved by a third reviewer (A. S.). Studies were not excluded based on their bias assessment. The certainty of the evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework (19) by one reviewer (A. S.).

**Statistical analysis.** Data are presented as effect size with 95% confidence interval (CI). Random-effects meta-analyses, were conducted using Comprehensive Meta-Analysis Version 3 software (Biostat Inc., Englewood, NJ). Significance was set at $P < 0.05$.

Standardized mean differences (SMD), reported as effect sizes and calculated from preintervention to postintervention scores between two groups for change in QoL, were expressed as Hedge's $g$ with 95% CI around the estimated effect size. If postintervention scores were not available, mean change scores were used to calculate effect sizes. Effect sizes of ≥0.2, ≥0.5, and ≥0.8 were considered small, moderate, and large, respectively (20). Pooled mean difference with 95% CI was calculated for all studies that assessed change in A1C. A univariate meta-regression analysis was performed to examine the relationship between change in QoL and change in A1C.

Statistical heterogeneity between studies was quantified using Cochran's $Q$ and $I^2$ statistic, both of which provide estimates of the degree of heterogeneity resulting from between-study variance, rather than by chance. Cochran's $Q$ with a $P$ value of <0.05 was classified as significant heterogeneity, and $I^2$ of 75%–100% was considered high-level heterogeneity, $I^2$ of 40%–74% was considered substantial heterogeneity, and an $I^2$ of less than 25% was considered as low heterogeneity. Publication bias was assessed using the Begg and Mazumdar Kendall's $\tau$ test, with a $P$ value <0.05 suggesting the presence of bias (21,22). Where significant bias was detected, a Duval and Tweedie trim-and-fill analysis (23) was conducted to recalculate the pooled effect size after removing any studies, which may introduce publication bias (i.e., small studies with large effect sizes from the positive side of the funnel plot). Sensitivity analyses were conducted by assessing the effect of exercise on QoL after removing studies deemed to have high-risk of bias (i.e., where four or more items were classified as unclear or high risk of bias on the modified risk of bias tool) (24–33).

The primary analysis involved determining the effect of exercise on overall QoL. Where studies did not report overall QoL, the within-study individual effects of exercise versus control for each domain of QoL were pooled and used in the primary analysis. The secondary analysis involved assessing the effect of exercise versus control on physical and mental component scores of QoL, respectively, from studies that assessed HRQoL using either the Short-Form 36 or Short-Form 12 questionnaire. Where studies did not report a physical component score or mental component score, the within-study effects of exercise versus control on the four domains pertaining to the mental component score and physical component score, respectively, were pooled and used in the secondary analysis.

## RESULTS

### Identification of Studies

The search returned a total of 12,640 results, and a further two studies were identified through searching the reference lists of cited studies. After the removal of duplicates and screening based on the eligibility criteria, 29 studies were included (Fig. 1).

### Participant Characteristics

Participant characteristics are detailed in Table 1. Briefly, there were a total of 2354 participants at baseline, of whom 51% were male with an average (mean ± SD) age of 57.5 ± 7.6 yr, body mass index of 31.2 ± 3.7 kg·m$^{-2}$, and A1C of 7.4% ± 0.5%. Three studies did not report sex (37,49,51). Four studies recruited participants with T2D and comorbid conditions such as chronic heart failure (36), nonalcoholic fatty liver disease (24), peripheral artery disease (40), and peripheral neuropathy (26).

### Intervention Characteristics

Intervention characteristics are summarized in Table 2. Twelve studies compared an aerobic exercise intervention versus control (24,26,28,30,37,40–42,47,51–53); nine studies compared a combined aerobic and resistance exercise intervention versus control (25,27,29,32,33,35,36,44,49); five studies compared a resistance training intervention versus control (31,38,39,43,46); two studies included several intervention groups including aerobic exercise, resistance training, and combined aerobic and resistance exercise versus control (48,50); and one study compared a combined aerobic and resistance exercise intervention and an aerobic exercise intervention alone versus control (45). The intervention duration ranged from 8 to 52 wk, with 8-wk (33,38,43–45,47,51,53) and 12-wk (24–26,29,35–37,52) interventions being the most common. The frequency of exercise sessions ranged from two to five times per week, with most studies implementing a training

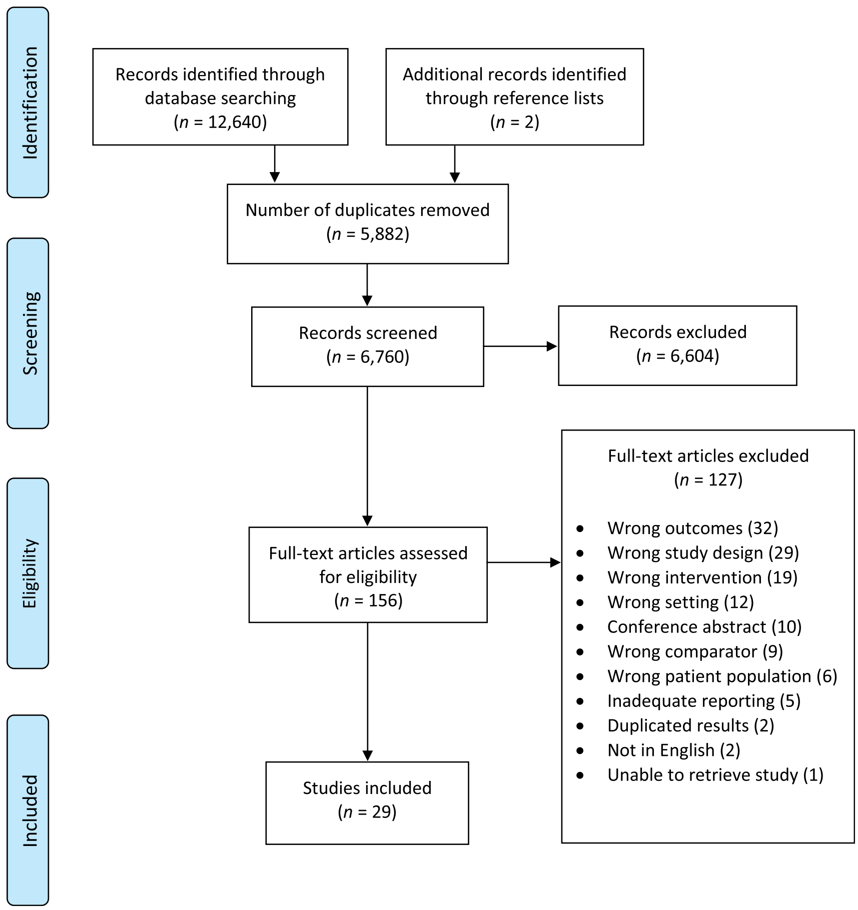


**FIGURE 1—PRISMA flow diagram of search strategy.**

frequency of three times per week (9,34,46,54–62). Fifteen studies involved supervised or monitored exercise interventions (28,32,36–39,41–45,48–51), and 20 studies reported adherence (25,27–30,32,33,36–38,40–44,47–52).

