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Effectiveness of resistance training to improve muscle strength and physical performance of patients with diabetes mellitus: a meta-analysis

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ABSTRACT

Introduction: Metabolic disorders in diabetes mellitus (DM) sufferers, caused by insulin resistance, chronic muscle inflammation, and mitochondrial dysfunction, can affect muscle structure and function and reduce physical performance (PP). Thus, rehabilitation in the form of resistance training (RT) is needed to overcome these problems. This study aims to determine the effect of RT on muscle strength (MS; lower and upper limbs) and PP (primary outcome), as well as body mass index (BMI), VO2 peak, lean muscle mass, HbA1c, blood pressure (BP), and adverse events (secondary outcome) in patients with DM.

Methods: Six databases were used in a comprehensive search conducted from March to April 2025 to locate relevant articles. We used Standard Mean Difference (SMD), Mean Difference (MD), and Risk Difference with a 95% Confidence Interval (CI), to determine the effect of RT. We assess the quality of studies using the Joanna Briggs Institution checklist.

Results: 26 articles randomized controlled trial articles were included, showing that RT has a significant effect on improving MS (lower and upper limbs), PP (primary outcome), and VO2 peak, LMM (secondary outcome); Additionally, RT has a significant effect in lowering HbA1c and systolic blood pressure (SBP), but not significantly in reducing diastolic blood pressure (DBP) (secondary outcome) between the intervention group and control group of patients with DM. There were no RT-related adverse events.

Conclusions: RT is a rehabilitation recommendation to improve MS and PP and is also a rehabilitative effort for those living with DM.

Keywords: diabetes mellitus, muscle strength, physical performance, resistance training

Introduction

Diabetes mellitus (DM) is a chronic metabolic disease characterized by hyperglycemia, resulting from insulin resistance or impaired insulin secretion (Yin et al., 2022). In addition to macrovascular and microvascular complications, DM also affects the musculoskeletal system, including muscle function (Li et al., 2024). According to several studies, DM patients experience muscle atrophy faster than the general population; moreover, insulin resistance contributes to deficiencies in muscle protein synthesis, which leads to muscle weakness and impaired physical function (Lin et al., 2021; Mahmoud et al., 2025; Tanaka et al., 2015). Similarly, chronic hyperglycemia can cause inflammation and oxidative stress, which can accelerate muscle degradation, sarcopenia, and a decrease in muscle strength (MS), potentially increasing the risk of morbidity and mortality, as well as reducing the physical performance (PP) of patients with DM (Vasbinder et al., 2022; Wrenn et al., 2021; Zhao et al., 2022).

MS is a key component of human physical function that is important for maintaining daily activities, body posture, mobility, and injury prevention (Baker et al., 2020; Tatangelo et al., 2022). Several studies show that, compared to the non-diabetic population, patients with DM have higher lean muscle mass (LMM) and slower muscle contraction rates, which significantly affect MS

(Chen et al., 2021; Nomura et al., 2018). Similarly with PP, several previous studies acknowledge that the decrease in PP in patients with DM can negatively impact their quality of life (Corral-Perez et al., 2024; Vongsirinavarat et al., 2020). Therefore, it is necessary to consider effective rehabilitation strategies to improve MS and PP in patients with DM.

Resistance training (RT) is one of the practical rehabilitation recommendations to improve MS(Zhao et al., 2022). In RT, muscles are forced to resist external loads such as dumbbells, resistance bands, or other types of resistance exercises that can influence neuromuscular adaptation, allowing muscle hypertrophy to occur (Acosta-Manzano et al., 2020; Yamamoto et al., 2021). Additionally, research has shown that RT significantly increases neural activity by affecting muscle size, as well as responding with enzyme adaptation and good metabolism in muscle tissue (Schoenfeld et al., 2016). Furthermore, by regularly performing RT, it can maintain good blood pressure (BP) through improved endothelial function and reduced vascular resistance (Mouser et al., 2019), and it can also help lower Body Mass Index (BMI) by increasing muscle mass and reducing overall body fat (Kataoka et al., 2018). On the other hand, previous studies found that RT can increase the use of free fatty acids as an energy source (Felix-Soriano et al., 2021), and improve insulin sensitivity as well as positively impact the reduction of HbA1c in patients with DM (Jansson et al., 2022); where these components play an essential role in improving MS and PP in patients with DM. However, several conditions experienced by patients with DM, such as peripheral neuropathy, retinopathy, and cardiovascular disorders, may increase the risks associated with RT. Additional barriers include the risk of hypoglycemia, musculoskeletal injuries, and slow muscle recovery, which may be barriers to performing RT. Moreover, while several reviews have examined the benefits of RT on HbA1c, BMI, and VO_2 peak (Fan et al., 2023; Ishiguro et al., 2016), few studies have specifically investigated its effects on MS (lower and upper limbs) in patients with DM. Therefore, evidence-based support is needed to validate the effects of RT for this population. The study aims to determine the impact of RT on MS and PP (primary outcomes), as well as BMI, VO_2 peak, LMM, HbA1c, BP, and serious events (secondary outcomes) in patients with DM.

