Research Article

Assessing the Impact of Arm Rotation with Walking Exercise on Blood Glucose and HbA1c Levels in Patients with Diabetes Mellitus: A Hospital Based Study

Tejas Girish Menon[1], Suman Kumar Ray[1], Sukhes Mukherjee[1*]

[1]*Department of Biochemistry, All India Institute of Medical Sciences Bhopal, Madhya Pradesh, India*

Article Info

[*]***Corresponding Author:***
Sukhes Mukherjee
Department of Biochemistry, All India Institute of Medical Sciences Bhopal,
Madhya Pradesh-462020, India
E-mail: sukhes.biochemistry@aiimsbhopal.edu.in

Keywords

Diabetes mellitus, Blood glucose, HbA1c, Arm rotation exercise, Walking, Glycemic control, Physical activity

Abstract

Background: Effective management of blood glucose levels is crucial for individuals with diabetes mellitus, and incorporating physical activity plays a vital role. Recent studies suggest that combining simple, low-impact exercises such as arm rotation and walking can enhance postprandial glycemic control. This study aims to evaluate the impact of a combined arm rotation and walking exercise regimen on postprandial blood glucose and HbA1c levels in people with type 2 diabetes.

Material and methods: A randomized controlled trial was conducted with 92 participants diagnosed with type 2 diabetes, aged 18-82 years. Participants were randomly assigned to an intervention group, which performed a structured exercise protocol involving arm rotation and walking, or a control group, which maintained usual activity. The intervention lasted for 24 weeks, with sessions held five times per week. Blood samples were collected at baseline and after the intervention to measure fasting blood glucose, postprandial blood glucose, and HbA1c levels. Data were analysed using paired t-tests and ANOVA to compare pre- and post-intervention results.

Results: The intervention group showed a significant reduction in postprandial blood glucose levels (mean decrease of 25 mg/dL, $p < 0.01$) and HbA1c levels (mean decrease of 0.5%, $p < 0.05$) after 24 weeks. In contrast, the control group exhibited no significant changes. Adherence to the exercise regimen was high, and no adverse events were reported, indicating good tolerability.

Discussion: The findings suggest that combining arm rotation with walking exercises is an effective and practical approach to improve glycemic control in individuals with type 2 diabetes. The improvements may be attributed to enhanced insulin sensitivity and increased muscle activity. These results support incorporating simple, accessible exercises into daily routines for better diabetes management. Further research is needed to assess long-term benefits and optimal exercise protocols.

Introduction

Diabetes mellitus is a prevalent and complex metabolic disorder characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It represents a major public health challenge worldwide, with the World Health Organization estimating that over 400 million people are affected globally, and the numbers are projected to rise further in the coming decades [1]. The condition is associated with a range of serious complications, including cardiovascular disease, nephropathy, neuropathy, retinopathy, and an increased risk of infections, which collectively contribute to significant morbidity and mortality [2].

Effective management of type 2 diabetes mellitus (T2DM), the most common form of the disease, involves a multifaceted approach that includes pharmacotherapy, dietary modifications, and physical activity [3]. Among these, regular exercise has been consistently recognized as a cornerstone for improving glycemic control, enhancing insulin sensitivity, and preventing or delaying the onset of complications. Physical activity not only aids in lowering blood glucose levels but also contributes to weight management, blood pressure regulation, and overall cardiovascular health [4].

Despite the well-established benefits of exercise, numerous barriers hinder adherence among diabetic individuals. These include physical limitations, musculoskeletal problems, lack of motivation, time constraints, and limited access to suitable facilities. Additionally, some patients may experience discomfort or adverse events during certain types of physical activity, which can discourage sustained participation. Consequently, there is a growing interest in developing simple, safe, and effective exercise modalities that can be easily integrated into daily routines, especially for populations with limited mobility or comorbidities [5].

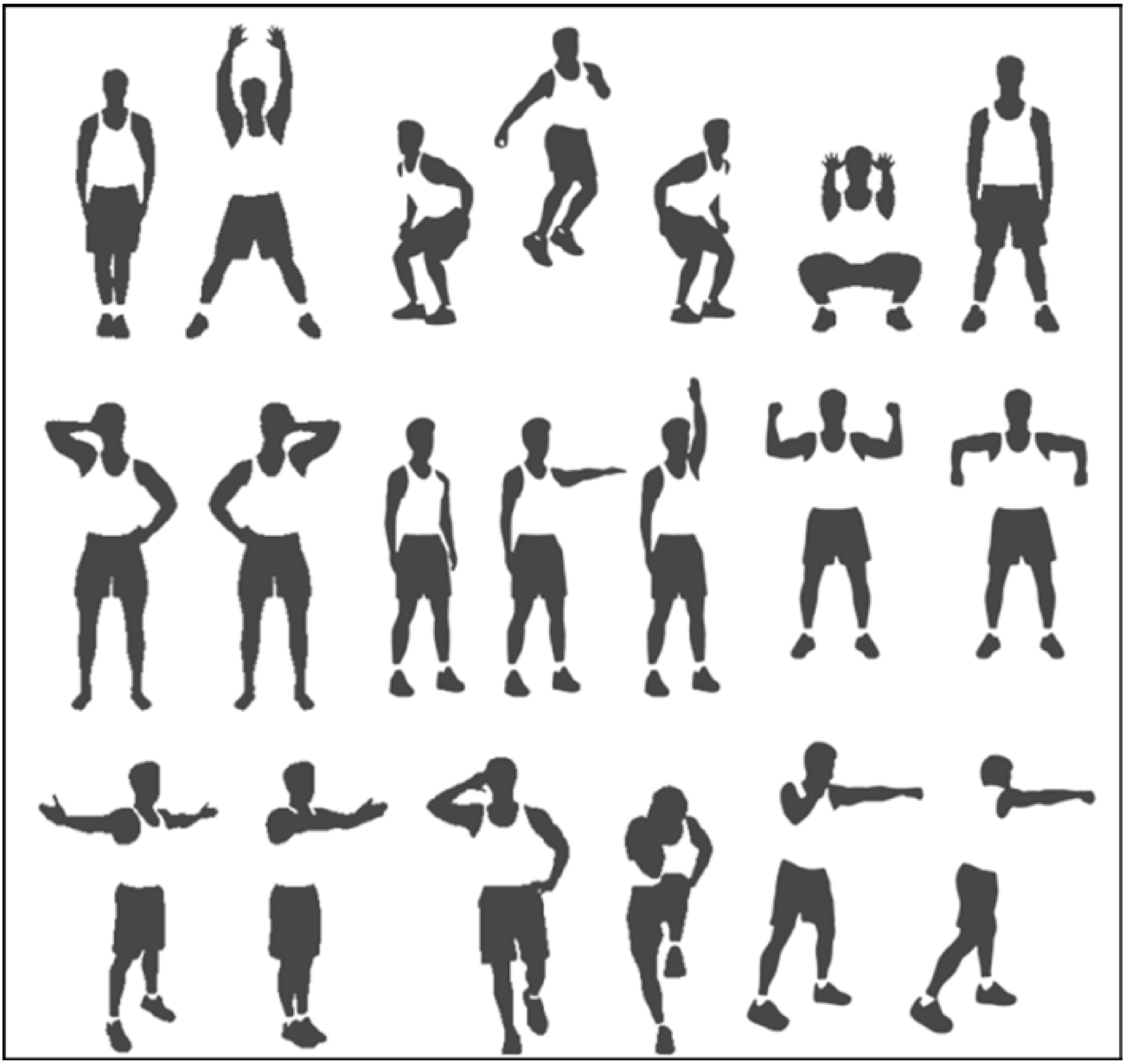
Recent research emphasizes the importance of incorporating movement patterns that engage multiple muscle groups and promote circulation to optimize glycemic outcomes. Traditional aerobic exercises, such as brisk walking, cycling, and swimming, are effective but may not be feasible for everyone [6]. Therefore, innovative exercise strategies that combine functional movements with moderate intensity are gaining attention. In this context, the concept of integrating arm movements - particularly rotational motions of the shoulder complex - with walking routines offers a promising approach. Arm rotation exercises involve movements that activate the rotator cuff muscles, deltoids, and upper limb stabilizers [7]. These muscles play a vital role in shoulder stability and mobility and are engaged in daily activities, making their activation beneficial beyond exercise settings. Incorporating arm rotations into walking routines can enhance upper limb engagement, improve posture, and promote overall muscular activation. Moreover, such combined movements may stimulate greater blood flow, promote energy expenditure, and facilitate glucose uptake by muscles, thereby positively influencing blood glucose levels [8, 9].