## Measurement of QoL

The most common tool used to measure QoL was the 36-Item Short Form Health Survey (SF-36), which was used in 14 studies (25,28–30,33,36,39,40,45–50,52), and an abbreviated version of the SF-36, the SF-12, was used in one study (31). One study only reported the SF-36 mental component score (46). Overall QoL was reported in 10 studies (24,26,32,35,37,38,43,44,51,52), whereas overall QoL was calculated using the pooled scores of individual domains in 18 studies.

## Risk of Bias and Certainty of Evidence

The results of the risk of bias assessment are summarized in Figure 2. Eleven of 29 studies scored unclear or high risk of bias on four or more items on the risk of bias assessment (Supplemental Table 1, Supplemental Digital Content, Risk of bias assessment detail, http://links.lww.com/MSS/C832) (24–33,46). The most prevalent risks pertained to blinding of outcome assessment and allocation concealment (Fig. 2).

The level of certainty (using GRADE) of the results produced is detailed in Supplemental Table 2 (Supplemental Digital Content, Assessment of certainty of evidence summary, http://links.lww.com/MSS/C832). Briefly, there was a moderate certainty of evidence showing that exercise probably results in small to moderate improvements in overall QoL and A1C when compared with control. There was a low certainty of evidence showing that exercise may improve physical components but not mental components of HRQoL.

## Primary Analysis

**Effect of exercise modalities on overall QoL.** ***Effect of any exercise modality on overall QoL.*** A total of 29 studies, involving 34 comparisons, provided sufficient data to determine the effect of any exercise modality on overall QoL in T2D (Fig. 3). Exercise elicited a small improvement in overall QOL when compared with control (SMD, 0.384; 95% CI, 0.257–0.512; $P < 0.001$, $\tau = 0.288$, $I^2 = 73.296$, $n = 2243$). The Begg–Mazumdar test indicated no publication bias ($P = 0.468$). The sensitivity analysis, which involved excluding studies deemed to have high risk of bias on the ROB tool, yielded similar results (SMD, 0.342; 95% CI, 0.179–0.505; $P < 0.001$, $\tau = 0.305$, $I^2 = 77.084$, $n = 1779$).

***Effect of aerobic exercise on overall QoL.*** A total of 16 studies provided sufficient data to determine the effect of

TABLE 1. Participant characteristics at baseline.

