



Home-based hybrid multicomponent exercise training in adults with diabetes and knee osteoarthritis

Yuni Astuti

Universitas Negeri Padang,
INDONESIA

Sameer Badri Al-Mhanna*

Saveetha Institute of
Medical and Technical
Sciences, INDIA & Al-
Qasim Green University,
IRAQ

Karrar Jasim Hamzah

Al-Qasim Green University,
IRAQ

Eldawaty

Universitas Negeri Padang,
INDONESIA

Erianti

Universitas Negeri Padang,
INDONESIA

Norsuhana Omar*

Universiti Sains Malaysia,
MALAYSIA

Haripah Lawanis

Universitas Negeri Padang,
INDONESIA

Ain' Sabreena Mohd
Noh

Universiti Sains Malaysia,
MALAYSIA

Marilyn Gilyana

University of Kalba,
UNITED ARAB EMIRATES

Mingyue Yin

Shanghai University of
Sport,
CHINA

Abubakar Ibrahim

Universiti Sains Malaysia,
MALAYSIA

Alexios Batrakoulis

European University Cyprus,
Nicosia, CYPRUS & Democritus
University of Thrace, GREECE

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Abstract

Background: Adults with type 2 diabetes mellitus (T2DM), excess adiposity, and knee osteoarthritis (OA) require exercise prescriptions that address cardiometabolic risk without unnecessarily increasing joint symptoms. **Aims:** This randomized controlled trial evaluated whether 12 weeks of home-based hybrid multicomponent exercise training (HMET) altered metabolic (FBG), hemodynamic (SBP/DBP), anthropometric (BMI), and walking-capacity (6MWD) outcomes in adults with diabetes and radiographic knee OA. **Methods:** Forty-two adults aged >50 years with T2DM, BMI ≥ 23 kg/m², and Kellgren-Lawrence grade 2–3 knee OA were randomized 1:1 to HMET (n = 21) or control (n = 21). HMET was performed three times weekly. Prespecified co-outcomes were BMI, fasting blood glucose (FBG), systolic and diastolic blood pressure (SBP/DBP), and 6-minute walk distance (6MWD). Group $\times$ time effects were evaluated using repeated-measures ANOVA; Holm-adjusted p-values were used as a multiplicity sensitivity analysis.

Results: The group $\times$ time interaction was strongest for FBG [F(1,40) = 8.83, nominal p = .005, Holm p = .025, partial η^2 = .18], with an HMET-versus-control difference in change of -82.0 mg/dL (95% CI -137.7 to -26.2). DBP showed a nominal interaction [F(1,40) = 4.31, p = .044, Holm p = .176, partial η^2 = .10; difference in change -4.9 mmHg, 95% CI -9.7 to -0.1], but did not remain statistically significant after multiplicity adjustment. Interactions for BMI, SBP, and 6MWD were not statistically significant. All 42 participants completed follow-up; HMET adherence was $\geq 90\%$, and no adverse events were recorded. **Conclusion:** Twelve-week home-based HMET produced a statistically significant FBG group $\times$ time effect after Holm adjustment and a more tentative DBP signal, without statistically significant evidence of parallel change in BMI, SBP, or 6MWD. These findings support further confirmatory trials with a prespecified primary endpoint and longer follow-up.

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* Corresponding authors:

Sameer Badri Al-Mhanna, Al-Qasim Green University, IRAQ, ✉sameerbadri9@gmail.com

Norsuhana Omar, Universiti Sains Malaysia, MALAYSIA, ✉suhanakk@usm.my

INTRODUCTION

Type 2 diabetes mellitus (T2DM), excess adiposity, and knee osteoarthritis (OA) commonly coexist in middle-aged and older adults and create a clinically difficult exercise phenotype. T2DM and adiposity increase cardiovascular and metabolic risk, whereas knee OA adds pain, impaired mobility, and reduced tolerance for sustained activity. In this study, diabetes denotes T2DM occurring with excess adiposity. This framing is particularly relevant in Asian populations, where cardiometabolic risk may occur at lower BMI values than in many Western populations ([American Diabetes Association Professional Practice Committee, 2024a, 2024b](#)). Recent umbrella-level evidence also supports an association between T2DM and OA that remains evident after accounting for age, sex, and obesity ([Vaishya et al., 2025](#)).

The interaction between metabolic disease and knee OA extends beyond mechanical loading. Excess body mass increases knee-joint stress, but contemporary models of metabolic OA also implicate dysregulated glucose and lipid metabolism, adipokine signaling, chronic low-grade inflammation, oxidative stress, and altered cartilage and subchondral-bone homeostasis ([Wei et al., 2023](#)). These pathways help explain why metabolic disease may influence OA independently of load alone. Clinically, this overlap is important because metabolic multimorbidity can modify rehabilitation response; in a cohort of 80,893 people receiving education and exercise for hip or knee OA, coexisting diabetes, hypertension, and obesity were associated with worse pain outcomes over follow-up ([Dell'Isola et al., 2024](#)). Exercise remains a core intervention across the three conditions, but the optimal prescription is not necessarily the same for each. Structured aerobic and resistance exercise is recommended for T2DM because it improves glycemic regulation, cardiovascular risk, and physical function ([Kanaley et al., 2022](#)). Exercise is likewise a first-line non-pharmacological treatment for knee OA, with contemporary evidence supporting benefits for pain and function across aerobic, strengthening, neuromotor, flexibility, and mixed modalities ([Lawford et al., 2024](#); [Marriott et al., 2024](#); [Yan et al., 2025](#)). The clinical task is therefore not to establish whether exercise is useful, but to identify a tolerable combination that can address metabolic and functional targets in the same multimorbid patient.