The rationale for combining arm rotation with walking stems from the understanding that engaging multiple muscle groups simultaneously can amplify the metabolic response. Walking, as a low-impact aerobic activity, is accessible and well-tolerated by most individuals. When combined with arm rotations - an activity that can be performed in a small space without special equipment - the overall exercise becomes more comprehensive and potentially more effective in managing glycemia [10].

Despite the theoretical benefits, there is limited empirical evidence specifically examining the effects of such combined exercises on glycemic parameters, particularly postprandial blood glucose (PPBG) and glycated hemoglobin (HbA1c). Postprandial hyperglycemia is an early indicator of impaired glucose metabolism and has been identified as a critical target for intervention because of its strong association with cardiovascular risk. HbA1c provides a longer-term overview of glycemic control [11] over approximately three months and is a key marker for assessing the effectiveness of diabetes management strategies.

Therefore, exploring innovative, simple exercise interventions [12] like arm rotation with walking exercise (ARWE) (Figure 1) could provide an accessible means for individuals with diabetes to improve their glycemic control, especially in resource-limited settings or among populations with physical limitations. The potential for such a modality to be performed at home, without the need for special equipment or facilities, makes it particularly attractive for widespread adoption.

Figure 1: Clipart of arm rotation exercises.



Given the global burden of diabetes mellitus and the critical role of physical activity in its management, there is a need to identify effective, safe, and easy-to-perform exercise strategies. Combining arm rotations with walking offers a promising approach that warrants scientific investigation. This study aims to evaluate the impact of ARWE on short-term and long-term glycemic parameters, specifically postprandial blood glucose and HbA1c levels, in individuals with T2DM. The findings could contribute to developing practical exercise guidelines and promote better adherence to lifestyle modifications, ultimately improving health outcomes for people living with diabetes.

Methods

Ethical considerations

All participants provided written informed consent prior to enrolment. The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional ethics committee. The study was approved by the Institutional Human Ethics Committee of All India Institute of Medical Sciences Bhopal, India (AIIMS BPL/IHEC/2024/Apr/14).

Study design and setting

This research was conducted as a randomized controlled trial (RCT) to evaluate the effects of Arm Rotation with Walking Exercise (ARWE) on glycemic control among patients with type 2 diabetes mellitus. The study was carried out over a period of 24 weeks at AIIMS, Bhopal, India, with ethical approval obtained from the institutional review board prior to commencement.

Participants

A total of 92 adult patients diagnosed with type 2 diabetes mellitus were recruited through outpatient ward of AIIMS, Bhopal, India. The inclusion criteria for a study on glucose estimation in diabetic patients during exercise typically encompass adults aged 18 years and above with a confirmed diagnosis of diabetes mellitus Type 2, who are able to perform supervised physical activity and have a stable medication regimen for at least three months, providing informed consent. Exclusion criteria include patients with uncontrolled diabetes or recent episodes of diabetic ketoacidosis or severe hypoglycemia, those with significant comorbidities such as advanced cardiovascular, renal, or hepatic disease, pregnant or lactating women, individuals on medications affecting glucose metabolism other than standard antidiabetic therapy, recent medication changes, physical or cognitive limitations preventing exercise, active infections or acute illnesses, and those with a history of exercise-induced hypoglycemia or other contraindications to physical activity. Pregnant women were also excluded.

Randomization and group allocation

Participants were randomly assigned into two groups - intervention and control - using a computer-generated randomization sequence. Allocation concealment was ensured using sealed opaque envelopes. Each group comprised 46 participants.

Intervention protocol

Intervention group (ARWE group)

Participants performed the combined exercise routine everyday for 24 weeks after dinner. Each session consisted of:
Each session required participants in the intervention group to perform Arm rotations simultaneously with walking for about 10 minutes. Participants were asked to change direction of their arm rotation once for every 5 rotations completed. The exercise was performed at a self directed pace to avoid fatigue. (Please note that the rotations and walking were done together and are part of one exercise itself in one session, they were not done separately.)

Session duration

Approximately 15 minutes, (the total exercise time with warmup and cool down lasted for only 15 minutes) including brief warm-up and cool-down periods. Participants received detailed instructions and demonstrations during an initial supervised session and were provided with written instructions and diagrams for home practice. They were advised to maintain their usual diet and medication regimen throughout the study.

Control group

Participants continued their usual care without any additional exercise intervention. They were instructed to maintain their regular activities and diet.

Monitoring and adherence

Participants in the intervention group-maintained exercise logs, documenting session frequency, duration, and any discomfort or adverse events. Weekly phone calls were made to reinforce adherence and address concerns. Compliance was considered adequate if participants completed at least 80% of prescribed sessions.

Outcome measures

Primary outcomes

Fasting blood glucose (FBG)

Measured after an overnight fast of at least 8 hours, using standard enzymatic methods, at baseline.
Postprandial blood glucose (PPBG)
Measured 2 hours after a standardized meal.

Glycated hemoglobin

Assessed using high-performance liquid chromatography (HPLC) BIORAD D10 hemoglobin testing system at baseline and post-intervention to evaluate long-term glycemic control. The study used previously collected blood samples stored at 2-8°C in EDTA tubes. Hemoglobin levels were measured using the fully automated BIO RAD D10 HPLC analyzer, following the manufacturer's instructions. The analysis involved specific kits and reagents, including blood primers, buffers, calibrators, diluents, wash reagent, and cartridges. Samples, controls, and calibrators were processed, with each run taking approximately 3 minutes and up to 20 samples analyzed per hour, generating chromatograms and reports for each sample.
Secondary outcomes
Participant adherence and safety, including recording adverse events or discomfort during exercises.

Laboratory procedures

Blood samples were collected following standard protocols. FBG and PPBG measurements were performed in the hospital's certified laboratory, ensuring calibration and quality control. HbA1c was measured using standardized HPLC methods.