| Study | Group ($n$) | % Male | Age (yr) | HbA1c (%) | BMI (kg·m$^{-2}$) | Condition |
|---|---|---|---|---|---|---|
| Abdelbasset et al. (34) | AEX (16) | 63 | 54.4 ± 5.8 | 6.6 ± 0.4 | 36.3 ± 4.5 | Adults with T2D, NAFLD, and obesity |
| | CON (16) | 56 | 55.2 ± 4.3 | 6.7 ± 0.6 | 35.9 ± 5.3 | Adults with T2D, NAFLD, and obesity |
| Akinci et al. (35) | CE (22) | 18 | 53.6 ± 6.0 | 8.0 ± 1.2 | 31.8 ± 6.4 | Adults with T2D |
| | CON (22) | 38 | 53.6 ± 6.7 | 8.2 ± 1.2 | 32.2 ± 5.1 | Adults with T2D |
| Asa et al. (36) | CE (10) | 80 | 65.8 ± 5.8 | 7.9 ± 2.9 | NR | Adults with T2D and CHF |
| | CON (10) | 80 | 69 ± 8.2 | 6.9 ± 2 | NR | Adults with T2D and CHF |
| Aylin et al. (25) | CE (18) | 83 | 51.4 ± 8.6 | 7.67 ± 1.9 | 28.5 ± 4.0 | Adults with T2D |
| | CON (18) | 67 | 56.1 ± 6.3 | 6.75 ± 1.1 | 31.3 ± 5.1 | Adults with T2D |
| Bello et al. (37) | AEX (9) | NR | 43.3 ± 6.7 | 8.2 ± 1.7 | 28.3 ± 4.2 | Sedentary adults with T2D |
| | CON (9) | NR | 45.1 ± 11.8 | 7.9 ± 2.5 | 26.1 ± 3.5 | Sedentary adults with T2D |
| Botton et al. (38) | RT (22) | 55 | 70.6 ± 6.7 | 7.1 ± 1 | 28.2 ± 3.6 | Adults with T2D |
| | CON (22) | 64 | 68.6 ± 7.1 | 7.3 ± 1.2 | 28.6 ± 3.3 | Adults with T2D |
| Cheung et al. (39) | RT (20) | 35 | 59.0 ± 8.7 | 7.2 ± 1.6 | 39.7 ± 9.0 | Sedentary adults with T2D |
| | CON (17) | 29 | 62.0 ± 6.7 | 7.4 ± 1.0 | 37.7 ± 9.2 | Sedentary adults with T2D |
| Collins et al. (40) | AEX (72) | 65 | 66.2 ± 10.2 | 7.0 ± 1.3 | 35 ± 9.3 | Adults with T2D and PAD |
| | CON (73) | 73 | 66.8 ± 10.1 | 7.2 ± 1.1 | 33.7 ± 7 | Adults with T2D and PAD |
| Dixit et al. (26) | AEX (40) | 56 | 54.4 ± 1.2 | NR | 26.4 ± 3.8 | Adults with T2D and PN |
| | CON (47) | 65 | 59.5 ± 1.2 | NR | 26.0 ± 5.7 | Adults with T2D and PN |
| Ferrer-García et al. (27) | CE (44) | 41 | 65.6 ± 7.6 | 6.4 ± 1.5 | 31.2 ± 6.2 | Adults with T2D |
| | CON (40) | 40 | 67.9 ± 8.4 | 6.5 ± 0.8 | 32.2 ± 6.4 | Adults with T2D |
| Fritz et al. (41) | AEX (20) | 65 | 62.0 ± 4.0 | 7.0 ± 1.0 | 30.7 ± 5.2 | Adults with T2D |
| | CON (30) | 67 | 60.8 ± 4.7 | 6.7 ± 0.7 | 30.5 ± 4.7 | Adults with T2D |
| Guglani et al. (42) | AEX (35) | 80 | 54.4 ± 7.7 | NR | NR | Adults with T2D |
| | CON (32) | 63 | 50.9 ± 5.5 | NR | NR | Adults with T2D |
| Holton et al. (28) | AEX (9) | 78 | 55.1 ± 6.6 | 7.1 ± 0.9 | 33.3 ± 5.4 | Sedentary adults with T2D |
| | CON (12) | 58 | 55.4 ± 8.3 | NR | 30.0 ± 6.6 | Sedentary adults with T2D |
| Hsieh et al. (43) | RT (15) | 33 | 70.6 ± 4.2 | 7.2 ± 0.6 | 25.6 ± 2.6 | Adults with T2D |
| | CON (15) | 40 | 71.8 ± 4.5 | 7.3 ± 0.9 | 25.4 ± 3.4 | Adults with T2D |
| Jamshidpour et al. (29) | CE (15) | 80 | 64.9 ± 7.8 | NR | 27.8 ± 4.6 | Adults with T2D |
| | CON (13) | 61 | 58.5 ± 11.9 | NR | 26.8 ± 3.1 | Adults with T2D |
| Krousel-Wood et al. (44) | CE (45) | 32 | 56.6 ± 9.6 | 7.4 ± 1.5 | 38.2 ± 8.2 | Adults with T2D |
| | CON (49) | 32 | 56.6 ± 9.6 | 8.0 ± 1.5 | 37 ± 7.1 | Adults with T2D |
| Lambers et al. (45) | CE (19) | 41 | 55.8 ± 9.7 | 7.4 ± 1.5 | 28.9 ± 2.8 | Adults with T2D |
| | AEX (19) | 89 | 52.2 ± 8.3 | 7.4 ± 1.7 | 30.9 ± 4.0 | Adults with T2D |
| | CON (15) | 55 | 57.5 ± 8.7 | 6.7 ± 1.0 | 30.4 ± 4.3 | Adults with T2D |
| Lincoln et al. (46) | RT (29) | 31 | 66.0 ± 7.9 | NR | 30.9 ± 5.7 | Adults with T2D |
| | CON (29) | 41 | 66.6 ± 7.4 | NR | 31.2 ± 5.9 | Adults with T2D |
| Liu et al. (30) | AEX (30) | 0 | 58.1 ± 3.6 | 7.6 ± 0.7 | 25.3 ± 3.5 | Women with T2D |
| | CON (30) | 0 | 57.4 ± 4.1 | 7.4 ± 0.7 | 24.1 ± 4.2 | Women with T2D |
| Maharaj and Nuhu (47) | AEX (37) | 51 | 40.8 ± 5.6 | NR | NR | Adults with T2D (<5 yr, oral med only) |
| | CON (44) | 52 | 40 ± 6.13 | NR | NR | Adults with T2D (<5 yr, oral med only) |
| Myers et al. (48) | RT (52) | 44 | 58.3 ± 8.9 | 7.6 ± 0.9 | 34.8 ± 5.6 | Sedentary adults with T2D |
| | AEX (44) | 39 | 55.1 ± 7.5 | 7.4 ± 0.9 | 33.7 ± 5.8 | Sedentary adults with T2D |
| | CE (49) | 43 | 56.9 ± 7.9 | 7.5 ± 0.9 | 35.6 ± 6.5 | Sedentary adults with T2D |
| | CON (28) | 32 | 58.1 ± 8.3 | 8 ± 1.5 | 34.5 ± 6.3 | Sedentary adults with T2D |
| Nicolucci et al. (49) | CE (288) | NR | NR | NR | NR | Sedentary adults with T2D |
| | CON (275) | NR | NR | NR | NR | Sedentary adults with T2D |
| Plotnikoff et al. (31) | RT (27) | 30 | 55.0 ± 12.0 | 6.9 ± 1.5 | 35.0 ± 8.0 | Sedentary adults with T2D and obesity |
| | CON (21) | 38 | 54.0 ± 12.0 | 6.8 ± 0.8 | 36.0 ± 5.0 | Sedentary adults with T2D and obesity |
| Reid et al. (50) | CE (57) | 67 | 53.3 ± 7.2 | 7.7 ± 0.9 | 33.7 ± 6.1 | Physically inactive adults with T2D |
| | RT (58) | 66 | 54.7 ± 7.6 | 7.7 ± 0.9 | 32.9 ± 5.6 | Physically inactive adults with T2D |
| | AEX (51) | 65 | 53.8 ± 6.4 | 7.7 ± 0.9 | 34.3 ± 5.9 | Physically inactive adults with T2D |
| | CON (52) | 63 | 55.2 ± 6.9 | 7.7 ± 0.9 | 33.2 ± 5.5 | Physically inactive adults with T2D |
| Rekha et al. (51) | AEX (17) | NR | 48.1 ± 4.2 | 9 ± 0 | 27.8 ± 3.5 | Adults with T2D |
| | CON (17) | NR | 47.2 ± 7.1 | 8.21 ± 0.8 | 27.9 ± 4.4 | Adults with T2D |
| Rias et al. (52) | AEX (20) | 35 | 54.7 ± 4.9 | NR | NR | Adults with T2D |
| | CON (21) | 38 | 55.7 ± 5.0 | NR | NR | Adults with T2D |
| Soleimani et al. (53) | AEX (50) | 19 | 45.9 ± 6.9 | NR | 27.9 ± 3.5 | Adults with T2D |
| | CON (50) | 15 | 46.6 ± 5.3 | NR | 29.2 ± 4.1 | Adults with T2D |
| Tessier et al. (32) | CE (24) | 63 | 69.3 ± 4.2 | 7.5 ± 1.2 | 30.7 ± 5.4 | Older adults with T2D |
| | CON (21) | 55 | 69.5 ± 5.1 | 7.3 ± 1.7 | 29.4 ± 3.7 | Older adults with T2D |
| Tomas-Carus et al. (33) | CE (22) | 38 | 59.9 ± 7.6 | 7.1 ± 0.9 | 31.2 ± 4.8 | Adults with T2D (diagnosed >3 yr) |
| | CON (21) | 79 | 58.9 ± 7.1 | 7 ± 1.5 | 31.1 ± 4.5 | Adults with T2D (diagnosed >3 yr) |

AEX, aerobic exercise; BMI, body mass index, CE, combined aerobic and resistance exercise; CHF, chronic heart failure; CON, control; $HbA_{1c}$, glycated hemoglobin; NAFLD, nonalcoholic fatty liver disease; NR, not reported; PAD, peripheral artery disease; PN, peripheral neuropathy; RT, resistance training.

aerobic exercise on overall QoL in T2D (24,26,28,30,37,40–43, 45,47,48,50–53) (Fig. 3). Aerobic exercise elicited moderate improvements in overall QOL when compared with control (SMD, 0.475; 95% CI, 0.295–0.655; $P < 0.001$, $\tau = 0.271$, $I^2 = 72.925$, $n = 941$). There was no presence of publication bias ($P = 0.499$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.485; 95% CI, 0.258–0.713; $P < 0.001$, $\tau = 0.309$, $I^2 = 79.267$, $n = 762$).

