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The effect of home-based resistance exercise training in people with type 2 diabetes: A randomized controlled trial

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Abstract

Aims: To evaluate the effects of pragmatic home-based resistance exercise training on glycated haemoglobin (HbA1c) as well as muscle strength and body composition in people with type 2 diabetes.

Materials and Methods: People with type 2 diabetes were randomized (1:1) to usual care or usual care plus home-based resistance exercise for 32 weeks. The changes in HbA1c, body composition, physical function, quality of life, continuous glucose monitoring and liver fat were compared by randomized group using linear regression.

Results: This study recruited 120 participants (female: $n = 46$ [38%], age 60.2 (9.4) years, BMI 31.1 (5.4) kg.m^{-2}), 64 to intervention and 56 to usual care. Intention to treat analysis revealed no effect on HbA1c (difference in difference: −0.4 mmol/mol, 95% confidence interval [CI]: −3.26, 2.47; $p = 0.78$) but the intervention increased the number of push-ups (3.6 push-ups, 95% CI: 0.8, 6.4), arm lean mass (116 g, 95% CI: 6, 227) and leg lean mass (438 g, 95% CI 65, 810) and decreased liver fat (−1.27%, 95% CI -2.17, −0.38), with no differences in other outcomes. Per-protocol analysis revealed similar results.

Conclusions: Home-based resistance exercise is unlikely to lower HbA1c in people with type 2 diabetes but may be of benefit for maintaining muscle mass and function and reducing liver fat.

KEYWORDS
body composition, glycaemic control, muscle, resistance exercise, strength, type 2 diabetes

1 | INTRODUCTION

Currently, 537 million adults (age: 20–79 years) worldwide are living with diabetes, with a prevalence of 10%. This number is projected to reach 643 million by 2030 and 784 million by 2045.[1] Diabetes accounted for 6.7 million deaths in 2021.[1] Approximately 90%–95% of people with diabetes have type 2 diabetes, which increases the risk of microvascular diseases, such as neuropathy, nephropathy, and retinopathy, and macrovascular diseases, such as coronary artery disease, peripheral arterial disease, stroke, and other related complications.[2,3] Indeed, people with type 2 diabetes have a 2- to 3-fold higher risk of cardiovascular disease (CVD), which accounts for 80%

of deaths in patients with type 2 diabetes.[4] Undeniably, type 2 diabetes is a global issue but is of particular concern in countries, such as Kuwait, where the age-adjusted comparative prevalence of diabetes in adults (age: 20–79 years) is estimated to be 24.9%.[1]

Physical activity and exercise, alongside dietary intervention, are the key to type 2 diabetes treatment, and meta-analyses demonstrate that both aerobic and resistance exercise training can reduce glycated haemoglobin (HbA1c).[5,6] However, adherence to exercise interventions and physical activity guidelines is generally low, particularly for muscle strengthening activities, such as resistance exercise.[7–9] This is despite the evidence that resistance exercise can not only reduce HbA1c alongside but also have benefits for body composition, muscle function, and cardiometabolic health markers.[10–13] Previous research revealed age-related declines in muscle mass and function occur at a faster rate in people with type 2 diabetes, making them more susceptible to the deleterious effects of sarcopenia,[14,15] and muscle strengthening interventions are particularly important.

However, as detailed very few people perform any resistance exercise. Some studies have explored the barriers to resistance exercise participation. The reported barriers in older adults and people with type 2 diabetes are often similar to those reported for aerobic exercise, including time, work, illness/injury, vacations, tiredness, boredom, dislike of gyms, and family commitments, although some specific barriers for resistance exercise were reported, including looking too muscular and concerns about an increased risk of heart attack, stroke, or death.[16–19] A specific key barrier to resistance exercise includes access to and knowledge in using resistance training equipment.[17,18] This latter barrier is a particular problem for resistance exercise, as opposed to aerobic exercise which is composed of many simple, free, and accessible activities, such as walking or jogging, that do not require any specific training, knowledge, or equipment. Determining the effectiveness of simple resistance exercise interventions, which require minimal equipment in people with type 2 diabetes, is necessary. Whilst we acknowledge the potential benefits of aerobic exercise in people with type 2 diabetes as there are many intervention studies on this topic and due to more scarce data on resistance exercise we chose to focus on resistance exercise in the current study.