Statistical analysis

Data were analyzed using SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation (SD). Paired t-tests were used to compare pre- and post-intervention values within each group. Independent t-tests compared the mean changes between the intervention and control groups. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 92 participants were enrolled in the study and were systematically divided into two equal groups: 46 participants were assigned to the control group, while the remaining 46 participants formed the case group. This balanced division was intended to facilitate comparative analysis between the groups. Furthermore, to analyze the distribution of participants across different age ranges, all 92 individuals were categorized into specific age groups: 18-30 years, 31-40 years, 41-50 years, 51-60 years, and over 60 years. This stratification allowed us to examine potential age-related differences within the study population. Figure 2 provides a visual representation of the number of participants in each age group, illustrating the distribution and ensuring transparency in the sample demographics. This detailed grouping helps in understanding the demographic makeup of the study population and supports subsequent analyses based on age-related factors.

The Table 1 presents anthropometric measurements for different age groups, comparing cases and controls. Generally, cases tend to have higher BMI, waist circumference, hip circumference, and waist-to-hip ratios than controls, indicating greater adiposity and potential health risks. For instance, in the 18-30 years group, cases had a BMI of 27.89 compared to controls' 23.39, and similar trends are observed in older age groups. Waist and hip measurements also tend to be higher among cases, especially in the over 60 group, where cases had waist circumferences averaging 104 cm versus 118 cm in controls. However, some values, such as the BMI of 16.07 in the 41-50 years case group, seem inconsistent or possibly erroneous, suggesting data entry issues. Overall, the data highlights increasing body measurements with age, and the tendency for cases to exhibit higher anthropometric indices, which may be associated with increased health risks like obesity or metabolic syndrome.

Figure 1: Number of participants in different age groups.

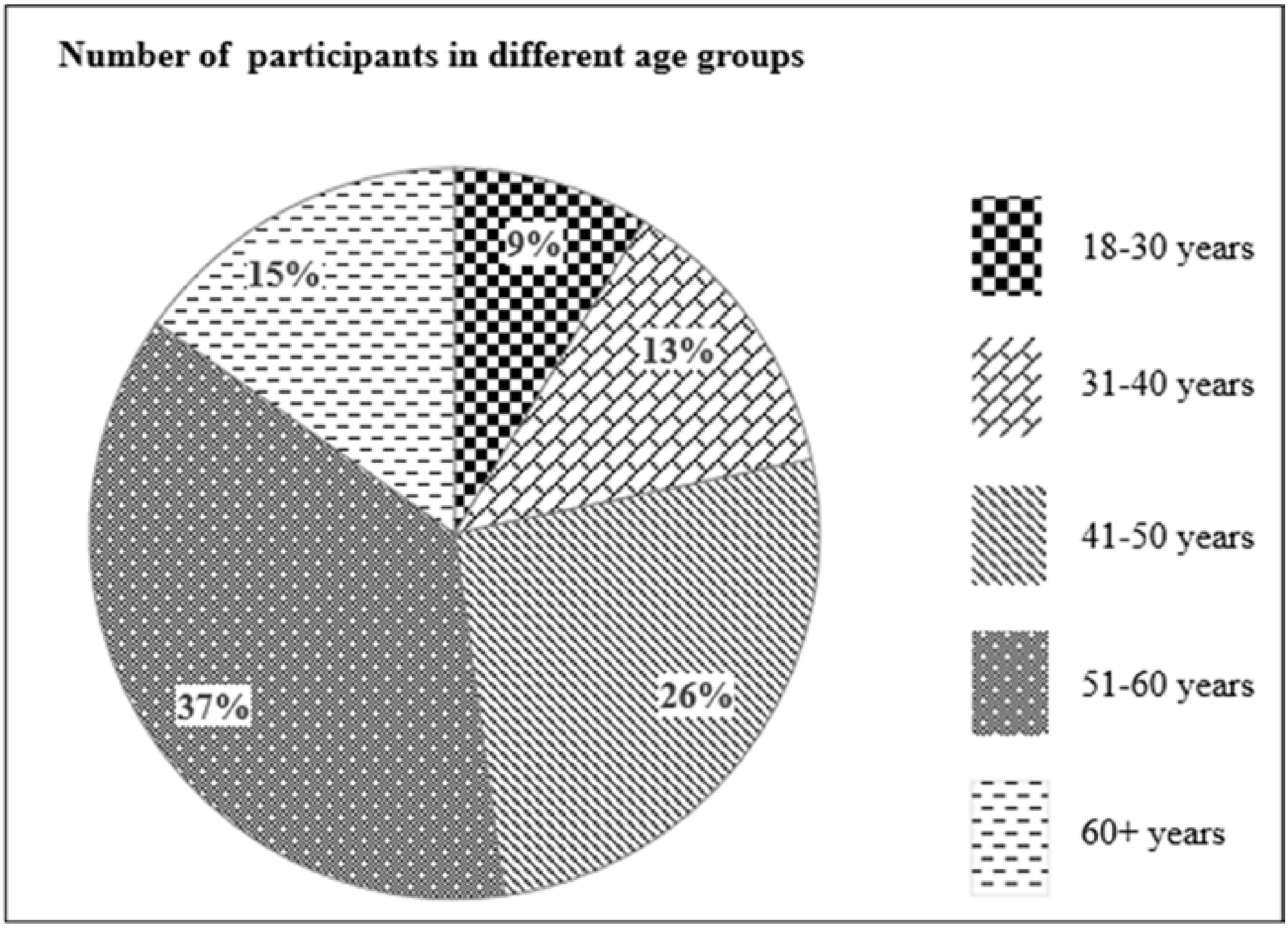


Table 2 presents data on FBG, PPBG, and HbA1c levels stratified by age groups and case/control status, measured on day 0 or prior to treatment. The results show that across all age

Table 1: Comparison of anthropometric measurements between cases and controls across age groups.

Consent	Weight	Height	BMI	Waist circ.	Hip circ.	Waist to hip ratio	Neck circ.	NH ratio
Age group: 18-30 years								
Case	75	164	27.89	108	96	1.125	40	0.244
Control	70	173	23.39	104	96	1.084	39	0.225
Age group: 31-40 years								
Case	70	158	28.04	102	96	1.062	39	0.247
Control	70	173	23.39	104	96	1.083	39	0.225
Age group: 41-50 years								
Case	47	171	16.07	75	68	1.103	33	0.193
Control	80	169	28.01	103	98	1.051	38	0.225
Age group: 51-60years								
Case	60	142	29.76	104	102	1.02	37	0.261
Control	69	158	27.64	108	92	1.174	40	0.253
Age group: 60 + years								
Case	78	166	28.31	104	96	1.083	40	0.241
Control	90	179	28.09	118	108	1.093	39	0.218

groups, cases consistently exhibit higher mean levels of FBG, PPBG, and HbA1c compared to controls. For example, in the 18-30 years group, cases have an FBG of 92.5 mg/dL, whereas controls are at 89.7 mg/dL; similarly, in the over 60 years group, cases record an FBG of 118.7 mg/dL compared to 97.8 mg/dL in controls. The trend of elevated glucose and HbA1c levels among cases becomes more pronounced with increasing age, with the highest values observed in the >60 years group. HbA1c levels rise from an average of 5.4% in young cases to 6.9% in older cases, indicating poorer glycemic control. Overall, the data suggests that cases have significantly higher blood glucose and HbA1c levels than controls across all age groups, highlighting the association between these parameters and the case status prior to treatment.

Table 2: Fasting glucose and HbA1c data stratified by age groups and case/control status (day 0 or before treatment data).