***Effect of resistance training on overall QoL.*** A total of six studies provided sufficient data to determine the effect of

TABLE 2. Study intervention and outcome characteristics.

| Study | Group | Intervention | Frequency (d·wk$^{-1}$) | Duration | Intervention Details | QoL Measure |
|---|---|---|---|---|---|---|
| Abdelbasset et al. (34) | AEX | Unsupervised high-intensity interval cycling | 3/7 | 8 wk | WU and CD of 5 min each<br>Work: 3 × 4 min bouts at 80%–85% $\dot{V}O_{2max}$ interspersed with 2-min recovery intervals at 50% $\dot{V}O_{2max}$<br>Total: 40 min | Chronic liver disease questionnaire |
| | CON | | | | Usual care | |
| Akinci et al. (35) | CE | Supervised AEX and RT group exercise | 3/7 | 8 wk | AEX: 20 min at 11–14 RPE<br>RT: 8–10 repetitions for 1–3 sets with red, green, and blue TheraBands of major muscle groups<br>Total: 50–60 min | EuroQoL-5D |
| | CON | Physical activity advice | | | Participants received a brochure detailing the benefits of physical activity and practical tips for achieving a healthy lifestyle | |
| Asa et al. (36) | CE | Supervised group aquatic exercise sessions | 3/7 | 8 wk | 45-min sessions of peripheral muscle training and central circulatory exercises at 40%–75%HRR | SF-36 |
| | CON | | | | Instructed to live their life as normal and to not increase their habitual physical activity for 8 wk | |
| Aylin et al. (25) | CE | Supervised RT and unsupervised walking | 4/7 | 8 wk | AEX: WU and CD of 5–10 min<br>15–45 min of walking at 60%–79% HRmax<br>RT: WU and CD 10 min. 8 exercises, 2 sets, 8–10 reps at 50%–60%1RM | SF-36 |
| | CON | | | | Instructed to not undertake any formal exercise or change their physical activity levels during the study period | |
| Bello et al. (37) | AEX | Supervised cycling | 3/7 | 8 wk | 3-min WU at 10–20 W and 4-min CD<br>30 min at ~25–30 W; 50%–75% HRmax | WHOQoL-BREF |
| | CON | | | | Usual care | |
| Botton et al. (38) | RT | Traditional and functional RT | 3/7 | 12 wk | Up to 11 exercises, 10–15 reps, 2–3 sets, 60- to 90-s rest between sets at 12–15RM | DQOL |
| | CON | Stretching | 1/7 | | Joint mobilization and static stretching for large muscle groups; low intensity; 20–30 s each | |
| Cheung et al. (39) | RT | Semisupervised RT with TheraBand | 5/7 | 4 mo | 4 upper body and 3 lower body exercises, 2 sets, 12 reps | SF-36 |
| | CON | | | | No intervention | |
| Collins et al. (40) | AEX | Walking | 4/7 | 6 mo | 50-min walking | SF-36 |
| | CON | | | | Attention control involving educational material, and a calendar to record daily blood glucose and weekly blood pressure readings | |
| Dixit et al. (26) | AEX | Supervised treadmill walking | 5–6/7 | 8 wk | 30–60 min at 40%–60% HRR | NQOL |
| | CON | | | | Weekly visits consisting of education on foot care and diet | |
| Ferrer-García et al. (27) | CE | Home-based RT and AEX | 3/7 | 6 mo | AEX: choice of various aerobic activities 1× per week<br>RT: circuit involving large muscle groups at 75%–95% 1RM for 40 s 2× per week | EuroQoL-5D |
| | CON | | | | Usual care with dietary and exercise counseling | |
| Fritz et al. (41) | AEX | Unsupervised Nordic walking | 5 h·wk$^{-1}$ | 4 mo | Nordic walking for 5 h·wk$^{-1}$ | SWED-QUAL |
| | CON | | | | Directed to maintain habitual daily activities | |
| Guglani et al. (42) | AEX | Supervised walking | 5/7 | 16 wk | 5-min WU<br>4000 steps/30–40 min at RPE 12–14 (150 min·wk$^{-1}$) | ADDQoL19 |
| | CON | | | | Asked to maintain their lifestyle and were encouraged to walk | |
| Holton et al. (28) | AEX | Supervised AEX | 3/7 | 10 wk | 20–45 min at 50%–65% HRR | SF-36 |
| | CON | | | | Required to maintain sedentary status | |
| Hsieh et al. (43) | RT | Supervised RT | 3/7 | 12 wk | 8 exercises, 3 sets of 8–12 reps, 40%–75% 1RM | ADDQoL19 |
| | CON | | | | Usual care and asked to maintain daily activities and lifestyle | |
| Jamshidpour et al. (29) | CE | Combined supervised AEX and lower body RT | 3/7 | 8 wk | WU: 3–5 min of ROM exercises<br>AEX: 20–45 min at 60%–75% HRmax<br>RT: 3 sets of 8–12 reps at 60% 3RM with 1-min rest between sets. Number of exercises not reported | SF-36 |
| | CON | | | | Asked to continue daily activities and not increase their physical activity level | |
| Krousel-Wood et al. (44) | CE | Home-based combined AEX and RT video tapes | 5/7 | 12 wk | Up to 30 min per session (~3–6 METs) | PF-10 |
| | CON | | | | Usual care. Participants in both groups also received 5 × 2.5-h self-education program | |
| Lambers et al. (45) | CE | Supervised AEX and RT circuit training exercises | 3/7 | 12 wk | 50-min circuit training (plus WU and CD), alternating between AEX (60%–85% HRmax) and RT (4 exercises, 60%–85%1RM, 3 sets, 10–15 reps) every 10 min | SF-36 |
| | AEX | Supervised AEX on treadmill, stepper or cycling | 3/7 | | 50 min at 60% HRR (plus WU and CD) | |
| | CON | | | | Continued normal daily activities | |
| Lincoln et al. (46) | RT | Supervised RT | 3/7 | 16 wk | 3 sets of 8 reps at 60%–80% 1RM for 5 exercises plus WU and CD | SF-36 (mental component score only) |
| | CON | | | | Usual care and received weekly phone calls | |