This prescription problem is especially relevant when joint symptoms constrain the intensity or volume of cardiometabolic exercise. Weight-bearing aerobic exercise may provide a strong metabolic stimulus but can be difficult to sustain when knee pain is prominent; resistance, neuromotor, or lower-load approaches may be more tolerable but can produce a different physiological profile. The TARGET randomized trial showed that both weight-bearing and non-weight-bearing exercise can improve outcomes in people with knee OA and obesity, with neither modality uniformly superior ([Bennell et al., 2020](#)). More recent evidence similarly supports modality-specific rather than universal effects, including short-term responses to low-intensity resistance approaches in older adults with knee OA ([Kim et al., 2024](#)) and network evidence favoring different modalities for different OA outcomes ([Yan et al., 2025](#)). Home-based delivery adds a pragmatic dimension by reducing travel, cost, and access barriers, but effectiveness depends on program design, progression, monitoring, and support. Meta-analyses indicate that home-based exercise can improve pain and physical function in knee OA and may approach center-based rehabilitation for several outcomes ([Mao et al., 2024](#); [Zhang et al., 2024](#)). More recent syntheses of home-based and remotely supported rehabilitation likewise show benefits for pain and selected functional outcomes while emphasizing heterogeneity in delivery and engagement ([Pasqualotto et al., 2025](#)). Thus, home delivery should be considered a mode of implementation rather than an intervention mechanism.

Parallel evidence from exercise medicine supports combining modalities in T2DM and excess adiposity. Combined and multicomponent exercise can improve cardiometabolic and physical-function outcomes, while the magnitude and pattern of response vary by exercise mode, dose, baseline phenotype, and intended endpoint ([Batrakoulis et al., 2022](#); [Khalafi et al., 2025, 2026](#); [Li et al., 2025](#); [Mengistu et al., 2025](#)). For blood pressure specifically, recent network evidence in T2DM suggests that baseline pressure and total activity dose may modify the magnitude of SBP and DBP responses ([Álvarez-Barbosa et al., 2026](#)). Hybrid multicomponent exercise training (HMET) aligns with this outcome-specific logic because it combines aerobic, resistance, balance, flexibility, and functional stimuli rather than relying on a single exercise mode. Hybrid and circuit-based programs have produced favorable adaptations in cardiometabolic health, musculoskeletal fitness, energy expenditure, body composition, and exercise behavior in adults with overweight or obesity

(Batrakoulis et al., 2020, 2021a, 2023; Chatzikamagianni et al., 2025; Gilyana et al., 2024; Govindasamy et al., 2024; Poullos et al., 2024). Importantly, home-based circuit-training trials have begun to extend this approach to adults with knee OA, T2DM, and excess weight (Al-Mhanna et al., 2024, 2026). These studies show that comorbidity-adapted home exercise is feasible. Still, they do not clarify whether metabolic, hemodynamic, anthropometric, and walking-capacity outcomes improve in parallel in a separate Indonesian cohort.

An evidence gap remains in whether a single, comorbidity-adapted home program produces concordant or domain-specific responses across metabolic, hemodynamic, anthropometric, and functional outcomes. OA trials traditionally prioritize pain, disability, strength, and mobility, whereas T2DM-obesity trials prioritize glycemia, body composition, blood pressure, lipids, and cardiorespiratory fitness. Even when multimorbidity is explicitly studied, outcome sets and intervention structures vary, and relatively few trials evaluate several clinically distinct domains within the same experiment. This matters because a multicomponent intervention may be physiologically broad in design but selective in its measurable effects. The present trial addresses that gap by evaluating a 12-week home-based HMET program in adults with T2DM, excess adiposity, and radiographic knee OA. We examined FBG, SBP, DBP, BMI, and 6MWD together to determine whether metabolic improvement was accompanied by hemodynamic, anthropometric, and walking-capacity adaptation. This outcome-spanning approach allows us to interpret the intervention as a response profile rather than a single favorable endpoint. Accordingly, this randomized controlled trial examined whether 12 weeks of home-based HMET performed three times per week would produce greater pre-to-post improvement than usual care in BMI, FBG, SBP, DBP, and 6MWD. We hypothesized that HMET would reduce BMI, FBG, SBP, and DBP and increase 6MWD relative to usual care, while allowing the magnitude of response to differ by physiological domain.

METHOD

Study Design and Ethical Oversight

This study was a two-arm, parallel randomized controlled trial with measurements at baseline and 12 weeks. Reporting was prepared with reference to applicable CONSORT 2025 recommendations (Hopewell et al., 2025). The Human Ethics Committee of Universitas Negeri Padang approved the protocol (ref. (number 010/KEPK-UNP/6/2025)). All participants received an explanation of the study procedures and provided written informed consent before enrollment. The research team handled study data confidentially and made them accessible only to the team.

Participants and Eligibility

We recruited participants from an existing population of patients with diabetes in Koto Tuo, Agam Regency, West Sumatra, Indonesia. Eligibility was determined through physical examination, medical history review, laboratory assessment, and radiographic confirmation of knee OA. Inclusion criteria were primary knee OA with T2DM and fasting glucose ≥ 126 mg/dL (American Diabetes Association Professional Practice Committee, 2024a); excess adiposity defined using an Asian-specific threshold of BMI ≥ 23 kg/m² (American Diabetes Association Professional Practice Committee, 2024b); Kellgren-Lawrence grade 2 or 3 knee OA; age >50 years; chronic knee pain for >3 months; and receipt of the usual physiotherapy regimen. Because recruitment was restricted to patients already identified as having diabetes, the study FBG criterion functioned as an additional eligibility requirement rather than the sole basis for initial case identification. Exclusion criteria were secondary knee OA, acute knee pain, a medication change during the preceding 3 months, intra-articular hyaluronic acid injection during the preceding year, dementia or psychiatric disease that could impair participation, and current smoking.