Therefore, this randomized controlled trial primarily aimed to test the hypothesis that home-based resistance exercise training reduces HbA1c levels in people with type 2 diabetes compared with control and to investigate the effects of home-based resistance exercise training on muscle strength and body composition.

2 | MATERIALS AND METHODS

2.1 | Study setting and participants

This study recruited people with type 2 diabetes at the Dasman Diabetes Institute in Kuwait from August 2019 to June 2021. Inclusion criteria were ages of ≥21 years at the time of consent, physician-diagnosed type 2 diabetes, constant anti-diabetic medication in the last 3 months, body mass index of <45 kg.m^2, blood pressure of <160/100 mmHg, and a Kuwaiti resident. Exclusion criteria were receiving insulin therapy, participating in any vigorous aerobic activity (>1 h per week), participating in any resistance exercise training, and any other condition that prevents exercise safety. This study was fully explained to participants, both oral and written, before obtaining written informed consent from them. This study was approved by the Ethical Review Committee of Dasman Diabetes Institute, followed the tenets of the Declaration of Helsinki, and registered on clintrials.gov (NCT04136730) and the protocol paper published.[20]

2.2 | Trial design

The current study was originally designed as a three-arm trial with participants randomized (1:1:1) to usual care, usual care + home-based resistance exercise, or usual care + gym-based resistance exercise. However, a national lockdown was put in place in Kuwait in March 2020, which meant that the gym-based group could no longer conduct their training; hence, this arm was dropped from the study based on our criteria of considering an arm terminated, where we stopped recruiting before 20% (10 participants) had completed the arm (Figure 1). The control and home-based groups continued the intervention although study visits were severely disrupted, particularly the 16-week study visits.

2.3 | Randomisation and allocation concealment

Randomisation was conducted using randomly permuted blocks via the electronic data capture system (www.castoredc.com) following the baseline assessment with allocation concealment from the researchers provided by the system. All statistical analysis was conducted by a statistician blinded to group assignment.

2.4 | Intervention

The intervention was on top of usual care, and participants were instructed to maintain their normal dietary and physical activity habits other than the intervention itself. We chose to apply a pragmatic home-based resistance exercise intervention, without an additional aerobic component, due to the aforementioned paucity of studies focusing on resistance exercise and the low participation rates in the resistance exercise part of the physical activity recommendations. Participants assigned to the intervention group were asked to perform home-based resistance exercises 3 times per week for 6 months. The first 3 sessions were supervised either within the exercise facility or via video call, and video files demonstrating the exercises were sent to the participants. A further supervised session was offered to participants once a month to overcome any issues and ensure appropriate intensity progression. Participants were asked to record their intervention adherence via an online exercise log to
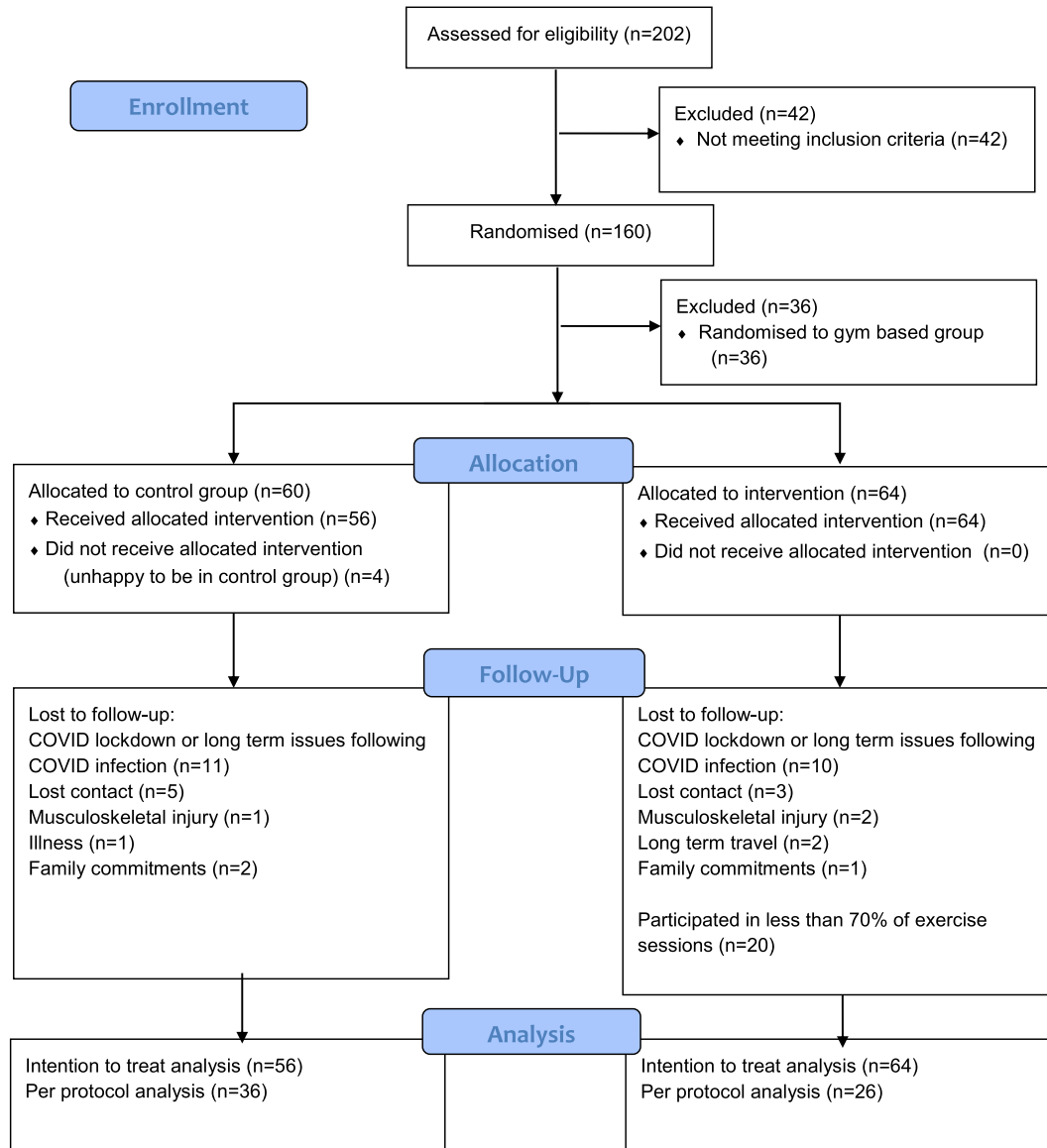
FIGURE 1 Consort flow diagram.

