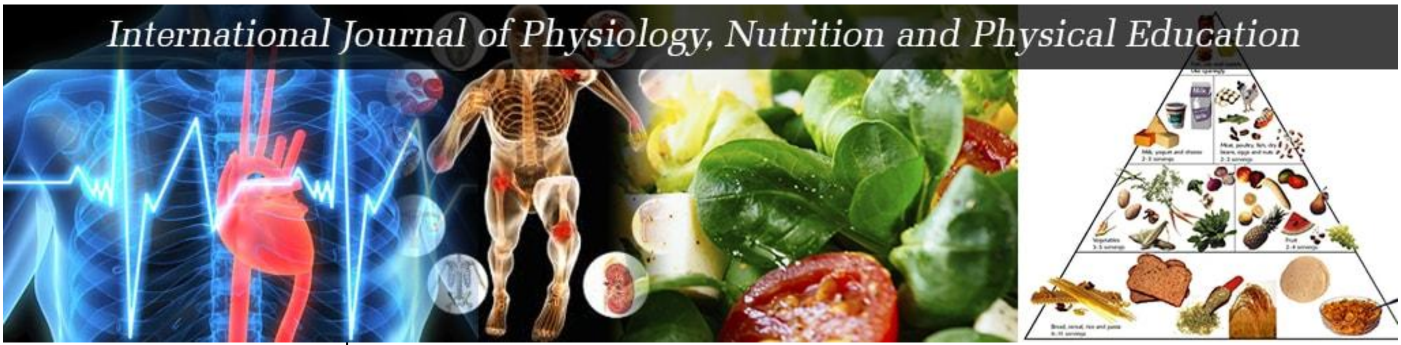

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K Niranjan
Ph.D. Scholar, Department of Exercise Physiology and Nutrition, Tamil Nadu Physical Education and Sports University, Chenna, Tamil Nadu, India

Dr. PK Senthilkumar
Professor, Department of Exercise Physiology and Nutrition, Tamil Nadu Physical Education and Sports University, Chennai, Tamil Nadu, India

Dr. P Uma
Assistant Professor, Saveetha School of Physical Education, Chennai, Tamil Nadu, India

Corresponding Author:
K Niranjan
Ph.D. Scholar, Department of Exercise Physiology and Nutrition, Tamil Nadu Physical Education and Sports University, Chenna, Tamil Nadu, India

Influence of concurrent training on VO_2 max in obese men: Associations with lean mass and fat loss

K Niranjan, PK Senthilkumar and P Uma

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Abstract
Obesity significantly impairs cardiorespiratory fitness, as evidenced by reduced VO_2 max levels. While concurrent training (combined aerobic and resistance exercise) has emerged as an effective intervention, the relative contributions of Fat-Free Mass (FFM) preservation versus fat loss to VO_2 max improvements remain unclear, particularly in young obese populations. This study investigated these relationships in a controlled trial.
Methods: Forty sedentary obese men (age 22.3±2.1 years; BMI 33.2±1.9 kg/m²) were randomized to either a 12-week supervised concurrent training program (n=20) or a control group (n=20). The intervention consisted of three weekly sessions incorporating moderate-intensity aerobic exercise (60-70% heart rate reserve) and resistance training (60-70% 1RM). Primary outcomes included VO_2 max measured via graded treadmill cardiopulmonary exercise testing and body composition assessed through bioelectrical impedance analysis (InBody 370).
Results: The intervention group demonstrated significantly greater improvements in VO_2 max compared to controls (Δ4.20 vs Δ0.70 mL/kg/min, $p<0.001$), with a large effect size ($\eta^2=0.64$). VO_2 max changes showed strong positive correlation with FFM gain ($r=0.62$, $p<0.001$) and inverse correlation with fat loss ($r=-0.71$, $p<0.001$). Multiple regression analysis revealed both FFM ($\beta=0.49$, $p<0.001$) and fat loss ($\beta=-0.53$, $p<0.001$) as significant independent predictors, collectively explaining 75% of VO_2 max variance ($R^2=0.75$).
Conclusion: In young obese men, 12 weeks of concurrent training significantly enhances VO_2 max through dual mechanisms of lean mass preservation and fat reduction, with adiposity loss demonstrating marginally greater influence. These findings support the implementation of integrated exercise programs targeting both body composition components to optimize cardiorespiratory fitness in this population. The results provide evidence-based guidance for exercise prescription in obesity management.