Sample Size Determination

We conducted an a priori power analysis in G*Power version 3.1.9.2 for the group $\times$ time interaction in a two-group, two-measurement repeated-measures design. With $\alpha = .05$, 80% power, a conventional medium planning effect ($f = .25$), an assumed repeated-measures correlation of .50, and $\epsilon = 1.0$, the minimum complete-case sample was 34. The effect-size and correlation values were planning assumptions, not estimates from an identical prior HMET trial. Allowing approximately

20% attrition increased the recruitment target to 41, which was rounded to 42 participants (21 per group).

Randomization and Participant Flow

We assessed 103 volunteers for eligibility. Sixty-one were excluded: 56 did not meet the inclusion criteria, four declined participation, and one was excluded for another screening reason. The remaining 42 participants were assigned study numbers and randomized 1:1 to HMET or control using a computer-generated sequence obtained from randomization.com. The sequence was implemented by a study researcher. The authors did not specify separate personnel for sequence generation, enrollment, and intervention assignment, and they did not document allocation concealment or blinded outcome assessment. Both groups were followed for 12 weeks. Baseline testing was completed during the week before intervention, and post-intervention testing was conducted five days after the final exercise session. Figure 1 shows participant flow.

HMET Intervention and Comparator

Participants allocated to HMET completed a home-based program three days per week for 12 weeks. The program used an intermittent multicomponent circuit integrating low-impact aerobic activity, functional and resistance exercise, balance training, and flexibility work, adapted from previous multicomponent and home-based circuit-training protocols (Al-Mhanna et al., 2024; Batrakoulis et al., 2023). Each session began with 5 min of low-impact warm-up and mobility work, followed by a circuit consisting of supported marching or step-touch, chair sit-to-stand, wall push-up, supported standing hip abduction, seated knee extension through a pain-free range, standing heel raises with support, and semi-tandem or tandem balance practice; calf and hamstring stretching were completed during the cool-down. During weeks 1–6, resistance/functional movements were performed for 15 repetitions (per side where applicable) for two rounds, aerobic stations for approximately 60 s, and balance holds for 20–30 s per side, targeting RPE 11–13 on the Borg 6–20 scale. During weeks 7–12, resistance/functional volume progressed to 30 repetitions per exercise for three rounds, aerobic stations to approximately 90 s, and balance holds to 30–45 s per side, targeting RPE 14–16. Participants were allowed 1 minute of passive recovery between exercises and rounds. Participants reduced exercise range, repetitions, or support when knee pain exceeded 5/10 during exercise or increased by >2 points from the pre-session level and remained elevated the following morning; sessions were stopped for acute joint swelling, chest pain, dizziness, or unusual dyspnea.

Participants received an instructional video and a logbook to record completed sessions, perceived exertion, symptoms, and potential adverse events. Researchers contacted participants weekly by telephone or text message to review progress and address exercise-related questions. The prespecified adherence criterion was completion of at least 90% of the 36 planned sessions. Both groups continued their prescribed medical management and usual physiotherapy; the control group did not receive the structured HMET program. The study did not standardize the frequency and content of usual physiotherapy, and it did not record exposure in sufficient detail to verify between-group comparability or allow component-level comparison.

Table 1. HMET Intervention and Comparator Specification

Component / Movement	Weeks 1–6	Weeks 7–12 / Progression
Setting and frequency	Home-based; 3 sessions/week (36 planned sessions)	Home based; 3 sessions/week; same weekly frequency
Warm-up	5 min: slow supported marching, ankle pumps, shoulder rolls, gentle knee/hip mobility	5 min; same sequence with slightly larger comfortable movement amplitude
Aerobic station	Supported marching in place or low-impact step-touch; ~60 s/round	~90 s/round; cadence increased only if joint symptoms remained acceptable
Chair sit-to-stand	15 repetitions; use chair arms or external support if needed	30 repetitions; reduce hand support when tolerated
Wall push-up	15 repetitions	30 repetitions; greater body inclination used only if RPE remained below target
Supported hip abduction	15 repetitions/side; upright posture with chair support	30 repetitions/side; less upper-limb support when balance allowed
Seated knee extension	15 repetitions/side through pain-free range	30 repetitions/side; maintain pain-free range and controlled tempo
Standing heel raise	15 repetitions with chair/wall support	30 repetitions; progress toward lighter hand support

Component / Movement	Weeks 1–6	Weeks 7–12 / Progression
Balance station	Semi-tandem or tandem stance, 20–30 s/side	30–45 s/side; progress stance difficulty before removing support
Circuit dose	2 rounds; 1-min passive recovery between exercises and rounds	3 rounds; 1-min passive recovery between exercises and rounds
Intensity target	Borg RPE 11–13	Borg RPE 14–16
Flexibility / cool-down	5 min: calf and hamstring stretching, 20–30 s/side, plus slow breathing	5 min: same stretches, 30–45 s/side, plus slow breathing
Pain-modification rule	Reduce range/repetitions/support demand if knee pain >5/10 during exercise or >2 points above pre-session level the next morning	Same rule; regress to prior tolerated dose when symptoms exceed threshold
Safety stop criteria	Stop for acute joint swelling, chest pain, dizziness, or unusual dyspnea; contact study team	Same criteria
Monitoring and adherence	Instructional video, logbook, weekly researcher contact; adherence target $\geq 90\%$ of 36 sessions	Same monitoring; progression reviewed during weekly contact
Comparator	Both groups continued prescribed medical management and usual physiotherapy	Control received no structured HMET; usual care otherwise continued

Note. RPE = rating of perceived exertion. Progression was symptom-contingent: participants were instructed to preserve controlled movement quality and remain within the specified knee-pain monitoring rule rather than complete the target dose at the expense of joint tolerance.