measure adherence to the intervention. Online or phone text messages were sent to participants as reminders for each exercise session. Exercises included press ups, band lateral raises, band seated low row, squat, lunge, calf raise, and plank. The order of each session was (1) squat, (2) press up, (3) calf raise, (4) band seated low row, (5) lunge, (6) band lateral raise, and (7) plank. Participants who were unable to perform any of these exercises were provided with suitable alternatives.

Participants were asked to perform a single set of each exercise and aim for 5–10 repetitions that were tiring but comfortably achievable for the first week of the intervention. Participants were asked to perform, during each session in weeks 2–4, a single set of each exercise performed to voluntary muscular failure, which is defined as not being able to perform another repetition. This progressed to 2 sets in each session of each exercise with both sets performed to voluntary muscular failure in weeks 5–8. Participants

performed 3 sets of each exercise in every session, with all sets to voluntary muscular failure in weeks 9–32. Sets to failure, rather than a set number of repetitions, was a pragmatic choice for delivery of the intervention in that it is effective for hypertrophy/strength and is a simple way to match physical effort between individuals. Multiple sets (weeks 5 onwards) of each performed exercise were sequential with 2 min rest between each set. Each exercise had different difficulty levels to ensure participants were able to perform the exercise with correct form and reach voluntary muscle failure within a reasonable number of repetitions of approximately 15–20.

2.5 | Control

Participants in the control group received usual clinical care and were instructed to maintain their normal dietary and physical activities.

2.6 | Outcome measures

2.6.1 | Blood samples

Plasma samples were collected, stored as frozen aliquots of plasma and whole blood, and batch analysed at the end of the study for HbA1c, plasma total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides using an automated clinical chemistry analyser and the manufacturers' calibrators and quality control material (c311, Roche Diagnostics, Burgess Hill, UK).

2.6.2 | Muscle strength and functional abilities

Grip strength was measured in both hands and the average was used for analysis. The number of participants who correctly or incorrectly performed press-ups (full or on knees) before stopping was recorded by the researcher. The short physical performance battery (SPPB) test,[21] compromised 4 m walk at a habitual pace, fastest time to perform 5 chair rises and holding side-by-side, and semi- and full-tandem stands for 10 s were performed. We also planned to measure a one-repetition maximum of leg extension and pull-down exercises, but these outcomes were dropped due to coronavirus disease 2019 (COVID-19) restrictions.

