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Changes in VAI and LAP as effective markers of obesity in non-athletic postmenopausal women after ten weeks of combined training

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Abstract

Purpose: Menopause is associated with increased visceral adiposity and worsening cardiometabolic risk, and physically inactive postmenopausal women may be particularly vulnerable. This study aimed to examine the effects of 10 weeks of combined (aerobic–resistance) training on visceral adiposity indices LAP and VAI, as well as triglycerides (TG), in inactive postmenopausal women. **Method:** This quasi-experimental study used a pretest–posttest design with a control group. A total of 24 inactive postmenopausal women were randomly assigned to a combined training group or a control group (n = 12 each). The training group completed 10 weeks of aerobic exercise at approximately 65–75% HRmax and resistance training at about 55–65% 1RM. Fasting blood samples were obtained at baseline and post-intervention, and LAP and VAI were calculated using anthropometric and lipid variables. **Results:** In the control group, LAP did not change significantly (p=0.117), whereas it decreased significantly in the training group (p=0.001), with a significant between-group difference in change (p=0.021). For VAI, the control group showed no significant change (p=0.379), while the training group demonstrated a significant reduction (p =0.001), and the between-group difference in change was significant (p=0.001). TG did not change significantly in the control group (p=0.231) but decreased significantly in the training group (p=0.001), with a significant between-group difference in change (p=0.003). **Conclusion:** Ten weeks of combined aerobic–resistance training improves visceral adiposity indices (LAP and VAI) and triglyceride levels in inactive postmenopausal women, supporting concurrent training as a practical non-pharmacological strategy to reduce cardiometabolic risk.

Keywords: Menopause; Training; Lipid Accumulation Product; Visceral Adiposity Index; Triglycerides.

Introduction

Menopause defined as the permanent cessation of menstruation for at least 12 consecutive months due to the loss of ovarian follicular activity—typically occurs around midlife and marks a major biological transition for women (Sarmadiyan et al., 2016). In physically inactive postmenopausal women, a cluster of somatic and psychological complaints such as hot flashes, mood disturbances (e.g., anxiety/depressive symptoms), and reductions in physical function can negatively influence overall well-being and, importantly, reduce engagement in regular physical activity (Sarmadiyan et al., 2016; Lee et al., 2014). From a cardiometabolic perspective, menopause is frequently accompanied by unfavorable changes in body-fat distribution, with a tendency toward greater central and visceral adiposity (Barrett-Connor, 2013; Milla et al., 2023). Visceral fat accumulation is closely linked to insulin resistance and heightened cardiometabolic risk and, in many contexts, may predict metabolic complications more strongly than general obesity indicators alone (Milla et al., 2023; Barrett-Connor, 2013). Therefore, simple and low-cost indices of visceral adiposity—such as the lipid accumulation product (LAP) and the visceral adiposity index (VAI)—have gained attention as practical clinical tools for estimating visceral fat–related risk and monitoring intervention responses in vulnerable populations, including inactive postmenopausal women (Milla et al., 2023; Kahn, 2005; Amato et al., 2010).

LAP is a clinical marker of visceral adiposity calculated using waist circumference and fasting triglycerides, commonly expressed in women as (WC − 58) × TG (Kahn, 2005; Milla et al., 2023). Because LAP integrates an anthropometric parameter (waist circumference) with a metabolic parameter (triglycerides), it may capture the combined structural–metabolic burden underlying metabolic syndrome and cardiometabolic risk more effectively than some single-dimension indices (Milla et al., 2023; Kahn, 2005). Evidence from exercise interventions suggests that physical activity can improve LAP; for example, a continuous aerobic walking program has been reported to

significantly reduce LAP following the intervention period (Baqersalimi et al., 2020). In the same line, significant group × time interactions for LAP have been documented, indicating a more favorable trajectory in exercising participants compared with non-exercising controls across the intervention period (Baqersalimi et al., 2020).