Materials and Methods

Review Design of Literature and Data Sources

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were followed in this study (see Figure 1). We utilized five databases, Embase, CINAHL, Medline, Cochrane, and PEDro, to gather articles for this review, structuring them according to the PICO framework. The population (P) consisted of patients with diabetes mellitus (DM), the intervention (I) was resistance training (RT), the comparison (C) was usual care, and the outcome (O) included muscle strength (MS) and physical performance (PP). The search strategy incorporated Emtree/MESH terms and keywords such as diabetes, diabetic, unspecified diabetes mellitus, resistance exercise, resistance exercise training, strength training, weight-bearing exercise, muscle strength, muscle force, muscle power, and muscular dynamic strength.

Only articles published in English that employed a randomized controlled trial (RCT) design and focused on RT as an intervention for patients with DM were included. The review excluded systematic reviews/meta-analyses, RCTs without a control group, animal studies, studies not involving patients with DM, and studies unrelated to MS and PP. The literature review was conducted in March and April 2025. After identifying relevant studies through the PICO framework, duplicates were carefully removed. The screening process involved evaluating abstracts and titles, followed by a comprehensive review of reference lists and full text articles. Ultimately, the three reviewers concluded the search without identifying additional studies that met the established inclusion and exclusion criteria. This study was registered with PROSPERO (CRD420251061821).

Extracting Data and Assessment Quality of the Studies

Data extraction was conducted in duplicate, independently by two reviewers. Both reviewers collected information on study design, participant age, intervention characteristics (type of RT and frequency/duration), and outcomes, as summarized in Table 1. Any discrepancies were discussed and resolved by consensus, with a third reviewer consulted if necessary. To assess methodological quality, the two reviewers independently applied the Joanna Briggs Institute (JBI) critical appraisal checklist (see Table 1). Egger's test and the Funnel plot were employed to assess publication bias in the meta-analysis.

Statistical Analysis and Data Synthesis

Data synthesis was performed using RevMan version 5.4, with changes from baseline to follow-up employed to demonstrate intervention effects. Standard Mean Difference (SMD), Mean Difference (MD), and Risk Difference (RD) were used to aggregate data. A 95% Confidence Interval (CI) was applied to determine statistical significance; furthermore, alterations in MS and PP (primary outcome), along with BMI, VO_2 peak, LMM, HbA1c, SBP, and Diastolic Blood Pressure (DBP), and adverse events (secondary outcome), were expressed as effect sizes (ES). The I^2 test evaluates study heterogeneity; a heterogeneity beyond 50% employs the random effects model, while a heterogeneity below 50% utilizes the fixed effects model.