2.6.3 | Body composition

Total fat mass and total, arm, leg, and trunk lean mass were measured using a GE Lunar iDXA scanner.

2.6.4 | Physical activity levels

Participants were asked to wear a Geneactive accelerometer 24 h/day for 7 days. The accelerometer was set to record at 100 Hz. GGIR was used to generate physical activity and sedentary behaviour analysis.[22] The collected acceleration data were calibrated to local gravity using the methods established by van Hees et al.[23] Physical activity levels were quantified using the previously described methods.[24,25] Sleep was detected, without a sleep log, using previously established methods.[26] A valid day was defined as having >16 h of data, and participants with <3 valid days of data or without data for every 15 min of the 24-h cycle were excluded. From this analysis, we quantified the overall physical activity using the Euclidian Norm Minus One variable, which is a valid metric to describe physical activity levels.[25] We also quantified time spent sedentary (0–40 mg), time spent doing light (40–100 mg), moderate (100–400 mg), and vigorous physical activities (>400 mg) and sleep duration and efficiency.

2.6.5 | Quality of life

Participants completed the EQ-5D-DL questionnaire.

2.6.6 | Subset for exploratory outcomes

Continuous glucose monitoring and liver fat measurement were carried out in a subset of participants who volunteered to have these measurements made. A sample size calculation for these exploratory outcomes was not carried out a priori and data are considered exploratory.

2.6.7 | Continuous glucose monitoring

Continuous glucose monitors (Pro 2 blinded system, Medtronic MiniMed, Inc. Northridge, CA) were used in a subset of participants ($n = 22$ in control and $n = 20$ in intervention) for 5 days. Data were processed to calculate the glucose area under the curve, time in normoglycemia (4–7.8 mmol/L), hypoglycemia (<4 mmol/L), and hyperglycemia (>7.8 mmol/L), and the standard deviation and coefficient of variation.

2.6.8 | Liver fat

Liver fat was quantified using magnetic resonance imaging using the Proton Density Fat Fraction (PDFF) technique in a subset of participants ($n = 32$ in control and $n = 21$ in intervention). Scans were performed on a 1.5 T scanner (Signa Artist, GE Medical systems, USA), and the PDFF calculation was done with IDEAL-IQ sequence provided by the manufacturer (slice thickness: 8 mm, echo time: 6 ms, and echo repetition time: 13.3 ms). The fat fraction of the liver tissue was calculated by placing four rounded regions of interest (ROI) of an average area of 400 square millimetres in segments II/III, V/VI, VII, and VIII of the liver. The average fat fraction of the four readings was used as the final observation. An additional reference ROI was placed in the anterior abdominal subcutaneous fat.[27]

2.7 | Statistical analysis

We would require 40 participants per group at 80% power at the 5% significance level to detect a 5.5 mmol/mol (0.5%) decrease in HbA1c (standard deviation within groups 0.79%) in either intervention or control group. We aimed to recruit 50 participants to each randomized group to account for the dropout.

Data were reported and analysed using a modified intention to treat (ITT) approach and a per-protocol (PP) approach, reflecting

the afore-described disruption due to the COVID-19 pandemic. Participants randomized to the gym intervention group were not included in the analyses. The 16-week visit was not specifically analysed as a separate timepoint due to the high degree of incomplete data. The ITT analysis included all participants with a baseline measurement within each outcome variable of interest (all participants had measured baseline HbA1C). The ITT analysis used the last observation carried forward (baseline or 16-week observation) for those without a 32-week measurement. A value of zero was imputed in the ITT analysis for the change between baseline and 32 weeks in the missing baseline measurement. The PP analysis was a complete analysis of each variable for those who gave measurements at both the baseline and 32-week visit and self-reported completion of 70% of the prescribed exercise sessions.

Outcome variables of interest (at baseline, week 32, and change in the variable) were summarised overall and separately by treatment groups. Approximately normally distributed continuous variables were reported as mean and standard deviation and median and interquartile intervals for skewed. Categorical data were reported as the number of observed values, number of missing values, and number and percentage in each category.