VAI is another widely used surrogate of visceral fat dysfunction, computed from waist circumference, BMI, triglycerides, and HDL-C; for women, a commonly cited formula is [WC/{36.58 + (1.89 × BMI)}] × (TG/0.81) × (1.52/HDL-C) (Amato et al., 2010; Milla et al., 2023). This index is proposed to reflect visceral adipose tissue function indirectly and has been associated with cardiometabolic outcomes such as insulin resistance and type 2 diabetes risk (Milla et al., 2023; Amato et al., 2010). Exercise training appears capable of improving VAI; for instance, 12 weeks of high-intensity interval training was reported to significantly reduce VAI in women (e.g., from 33.37 ± 8.28 to 30.11 ± 7.62, p < 0.05) (Faryadian et al., 2020). Similarly, aerobic training studies have reported significant group × time interactions for VAI, with a tendency toward improvement in exercise groups relative to controls (Baqersalimi et al., 2022)..

Because both LAP and VAI are mathematically dependent on components such as waist circumference, BMI, triglycerides, and HDL-C, interventions that improve body composition and lipid profiles are theoretically positioned to reduce both indices simultaneously (Milla et al., 2023; Amato et al., 2010). Combined (concurrent) aerobic–resistance training is particularly relevant for inactive postmenopausal women because it merges cardiorespiratory adaptations with muscular and metabolic benefits within a single program (Sarmadiyan et al., 2016). Practical models of combined training in this population have included ~10 weeks of exercise with aerobic intensity around 65–75% of maximal heart rate alongside resistance training at approximately 55–65% of one-repetition maximum (Sarmadiyan et al., 2016). Empirical findings in postmenopausal women suggest that such combined training can improve health-related outcomes (e.g., certain

dimensions of quality of life and functional indicators), supporting its feasibility and clinical relevance (Sarmadiyan et al., 2016). However, despite the increasing use of LAP and VAI as pragmatic markers of visceral adiposity, evidence specifically addressing the effects of combined aerobic–resistance training on these two indices in inactive postmenopausal women remains limited and warrants focused investigation (Milla et al., 2023; Sarmadiyan et al., 2016).

Given the central role of visceral adiposity in the development of insulin resistance and cardiovascular risk, identifying and monitoring changes in visceral-fat–related indices in inactive postmenopausal women is a meaningful clinical and public health priority (Milla et al., 2023; Barrett-Connor, 2013). At the same time, more direct or "gold-standard" assessments of visceral fat and metabolic risk can be costly and less accessible in routine or field settings, which strengthens the rationale for using low-cost indices such as LAP and VAI to evaluate intervention effectiveness (Milla et al., 2023; Kahn, 2005; Amato et al., 2010). Furthermore, it has been emphasized that well-designed exercise programs and additional research are needed to reach clearer conclusions regarding optimal exercise strategies in postmenopausal women (Sarmadiyan et al., 2016). Therefore, the aim of the present study is to examine the effect of 10 weeks of combined (aerobic–resistance) training on visceral adiposity–related indices, specifically LAP and VAI, in physically inactive postmenopausal women.

Methods

Study design and participants

This study was conducted using a quasi-experimental design with a pretest–posttest control-group framework. Following the approach used in exercise-intervention research, 24 physically inactive postmenopausal women were recruited and randomly assigned to either a combined training group or a control group (n = 12 per group).

Inclusion criteria were: being postmenopausal; no regular exercise participation in recent months; no use of relevant hormonal/pharmacological therapies; no intake of antioxidant supplements; absence of major chronic diseases (e.g., cardiovascular, pulmonary, metabolic disorders, etc.); and non-smoking status. Exclusion criteria included non-compliance or withdrawal, frequent absence from training sessions, occurrence of injury or a new illness during the intervention, and major changes in medication or supplement use throughout the study period.

The training program was implemented for 10 weeks and consisted of aerobic exercise at 65–75% of maximal heart rate and resistance training at 55–65% of one-repetition maximum (1RM). Aerobic sessions (e.g., treadmill walking/running or comparable cyclic activities) were performed while controlling intensity through heart-rate monitoring. The resistance component included selected multi-joint and single-joint exercises (e.g., bench press, lat pulldown, biceps curl, triceps extension, leg press, knee extension/flexion, etc.) according to the prescribed intensity. To evaluate LAP and VAI, standard anthropometric assessments were performed, including height, body mass, BMI, and waist circumference. Blood samples were collected under fasting conditions (at least 12 hours) at a fixed morning time-point; samples were obtained before the intervention and after completion of the program (approximately 48 hours after the final session), then centrifuged at 3000 rpm, and the serum was stored at −80°C. For index calculation, the required variables (TG and HDL-C along with waist circumference and BMI) were measured, and LAP and VAI were computed using their respective equations. VAI and LAP indices were calculated according to the following formula.