Outcome Measures and Measurement Procedures

The prespecified outcomes were BMI, FBG, resting SBP and DBP, and cardiovascular functional capacity assessed by 6MWD. BMI was calculated as body mass in kilograms divided by height squared in meters. We measured FBG from venous blood obtained after a 12-hour overnight fast. Blood was collected into heparinized sterile tubes, kept chilled until processing, and centrifuged at 1,500 rpm for 15 min at 4°C; plasma aliquots were stored at –70°C until analysis using the Radox Glucose GOD-PAP reagent (catalog GL8318; Radox Laboratories Ltd., Crumlin, United Kingdom) according to the manufacturer's instructions for quantitative glucose determination in plasma. Resting SBP and DBP were measured using an automated oscillometric monitor (OMRON HEM-907XL; OMRON Healthcare, Kyoto, Japan) with an appropriately sized upper-arm cuff. Participants rested seated for at least 5 min with back supported, feet flat on the floor, legs uncrossed, and the measurement arm supported at heart level. We obtained three readings at 1-min intervals and used the mean of the final two readings for analysis. Participants completed the 6-minute walk test on a flat 30-m indoor corridor with standardized instructions and encouragement; total distance walked in 6 min was recorded in meters. These procedures were selected to standardize anthropometric, metabolic, hemodynamic, and functional assessment across the two measurement occasions.

Safety Monitoring and Adherence

We recorded potential adverse events in participant logbooks and reviewed them during weekly contact and scheduled study visits. An adverse event was defined as any unfavorable medical occurrence, symptom, injury, or illness arising during the intervention period. Adherence was calculated as completed HMET sessions divided by the 36 planned sessions $\times 100$ and was cross-checked using logbooks and weekly contact records.

Statistical Analysis

We analyzed data using IBM SPSS Statistics version 27.0. We evaluated data-entry accuracy and distributional assumptions before inferential analysis. Because there were only two time points, the sphericity assumption does not apply. Continuous baseline variables are presented as mean $\pm$ SD; Cohen's d is reported descriptively to show standardized baseline separation rather than to test randomization success. We analyzed each of the five prespecified co-outcomes using a 2 (group: HMET vs control) $\times$ 2 (time: baseline vs 12 weeks) repeated-measures ANOVA, with the group $\times$ time interaction representing the intervention effect. Partial η^2 is reported as an effect-size index. Because the analysis plan did not specify a single hierarchical primary endpoint or family-wise multiplicity correction, we report nominal p -values cautiously; we present Holm-adjusted p -values across the

five co-outcomes as a post hoc multiplicity sensitivity analysis. For FBG and DBP, we report the between-group difference in change ($\Delta\text{HMET} - \Delta\text{control}$) and its 95% confidence interval from the interaction contrast. We set statistical significance at $p < .05$. All randomized participants completed follow-up and were analyzed in their assigned groups; therefore, the intention-to-treat and per-protocol analysis sets were identical.

RESULTS AND DISCUSSION

Results

All 42 randomized participants (21 HMET and 21 control) completed the 12-week follow-up and were analyzed in their originally assigned groups. No participant was lost to follow-up; no intervention discontinuation or major protocol deviation was recorded; all HMET participants completed at least 90% of planned sessions; and no adverse event was documented. Figure 1 presents participant flow from screening through analysis.

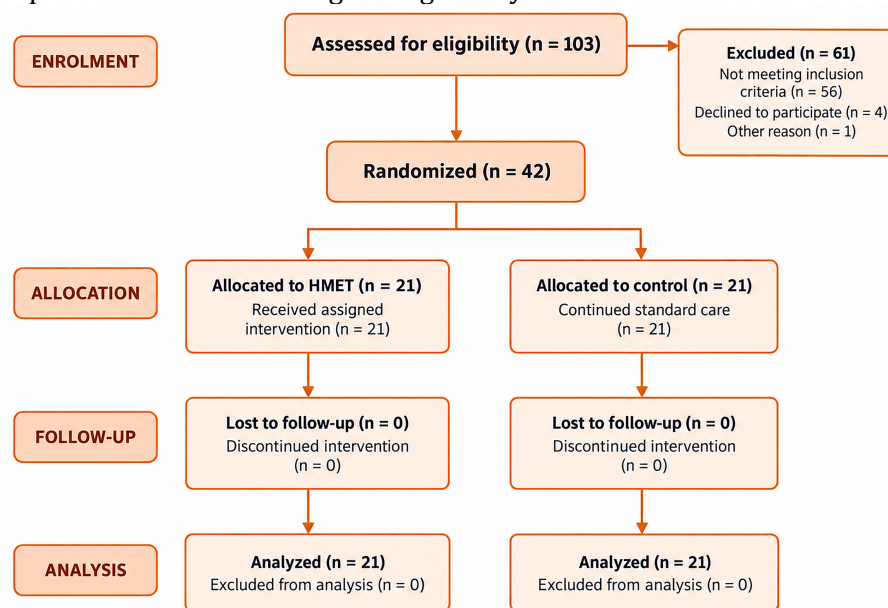


Figure 1. CONSORT-Style Participant Flow through Screening, Randomization, Follow-Up, and Analysis

Figure 1 summarizes screening, randomization, follow-up, and analysis. All 42 randomized participants contributed post-intervention data. Complete follow-up reduces attrition-related bias but does not resolve uncertainty regarding allocation concealment, assessor blinding, or between-group co-intervention exposure.

Table 2 presents baseline characteristics. Table 2 shows age, BMI, blood pressure, FBG, and 6MWD for each randomized group, along with descriptive standardized differences. These values describe the realized sample after randomization and are not used to test randomization quality. Sex, diabetes duration, medication class, Kellgren-Lawrence grade distribution, and OA pain severity were not included in the baseline reporting available for this manuscript and should be considered when interpreting generalizability.