The intervention effect was estimated using the differences between groups and was calculated via linear regression using the change in the outcome variable between baseline and 32 weeks as the outcome and the randomized group as the exposure of interest. Intervention effects were considered significant on the basis of the 95% confidence intervals for the treatment effect excluding the null, and with the HbA1C measurement as the primary outcome, and other effects as exploratory.

3 | RESULTS

3.1 | Participant characteristics

This study included 160 participants (female: $n = 46$ [38%], age 60.2 (9.4) years, BMI 31.1 (5.4) kg m^{-2}) (NCT04136730) from August 2019 to September 2021 (Figure 1). The gym-based resistance exercise group consisted of 36 participants before this arm was stopped during the national lockdown. Four people dropped out post-randomisation in the control group, leaving 120 participants in our ITT analysis (56 control vs. 64 exercise). With 20 participants lost to follow-up in the control group and 18 lost to follow-up and 20 who did not meet the criteria of 70% adherence in the intervention group, our PP analysis included 36 and 26 participants in the control and exercise groups, respectively. Baseline characteristics of the randomized group were generally well-balanced, and those included in the ITT and PP analysis are presented in Table 1 and Supplementary Table 1, respectively. There were no major differences in the characteristics of participants who dropped out relative to those who remained in the study.

TABLE 1 Baseline characteristics (intention to treat (ITT)) by randomised intervention group.

	Control ($n = 56$)	Home based intervention ($n = 64$)
Age (years)	60.99 (10.32)	59.45 (8.55)
Female sex (n (%))	23 (41%)	23 (36%)
Weight (kg)	86.32 (18.12)	85.04 (18.35)
Height (cm)	164.51 (9.56)	166.48 (9.63)

3.2 | Adherence to the intervention

Overall participants completed 49 (43)% of sessions in those included in the ITT analysis and 96.6 (7.3)% in those included in the per protocol analysis. Completion of a session was defined as completing the required number of sets, 1-3 depending on the week number.

3.3 | Blood biochemistry and body composition

The intervention had no effects on our primary outcome of HbA1c (Table 2), as well as the total, HDL or LDL cholesterol, or whole body fat and fat-free mass. The comparison of the appendicular lean mass revealed increases in both arm and leg fat-free mass but not fat mass with the intervention. MRI-measured liver fat was reduced following the intervention, similar to the PP analysis (Supplementary Table 2).

3.4 | Physical function and physical activity

The intervention did not affect the total SPPB score or the comparison of individual components (balance score, walk time, or chair rise time) between the groups (Table 3). Grip strength was not affected by the intervention but there was an increased number of completed push-ups in the intervention group. No differences were seen in physical activity variables between the two groups. Similar results were found in the PP analysis (Supplementary Table 3).

3.5 | CGM data

The exploratory analysis in a sub-group of participants revealed no differences in glucose AUC, SD, or CV or in the time spent in normoglycemia, hypoglycemia, or hyperglycemia. This data is presented in Table 4.

4 | DISCUSSION

The current study has demonstrated that 32 weeks of a home-based resistance exercise has no effect on HbA1c, whole body composition, grip strength, or functional abilities (as measured by the SPPB) in

TABLE 2 Effect of intervention on glycaemic, anthropometric, and metabolic outcomes of interest.