Women VAI= [WC / 36.58 + (1.89 × BMI)] × (TG / 0.81) × (1.52 / HDL).

Women LAP= (WC − 58) × TG.

For statistical analysis, data normality was first assessed using the Shapiro–Wilk test. To compare within- and between-group changes,

repeated-measures analysis of variance (general linear model; GLM) with a group × time interaction was applied, and when the interaction was significant, Bonferroni post-hoc tests were used. The significance level was set at $p < 0.05$, and analyses were performed using SPSS software.

Results
Participant Characteristics

Baseline anthropometric characteristics and metabolic variables were comparable between the two groups at pre-test. In the control group, body weight changed slightly from 74.29±9.04 kg to 74.21±9.13 kg, whereas in the combined training group it decreased from 80.86±10.70 kg to 78.37±10.31 kg. Body mass index (BMI) remained almost unchanged in the control group (28.74±3.48 to 28.71±3.51 kg/m²), while a reduction was observed in the training group (32.43±4.85 to 31.44±4.74 kg/m²). Waist circumference decreased minimally in the control group (97.74±6.59 to 97.38±6.24 cm) but showed a marked reduction in the training group (98.64±4.95 to 93.74±5.49 cm). Triglyceride (TG) levels and HDL-C showed negligible changes in the control group, whereas favorable changes were observed in the training group following the intervention (Table 1).

Table 1. Baseline Anthropometric Characteristics (Pre-test)

Variable	Control (Mean ± SD)	Training (Mean ± SD)
Weight (kg)	74.29 ± 9.04	80.86 ± 10.70
BMI (kg/m²)	28.74 ± 3.48	32.43 ± 4.85
Waist Circumference (cm)	97.74 ± 6.59	98.64 ± 4.95

*Significant sign

Data normality was assessed using the Shapiro–Wilk test. As shown in diagram number one (Chart 1), within- and between-group comparisons for the LAP were performed using repeated-measures analysis of variance (GLM) with a group × time interaction and Bonferroni post-hoc tests. In the control group, LAP showed a non-significant change from 73.78±23.03 to 71.70±22.46 (P=0.117). In contrast, the combined training group demonstrated a significant reduction in LAP from 76.64±20.90 to 59.57±19.32 (P=0.001). Between-group comparison of change scores revealed a significantly greater reduction in LAP in the training group compared with the control group (P =0.001).
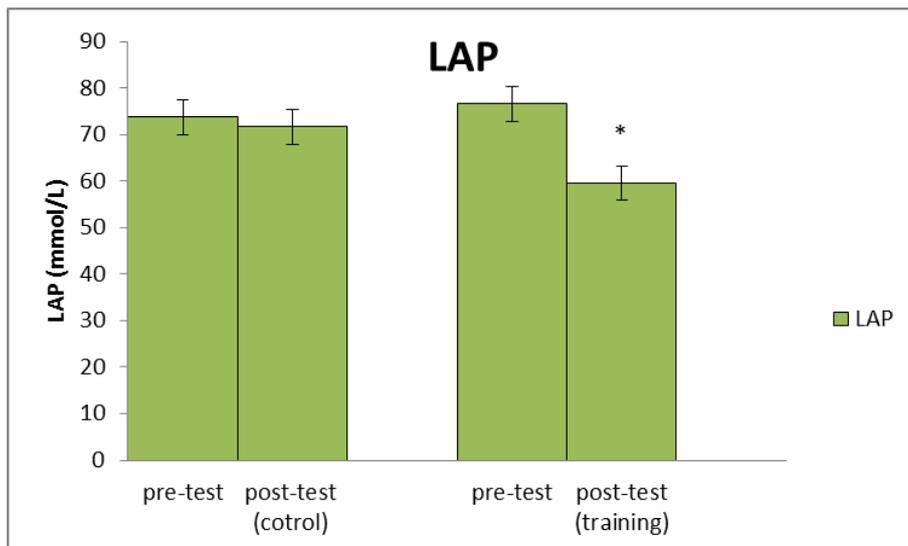