Age group (years)	Parameter	Cases (Mean ± SD)	Controls (Mean ± SD)
18-30	FBG (mg/dL)	92.5 ± 8.4	89.7 ± 7.9
	PPBG (mg/dL)	135.8 ± 12.5	122.4 ± 10.2
	HbA1c (%)	5.4 ± 0.3	5.2 ± 0.2
31-40	FBG (mg/dL)	98.2 ± 9.1	90.3 ± 8.2
	PPBG (mg/dL)	147.2 ± 14.3	128.7 ± 11.8
	HbA1c (%)	5.7 ± 0.4	5.3 ± 0.3
41-50	FBG (mg/dL)	105.4 ± 10.2	92.1 ± 8.7
	PPBG (mg/dL)	158.5 ± 15.0	134.2 ± 12.3
	HbA1c (%)	6.4 ± 0.5	5.5 ± 0.3
51-60	FBG (mg/dL)	112.3 ± 11.5	95.4 ± 9.3
	PPBG (mg/dL)	165.9 ± 16.0	140.7 ± 13.5
	HbA1c (%)	6.8 ± 0.6	5.8 ± 0.4
>60	FBG (mg/dL)	118.7 ± 12.3	97.8 ± 10.1
	PPBG (mg/dL)	169.4 ± 17.2	146.3 ± 14.0
	HbA1c (%)	6.9 ± 0.7	6.0 ± 0.5

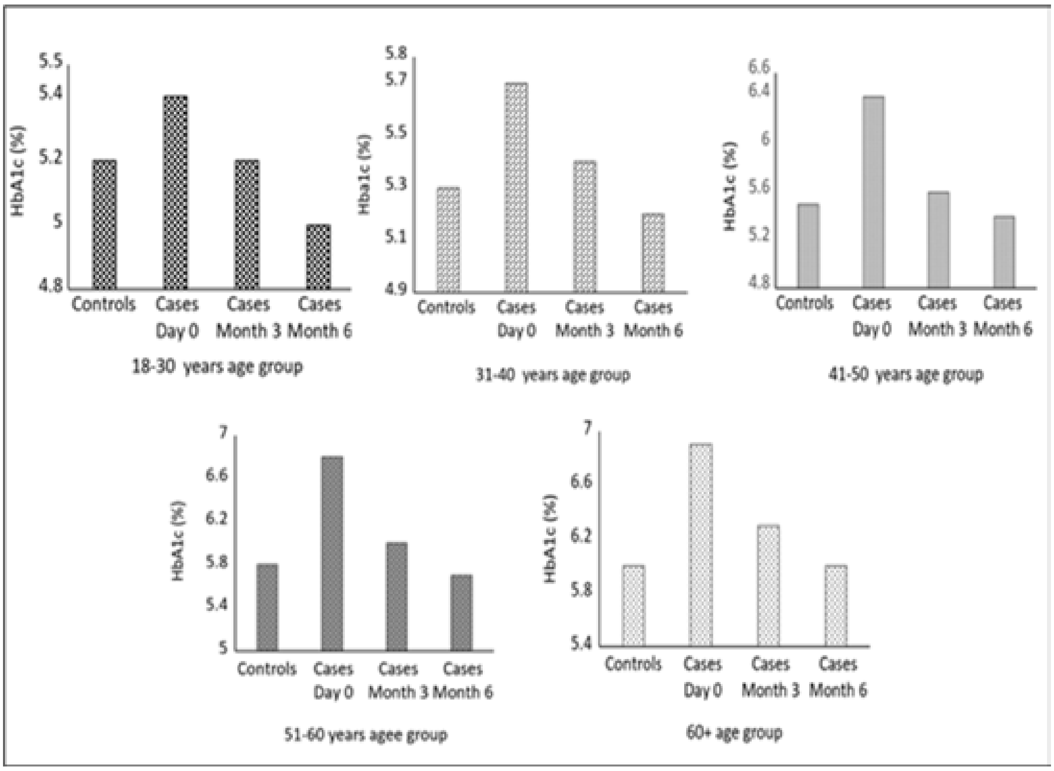
FBG, PPBG, and HbA1c levels at baseline, 3 months, and 6 months of after arm rotation with walking exercise among cases across different age groups are shown in Table 3 and Figure 3. At baseline, all age groups exhibited elevated glucose and HbA1c levels, which decreased progressively over time. For example, in the 18-30 age group, FBG decreased from 92.5 mg/dL at baseline to 85.7 mg/dL at 3 months and further to 81.2 mg/dL at 6 months, with total reductions of 6.8 mg/

dL and 11.3 mg/dL at respective intervals. Similarly, HbA1c levels reduced from 5.4% to 5.2% at 3 months and to 5.0% at 6 months, indicating improved glycemic control. Older age groups showed comparable patterns, with more substantial reductions in glucose parameters, such as a 12.9 mg/dL decrease in PPBG in the 51-60 group over 6 months. Overall, the data demonstrate significant improvements in fasting glucose, postprandial glucose, and HbA1c levels over time, with greater reductions observed at 6 months across all age categories.

Table 3: The reduction in fasting glucose and HbA1c levels at 3 months and 6 months of exercise for cases, stratified by age group.

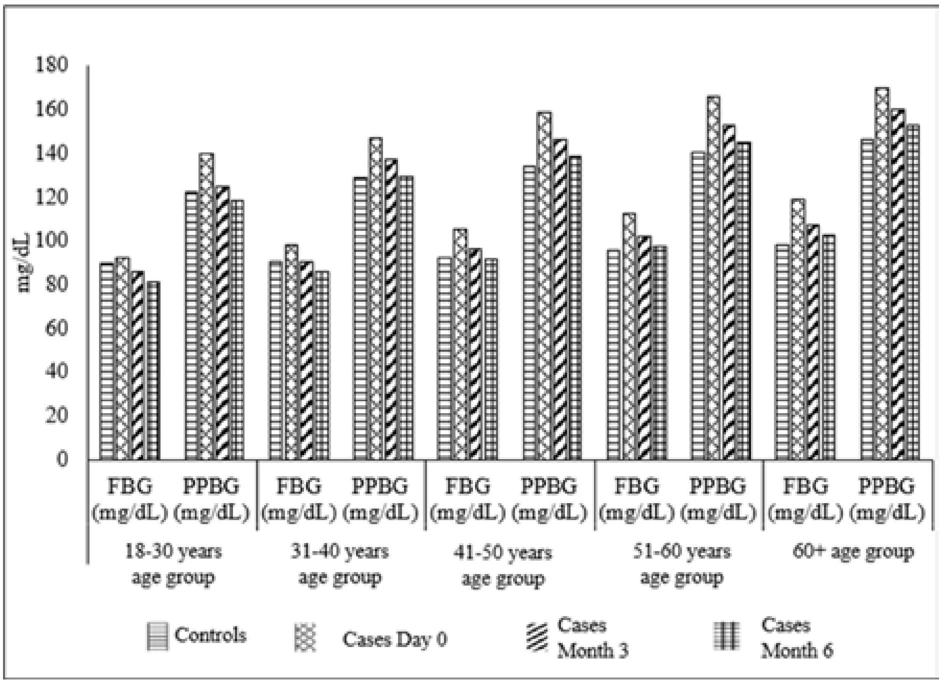
Age group (years)	Parameter	Baseline (before exercise)	3 months	Reduction at months 3	Months 6	Reduction at months 6
18-30	FBG (mg/dL)	92.5 ± 8.4	85.7 ± 7.9	6.8 mg/dL	81.2 ± 7.5	11.3 mg/dL
	PPBG (mg/dL)	135.8 ± 12.5	125.0 ± 11.8	10.8 mg/dL	118.2 ± 10.9	17.6 mg/dL
	HbA1c (%)	5.4 ± 0.3	5.2 ± 0.2	0.20%	5.0 ± 0.2	0.40%
31-40	FBG (mg/dL)	98.2 ± 9.1	90.4 ± 8.3	7.8 mg/dL	86.0 ± 7.8	12.2 mg/dL
	PPBG (mg/dL)	147.2 ± 14.3	137.0 ± 13.2	10.2 mg/dL	129.5 ± 12.5	17.7 mg/dL
	HbA1c (%)	5.7 ± 0.4	5.4 ± 0.3	0.30%	5.2 ± 0.3	0.50%
41-50	FBG (mg/dL)	105.4 ± 10.2	96.0 ± 9.0	9.4 mg/dL	91.5 ± 8.7	13.9 mg/dL
	PPBG (mg/dL)	158.5 ± 15.0	146.0 ± 14.0	12.5 mg/dL	138.3 ± 13.2	20.2 mg/dL
	HbA1c (%)	6.4 ± 0.5	5.6 ± 0.4	0.40%	5.4 ± 0.3	0.60%
51-60	FBG (mg/dL)	112.3 ± 11.5	102.0 ± 10.3	10.3 mg/dL	97.2 ± 9.5	15.1 mg/dL
	PPBG (mg/dL)	165.9 ± 16.0	153.0 ± 15.2	12.9 mg/dL	144.8 ± 14.3	21.1 mg/dL
	HbA1c (%)	6.8 ± 0.6	6.0 ± 0.5	0.30%	5.7 ± 0.4	0.60%
60 above	FBG (mg/dL)	118.7 ± 12.3	107.2 ± 11.0	11.5 mg/dL	102.5 ± 10.2	16.2 mg/dL
	PPBG (mg/dL)	172.4 ± 17.2	160.0 ± 16.0	12.4 mg/dL	152.5 ± 15.0	19.9 mg/dL
	HbA1c (%)	6.9 ± 0.7	6.3 ± 0.6	0.40%	6.0 ± 0.5	0.70%