	Control Baseline	32 weeks	Change	Home-based Baseline	32 weeks	Change	Treatment effect
HbA1C (mmol/mol)	55.67 (13.38)	55.03 (12.54)	−0.64 (7.71)	54.25 (14.24)	53.20 (10.90)	−1.04 (8.08)	−0.40 (95%CI −3.26,2.47)
Taking metformin	52 (93%)	52 (93%)	0.00 (0.00, 0.00)	58 (91%)	58 (91%)	0.00 (0.00, 0.00)	-
Number of diabetes medications	2.00 (1.00, 3.00)	2.00 (1.00, 3.00)	0.00 (0.00, 0.00)	2.00 (1.00, 3.00)	2.00 (1.00, 3.00)	0.00 (0.00, 0.00)	−0.02 (95%CI −0.07,0.04)
Total cholesterol (mmol/L)	4.14 (0.93)	4.16 (0.93)	0.02 (0.67)	4.19 (1.18)	4.03 (1.04)	−0.16 (0.81)	−0.18 (95%CI −0.45,0.09)
HDL cholesterol (mmol/L)	1.27 (0.31)	1.30 (0.33)	0.03 (0.15)	1.27 (0.41)	1.31 (0.44)	0.04 (0.18)	0.01 (95%CI −0.05,0.07)
LDL cholesterol (mmol/L)	2.17 (0.78)	2.16 (0.88)	−0.00 (0.58)	2.26 (1.10)	2.11 (0.91)	−0.16 (0.71)	−0.15 (95%CI −0.39,0.09)
Triglycerides (mmol/L)	1.29 (0.93, 1.74)	1.36 (0.97, 1.66)	−0.04 (0.64)	1.30 (0.96, 1.81)	1.26 (0.94, 1.73)	−0.06 (0.52)	−0.02 (95%CI −0.23,0.19)
BMI (kg/m^2)	31.84 (5.70)	31.42 (5.74)	−0.41 (1.21)	30.56 (5.15)	30.32 (4.98)	−0.24 (1.17)	0.17 (95%CI −0.26,0.60)
Fat free mass (g)	49878.66 (9355.08)	49550.31 (9421.32)	−328.35 (950.12)	51253.76 (10621.98)	51228.38 (10731.21)	−25.38 (1425.13)	302.97 (95%CI −151.07,757.00)
Fat mass (g)	34598.64 (11369.56)	33989.56 (11290.87)	−598.20 (2723.56)	32248.09 (10534.41)	31606.35 (10176.12)	−581.58 (2202.82)	16.62 (95%CI −874.51,907.75)
Arm fat free mass (g)	5485.65 (1230.56)	5449.31 (1232.42)	−35.70 (248.49)	5623.71 (1590.80)	5712.78 (1531.35)	80.72 (345.65)	*116.42 (95%CI 6.17,226.66)*
Leg fat free mass (g)	15126.73 (3635.94)	14843.93 (3618.17)	−277.75 (976.35)	15109.17 (3504.55)	15285.90 (3653.24)	160.16 (1071.32)	*437.91 (95%CI 65.35,810.46)*
Liver fat (%)	10.31 (6.74)	10.79 (6.70)	0.42 (2.46)	10.88 (8.86)	9.71 (7.58)	−0.85 (2.46)	*−1.27 (95%CI −2.17, −0.38)*

Note: Values are mean (SD) or median (Interquartile interval). Treatment effects in bold/italics are significant ($p < 0.05$).

people with type 2 diabetes, but it increases the number of performed push-ups and fat-free mass in the arms and legs, alongside a reduced liver fat. Therefore, the current home-based resistance exercise intervention is not effective in decreasing HbA1c or increasing functional abilities, although it may improve regional lean mass and muscle strength/function. The modest liver fat reduction is interesting, but this exploratory analysis must be carefully interpreted.

Previous work, which has investigated the effects of supervised gym-based resistance exercise on HbA1c, has demonstrated a 0.57% HbA1c reduction in people with type 2 diabetes.[6] The current study employed a home-based unsupervised resistance exercise intervention to develop a more pragmatic intervention that could be more easily delivered on a wider scale, which may explain the inadequate effect. This is unlikely due to the lack of supervision because a recent meta-analysis revealed no difference in the effects between supervised and unsupervised resistance exercise on HbA1c reduction.[5] Supervision or the lack thereof may have affected the current study, however, as it can affect adherence,[9] but the observed inadequate effect may also be due to an insufficient stimulus from the employed simple home-based exercises. It is also possible that the intervention did not reduce HbA1c as the participants we included had relatively

good diabetes control at baseline. The resistance exercise interventions employed in previous work may have clear heterogeneity, but it is prudent to compare the current study to previous similar studies.

One of the earliest studies that investigated a home-based resistance exercise intervention showed that the addition of 6-month supervised gym-based resistance exercise to a weight loss programme resulted in a greater HbA1c reduction compared to weight loss alone, but these improvements were not maintained when participants switched to a home-based resistance training intervention.[28] However, improvements in lean body mass and muscle strength were maintained by the home-based resistance exercise, which is partially congruent with the current data. These findings are of interest, but they are not directly comparable to the current study due to their inclusion of a weight loss programme alongside the exercise. Very few studies have investigated the effects of a home-based resistance exercise intervention in people with type 2 diabetes. One study revealed that 16 weeks of a home-based resistance exercise intervention using resistance bands resulted in a 1.34%-point HbA1c reduction in older adults with type 2 diabetes.[29] Unfortunately, this study had major limitations. Primarily the participants were not

TABLE 3 Effect of intervention on physical function and physical activity outcomes of interest.