Chart 1. Pre-test and post-test values of ALP

As shown in diagram number one (Chart 2), for the VAI, within- and between-group analyses were conducted using the same statistical approach. In the control group, VAI decreased slightly from 3.14±1.12 to 3.00±1.06, which was not statistically significant (P=0.379). However, in the combined training group, VAI decreased significantly from 3.45±1.03 to 2.78±0.84 (p=0.001). The between-group

comparison confirmed that the reduction in VAI was significantly greater in the training group than in the control group (P=0.001).
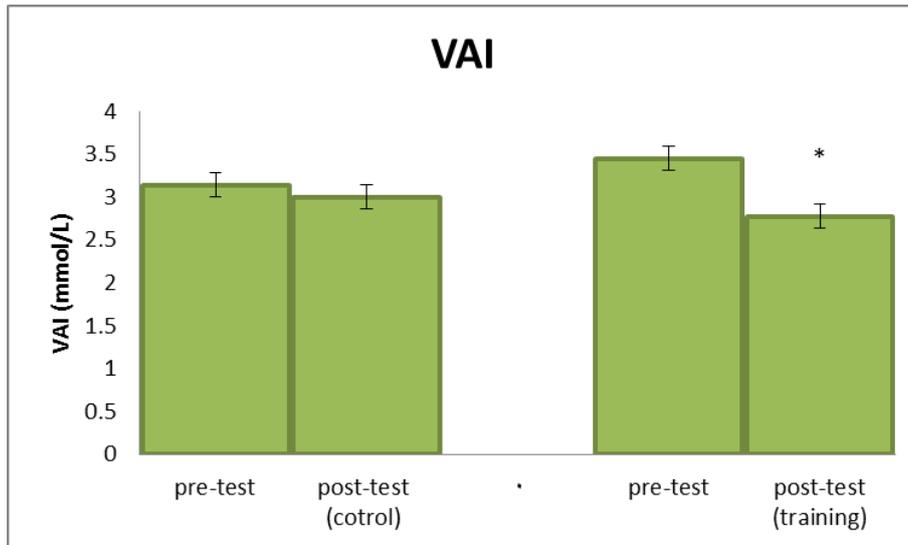

Chart 2. Pre-test and post-test values of VAI

As shown in diagram number one (Chart 3), for the triglycerides, within-group analysis showed no significant change in the control group (1.84±0.46 to 1.80±0.47 mmol/L, P=0.231). In contrast, the training group exhibited a significant reduction from 1.88 ± 0.42 to 1.65±0.40 mmol/L (P=0.001). Between-group comparison of changes indicated a significantly greater decrease in triglyceride levels in the combined training group compared with the control group (P= 0.003).
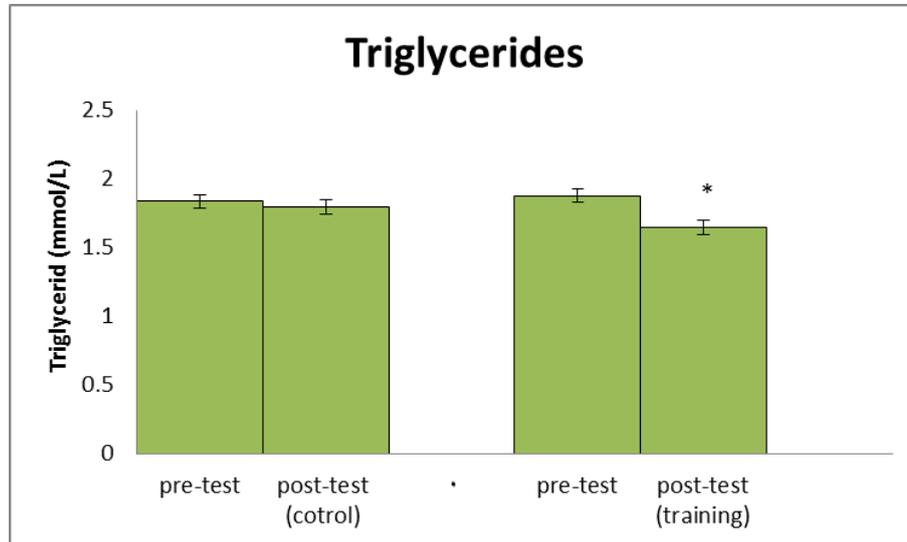
Chart 3. Pre-test and post-test values of triglycerides