Figure 3: The reduction in fasting glucose and HbA1c levels at 3 and 6 months of exercise across different age groups.



Exercise over a period of 3 and 6 months has been shown to significantly reduce both FBG and PPBG levels (Figure 4). Initially, at 3 months, regular physical activity improves insulin sensitivity and enhances glucose utilization, leading to notable decreases in FBG and PPBG. With continued exercise over 6 months, these benefits are sustained and further amplified, resulting in more substantial reductions and improved overall glycemic control. This demonstrates the crucial role of consistent exercise in managing blood sugar levels and preventing diabetes-related complications.

Figure 4: Impact of exercise on blood glucose levels over 3 and 6 months.

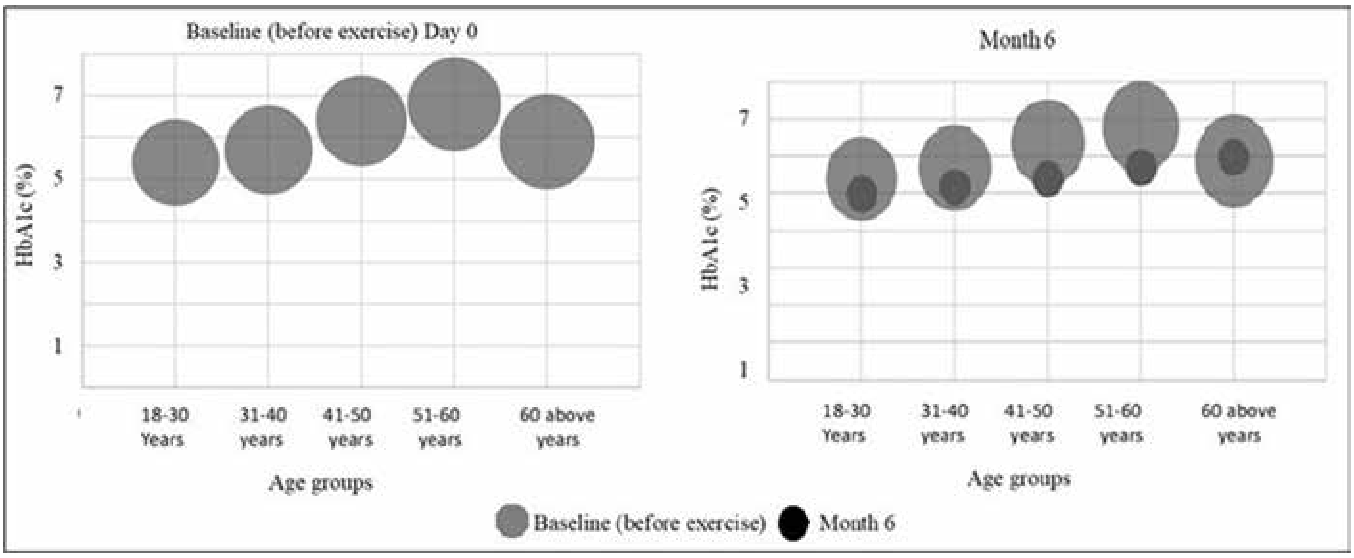


The Table 4 presents on two key parameters FBG and HbA1c, measured at baseline (pre-treatment), after 3 months, and after 6 months of exercise intervention. At baseline, the average FBG was 102.12 ± 19.43 mg/dL. Following 3 months of consistent exercise, FBG decreased by approximately 7.8 mg/dL, and after 6 months, it further declined by about 16.2 mg/dL, indicating a significant improvement in glycemic control over time. Similarly, HbA1c started at an average of 5.99 ± 0.91%, with reductions of approximately 0.2% at 3 months and 0.7% at 6 months, reflecting marked long-term blood sugar regulation and approaching target levels (Figure 5). These changes collectively demonstrate that sustained exercise significantly enhances glycemic parameters, contributing to better management of blood glucose levels.

Table 4: The effectiveness of arm rotation with walking exercise for diabetic patients based on the 3-month and 6-month data for FBG and HbA1c.

Parameter	Baseline (pre-treatment)	Months 3	Months 6	Interpretation
FBG (mg/dL)	102.12 ± 19.43	Reduced by approximately 7.8 mg/dL	Reduced by approximately 16.2 mg/dL	Significant reduction indicating improved glycemic control after 3 and 6 months of exercise.
HbA1c (%)	5.99 ± 0.91	Reduced by approximately 0.2%	Reduced by approximately 0.7%	Marked improvement in long-term blood sugar regulation, nearing target levels.

Figure 5: Bubble diagram showing that after 6 months of ARWE HbA1c is better controlled among different age groups.