	Control			Home-based			Treatment effect
	Baseline	32 weeks	Change	Baseline	32 weeks	Change	
Number of push ups	10.90 (6.17)	10.12 (7.30)	−0.71 (7.34)	11.75 (8.94)	14.70 (12.19)	2.91 (8.09)	*3.62 (95%CI 0.81,6.43)*
Grip strength (kg)	27.29 (8.65)	25.93 (7.98)	−1.33 (3.17)	29.68 (9.87)	29.21 (10.17)	−0.47 (2.70)	0.87 (95%CI −0.19,1.93)
SPPB score	10.15 (1.06)	10.05 (1.16)	−0.09 (0.92)	10.26 (1.01)	10.31 (1.08)	0.05 (0.55)	0.14 (95%CI −0.13,0.41)
ENMO (mg)	22.49 (5.39)	22.03 (6.05)	−0.45 (4.96)	23.66 (6.04)	22.81 (6.65)	−0.71 (4.05)	−0.25 (95%CI −1.88,1.37)
Sedentary time (min/day)	694.44 (119.54)	730.98 (151.02)	35.24 (147.91)	688.11 (125.23)	701.90 (117.22)	11.42 (79.77)	−23.82 (95%CI −66.07,18.43)
Light intensity physical activity (min/day)	301.35 (88.63)	285.08 (86.79)	−15.69 (74.66)	321.88 (97.37)	303.85 (94.56)	−14.93 (70.17)	0.76 (95%CI −25.44,26.96)
Moderate intensity physical activity (min/day)	42.85 (26.28)	45.49 (31.77)	2.55 (24.05)	47.84 (31.72)	45.57 (35.04)	−1.89 (15.27)	−4.43 (95%CI −11.63,2.76)
Vigorous intensity physical activity (min/day)	0.90 (3.09)	1.70 (6.49)	0.77 (6.37)	0.36 (0.79)	0.35 (0.95)	−0.01 (0.65)	−0.77 (95%CI −2.36,0.81)

Note: Values are mean (SD) or median (Interquartile interval). Treatment effects in bold/italics are significant ($p < 0.05$).

TABLE 4 Effect of intervention on glycaemic outcomes of interest measured via continuous glucose monitoring.

	Control			Home-based			Treatment effect
	Baseline	32 weeks	Change	Baseline	32 weeks	Change	
Area under the curve	2351.23 (662.49)	2451.27 (591.52)	39.30 (254.40)	2158.48 (421.08)	2215.08 (341.41)	23.88 (226.75)	−15.42 (95%CI −102.40,71.55)
Time in hypoglycaemia (%)	1.56 (2.17)	1.55 (3.08)	−0.00 (1.75)	0.77 (1.28)	1.53 (2.81)	0.32 (2.17)	0.33 (95%CI −0.39,1.05)
Time in normoglycaemia (%)	53.77 (27.16)	48.11 (28.91)	−2.23 (11.39)	62.01 (26.49)	55.56 (24.13)	−2.72 (15.30)	−0.49 (95%CI −5.43,4.44)
Time in hyperglycaemia (%)	44.66 (28.14)	50.34 (29.70)	2.23 (11.72)	37.23 (26.74)	42.91 (24.35)	2.39 (15.96)	0.16 (95%CI −4.96,5.29)
Standard deviation	1.77 (0.65)	1.83 (0.81)	0.02 (0.34)	1.61 (0.64)	1.69 (0.54)	0.03 (0.39)	0.01 (95%CI −0.12,0.14)
Coefficient of variation	20.02 (6.29)	20.29 (6.16)	0.11 (2.87)	18.48 (9.63)	19.51 (9.49)	0.43 (4.38)	0.33 (95%CI −1.03,1.69)

Note: Values are mean (SD) or median (Interquartile interval).

randomized to their respective groups, and thus there is a high chance of bias in the findings. Therefore, we suggest that current home-based resistance exercise interventions are not sufficient to improve glycaemic control, measured by both HbA1c and our exploratory CGM analysis, in people with type 2 diabetes, although they may be sufficient to increase muscle strength and fat-free mass, as indicated by the current study and Dunstan et al.