*Continued next page*

TABLE 2. *(Continued)*

| Study | Group | Intervention | Frequency ($d \cdot wk^{-1}$) | Duration | Intervention Details | QoL Measure |
|---|---|---|---|---|---|---|
| Liu et al. (30) | AEX | Home-based square AEX | ≥3/7 | 6 mo | 30- to 60-min sessions at self-determined intensity | SF-36 |
| | CON | | | | Usual care with medication adjusted according to changes in blood glucose | |
| Maharaj and Nuhu (47) | AEX | Supervised treadmill walking | 3/7 | 12 wk | Walking at 1.7 mph, 5% gradient, 40%–65% HRR, 20–30 min per session | SF-36 |
| | CON | Sitting | 3/7 | | 20–30 min per session, sitting/reading health magazines | |
| Myers et al. (48) | RT | Supervised RT | 150 $min \cdot wk^{-1}$, 3/7 d | 9 mo | 10–12 reps for 2 sets of 4 upper body exercises, 3 sets for 3 lower body exercises, 2 sets of core/back exercises | SF-36 |
| | AEX | Supervised Treadmill walking | 150 $min \cdot wk^{-1}$ | | 12 $kcal \cdot kg^{-1} \cdot wk^{-1}$ at 50%–80% $\dot{V}O_{2max}$ | |
| | CE | Supervised RT and AEX | 150 $min \cdot wk^{-1}$ | | RT: 2× a week (~30–40 $min \cdot wk^{-1}$), 1 set of 10–12 reps for 9 exercises (full body); AEX remainder of time (~110 $min \cdot wk^{-1}$), exercise dose = 10 $kcal \cdot kg^{-1} \cdot wk^{-1}$ at 50%–80% $\dot{V}O_{2max}$ | |
| | CON | Light intensity stretching/ relaxation class (optional) | 1/7 | | 1 × 45-min session per week (optional) | |
| Nicolucci et al. (49) | CE | Supervised AEX and RT | 2/7 | 12 mo | 150 $min \cdot wk^{-1}$ of progressive AEX and RT | SF-36 |
| | CON | | | | Structured individualized counseling aimed at achieve the recommended amount of physical activity | |
| Plotnikoff et al. (31) | RT | Home-based, partially supervised RT. | 3/7 | 16 wk | 2 sets of 10–12 reps at 50%–60% 1RM (with progression throughout) for 4 primary and 4 assistor exercises | SF-12 |
| | CON | | | | Not reported | |
| Reid et al. (50) | CE | Supervised AEX and RT | 3/7 | 6 mo | AEX + RT | SF-36 |
| | RT | Supervised machine-based RT | 3/7 | | 2–3 sets at 8RM for 8 machine exercises | |
| | AEX | Supervised treadmill or cycle ergometer | 3/7 | | Progressive AEX for 15–45 min at 60%–75% HRmax | |
| | CON | | | | Asked to revert to their prestudy activity levels and efforts were made to minimize dietary and medication cointervention | |
| Rekha et al. (51) | AEX | Unsupervised walking | ≥5/7 | 12 wk | Accumulate 10,000 steps a day (i.e., 150 $min \cdot wk^{-1}$ as recommended) | QLI |
| | CON | | | | Maintain normal physical activity levels | |
| Rias et al. (52) | AEX | Unsupervised walking | 5/7 | 8 wk | 150 $min \cdot wk^{-1}$; 30 min per session | SF-36 |
| | CON | | | | Advised to continue habitual diet and activity | |
| Soleimani et al. (53) | AEX | Unsupervised AEX | 5/7 | 12 wk | 30-min sessions at moderate intensity causing sweating and heavy breathing | WHOQoL-BREF |
| | CON | | | | Lifestyle education on healthy eating and physical activity | |
| Tessier et al. (32) | CE | Supervised AEX and RT | 3/7 | 16 wk | ~60-min sessions at 35%–79% HRmax: WU (10 min), brisk walking (20 min), RT exercises (2 sets, 20 reps, major muscle groups), stretching (10 min) | Combined DQOL and Modified Quality of Life Measure for Youths |
| | CON | | | | Instructions to continue usual activity regimen | |
| Tomas-Carus et al. (33) | CE | Supervised group fitness classes including AEX and body RT | 3/7 | 12 wk | WU: 10 min; AEX: 25 min at 60%–65% HRmax; RT: 2–4 sets of 10 reps, 15 min using body weight/light weights/soft rubber bands; CD: 10-min mobility stretches | SF-36 |
| | CON | | | | Usual care and continued their pretrial daily activities with no physical exercise | |

ADDQoL19, Audit of Diabetes Dependent Quality of Life 19; AEx, aerobic exercise; CD, cool down; CE, combined aerobic and resistance exercise; CON, control; DQOL, Diabetes Quality of Life Questionnaire; HR, heart rate; MET, metabolic equivalent; NQOL, Neuropathy Quality of Life; PF-10, Medical Outcomes Study 10-item Physical Functioning Scale; QLI, Ferrans and Powers' Quality of Life Index; RM, repetition maximum; RPE, rate of perceived exercise; SF-12, 12-Item Short Form Health Survey; SF-36, 36-Item Short Form Health Survey; SWED-QUAL, Swedish Health-Related Quality of Life Survey; $\dot{V}O_{2max}$, maximal oxygen consumption; WHOQoL-BREF, World Health Organization Quality of Life questionnaire (abbreviated version); WU, warm-up.



resistance training on overall QoL in T2D (31,38,39,46,48,50) (Fig. 3). Resistance training did not improve overall QOL when compared with control (SMD, 0.210; 95% CI, −0.332 to 0.752; $P = 0.447$, $\tau = 0.591$, $I^2 = 83.641$, $n = 377$). There was no presence of publication bias ($P = 0.851$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, −0.132; 95% CI, −0.443 to 0.178; $P = 0.404$, $\tau = 0.151$, $I^2 = 18.919$, $n = 271$).

***Effect of combined aerobic and resistance training on overall QoL.*** A total of 12 studies provided sufficient data to determine the effect of combined aerobic and resistance exercise on overall QoL in T2D (25,27,29,32,33,35,36,44,45,48–50) (Fig. 3). Combined aerobic and resistance exercise elicited a small improvement in physical components of QoL when compared with control (SMD, 0.363; 95% CI, 0.179–0.548; $P < 0.001$, $\tau = 0.245$, $I^2 = 64.495$, $n = 1096$). There was no presence of publication bias ($P = 0.411$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.350; 95% CI, 0.063–0.638; $P = 0.017$, $\tau = 0.318$, $I^2 = 74.467$, $n = 889$).