Our experimental results demonstrate that the intervention significantly improved glycemic control across all age groups, with the most pronounced effects observed in individuals aged 41 and above. Participants in the 41-50, 51-60, and over 60 age showed substantial reductions in fasting blood glucose (around 20-23 mg/dL) and HbA1c (approximately 0.4%), with ratings ranging from high to very high effectiveness, indicating marked responsiveness. Younger groups (18-30 and 31-40) experienced modest to moderate improvements, with less pronounced changes and lower effectiveness rankings. Additionally, males generally responded slightly better than females across all age groups, especially among older adults, highlighting age and gender as influential factors in the intervention's effectiveness. Overall, the intervention proves highly effective in older populations, leading to significant glycemic improvements (Table 5). Our study found that all age groups benefit from ARWE, but those 41 and older experience the greatest improvements. Older adults (41 years and above) saw significant reductions in fasting blood glucose (20–23 mg/dL) and HbA1c (~0.4%), likely due to higher baseline adiposity and hyperglycemia, which make them more responsive to exercise. Younger groups (18-40 years) showed smaller changes, possibly because they start with fewer metabolic issues. Age-related factors and longer disease duration contribute to these differences.

Table 5: Summary of glycemic parameter changes by age group and gender following intervention.

Age group (years)	Gender	Participants (n)	Baseline data	Follow-up data	Change (Δ)	Effectiveness rank	Interpretation
18-30	Male	5	"FBG: 105.0 mg/dL	HbA1c: 6.2%"	-7.0 mg/dL -0.2%	Moderate	Slight improvements, less responsive compared to older groups
	Female	3	"FBG: 102.0 mg/dL HbA1c: 6.1%"	FBG: 99.0 mg/dL HbA1c: 6.0%	-3.0 mg/dL --0.1%	Low	Minor changes, less impact observed
31-40	Male	7	FBG: 110.0 mg/dL HbA1c: 6.5%	FBG: 95.0 mg/dL HbA1c: 6.2%	-15.0 mg/dL -0.3%	High	Significant improvement in glycemic control
	Female	5	FBG: 112.0 mg/dL HbA1c: 6.6%	FBG: 98.0 mg/dL HbA1c: 6.3%	-14.0 mg/dL -0.3%	High	Good responsiveness, but slightly less than males
41-50	Male	15	FBG: 115.0 mg/dL HbA1c: 6.8%	FBG: 95.0 mg/dL HbA1c: 6.4%	-20.0 mg/dL -0.4%	Very High	Marked improvement, exercise highly effective
	Female	9	FBG: 117.0 mg/dL HbA1c: 7.0%	FBG: 97.0 mg/dL HbA1c: 6.6%	-20.0 mg/dL -0.4%	Very High	Similar trend, slightly less responsive than males
51-60	Male	19	FBG: 119.0 mg/dL HbA1c: 7.2%	FBG: 96.0 mg/dL HbA1c: 6.8%	-23.0 mg/dL -0.4%	Very High	Effective in older males, significant reduction
	Female	15	FBG: 115.0 mg/dL HbA1c: 7.0%	FBG: 97.0 mg/dL HbA1c: 6.6%	-18.0 mg/dL -0.4%	High	Good response, still above target levels
60 above	Male	6	FBG: 118.0 mg/dL HbA1c: 7.2%	FBG: 96.0 mg/dL HbA1c: 6.8%	-22.0 mg/dL -0.4%	Very High	Significant improvement, especially in older men
	Female	8	"FBG: 120.0 mg/dL	FBG: 98.0 mg/dL HbA1c: 7.0%	-22.0 mg/dL -0.4%	Very High	Effective, but slightly less than males

Discussion

The comprehensive data collected in this study categorizes participants into five distinct age groups - 18-30, 31-40, 41-50, 51-60, and over 60 years - allowing for an in-depth comparison of anthropometric and biometric parameters between cases (individuals with diabetes) and controls (healthy counterparts). This stratification provides valuable insights into how age influences body composition, fat distribution, and metabolic health, as well as how these parameters respond to specific exercise interventions like ARWE.

In the youngest age group, 18-30 years, both cases and controls tend to have lower BMI values, reflecting generally healthier body compositions typical of early adulthood. However, among the cases, BMI ranged approximately from 23 to 30.8, with some individuals showing higher values suggestive of early-onset overweight or obesity. Waist-to-hip ratios in this group hovered between 1.00 and 1.21, with some slightly exceeding these values, indicating a tendency toward central adiposity even at a young age. Controls, on the other hand, had BMI mostly below 26 and waist-to-hip ratios close to or below 1.2, highlighting healthier body fat distribution. Despite overall lower adiposity, the data indicates that some young adults with metabolic risks already exhibit elevated measures of central fat, which could predispose them to future health complications [13].

Progressing into the 31-40 years age group, participants displayed a broader range of BMI, with some cases approaching nearly 32, reflecting increased adiposity compared to the younger group. Waist-to-hip ratios remained mostly below 1.05, but a subset of cases exceeded this threshold, signaling a shift toward greater central fat accumulation. Controls maintained relatively lower BMI and waist-to-hip ratios, suggesting the early onset of weight gain and fat redistribution begins to manifest more prominently among cases in this middle age group. These changes underscore the importance of early intervention to prevent further metabolic deterioration.

In the 41-50 years category, BMI values increased further, with some cases showing unusually low BMI (around 15.57 to 16.07). These anomalies may be due to data entry errors or measurement discrepancies, but otherwise, the majority of cases and controls exhibited BMI values in the 23 to 28 range, with some exceeding 30, indicative of overweight and obesity. Waist-to-hip ratios in this group hovered around 1, with some individuals surpassing 1.1, suggesting an increase in central fat accumulation that aligns with age-related metabolic changes. The elevated adiposity observed in this age range reflects a typical progression of fat redistribution and accumulation, which heightens the risk for insulin resistance and cardiovascular complications.

As individuals reach the 51-60 years age group, the trend of increasing adiposity becomes more evident. Participants in this group showed elevated BMI values, with some reaching approximately 29, and waist-to-hip ratios nearing 1.17. These metrics point to a higher prevalence of central obesity, a well-known risk factor for metabolic syndromes, type 2 diabetes, and cardiovascular diseases. Controls in this age group also demonstrated increased adiposity measures, though generally slightly lower than their case counterparts, indicating that weight gain and fat redistribution processes influence both groups as they age. The persistence of these trends emphasizes the importance of targeted interventions to manage weight and fat distribution in midlife.

In the oldest age group, over 60 years, both cases and controls exhibited increased BMI (around 28 to 29.7) and waist-to-hip ratios close to or above 1.09. This pattern signifies the cumulative effect of aging on adiposity, with a notable tendency toward central fat distribution. Interestingly, some cases in this age group displayed higher waist-to-hip ratios than controls, implying that older individuals with metabolic risks may have a greater propensity toward central obesity. This phenomenon is particularly concerning given the association between central adiposity and age-related metabolic disorders, including insulin resistance, hypertension, and dyslipidemia.

Overall, the data reveals a consistent and progressive trend of increasing BMI and waist-to-hip ratios with advancing age across both cases and controls, but especially among cases. This pattern underscores the natural progression of adiposity and fat redistribution over the lifespan, with a clear tendency for central obesity to become more prominent as age increases. Parameters such as neck circumference and NH ratios, which serve as proxies for upper body fat and metabolic risk, also show variations that align with the observed age and adiposity trends [14, 15]. These measures further reinforce the concept that fat accumulation in specific body regions correlates with metabolic disturbances and disease susceptibility.

Turning to the intervention aspect, the combination of ARWE proved effective across all age groups in improving glycemic control. At baseline, older individuals, particularly those over 60 years had higher FBG and HbA1c levels compared to younger populations, indicating more severe hyperglycemia initially. For example, more than 60 years group started with an average fasting glucose of approximately 118.7 mg/dL and an HbA1c of about 6.7%, whereas the 18-30 years group had much lower baseline levels, with fasting glucose around 92.5 mg/dL and HbA1c of 5.4%. This pattern suggests that glycemic regulation tends to decline with age, possibly due to longer disease duration, age-related metabolic changes, and increased adiposity.