Results

Studies description

The initial screening method identified 1,363 studies from six databases: Embase (n = 271), Medline (n = 161), Cochrane (n = 723), CINAHL (n = 157), PubMed (n = 37), and PEDro (n = 14). Thereafter, 266 articles were eliminated due to duplication, and 831 articles were eliminated based on title and abstract screening. 266 articles met the identification criteria after full-text screening, but 238 were excluded from the review because they did not meet the following requirements: Not RT (n = 39), no control group (n = 61), not in English (n = 13), review papers (Systematic, and meta-analysis) (n = 49), animal studies (n = 4), outcome not on MS (n = 45), and not focused on DM patients (n = 29). Finally, 26 studies published between years 1997 and 2023 met the inclusion criteria (see Figure 1) (Bacchi et al., 2012; Bassi et al., 2016; Brooks et al., 2006; Castaneda et al., 2002; Cauza et al., 2005; Chien et al., 2022; D'hooge et al., 2011; Dunstan et al., 2002; Dunstan et al., 2005; Hameed et al., 2012; Hsieh et al., 2018; Jamshidpour et al., 2020; Kataoka et al., 2018; Khan et al., 2022; Kobayashi et al., 2023; Kruse et al., 2010; Ku et al., 2010; Kwon et al., 2010; Lambers et al., 2008; Loimaala et al., 2009; Lubans et al., 2012; Plotnikoff et al., 2010; Taylor et al., 2009; Teychenne et al., 2015; Wycherley et al., 2010; Yamamoto et al., 2021).

Based on the data extraction (Table 1 in supplementary file), 26 studies using RCT study design from 2002 to 2023 are presented, with a total of 1,488 respondents consisting of men and women, divided into two groups: the intervention group (n = 761) and the control group (n = 727) of patients diagnosed with type I and II DM. The mean age of participants in the intervention groups ranged from 14.1 to 73.2 years. Additionally, based on the components of RT, the type of intervention from RT conducted in most studies involved using weight machines (bench press, chest cross, shoulder press, pull-downs, biceps curls, triceps extensions, upper back, knee extension/flexion, leg press, lateral pull, leg extension, and seated biceps curls); similarly, some studies used sandbags, progressive RT, strength exercises for RT, or RT combined with aerobic exercise, bicycle ergometry, walking, and inspiratory muscle training. The average for warming up/cooling down is 5 to 10 minutes, and the average RT exercise duration is 30 to 50 minutes. The frequency and duration of training ranged from 2 to 7 days per week, with intervention durations spanning 2 to 48 weeks.

Quality of the Studies and Risk of Bias

The quality assessment of the included studies was conducted using the JBI checklist, with scores ranging from 7 to 13 (out of 13) (See Table 1). The risk of bias is explained in Appendix 9, where about 50 to 60% of the articles perform random sequence generation and blinding of participants and personnel. In comparison, more than 60 to 70% demonstrate allocation concealment, blinding of outcome assessment, and other biases. In addition, more than 75% of the studies provide detailed reporting on incomplete outcome data and selective reporting.

Effect of RT on MS and PP in Patients with DM (Primary Outcome)

Effect of RT on MS

RT significantly increased MS (lower limb) in the intervention group (n = 728) (SMD = 2.31, 95% CI = 1.67 to 2.97, I^2 = 96%) compared with the control group (n = 683), as shown in Figure 2 and Table 2. In the same way, exercise using RT greatly helps improve MS (upper limb) in the intervention group (n = 531) (SMD = 1.04, 95% CI = 0.60 to 1.48, I^2 = 89%) when compared to the control group (n = 487), as shown in Figure 3 and Table 2.

Effect of RT on PP

According to the subgroup analysis of PP from DM patients shown in Figure 4 and Table 2, five RCT articles that looked at how exercise with RT affects PP using the 6MWT measurement tool found a significant increase in the intervention group (n = 71) compared to the control group (n = 62) (SMD = 1.10, 95% CI = 0.25 to 1.95, I^2: 79%). Additionally, four articles in the subgroup analysis using FTSST for PP showed that exercise with RT significantly reduced the time taken in FTSST for the intervention group (n = 62) (SMD = -0.78, 95% CI = -1.15 to -0.42, I^2: 0%) compared to the control group (n = 65); similarly, three articles from the subgroup analysis on PP using the SST measurement tool indicated that exercise with RT significantly improved SST in the intervention group (n = 43) (SMD = 2.38, 95% CI = 0.44 to 4.27, I^2: 88%) compared to the control group (n = 30). Additionally, four articles in the subgroup analysis using FTSST for PP explain that exercise using RT has a significant effect in reducing the time taken in FTSST in the intervention group (n = 62) (SMD = -0.78, 95% CI = -1.15 to -0.42, I^2: 0%) compared to the control group (n = 65); Similarly, three articles from the subgroup analysis on PP using the SST measurement tool showed that exercise using RT significantly improved SST in the intervention group (n = 43) (SMD = 2.38, 95% CI = 0.44 to 4.27, I^2: 88%) compared to the control group (n = 30).