***Relationship between change in glucose control and change in QoL.*** A total of 17 studies, involving 20 comparisons, provided sufficient data to determine the effect of exercise on A1C (24,25,27,30–33,35–39,43–45,50,51) (Supplemental Fig. 1, Supplemental Digital Content, Effect of exercise on A1C, http://links.lww.com/MSS/C832). Exercise significantly improved A1C % (weighted mean difference, −0.509%; 95% CI, −0.806 to −0.212; $P = 0.001$, $\tau = 0.549$, $I^2 = 82.928$, $n = 878$). The meta-regression analysis found that change in A1C % was significantly correlated with change in QoL

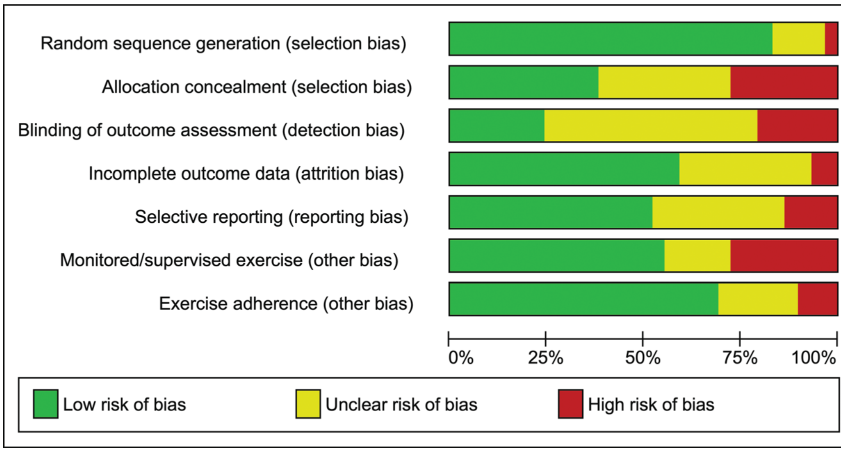


**FIGURE 2—Risk of bias summary.**

($B = -0.296$, SE = 0.110, $Z = -2.70$, $P = 0.007$), which explained 73% of the variance in the primary result ($R^2 = 0.73$).

## Subanalysis

**Effect of exercise modalities on physical components of HRQoL.** ***Effect of any exercise modality on physical components of HRQoL.*** A total of 15 studies, involving 20 comparisons, provided sufficient data to determine the effect of any exercise modality on physical components of HRQoL in T2D (25,28–31,33,36,39,40,45,47–50,52) (Fig. 4). Exercise elicited a small improvement in overall HRQoL when compared with control (SMD, 0.403; 95% CI, 0.223–0.584; $P < 0.001$, $\tau = 0.333$, $I^2 = 77.667$, $n = 1518$). There was no presence of publication bias ($P = 0.127$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.420; 95% CI, 0.188–0.651; $P < 0.001$, $\tau = 0.377$, $I^2 = 84.228$, $n = 1323$).

***Effect of aerobic exercise on physical components of HRQoL.*** A total of eight studies provided sufficient data to determine the effect of aerobic exercise on physical components of HRQoL in T2D (28,30,40,45,47,48,50,52) (Fig. 4). Aerobic exercise elicited a moderate improvement in physical components of HRQoL when compared with control (SMD, 0.561; 95% CI, 0.228–0.894; $P = 0.001$, $\tau = 0.417$, $I^2 = 86.446$, $n = 551$). There was no presence of publication bias ($P = 0.063$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis. The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis

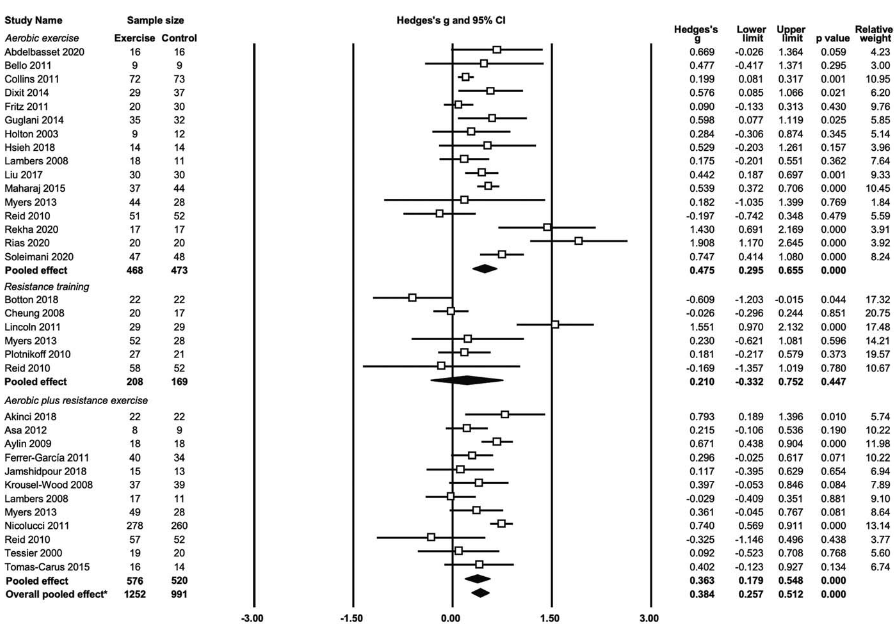


**FIGURE 3—Effect of exercise on QoL stratified by modality. *Overall pooled effect size generated by halving sample sizes of control groups that were compared with multiple interventions from the same study.**

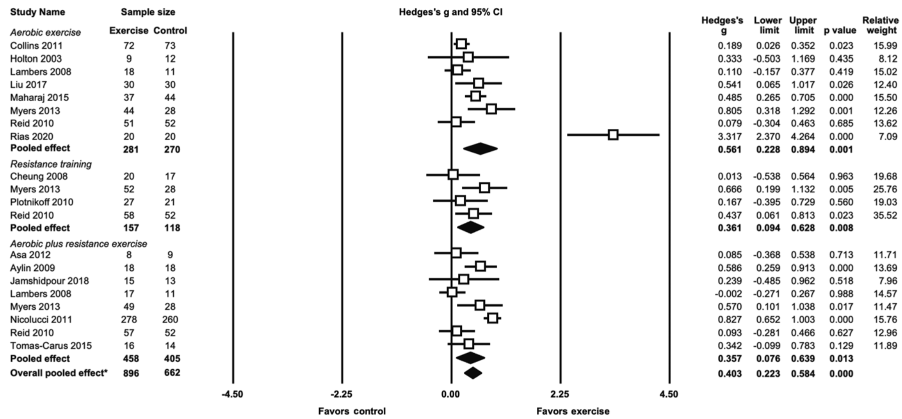


**FIGURE 4—Effect of exercise on physical components of HRQoL stratified by modality. *Overall pooled effect size generated by halving sample sizes of control groups that were compared with multiple interventions from the same study.**

(SMD, 0.604; 95% CI, 0.207–1.000; $P = 0.003$, $\tau = 0.447$, $I^2 = 90.157$, $n = 470$).