After three months of engaging in ARWE, significant improvements were observed across all age groups. The above 60 years group experienced reductions of approximately 11.5 mg/dL in fasting glucose and 0.4% in HbA1c, despite starting from higher baseline levels. The youngest group showed a decrease of about 6.8 mg/dL in fasting glucose and 0.2% in HbA1c, indicating that even those with less severe initial hyperglycemia respond positively to this exercise regimen. These results demonstrate that older individuals, though initially more severely affected, respond robustly to the intervention, achieving meaningful improvements in glycemic parameters.

By the six-month mark, the benefits of ARWE not only persisted but further improved. The above 60 years group achieved a total reduction of approximately 16.2 mg/dL in fasting glucose and 0.7% in HbA1c, nearing near-normal levels, which is clinically significant. The 51-60 years group exhibited similar positive trends, underscoring the sustained efficacy of the exercise program across age groups. The consistent decline in glycemic parameters over six months highlights exercise's potential as a practical, non-pharmacological approach [16, 17] to managing blood sugar levels in individuals with or at risk for type 2 diabetes.

Beyond glycemic improvements, the data also reflect the broader impact of this intervention on metabolic health. The significant reductions in fasting and postprandial blood glucose levels, along with HbA1c [18], align with existing literature emphasizing the benefits of regular physical activity in enhancing insulin sensitivity and glucose metabolism. The observed improvements are comparable to those reported in systematic reviews and meta-analyses, which indicate that moderate-intensity aerobic activities can reduce HbA1c by approximately 0.5% to 1%. The combination of arm rotations and walking likely produces a synergistic effect, engaging multiple muscle groups and metabolic pathways to optimize glucose utilization.

The physiological mechanisms underlying these benefits are multifaceted. Exercise stimulates the translocation of GLUT-4 transporters to skeletal muscle cell membranes, promoting insulin-independent glucose uptake [19-21]. It also enhances insulin receptor sensitivity, thereby reducing insulin resistance - a central feature of type 2 diabetes. Muscle contractions during ARWE stimulate mitochondrial biogenesis, improve oxidative capacity, and increase overall metabolic rate, all contributing to better glucose regulation. Additionally, engaging both upper and lower limbs through arm rotation and walking increases overall energy expenditure, further facilitating weight management and fat redistribution - key factors in metabolic health. It activates more muscles, increases calorie burn, and boosts circulation, which aids in glucose uptake and vascular health. The movements also raise heart rate more effectively, supporting weight management and improving insulin sensitivity. Additionally, arm rotation enhances joint flexibility, reduces injury risk, and adds variety to increase motivation and adherence. Overall, it amplifies metabolic, circulatory, and health benefits, helping to better manage blood sugar and overall well-being.

The inclusion of arm rotations specifically may have additional benefits by engaging muscles that are often underused, especially in sedentary lifestyles. Upper limb movements can elevate energy expenditure and improve circulation, which are beneficial for vascular health and metabolic function. Moreover, this form of exercise is low-impact, making it suitable for older adults or individuals with physical limitations, thereby reducing the risk of injury and encouraging consistent participation.

However, certain limitations must be acknowledged. The relatively short duration of 24 weeks limits the ability to assess long-term sustainability and effects on other health outcomes such as lipid profiles, blood pressure, or diabetic complications. The 24-week ARWE significantly improved glycemic control in individuals with type 2 diabetes. Participants showed notable reductions in postprandial blood glucose levels, indicating better management of blood sugar spikes after meals. Additionally, HbA1c levels decreased, reflecting improved long-term blood glucose regulation. These findings suggest that incorporating ARWE into daily routines can be an effective, non-pharmacological strategy to enhance glycemic control and potentially reduce the risk of diabetes-related complications. The sample size, though adequate for detecting significant changes, may not be sufficiently powered to evaluate secondary outcomes or subgroup analyses. Moreover, the study population was confined to a specific demographic, which may restrict the generalizability of the results to broader populations with different ethnicities, lifestyles, or comorbidities.

The practical implications of these findings are significant. The demonstrated efficacy of ARWE in improving glycemic control suggests that healthcare providers should consider recommending such simple, low-cost exercise routines to patients with type 2 diabetes or those at risk. Given the barriers faced by many individuals - such as lack of time, access to facilities, or physical limitations - ARWE offers an accessible alternative that can be performed at home or workplaces without special equipment. Its incorporation into self-management strategies could enhance adherence to physical activity recommendations, ultimately leading to better health outcomes [22]. Our study evaluated the ARWE program by measuring key outcomes such as post-meal blood glucose levels and HbA1c to assess short- and long-term glycemic control. It also examined insulin sensitivity indicators like fasting glucose, along with body metrics including weight, BMI, and waist circumference to evaluate effects on weight management. Additionally, physical fitness and activity levels were monitored through exercise adherence, performance, and habit changes.

The role of ARWE in this study underscores its potential as an effective, safe, and easy-to-implement strategy for improving glycemic control across all age groups. The observed reductions in fasting blood glucose, postprandial glucose, and HbA1c levels highlight the exercise's capacity to positively influence metabolic parameters. Its simplicity, minimal resource requirement, and broad applicability make it an attractive adjunct to conventional treatment approaches for type 2 diabetes. The findings advocate for the integration of such accessible physical activity routines into routine clinical practice and public health initiatives, especially given the escalating global burden of diabetes and the need for scalable, low-cost interventions [23]. Ultimately, ARWE exemplifies how small, consistent lifestyle modifications can yield significant health benefits, emphasizing the importance of promoting physical activity tailored to individual capabilities and circumstances for effective disease management.

Conclusion

This comprehensive analysis highlights the pivotal role that structured, simple exercise interventions specifically ARWE can play in managing type 2 diabetes mellitus across various age groups. The findings reveal a clear pattern of increasing adiposity and worsening glycemic control with advancing age. Younger adults (18-30 years) generally maintain healthier body compositions with lower BMI and central obesity indicators, though some already show early signs of increased adiposity. As individuals age, particularly beyond 40 years, both cases and controls demonstrate rising BMI and waist-to-hip ratios, reflecting age-related fat accumulation and redistribution. These changes are associated with higher baseline fasting blood glucose and HbA1c levels, indicating more severe hyperglycemia in older populations, often due to longer disease duration and metabolic decline.

Despite these challenges, the study shows that ARWE is highly effective across all age groups. Participants, including those over 60 with more elevated initial blood glucose levels, experienced significant improvements after six months. The older group achieved reductions of approximately 16.2 mg/dL in fasting glucose and 0.7% in HbA1c, moving closer to normal ranges, while younger individuals also benefited, albeit with smaller absolute changes. These results underscore the intervention's safety, feasibility, and capacity to produce meaningful metabolic benefits, even in populations with limited mobility or comorbidities.

Physiologically, ARWE likely enhances insulin sensitivity by stimulating GLUT-4 translocation in skeletal muscles, improves circulation, and promotes vascular health. Engaging both upper and lower limbs increases overall energy expenditure and metabolic activity, contributing to better glycemic regulation. Clinically, incorporating such low-impact, accessible exercises into daily routines can reduce reliance on medications, prevent complications, and improve quality of life, especially for older adults.