Discussion

The menopause transition is associated with distinct cardiometabolic changes, including a tendency toward central fat accumulation and deterioration of lipid-related risk, which makes lifestyle strategies particularly important in postmenopausal women (El Khoudary et al., 2020). In this context, the present study demonstrates that a 10-week concurrent (aerobic–resistance) training program improves visceral-adiposity–related surrogate markers and triglyceride status in previously inactive postmenopausal women, whereas minimal change is observed in the control condition (Sarmadiyan et al., 2016). Improvements in LAP and VAI are clinically meaningful because these indices combine anthropometric and lipid inputs that are strongly linked to cardiometabolic risk and may reflect changes in visceral fat function rather than body weight alone (Amato et al., 2010; Kahn, 2005). Taken together, the main findings suggest that combined training is a feasible non-pharmacological approach to attenuate menopause-related risk trajectories by targeting central adiposity surrogates and lipid metabolism (Bernal et al., 2025; Paluch et al., 2024).

Regarding LAP, our findings indicate that concurrent training reduces lipid accumulation product in inactive postmenopausal women, supporting the responsiveness of this index to exercise-based interventions (Kahn, 2005This result is consistent with evidence showing that structured aerobic training can reverse unfavorable trends in LAP-related risk markers in female cohorts (Baghersalimi et al., 2020). The direction of change also aligns with interventional work indicating that exercise can improve composite indices that incorporate triglycerides and central adiposity, particularly when the program is long enough and adequately supervised (Mohammadi et al., 2022; Rao et al., 2019). From a mechanistic perspective, concordant findings are plausible because LAP is derived from waist circumference and fasting triglycerides, both of which can improve through enhanced lipid oxidation, reduced hepatic VLDL-TG production, and reductions in abdominal adiposity with training (Kahn, 2005; Lemes et al., 2018). However, some studies report smaller or non-significant changes in lipid-related indices when baseline dyslipidemia is mild, intervention dose is insufficient, or dietary intake is not controlled, which can attenuate the net effect on LAP (Bernal et al., 2025; He et al., 2023). Additionally, heterogeneity across studies is expected because LAP is mathematically sensitive to changes in TG and waist circumference, and the relative contribution of each component may differ by phenotype, adherence, and training intensity (Ioachimescu et al., 2010; Taverna et al., 2011).

For VAI, the current results show that concurrent training improves the visceral adiposity index, which is consistent with the conceptual framework that VAI indirectly captures visceral fat dysfunction using BMI, waist circumference, triglycerides, and HDL-C (Amato et al., 2010). This finding aligns with observational evidence linking higher physical activity to more favorable VAI profiles, suggesting behavioral sensitivity of this index across weight strata (Tao et al., 2024). It is also in agreement with interventional research in women and other metabolic-risk populations showing reductions in VAI following structured training, including programs emphasizing aerobic or

combined modalities (Faryadian et al., 2020; Mohammadi et al., 2022). Moreover, recent randomized work has increasingly used VAI as a clinically convenient outcome in combined training trials, reinforcing its relevance as an accessible surrogate for metabolic phenotype changes in obesity-related contexts (Ronsani et al., 2025). In contrast, some studies report variable VAI responsiveness, likely because VAI requires coordinated improvement across multiple components, and a lack of change in HDL-C or TG may blunt the overall index shift even if waist circumference improves (Amato et al., 2010; He et al., 2023Differences in menopausal status, baseline obesity, medication use, and program characteristics (duration, intensity progression, and adherence) further contribute to inconsistent VAI outcomes across the literature (Bernal et al., 2025; Uddenberg et al., 2024).