***Effect of resistance training on physical components of HRQoL.*** A total of five studies provided sufficient data to determine the effect of resistance training on HRQoL in T2D (31,39,48,50) (Fig. 4). Resistance training elicited a small improvement in physical components of HRQoL when compared with control (SMD, 0.361; 95% CI, 0.094–0.628; $P = 0.008$, $\tau = 0.125$, $I^2 = 20.599$, $n = 275$; Fig. 4). There was no presence of publication bias ($P = 0.734$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis control (SMD, 0.401; 95% CI, 0.069–0.734; $P = 0.018$, $\tau = 0.179$, $I^2 = 36.864$, $n = 227$).

***Effect of combined aerobic and resistance exercise on physical components of HRQoL.*** A total of eight studies provided sufficient data to determine the effect of combined aerobic and resistance exercise on physical components HRQoL in T2D (25,29,33,36,45,48–50) (Fig. 4). Combined aerobic and resistance exercise elicited a small improvement in physical components of HRQoL when compared with control (SMD, 0.357; 95% CI, 0.076 to 0.639; $P = 0.013$, $\tau = 0.351$, $I^2 = 80.427$, $n = 863$). There was no presence of publication bias ($P = 0.902$). The results were no longer significant after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.323; 95% CI, −0.093 to 0.738; $P = 0.128$, $\tau = 0.437$, $I^2 = 88.424$, $n = 769$).

**Effect of exercise modalities on mental components of HRQoL.** ***Effect of any exercise modality on mental components of HRQoL.*** A total of 15 studies, involving 20 comparisons, provided sufficient data to determine the effect of any exercise modality on mental components of HRQoL in T2D (25,28–31,33,36,39,40,45,47–50,52) (Fig. 5). Exercise did not improve mental components of HRQoL when compared with control (SMD, 0.177; 95% CI, −0.028 to 0.383; $P = 0.091$, $\tau = 0.409$, $I^2 = 82.338$, $n = 1576$). There was no presence of publication bias ($P = 0.928$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.030; 95% CI, −0.217 to 0.277; $P = 0.811$, $\tau = 0.414$, $I^2 = 84.852$, $n = 1323$).

***Effect of aerobic exercise on mental components of HRQoL.*** A total of eight studies provided sufficient data to determine the effect of aerobic exercise on mental components of HRQoL in T2D (28,30,40,45,47,48,50,52) (Fig. 5).

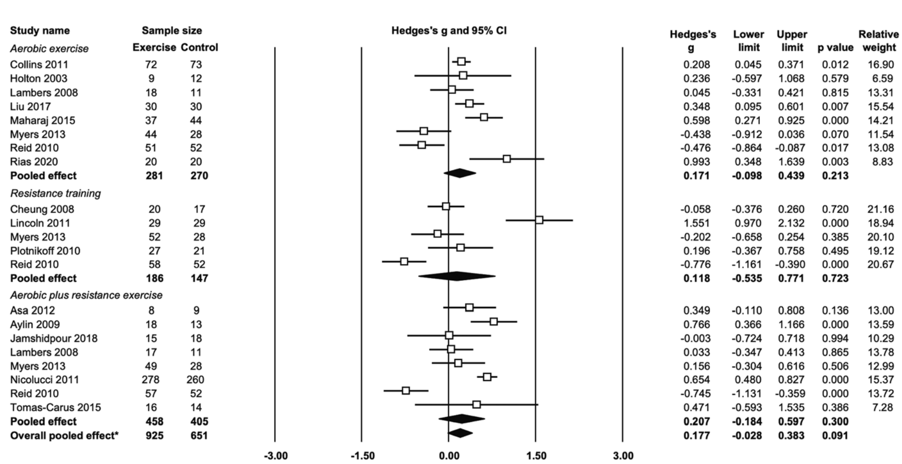


**FIGURE 5—Effect of exercise on mental components of HRQoL stratified by modality. *Overall pooled effect size generated by halving sample sizes of control groups that were compared with multiple interventions from the same study.**

Aerobic exercise did not improve mental components of HRQoL when compared with control (SMD, 0.171; 95% CI, −0.098 to 0.439; $P = 0.213$, $\tau = 0.323$, $I^2 = 78.141$, $n = 551$). There was no presence of publication bias ($P = 0.711$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.133; 95% CI, −0.219 to 0.485; $P = 0.459$, $\tau = 0.390$, $I^2 = 83.527$, $n = 470$).

***Effect of resistance training on mental components of HRQoL.*** A total of five studies provided sufficient data to determine the effect of resistance training on mental components of HRQoL in T2D (31,39,46,48,50) (Fig. 5). Exercise did not improve mental components of HRQoL when compared with control (SMD, 0.118; 95% CI, −0.535 to 0.771; $P = 0.723$, $\tau = 0.706$, $I^2 = 90.899$, $n = 333$). There was no presence of publication bias ($P = 0.221$). The results of the sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis, showed a small nonsignificant effect favoring control (SMD, −0.341; 95% CI, −0.791 to 0.108; $P = 0.136$, $\tau = 0.345$, $I^2 = 75.724$, $n = 227$).

***Effect of combined aerobic and resistance exercise on mental components of HRQoL.*** A total of eight studies provided sufficient data to determine the effect of combined aerobic and resistance exercise on mental components of HRQoL in T2D (25,29,33,36,45,48–50) (Fig. 5). Combined exercise did not improve physical components of HRQoL when compared with control (SMD, 0.207; 95% CI, −0.184 to 0.597; $P = 0.300$, $\tau = 0.500$, $I^2 = 86.269$, $n = 863$). There was no presence of publication bias ($P = 0.902$). The results remained unchanged after a sensitivity analysis, where studies deemed to have high risk of bias were removed from the analysis (SMD, 0.097; 95% CI, −0.426 to 0.621; $P = 0.716$, $\tau = 0.565$, $I^2 = 91.306$, $n = 769$).