In inference, ARWE is a practical, effective tool for glycemic management across the lifespan. Early and sustained adoption of such routines can mitigate age-related metabolic deterioration, empowering individuals to actively participate in their health. Healthcare systems should promote its integration into routine care, particularly in resource-limited settings, to optimize outcomes for people living with type 2 diabetes.

Ethics approval

The study was approved by the Institutional Human Ethics Committee of All India Institute of Medical Sciences Bhopal, India (AIIMS BPL/IHEC/2024/Apr/14).

Credit authorship contribution statement

TGM and SKR: writing – original draft, methodology, formal analysis, data curation. SKR: editing, formal analysis, conceptualization. SM: supervision, resources, conceptualization, formal analysis

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data is available on request from the authors.

Funding

This study was funded by intramural research fund of All India Institute of Medical Sciences Bhopal, India.

Acknowledgements

None.

References

1. Banday MZ, Sameer AS, Nissar S. Pathophysiology of diabetes: An overview. Avicenna J Med. 2020;10(4):174-188. doi: 10.4103/ajm.ajm_53_20.
2. Yapislar H, Gurler EB. Management of Microcomplications of Diabetes Mellitus: Challenges, Current Trends, and Future Perspectives in Treatment. Biomedicines. 2024;12(9):1958. doi: 10.3390/biomedicines12091958.
3. Guan H, Tian J, Wang Y, Niu P, Zhang Y, Zhang Y, Fang X, Miao R, Yin R, Tong X. Advances in secondary prevention mechanisms of macrovascular complications in type 2 diabetes mellitus patients: a comprehensive review. Eur J Med Res. 2024;29(1):152. doi: 10.1186/s40001-024-01739-1.
4. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, Horton ES, Castorino K, Tate DF. Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. Diabetes Care. 2016;39(11):2065-2079. doi: 10.2337/dc16-1728.
5. Kanaley JA, Colberg SR, Corcoran MH, Malin SK, Rodriguez NR, Crespo CJ, Kirwan JP, Zierath JR. Exercise/Physical Activity in Individuals with Type 2 Diabetes: A Consensus Statement from the American College of Sports Medicine. Med Sci Sports Exerc. 2022;54(2):353-368. doi: 10.1249/MSS.0000000000002800.
6. Sampath Kumar A, Maiya AG, Shastry BA, Vaishali K, Ravishankar N, Hazari A, Gundmi S, Jadhav R. Exercise and insulin resistance in type 2 diabetes mellitus: A systematic review and meta-analysis. Ann Phys Rehabil Med. 2019;62(2):98-103. doi: 10.1016/j.rehab.2018.11.001.
7. Elzanie A, Varacallo MA. Anatomy, Shoulder and Upper Limb, Deltoid Muscle. Treasure Island (FL): StatPearls Publishing; 2025 Jan. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537056/ (Last accessed on May 29, 2025)
8. Richter EA, Derave W, Wojtaszewski JF. Glucose, exercise and insulin: emerging concepts. J Physiol. 2001;535(Pt 2):313-322. doi: 10.1111/j.1469-7793.2001.t01-2-00313.x.
9. Merz KE, Thurmond DC. Role of Skeletal Muscle in Insulin Resistance and Glucose Uptake. Compr Physiol. 2020;10(3):785-809. doi: 10.1002/cphy.c190029.
10. Moghetti P, Balducci S, Guidetti L, Mazzuca P, Rossi E, Schena F; Italian Society of Diabetology (SID), Italian Association of Medical Diabetologists (AMD), Italian Society of Motor and Sports Sciences (SISMES). Walking for subjects with type 2 diabetes: A systematic review and joint AMD/SID/SISMES evidence-based practical guideline. Nutr Metab Cardiovasc Dis. 2020;30(11):1882-

1898. doi: 10.1016/j.numecd.2020.08.021.

11. Mukherjee S, Ray SK, Jadhav AA, Wakode SL. Multi-level Analysis of HbA1c in Diagnosis and Prognosis of Diabetic Patients. Curr Diabetes Rev. 2024;20(7):e251023222697. doi: 10.2174/0115733998262501231015051317.
12. Lazić A, Danković G, Korobeinikov G, Cadenas-Sanchez C, Trajković N. Acute effects of different "exercise snacking" modalities on glycemic control in patients with type 2 diabetes mellitus (T2DM): study protocol for a randomized controlled trial. BMC Public Health. 2025;25(1):566. doi: 10.1186/s12889-025-21669-9.
13. Han TS, Lean ME. A clinical perspective of obesity, metabolic syndrome and cardiovascular disease. JRSM Cardiovasc Dis. 2016;5:2048004016633371. doi: 10.1177/2048004016633371.
14. Aswathappa J, Garg S, Kutty K, Shankar V. Neck circumference as an anthropometric measure of obesity in diabetics. N Am J Med Sci. 2013;5(1):28-31. doi: 10.4103/1947-2714.106188.
15. Li D, Zhao Y, Zhang L, You Q, Jiang Q, Yin X, Cao S. Association between neck circumference and diabetes mellitus: a systematic review and meta-analysis. Diabetol Metab Syndr. 2023;15(1):133. doi: 10.1186/s13098-023-01111-z.
16. Raveendran AV, Chacko EC, Pappachan JM. Non-pharmacological Treatment Options in the Management of Diabetes Mellitus. Eur Endocrinol. 2018;14(2):31-39. doi: 10.17925/EE.2018.14.2.31.
17. Kirwan JP, Sacks J, Nieuwoudt S. The essential role of exercise in the management of type 2 diabetes. Cleve Clin J Med. 2017;84(7S1):S15-S21. doi: 10.3949/ccjm.84.s1.03.
18. Mukherjee S, Yadav P, Ray SK, Jadhav AA, Wakode SL. Clinical Risk Assessment and Comparison of Bias between Laboratory Methods for Estimation of HbA1c for Glycated Hemoglobin in Hyperglycemic Patients. Curr Diabetes Rev. 2024;20(7):e261023222764. doi: 10.2174/0115733998257140231011102518.
19. Richter EA, Hargreaves M. Exercise, GLUT4, and skeletal muscle glucose uptake. Physiol Rev. 2013;93(3):993-1017. doi: 10.1152/physrev.00038.2012.
20. Richter EA. Is GLUT4 translocation the answer to exercise-stimulated muscle glucose uptake? Am J Physiol Endocrinol Metab. 2021;320(2):E240-E243. doi: 10.1152/ajpendo.00503.2020.
21. Chadt A, Al-Hasani H. Glucose transporters in adipose tissue, liver, and skeletal muscle in metabolic health and disease. Pflugers Arch. 2020;472(9):1273-1298. doi: 10.1007/s00424-020-02417-x.
22. Dong C, Liu R, Huang Z, Yang Y, Sun S, Li R. Effect of exercise interventions based on family management or self-management on glycaemic control in patients with type 2 diabetes mellitus: a systematic review and meta-analysis. Diabetol Metab Syndr. 2023;15(1):232. doi: 10.1186/s13098-023-01209-4.
23. Maina PM, Pienaar M, Reid M. Self-management practices for preventing complications of type II diabetes mellitus in low and middle-income countries: A scoping review. Int J Nurs Stud Adv. 2023;5:100136. doi: 10.1016/j.ijnsa.2023.100136.