Table 2. Baseline Characteristics of Randomized Participants

Variable	HMET (n = 21), mean $\pm$ SD	Control (n = 21), mean $\pm$ SD	Cohen's d
Age (years)	54.96 $\pm$ 11.85	56.59 $\pm$ 9.41	-0.15
BMI (kg/m ²)	24.46 $\pm$ 2.13	24.45 $\pm$ 2.12	0.00
SBP (mmHg)	138.96 $\pm$ 15.01	138.47 $\pm$ 15.90	0.03
DBP (mmHg)	85.92 $\pm$ 5.48	84.82 $\pm$ 5.05	0.21
FBG (mg/dL)	218.58 $\pm$ 8.70	216.92 $\pm$ 9.74	0.18
6MWD (m)	443.52 $\pm$ 105.92	425.06 $\pm$ 55.09	0.21

Note. BMI = body mass index; DBP = diastolic blood pressure; FBG = fasting blood glucose; HMET = hybrid multicomponent exercise training; SBP = systolic blood pressure; 6MWD = 6-minute walk distance. Cohen's d values are descriptive; positive values indicate higher HMET means.

Table 2 shows modest, realized baseline separation across the reported variables (absolute Cohen's $d = 0.00\text{--}0.21$). These descriptive differences provide context for the sample but should not be interpreted as evidence for or against the validity of randomization.

Table 3 summarizes the prespecified group $\times$ time tests for all five outcomes. FBG showed the strongest signal and was the only interaction that remained below .05 after Holm adjustment. DBP met the nominal .05 threshold but did not remain statistically significant after multiplicity adjustment, whereas BMI, SBP, and 6MWD did not meet the nominal threshold. The inferential profile is therefore interpreted according to effect magnitude, multiplicity-adjusted evidence, and clinical context rather than nominal significance alone.

Table 3. Group $\times$ Time Effects of 12-Week HMET on Prespecified Outcomes

Outcome	F(1, 40)	Nominal p	Holm-adjusted p	Partial η^2
FBG	8.83	.005	.025	.18
DBP	4.31	.044	.176	.10
BMI	2.40	.128	.384	.06
SBP	1.10	.300	.600	.03
6MWD	0.13	.720	.720	.003

Note. Nominal p-values correspond to the prespecified group $\times$ time interaction tests. Holm-adjusted p-values provide a post hoc family-wise multiplicity sensitivity analysis across the five co-outcomes. Partial η^2 is reported as the effect-size index. Only the FBG interaction remained below .05 after Holm adjustment. Figure 2 reports original-unit interaction contrasts with 95% confidence intervals for FBG and DBP.

As shown in Table 3, FBG had the largest interaction [$F(1,40) = 8.83$, nominal $p = .005$, Holm $p = .025$, partial $\eta^2 = .18$]. DBP had a smaller nominal interaction [$F(1,40) = 4.31$, $p = .044$, Holm $p = .176$, partial $\eta^2 = .10$]. Figure 2 re-expresses these findings in a more outcome-centered format by showing both observed group means and treatment-effect estimates with 95% confidence intervals.

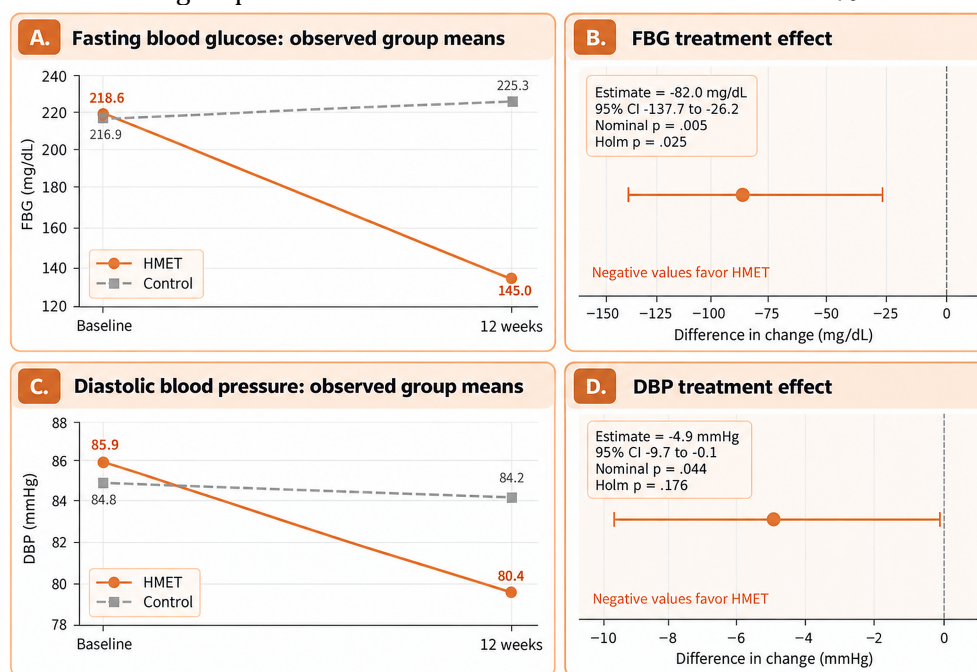


Figure 2. (A) FBG changes in HMET and control groups. (B) FBG treatment effect with 95% CI. (C) DBP changes in HMET and control groups. (D) DBP treatment effect with 95% CI.

Figure 2 shows that FBG and DBP moved in a direction favoring HMET, but the strength of evidence differed. For FBG, the between-group difference in change was -82.0 mg/dL (95% CI -137.7 to -26.2), and the group $\times$ time interaction remained below .05 after Holm adjustment. For DBP, the corresponding difference in change was -4.9 mmHg (95% CI -9.7 to -0.1). Still, the Holm-adjusted p-value remained above .05. Presenting both the mean profiles and the treatment contrasts makes the magnitude, direction, and precision of these two leading signals more transparent.