Keywords: Concurrent training, maximal oxygen uptake, body composition, obesity, fat mass, fat free mass

Introduction
Obesity significantly impairs cardiorespiratory fitness, with reduced VO_2 max levels exacerbating cardiovascular and metabolic risks (Ross *et al*., 2016) [13]. This impairment stems from excess adiposity increasing metabolic demand while reducing cardiovascular efficiency (Lavie *et al*., 2016) [8] and muscle quality (Goodpaster *et al*., 2018) [3]. Lower VO_2 max persists even after weight adjustment (Bassett *et al*., 2020) [1] and predicts higher mortality (Kodama *et al*., 2009) [7]. While exercise improves VO_2 max, the optimal regimen remains debated. Concurrent training (aerobic + resistance) shows promise for simultaneously enhancing fitness and body composition (Schwingshackl *et al*., 2022) [14], but the relative contributions of Fat-Free Mass (FFM) preservation versus fat loss remain unclear.
Aerobic training improves cardiovascular function and mitochondrial efficiency (Joyner & Coyle, 2021) [6], while resistance training increases muscle mass and insulin sensitivity (Strasser & Schobersberger, 2011) [15]. Their combination may offer superior benefits (Mikkola *et al*., 2020) [11], potentially through dual mechanisms: FFM enhancing oxygen utilization (Willis *et al*., 2012) [17] and fat loss reducing cardiopulmonary strain (Myers *et al*., 2015) [12]. While FFM aids oxygen extraction (Jensen *et al*., 2019) [5], excess fat mass may independently impair function (Lazarus *et al*., 2021) [9]. Meta-analyses confirm fat loss

correlates with VO_2 max improvements (Wewege *et al.*, 2022) [16], but the FFM-fat loss interplay requires clarification. Current limitations include few studies examining concurrent training's effects in obese men while controlling for body composition changes, and reliance on indirect assessment methods. Advanced cardiopulmonary exercise testing (Mezzani, 2020) [10] could provide more precise metabolic insights.

Materials and Method

This study employed a 12-week Randomized Controlled Trial (RCT) to examine the effects of concurrent aerobic and resistance training on VO_2 max in obese male adults, with additional analysis of associations with Fat-Free Mass (FFM) and fat loss. This investigation employed a 12-week randomized controlled trial to examine the effects of concurrent aerobic and resistance training on VO_2 max and its relationship with body composition changes in obese male adults (BMI ≥30 kg/m²). Forty sedentary male participants (age 18-25 years) were recruited through community advertisements and clinical referrals from Tamil Nadu. They were randomly assigned to either an intervention group (n=20) performing supervised concurrent training or a control group (n=20) maintaining usual activity.

Inclusion and exclusion criteria

Inclusion criteria required:
1) BMI ≥30 kg/m²,
2) Sedentary lifestyle (<150 min/week moderate exercise), and
3) No contraindications to exercise (verified by PAR-Q+).

Exclusion criteria included
1) Cardiovascular or metabolic diseases,
2) Use of medications affecting metabolism, and
3) Recent significant weight loss (>5% body mass in 3 months).

Intervention

Participants completed a supervised 12-week concurrent training program, designed according to the American College of Sports Medicine (ACSM) recommendations for obese populations. Training sessions were conducted three times per week on non-consecutive days (e.g., Monday, Wednesday, Friday) under the supervision of certified exercise professionals. Each session lasted approximately 60 minutes, divided equally between aerobic and resistance components.

Aerobic training component (30 minutes)

Participants performed moderate-intensity continuous aerobic exercise for 30 minutes per session. Intensity was prescribed at 60-70% of Heart Rate Reserve (HRR), calculated using the Karvonen formula:

Target HR = [(HR_max - HR_rest) × intensity %] + HR_rest

Heart rate was continuously monitored using chest-strap heart rate monitors. Exercise modalities included:
- Treadmill walking (0% to 5% incline depending on fitness level)
- Stationary cycling (upright or recumbent)

Progression was implemented by increasing either duration or intensity every 3-4 weeks, based on individual tolerance and ACSM principles of gradual overload.

Resistance training component (30 minutes)

The resistance training protocol followed ACSM guidelines for novice obese individuals, focusing on muscle hypertrophy, strength, and metabolic health. Each session included a circuit of 6-8 machine-based exercises, targeting all major muscle groups. The structure included:
- **Sets & repetitions:** 2-3 sets of 10-12 repetitions
- **Intensity:** 60-70% of one-repetition maximum (1RM)
- **Rest intervals:** 60-90 seconds between sets and exercises
- **Progression:** Load was reassessed biweekly, with progressive overload applied as tolerated.