## DISCUSSION

To our knowledge, this study is the first meta-analysis and most up-to-date systematic review undertaken to determine the effect of exercise on QoL in adults with T2D. The results of the analyses showed that aerobic exercise alone, or in combination with resistance training, was effective for improving overall QoL; however, resistance training alone did not elicit significant improvements in overall QoL or in mental components of HRQoL. The regression analysis showed that exercise improved glycemia and that such improvements were significantly associated with improvements in QoL. The results of the subanalyses showed that all exercise modalities improved physical components of HRQoL, but exercise in general, or when assessed based on modality, was ineffective for improving mental components of HRQoL. Thus, healthcare professionals should advocate for the use of exercise in the routine management of T2D.

Regular exercise has been shown to improve QoL in multiple health conditions such as cancer (63), stroke (64), and heart failure (65). The first systematic review to assess the efficacy of exercise for improving QoL in T2D was conducted by van der Heijden and colleagues (66) a decade ago. The aforementioned review included 16 studies; however, these included mind–body exercises such as Tai Chi. In 2017, a systematic review by Cai and colleagues (16) aimed to update the literature surrounding the effects of exercise on QoL, but as mentioned earlier, this study had several limitations including the inclusion of nonrandomized studies and studies without a control group. Importantly, both reviews did not pool data via meta-analysis and as a result were unable to provide a quantitative effect of exercise on QoL. This systematic review and meta-analysis goes beyond previous reviews by providing the most comprehensive and up-to-date data, which not only provides a quantitative effect of exercise on QoL but also details the effects of different exercise modalities on overall QoL as well as physical and mental components of HRQoL.

Given the disparate findings between studies included in former reviews, it was unclear whether exercise improves QoL and, if so, which modality of exercise would be most effective. The results of this study showed that aerobic exercise is effective when used as a stand-alone therapy or when combined with resistance training. Meanwhile, the efficacy of resistance training for improving QoL seems contingent on aerobic exercise also being prescribed. Although these findings support the prioritization of aerobic exercise for QoL in T2D, given the interconnected nature of aging with T2D (67) and the powerful effects of resistance training on frailty and muscle strength (68), resistance training should also be prescribed in addition to, but not instead of, aerobic exercise if the individual's goal is to improve general well-being and QoL.

The results of the subanalyses suggest that exercise-mediated improvements in QoL are driven primarily through changes in physical components of HRQoL, as the pooled mental component scores remained unchanged. However, this does not necessarily mean that exercise is ineffective for improving mental health outcomes in people with T2D despite the mental component score of the SF-36 being associated with poor mental health outcomes such as depression and anxiety (69). In fact, given that the mental component of the SF-36 asks questions related to energy and tiredness, it may be that the proximity of the last exercise session, or exercise tests, to the assessment of QoL may have influenced this domain. In addition, as the vast majority of mean mental component scores was higher than mean physical component scores at baseline, it may be that their mental health was not compromised enough for an effect to be observed after the intervention. Although the reason for this finding is unclear, it may be that people with T2D who are willing to participate an exercise trial may not have significant mental health issues. Consequently, a more targeted recruitment strategy is warranted for future studies investigating the effects of exercise on mental health outcomes in adults with T2D. This point is further highlighted in a previous systematic review where exercise was shown to be most effective for improving mental health outcomes in adults who presented with, at minimum, mild depressive symptoms (70). Consequently, further studies are required to determine the effect of exercise on mental health outcomes in individuals with T2D and poor mental health.

The role of exercise in the management of T2D has largely centered on its efficacy for improving glucose levels and reducing other cardiometabolic risk factors (8). The results of the analyses undertaken in this study demonstrate that exercise elicits significant moderate improvements in A1C and that such changes are associated with improvements in QoL. Importantly, although the effect size for exercise on QoL was statistically small, the results of the regression analyses show that even small effects (SMD, 0.384) correlate with clinically significant improvements in A1C (−0.509%). However, it is important to note that because individuals with T2D often monitor their blood glucose levels daily, we cannot exclude that knowledge of real-time improvements in glycemia may have impacted their scoring on the QoL questionnaires.

This study has limitations that should be considered when interpreting the results. First, although the vast majority of studies assessed QoL with the SF-36 questionnaire (25,28–30,33, 36,39,40,45,47–50,52), the results may have been affected by differences in QoL assessment tools used among studies. However, this effect, if any, was likely minimal as there was no difference in effect sizes when data were pooled from studies assessing QoL using various instruments versus those solely assessing HRQoL with the SF-36 (SMD of 0.384 (95% CI, 0.257–0.512; $P < 0.001$) vs SMD of 0.328 (95% CI, 0.167–0.489; $P < 0.001$), respectively). Second, where specific studies did not report overall QoL or mental and physical component scores, these were calculated by pooling relevant domains into one score to provide a value for either overall QoL, physical component score, or mental component score. However, because the weighting of each domain may differ between assessment tools in the calculation of overall QoL, this may have affected the results. Third, the analyses involved combining studies that differed in intervention duration, intensity, and frequency. As a result, it is unclear whether a dose–response exists. For example, this may, in part, explain why no significant effect was observed with resistance training given that the studies included in this review implemented low- to moderate-intensity resistance training, whereas previous findings have shown that higher-intensity resistance training elicits superior improvements in A1C when compared with lower intensities in T2D (71). Similarly, although most studies involving aerobic exercise prescribed interventions that adhered to the current physical activity guidelines, the frequency of exercise varied between studies. As a result, it is unclear whether total exercise volume accumulated per week is more or as important as frequency of exercise in the context of well-being and QoL. Fourth, the lack of attention control conditions involving balanced attention and treatment contact between groups meant that we are unable to account for the relative impact of nonspecific effects of the interventions. This is especially important given the psychological nature of the primary outcome. Finally, the degree to which QoL was impaired among studies differed. As a result, we cannot exclude that the results pertaining to the effects of exercise on mental components of HRQoL would have differed had the participants presented with greater impairments, as mental components were less impaired than physical components of HRQoL among study participants.

## CONCLUSIONS

The results of this systematic review and meta-analysis provide robust evidence that exercise is effective for improving QoL in adults with T2D. Furthermore, such improvements seem to be mediated through improvements in physical components of HRQoL and are associated with concomitant improvements in glucose control. Where possible, aerobic exercise should be prioritized; however, resistance training should also be prescribed in addition to, but not instead of, aerobic exercise.

A. S. led the research and was supported by a Research Support Program Fellowship from Western Sydney University. The authors declare no competing interests. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Availability of data and materials: The protocol and data sets generated and/or analyzed for this review are available from the corresponding author on reasonable request.

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