The current study revealed that home-based resistance exercise resulted in an increased number of performed push-ups, although without an increased grip strength. It is likely that as a relatively small muscle group is involved in performing the push up, this is not associated with a concomitant change in HbA1c. The lack of effect on grip strength is perhaps not surprising because grip strength is not a valid measure to quantify muscle strength changes in response to resistance exercise training.[30] The increased number of push-ups indicates a benefit of the intervention as a higher push-up capacity is associated with a lower CVD incidence,[31] as other measures of muscle strength also are.[32,33] Although there are no universally accepted minimal clinically important differences for the push up test, these are estimated to be 2-3 repetitions which the current improvement exceeds.[34,35] The current findings are related to previous work in older adults, where a recent meta-analysis revealed that home-based resistance exercise results in modest increases in muscle strength, although this does not translate into functional ability improvements, such as the SPPB,[36] which was also seen in the current study. The lack of SPPB score improvement may either indicate that the included exercises in the intervention are not of sufficient intensity or form to translate into functional benefits or because our participants were relatively young and scored ˜10/12 on the SPPB at baseline, and thus there may be a ceiling effect for this measure. Similar trials in more sarcopenic or frail people with type 2 diabetes may therefore be of interest. The benefits in functional, and other outcomes, in the current study could be modulated by habitual physical activity levels. In the current study, participants had higher levels of light but lower levels of moderate and vigorous and overall physical activity levels in comparison to a similar UK-based sample of people with type 2 diabetes,[37] making high levels of physical activity unlikely to be a mediating factor in our results.

The increased push-up capacity is also supported by the increased fat-free mass in both legs and arms, although not whole body fat-free mass, which we assume represents a primarily increased muscle tissue in the muscle groups performing the exercises. The lack of effect on the whole body fat free mass is in agreement with a recent meta-analysis[38] and highlights the need to measure regional, rather than whole body fat-free mass. The increased muscle function and mass highlight that a home-based exercise intervention may be of benefit for sarcopenia treatment and prevention in people with type 2 diabetes, although larger studies with longer-term follow-up are required, with muscle mass and function as the primary outcomes. Besides the changes in arm and leg fat-free mass in our sub-group exploratory analysis, we found that home-based resistance exercise resulted in decreased liver fat.

This was not previously demonstrated with a pragmatic home-based resistance exercise intervention, but it is congruent with previous studies of supervised gym-based resistance exercise training, with studies in patients with non-alcoholic fatty-liver disease (NAFLD).[39–41] Therefore, the current pragmatic intervention may be a useful intervention for ectopic liver fat accumulation and NAFLD prevention and treatment, which frequently and negatively affect people with type 2 diabetes,[42] although further work is required to confirm this assertion.

The current study has limitations. The original study design was severely changed due to the global COVID-19 pandemic, which occurred during this trial, resulting in the cessation of the gym-based resistance exercise group, which would have allowed us to compare the effects of our home-based pragmatic intervention with a fully supervised and controlled intervention. Additionally, we had relatively high dropout rates and missing data, primarily due to COVID-19 and in our per-protocol analysis had relatively low participant numbers; thus, the data may be biased to the null, and our conclusions from this trial are tentative. The impact of lockdown and associated changes with diet and physical activity levels may have increased variability in our results. Our continuous glucose monitoring and liver fat data were collected in a subset of volunteers willing to have these measurements made, with no a priori sample size estimation made. These data should, therefore, be considered exploratory and require validation in future work. Therefore, the current findings are useful pilot data that can be used to further develop a pragmatic home-based resistance exercise intervention for people with type 2 diabetes to investigate if feasible to incorporate into the long-term treatment plan of patients with type 2 diabetes.

The current study revealed that home-based resistance exercise intervention did not affect the primary outcome measure of HbA1c, although some improvements in muscle mass, strength, and liver fat were seen. This may indicate the benefit of such a pragmatic intervention for preventing or treating sarcopenia, which is accelerated in people with type 2 diabetes. However, further work is necessary.

AUTHOR CONTRIBUTIONS

EAO, DA, JNRG, NS, PW and SRG conceived and designed the study. DA, DAR, MJ, AM, DT and AA acquired the data. SRG and PW analysed the data. All authors were involved in the interpretation of the data. EAO, SRG and PW drafted the manuscript and all other authors critically revised it. All authors gave final approval to the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

ETHICS STATEMENT

This study was approved by the Dasman Diabetes Institute Ethics Committee (RA HM-2019-021).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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