Figure 3 synthesizes the interaction evidence across all five prespecified outcomes by displaying F statistics, partial η^2 , nominal p values, and Holm-adjusted p values in a single response-profile dashboard. This integrated view complements Table 3 and helps readers compare relative signal strength across outcomes without inferring equivalence from non-significant tests.

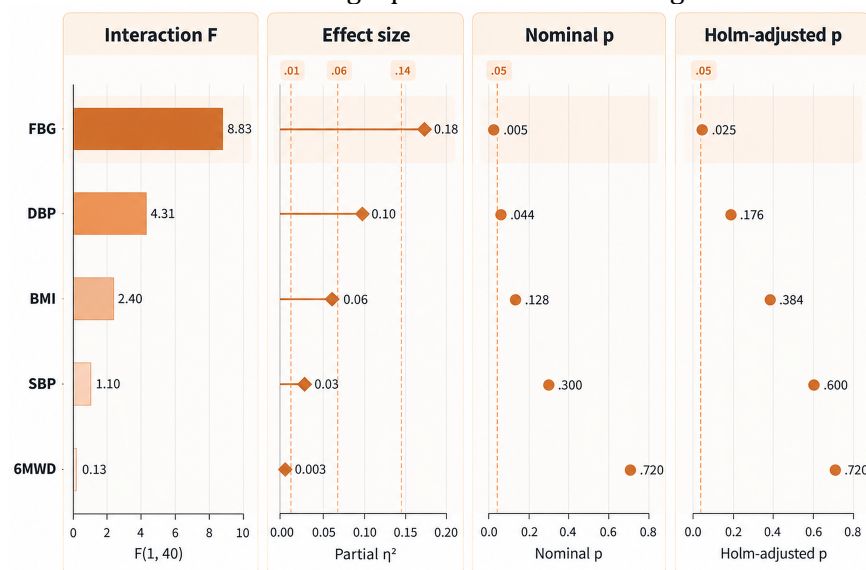


Figure 3. Integrated response profile across prespecified outcomes, showing interaction F statistics, partial η^2 , nominal p values, and Holm-adjusted p values. Dashed guideposts at partial $\eta^2 = .01, .06$, and $.14$ aid effect-size interpretation; $p = .05$ is shown in the p-value panels. Only FBG remained below $.05$ after Holm adjustment.

Figure 3 shows convergent evidence that FBG carried the strongest interaction signal across all four summary indicators. DBP ranked second by both F statistic and partial η^2 but lost evidential strength after multiplicity adjustment. BMI showed a modest effect-size estimate without nominal significance, whereas SBP and 6MWD had comparatively small interactions. This profile reinforces the interpretation that HMET generated selective rather than parallel adaptation across outcome domains.

Discussion

The trial demonstrated a selective response profile across metabolic, hemodynamic, anthropometric, and functional domains rather than a uniform pattern of improvement across all targeted outcomes. Evidence was strongest for FBG, which remained statistically significant after Holm adjustment, whereas DBP showed only a nominal signal and BMI, SBP, and 6MWD did not reach statistical significance. This differentiated pattern matters because it suggests that the physiological effects of HMET were outcome-specific rather than distributed across all measured domains. A multicomponent intervention may simultaneously expose participants to aerobic, resistance, balance, flexibility, and functional stimuli. Still, these components do not necessarily generate adaptations of comparable magnitude or within the same time frame. Metabolic variables may respond relatively rapidly to repeated muscular activity and altered substrate utilization. In contrast, anthropometric or functional outcomes may require a longer intervention period, a greater cumulative training dose, or more outcome-specific progression. Consequently, interpreting the intervention through a simple significant/non-significant framework would obscure meaningful differences in the magnitude and direction of responses. The overall profile instead supports a domain-sensitive interpretation in which HMET appears to have produced its clearest short-term effect on glycemic regulation, with substantially weaker evidence for simultaneous adaptation in other physiological systems.

The FBG finding is consistent with contemporary evidence that structured exercise can improve cardiometabolic health in T2DM and excess adiposity. At the same time, the magnitude of response depends on exercise modality, intensity, dose, baseline metabolic status, and the characteristics of

the population being treated ([Kanaley et al., 2022](#); [Batrakoulis et al., 2022](#); [Mengistu et al., 2025](#)). This perspective is particularly relevant to HMET because the intervention combines several training stimuli rather than relying on a single exercise mode. The marked FBG response therefore may reflect the cumulative metabolic demand generated by repeated aerobic and resistance-based activity within the same program. At the same time, the absence of comparable effects across all outcomes reinforces the principle that exercise should be selected and progressed according to the intended clinical target rather than being viewed as a physiologically homogeneous exposure. For patients with T2DM and knee OA, this distinction is especially important because maximizing metabolic stimulus must be balanced against musculoskeletal tolerance. The present study extends this literature to an Indonesian sample with radiographic knee OA, a population in which pain, reduced mobility, and joint-loading constraints may limit the amount or intensity of exercise that can be safely accumulated. From this perspective, the FBG result is clinically meaningful not simply because glucose declined, but because the improvement occurred within a home-based program specifically designed to accommodate coexisting metabolic and musculoskeletal limitations.