Concerning triglycerides (TG) as the third study variable, our findings indicate that concurrent training reduces TG in inactive postmenopausal women, which is consistent with broader evidence that exercise training improves elements of the lipid profile (Bernal et al., 2025; Smart et al., 2025). This result is coherent with meta-analytic data showing that resistance training can reduce TG in postmenopausal females, with larger effects often observed in those with obesity or dyslipidemia and in shorter interventions of sufficient intensity (He et al., 2023). Our triglyceride improvement is also consistent with systematic evidence that aerobic training can reduce waist circumference and increase HDL-C in cardiometabolic-risk populations, which together may support better lipid handling and lower TG exposure (Lemes et al., 2018). Because TG is a component of both LAP and VAI, TG reductions likely contributed directly to the observed improvements in these composite indices in the training group (Amato et al., 2010; Kahn, 2005). However, discordant TG responses are reported in some trials, particularly when baseline TG is within normal limits, energy balance is unchanged, or dietary fat/carbohydrate intake is not monitored, which may partially explain variability across studies (Bernal et al., 2025; Kim et al., 2019). These observations support the idea that the magnitude of lipid response depends on baseline risk phenotype and the achieved

training "dose" (frequency × intensity × duration) rather than exercise modality alone (Paluch et al., 2024; Smart et al., 2025).

Several limitations should be considered when interpreting the present findings. First, LAP and VAI are surrogate indices and do not directly quantify visceral adipose tissue via imaging, which may limit mechanistic interpretation of "true" VAT change (Amato et al., 2010; Rao et al., 2019). Second, composite indices are mathematically dependent on multiple components (e.g., waist, BMI, TG, HDL-C), making it difficult to isolate which physiological pathway primarily drove improvement without additional biomarkers or imaging (Amato et al., 2010; Kahn, 2005). Third, dietary intake and other lifestyle factors (sleep, stress, non-exercise activity) may confound lipid and waist outcomes if not rigorously controlled, which is a commonly noted limitation in exercise trials (Bernal et al., 2025; Smart et al., 2025). Future studies should (a) include dietary monitoring/standardization, (b) incorporate imaging-based VAT assessments or validated ultrasound proxies alongside LAP/VAI, and (c) compare concurrent training with isolated aerobic and isolated resistance arms matched for energy expenditure to clarify additive effects (Rao et al., 2019; Paluch et al., 2024). In addition, longer follow-up with detraining assessments could determine the durability of improvements and identify the minimum maintenance dose needed for sustained benefit in postmenopausal inactive women.

Conclusion

In conclusion, the findings of the present study demonstrate that ten weeks of combined aerobic–resistance training significantly improve visceral adiposity–related indices, namely the Lipid Accumulation Product (LAP) and the Visceral Adiposity Index (VAI), as well as triglyceride levels in physically inactive postmenopausal women.

While no meaningful changes were observed in the control group, participants who engaged in concurrent training exhibited significant

reductions in all primary outcome variables, highlighting the sensitivity of these indices to structured exercise interventions.

Given that LAP and VAI integrate anthropometric and lipid parameters associated with cardiometabolic risk, their improvement suggests favorable alterations in visceral fat distribution and metabolic function. Importantly, these changes occurred within a relatively short intervention period, supporting the practicality and clinical relevance of moderate-intensity concurrent training for this population.

Considering the increased cardiometabolic vulnerability associated with menopause, especially among physically inactive women, combined aerobic–resistance training appears to be an effective, accessible, and non-pharmacological strategy for reducing central adiposity surrogates and improving lipid metabolism. Future research incorporating dietary control, longer follow-up periods, and direct measures of visceral fat would further clarify the mechanisms and long-term sustainability of these benefits.

Overall, the present study reinforces the value of structured concurrent exercise programs as a preventive and therapeutic approach to attenuate menopause-related cardiometabolic risk and promote healthier aging trajectories in postmenopausal women.

Institutional Review Board Statement:

Not applicable.

Informed Consent Statement:

Not applicable.

Acknowledgments:

Conflicts of Interest:

There are no conflicts of interest.

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