Effect of RT on BMI, VO_2 peak, LMM, Hba1c, BP, and serious events in Patients with DM (Secondary Outcome)

Effect of RT on BMI

In Appendix 1 to 6, and Table 2, it is explained that exercise using RT significantly reduces BMI in patients with DM in the intervention group (n = 232) (SMD = -0.32, 95% CI = -0.62 to -0.03, I^2: 57%) compared to the control group (n = 211), as shown in Figure 1 and Table 2. Similarly, exercise using RT reduces HbA1c in the intervention group (n = 356) (MD: -0.71, 95% CI = -1.38 to

-0.05, I^2: 93%) compared to the control group (n = 330). Additionally, exercise using RT can also significantly reduce SBP in patients with DM who have high blood pressure in the intervention group (n = 234) (SMD = -0.86, 95% CI = -1.48 to -0.25, I^2 = 89%) compared to the control group (n = 218); however, exercise with RT did not significantly lower DBP between the intervention group (n = 187) and the control group (n = 173). Similarly, exercise with RT significantly increased VO_2 peak in the intervention group (n = 103) (SMD = 1.60, 95% CI = 0.43 to 2.78, I^2: 92%), compared to the control group (n = 99); similarly, exercise with RT has significant effects on increasing LMM in the intervention group (n = 295) (SMD = 0.26, 95% CI = 0.10 to 0.43, I^2: 23%), compared to the control group (n = 277). On the other hand, exercise using RT did not result in serious events in the intervention group (n = 187) (RD: 0.02, 95% CI = -0.03 to 0.07, I^2 = 0%), compared to the control group (n = 173).

Discussions

The current review examines the impact of RT on MS and PP, as well as addresses concerns about how well RT improves MS and PP in patients with DM, comparing the intervention group and control group (primary outcome). The current analysis is also conducted to see whether RT has an impact on BMI, VO_2 peak, LMM, HbA1c, BP, and serious events in the two groups of patients with DM (Secondary outcome). On the other hand, the quality of the studies from the articles included in the current review is classified as moderate to high quality.

Effect of RT on MS and PP in Patients with DM (Primary outcome)

Patients with DM often experience significant reductions in MS (Yuxi Lin, Yongze Zhang, Ximei Shen, Lingning Huang, & Sunjie Yan, 2021) a condition sometimes referred to as myopathic diabetes, characterized by disturbances in skeletal muscles and closely linked to chronic hyperglycemia (D'Souza et al., 2013; Hernández-Ochoa et al., 2017). Similarly, patients with DM often experience mild systemic inflammation that leads to increased levels of pro-inflammatory cytokines (tumor necrosis factor alpha (TNF-α) and interleukin-6 (IL-6), which affects muscle fiber damage and accelerates muscle atrophy (Pedersen et al., 2003; Tsai et al., 2022); Additionally, the influence of peripheral neuropathy experienced by patients with DM contributes to disuse atrophy of muscles and muscle weakness, especially in the lower limb (Jung et al., 2024). Therefore, RT is one of the practical recommendations in preventive efforts to increase MS and in efforts to improve the inflammatory process by increasing IL-6 (Asghari et al., 2020; Tsai et al., 2022). This conclusion is supported by the current review, which found that patients with DM who engage in RT 1 to 7 days a week for 2 to 48 weeks show improvement in MS in both the lower limb and upper limb (Figures 3 and 4).

Similarly, patients with DM are at increased risk of reduced, which negatively impacts daily activities, quality of life, and the risk of disability. The current review finds that RT has been proven to improve PP in patients with DM, as demonstrated by the 6mwt, FTSST, and SST measurement tools (Figure 4 and Table 2). Routine in performing RT exercise is beneficial for improving cardiometabolic function (Cano-Montoya et al., 2025), where there is an increase in VO_2 peak and exercise tolerance (Ruku et al., 2021); This benefit is also supported by the current review findings, which show that the increase in VO_2 peak occurs in the intervention group that performed exercises using RT (Appendix; Figure 2). Furthermore, RT enhances mitochondrial capacity and muscle metabolism, helping patients resist fatigue and sustain physical activity for longer durations (Costa et al., 2021).