Several physiological mechanisms could plausibly contribute to the observed glycemic response, although the present study did not directly measure them. Repeated skeletal-muscle contraction can promote glucose uptake through both insulin-dependent and insulin-independent pathways, thereby increasing peripheral glucose disposal during and after exercise. Resistance-oriented components may also help preserve or increase metabolically active muscle tissue, whereas aerobic and interval-like components can increase energy expenditure, post-exercise oxygen consumption, and substrate oxidation ([Batrakoulis et al., 2021b](#); [Bo et al., 2023](#); [Jiang et al., 2024](#)). Within a multicomponent program, these processes may operate concurrently and could partly explain why glycemic regulation showed a clearer response than BMI or walking capacity. Repeated exposure across three weekly sessions may also have produced cumulative metabolic effects even if each session was relatively moderate and adapted to knee symptoms. Nevertheless, mechanistic interpretation should remain conservative because insulin sensitivity, glucose transport, skeletal-muscle adaptation, and substrate oxidation were not directly quantified. Fasting glucose is also influenced by short-term dietary behavior, medication adherence, stress, sleep, timing of the preceding exercise bout, and normal biological variability. Accordingly, interpret the present result primarily as a group-level treatment signal rather than evidence that every participant experienced a comparable or clinically identical improvement in glucose control. The finding therefore supports the metabolic potential of HMET while simultaneously emphasizing the need for future studies to combine glucose measures with HbA1c, insulin-related indices, and repeated metabolic assessments.

The DBP finding requires even greater caution because its statistical support was less robust than that observed for FBG. Exercise may lower blood pressure through multiple pathways, including reduced peripheral vascular resistance, improved endothelial function, favorable changes in autonomic balance, and increased arterial compliance, and structured exercise remains an important component of cardiovascular risk management in people with T2DM ([Kanaley et al., 2022](#)). However, blood-pressure adaptation depends heavily on baseline cardiovascular status, antihypertensive medication, exercise dose, modality, and the duration over which training is sustained. Recent dose-response network evidence further suggests that baseline blood pressure and overall physical-activity exposure influence the magnitude of both SBP and DBP responses in T2DM ([Álvarez-Barbosa et al., 2026](#)). In the present study, DBP moved in a favorable direction. Still, the effect was modest; the confidence interval approached the null, and the nominal p-value of .044 did not remain significant after Holm adjustment. This distinction matters because reporting DBP as definitively improved would overstate the evidence. A more appropriate interpretation is that HMET may have produced an early or modest hemodynamic signal that deserves confirmation in a larger trial. The absence of an SBP interaction further indicates that vascular adaptation was not uniform across blood-pressure components. This discrepancy may reflect limited statistical precision, relatively moderate baseline blood-pressure elevation, medication-related stabilization, or an exercise stimulus that was sufficient to influence diastolic regulation but not strong or prolonged enough to produce consistent systolic change.

The BMI result should likewise not be interpreted as evidence that HMET did not influence body composition or energy balance. BMI is a relatively crude anthropometric indicator because it does not distinguish between fat mass and fat-free mass and is insensitive to regional changes in adiposity.

Consequently, reductions in fat mass could be partly offset by preservation or gain of lean tissue, producing little net change in BMI despite physiologically meaningful adaptation. Concurrent and multicomponent exercise effects on body composition depend on training dose, intervention duration, baseline adiposity, and nutritional exposure (Khalafi et al., 2025). This limitation is particularly relevant in a 12-week program in which exercise was designed not solely for weight reduction but also for metabolic regulation, functional capacity, balance, and joint tolerance. Multicomponent and body-weight exercise can generate substantial physiological loading and energy expenditure without necessarily producing a detectable reduction in BMI over a relatively short period (Chatzikamagianni et al., 2025; Gilyana et al., 2024; Poullos et al., 2024). The stable BMI observed here may therefore indicate that body mass was less responsive than glucose regulation, rather than demonstrating an absence of body-composition adaptation. Future trials should include waist circumference, percentage body fat, visceral adiposity, lean mass, and preferably direct or validated body-composition measures. These outcomes would allow investigators to determine whether HMET induces favorable recomposition not captured by BMI and to examine whether changes in body composition mediate subsequent improvements in metabolic or functional health.

The lack of a statistically significant 6MWD interaction also requires contextual interpretation rather than being treated as evidence of no functional benefit. Walking performance in individuals with knee OA represents the combined influence of aerobic capacity, knee pain, muscular strength, balance, confidence, pacing strategy, gait mechanics, and day-to-day symptom fluctuation (Lawford et al., 2024; Yan et al., 2025). Therefore, improvements in one or more physiological components of function may not necessarily translate into a sufficiently large increase in six-minute walking distance within 12 weeks. Home-based rehabilitation can improve pain and selected dimensions of physical function, although the magnitude of benefit varies according to supervision, exercise content, adherence, and the outcome used to quantify functional change (Mao et al., 2024; Pasqualotto et al., 2025; Zhang et al., 2024). Exercise dose is another important consideration, because higher doses do not invariably produce proportionally greater clinical improvement in knee OA (Torstensen et al., 2023), while lower-intensity approaches can remain clinically useful for selected older adults who may not tolerate more demanding loading (Kim et al., 2024). In the present program, training progression was intentionally constrained by knee symptoms and safety considerations, which may have favored adherence and metabolic benefit but limited the sustained aerobic volume needed to markedly improve walking endurance. The 6MWD may also have been insufficiently sensitive to changes in pain, balance, movement confidence, or task-specific function. Future studies could therefore combine 6MWD with OA-specific pain and function scales, gait measures, chair-rise performance, lower-limb strength, and objective activity monitoring. A longer intervention or a more explicitly endurance-oriented component may also be required to determine whether improvements in walking capacity emerge after metabolic and early functional adaptations have already occurred.