Effect of RT on BMI, VO2 peak, LMM, HbA1c, Bp, and serious events in Patients with DM (Secondary Outcome)

The current review demonstrates that regular RT is beneficial in lowering BMI in patients with DM (see Appendix 1). RT enhances insulin sensitivity in the muscles, thereby helping the body use glucose more efficiently (Park et al., 2016). Furthermore, routine RT can accelerate calorie burning and help manage weight, which directly impacts BMI reduction (Park et al., 2016; Shaban et al., 2014). Similarly, regularly performing RT can increase LMM in patients with DM (Appendix 3); the contributing factor to this finding is that during routine RT, insulin sensitivity in the body will improve and impact the increase of glucose transporter (GLUT-4), which is the key player in glucose metabolism in the muscles, thereby leading to a rise in LMM (Strasser & Pesta, 2013).

In addition, the benefits of RT have an impact on increasing the VO_2 peak and lowering HbA1c in patients with DM (Appendix 2 and 4). The increase in VO_2 peak can reflect cardiovascular and metabolic fitness as well as improved functional capacity; however, the occurrence of insulin resistance in patients with DM can affect this, so one way to maintain VO_2 peak at its maximum is by performing routine exercise using RT for those living with DM. Furthermore, Appendix 4 has proven the benefits of RT in lowering HbA1c. The American Diabetes Association (ADA) has recommended performing resistance training (RT) exercises routinely alongside the use of medication therapy to maintain better HbA1c levels (Badaam & Zingade, 2021).

On the other hand, RT can help lower blood pressure more consistently by increasing nitric oxide (NO) and reducing sympathetic tone, which decreases peripheral resistance (Salmanpour et al., 2022). The current review results, which found a significant decrease in SBP in the group that performed RT routinely

(Appendix 5), support this. However, although there was a decrease in DBP in the intervention group, it was not significant when compared to the control group (Appendix 6). Several factors can influence these results, as DBP is less sensitive to changes in vascular resistance than SBP (Cornelissen & Smart, 2013). Additionally, RT is more dominant in reducing afterload (SBP) compared to DBP (preload) (Cornelissen & Smart, 2013; de Sousa et al., 2017); therefore, the effect of RT can reduce DBP in patients with DM, albeit less significantly than its effect on SBP. On the other hand, the current review finds that rehabilitation using RT is very beneficial for patients with DM and does not cause serious events in those who undergo it (Appendix 7).

The current review has several limitations. First, it only includes articles published in English, which may have excluded relevant studies; including articles from several countries could provide a more global representation. Second, Appendix 9 illustrates that some of the included studies have unavoidable publication bias. However, the authors worked independently; the current review used six databases, and with the use of excellent analysis methods, publication bias can be addressed. Third, the review does not distinguish between the DM types or participant age groups. Therefore, we recommend conducting a subgroup analysis based on DM Type and age in future research. Fourth, the sample sizes of several included studies were small, and control groups were not restricted to standard care, which may have contributed to elevated levels of heterogeneity. Moreover, most studies neglected to do subgroup analyses to ascertain factors influencing heterogeneity, especially regarding the primary and secondary outcomes. Consequently, it is advisable to utilize bigger sample sizes in future intervention research to corroborate these findings and to conduct subgroup analyses to enhance the homogeneity of the studies included.

Conclusion

The current review demonstrates that RT using weight machines, sandbags, progressive resistance training, elastic bands, or RT combined with walking, cycling, aerobics, and a bicycle ergometer every three to seven days for two to 48 weeks has benefits for those living with DM. Performing routine exercise using RT effectively can improve MS and PP (primary outcome). Additionally, RT can lower BMI, SBP, and HbA1c to more normal levels, as well as increase VO_2 peak and LLM for those who do it. In general, RT is a safe recommendation without causing serious side effects, and it is one of the rehabilitation strategies recommended to be undertaken in addition to medical therapy. However, conducting RT requires supervision from nurses and health providers, especially for those with unstable blood sugar conditions. Finally, as this review focused on patients with type II DM, so to strengthen the evidence-based benefits of RT in patients with DM, future research needs to consider the type of DM, as well as the age of the patient.

Appendix A. Supplementary data

Supplementary data to this article can be found online at supplementary link

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