Implications

The selective pattern is particularly relevant in metabolic multimorbidity. Dell'Isola et al. (2024) showed that diabetes, hypertension, and obesity can be associated with poorer pain trajectories after education and exercise for OA, suggesting that comorbidity alters rehabilitation response rather than simply adding diagnoses. The present RCT approaches the same problem from a different direction: a multicomponent program designed to accommodate both metabolic and musculoskeletal constraints still produced domain-specific effects. Together, these observations argue against a one-size-fits-all concept of exercise for patients with complex OA and support monitoring multiple outcomes so that progression can be adjusted to the patient's dominant clinical priorities. The feasibility observations are encouraging but should not be generalized beyond the monitored trial context. All randomized participants completed follow-up, HMET adherence was at least 90%, and no adverse event was recorded. Home-based exercise and remotely supported rehabilitation can reduce access barriers and achieve clinically useful outcomes in knee OA (Mao et al., 2024; Pasqualotto et al., 2025; Zhang et al., 2024), while prior hybrid programs suggest that structured progression can support exercise behavior and adherence in adults with obesity (Batrakoulis et al., 2020). In the present trial, instructional video, logbooks, and weekly contact likely supported

implementation. These supports are part of the intervention context and should not be assumed to occur in routine care without equivalent resources.

Research Contributions

The principal contribution of this trial is therefore the response profile rather than the generic observation that exercise can be beneficial. Previous home-based circuit trials in adults with knee OA and diabetes have reported improvements across broader cardiometabolic, functional, and quality-of-life outcomes. The current study adds a separate Indonesian setting, a distinct sample size and protocol specification, and simultaneous analysis of FBG, blood pressure, BMI, and walking capacity. The contrast between the Holm-adjusted FBG signal and weaker signals elsewhere illustrates why multicomponent programs should not be assumed to produce parallel adaptation across all physiological systems.

Limitations

Several limitations constrain inference. First, the sample was small and drawn from a single Indonesian setting, limiting precision and external validity. Second, the authors did not document allocation concealment or assessor blinding, leaving a potential risk of bias. Third, the authors did not standardize or describe usual physiotherapy in sufficient detail, so they could not verify comparability of co-intervention exposure between groups. Fourth, adherence relied partly on self-report despite weekly cross-checking, and the study did not use an objective wearable measure of training dose. Fifth, the authors did not report sex, Kellgren-Lawrence distribution, diabetes duration, medication classes, OA pain severity, diet, habitual physical activity, or sleep in sufficient detail for effect-modification analyses. Sixth, the study did not include HbA1c, insulin resistance, direct body-composition measures, inflammatory biomarkers, or OA-specific pain/function outcomes. Finally, the authors did not prespecify a single hierarchical primary endpoint. However, the Holm-adjusted analysis strengthens the FBG finding; the DBP signal remains exploratory, and the non-significant outcomes should not be interpreted as evidence of equivalence.

Suggestions

Future trials should prespecify a primary endpoint, use larger multicenter samples, document allocation concealment and assessor masking where feasible, and quantify intervention fidelity using objective session-level measures in addition to logs and researcher contact. Repeated glucose assessment, HbA1c, medication and dietary tracking, direct body-composition measures, OA-specific pain/function scales, and objective activity monitoring would provide a more complete response phenotype. Longer follow-up is also needed to determine whether glycemic changes persist and whether functional adaptation emerges later. Factorial or dose-response designs could test whether greater aerobic exposure improves SBP and walking capacity without compromising knee tolerability. At the same time, resistance-focused progression could target lean mass and functional reserve.

CONCLUSION

In adults with T2DM, excess adiposity, and knee OA, 12 weeks of home-based HMET performed three times per week produced a statistically significant group $\times$ time effect for fasting blood glucose that remained below .05 after Holm correction. DBP showed a smaller nominal effect that did not remain significant after multiplicity adjustment, while BMI, SBP, and 6MWD did not show statistically significant differential change. HMET may therefore be a feasible adjunct to usual care with particular promise for short-term glycemic control at the group level. The overall response profile nevertheless indicates that a multicomponent exercise program should not be assumed to produce parallel adaptation across all cardiometabolic and functional domains.

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AUTHOR CONTRIBUTION STATEMENT

A., S.B.A.-M., N.O., and A.B. contributed to the conceptualization of the study. Methodological development was undertaken by Y.A., S.B.A.-M., K.J.H., N.O., M.G., M.Y., and A.B. Data collection and investigation were conducted by Y.A., K.J.H., E., E.R., and H.L., with E. and E.R. providing research resources. Data curation was performed by Y.A., K.J.H., E., H.L., and A.I., while formal analyses were conducted by S.B.A.-M., A.S.M.N., M.Y., and A.I. Validation was undertaken by N.O., A.S.M.N., M.G., M.Y., and A.B., and visualization was prepared by S.B.A.-M., A.S.M.N., and M.G. Y.A. and H.L. coordinated project administration, while E.R., N.O., and A.B. provided supervision. Y.A. and S.B.A.-M. prepared the original draft, and all authors contributed to reviewing and editing the manuscript. All authors reviewed and approved the final version submitted for publication.

AI DISCLOSURE STATEMENT

During manuscript preparation, the authors used ChatGPT (OpenAI) for language editing, structural formatting, and refinement of data visualizations. The tool was not used for data collection, statistical analysis, or generating or altering study results. The authors critically reviewed and edited all AI-assisted output and take full responsibility for the scientific content, interpretation, reference accuracy, integrity, and the final submitted manuscript.

CONFLICTS OF INTEREST

The authors declare no financial, institutional, or personal conflict of interest that could have influenced the conduct of the study, analysis of the data, preparation of the manuscript, or publication.

DATA AVAILABILITY STATEMENT

Participant-level data are not available for secondary reanalysis or public sharing. The aggregate statistical results and study information required to interpret the findings are reported in this article.

ETHICAL APPROVAL

The Human Ethics Committee of Universitas Negeri Padang approved the study (Approval No. 010/KEPK-UNP/6/2025). All participants received an explanation of the study and provided written informed consent before participation. The trial was conducted in accordance with the Declaration of Helsinki.

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