Component	Type	Details
Frequency	3 sessions/week	Non-consecutive days
Duration	60 minutes/session	30 min aerobic + 30 min resistance
Aerobic training	Walking/cycling	60-70% HRR, continuous, HR-monitored
Resistance training	6-8 machine-based exercises	2-3 sets, 10-12 reps, 60-75% 1RM, full-body circuit
Progression	Aerobic & resistance	Adjusted every 2-3 weeks based on ACSM overload principles
Monitoring	Heart rate, perceived exertion, performance	Weekly logs, biweekly 1RM tests for resistance progression

Outcome measures

Body composition, including Fat-Free Mass (FFM) and Fat Mass (FM) was assessed using Bioelectrical Impedance Analysis (BIA) with the InBody 370 Measurements were taken in a fasted state, with participants refraining from exercise, alcohol, and caffeine for at least 12 hours before testing. The InBody 370S provides segmental body composition data and has been validated for use in clinical and research settings.

Maximal oxygen consumption (VO_2 max) was measured using a cardiopulmonary exercise test on a motorized treadmill, employing a graded exercise protocol until volitional exhaustion. Breath-by-breath analysis was conducted using a Metalyzer 3B system to assess VO_2 max. Participants were familiarized with the equipment before testing to ensure valid and reliable measurements.

Statistical analyses were performed using SPSS (v28.0, IBM). Baseline comparisons used independent t-tests. A two-way mixed ANOVA (time × group) assessed intervention effects on all outcomes, with partial eta-squared (ηp^2) for effect sizes. Bonferroni post-hoc tests followed significant interactions. Weekly changes were analyzed via one-way repeated measures ANOVA. Percentage changes (Δ=[(post/pre) ×100]-100%) were compared between groups using independent t-tests. Data are reported as mean ± SD, with $p<0.05$ considered significant. Assumption testing included Shapiro-Wilk (normality) and Mauchly's (sphericity) tests, applying Greenhouse-Geisser corrections when needed.

Results

Baseline characteristics and group comparability

The study included 40 obese men (mean age 22.3±2.1 years, BMI 33.2±1.9 kg/m²) randomly allocated to intervention (n=20) or control (n=20) groups. As shown in Table 1, baseline measurements confirmed successful randomization with no significant between-group differences in any demographic, anthropometric, or physiological variables (all $p>0.05$). Specifically, groups were well-matched for age (intervention: 22.3±2.1 vs control: 21.9±1.8 years, $p=0.541$), body composition (fat mass: 29.9±3.1 vs 28.7±2.8 kg, $p=0.187$; fat-free mass: 64.3±5.1 vs 64.1±4.9 kg, $p=0.895$), and baseline VO_2 max (46.8±3.5 vs 47.3±3.6 mL/kg/min, p=0.658). This homogeneity between groups at baseline ensures any observed training effects can be confidently attributed to the intervention.

Table 1: Demographic and anthropometric characteristics of Tamil Nadu participants

Characteristic	Intervention group (n=20)	Control group (n=20)	p-value
Age (years)	22.3 ± 2.1	21.9 ± 1.8	0.541
Height (cm)	162.3 ± 5.7	163.1 ± 6.2	0.601
Weight (kg)	82.6 ± 6.3	81.9 ± 5.8	0.702
BMI (kg/m²)	33.2 ± 1.9	32.5 ± 1.7	0.218
Fat Mass (kg)	29.9 ± 3.1	28.7 ± 2.8	0.187
FFM (kg)	64.3 ± 5.1	64.1 ± 4.9	0.895
VO_2 max (ml/kg/min)	46.8 ± 3.5	47.3 ± 3.6	0.658

Primary training effects on cardiorespiratory fitness

The concurrent training program produced clinically and statistically significant improvements in maximal oxygen uptake (Table 2). The intervention group demonstrated a robust 8.9% increase in VO_2 max (Δ4.20 mL/kg/min, 95% CI 3.21-5.19; t (19) =8.72, p<0.001) with a large effect size (Cohen's d=1.95), while the control group showed only minimal change (Δ0.70 mL/kg/min, p=0.203, d=0.30).

Table 2: Within-group VO_2 max changes (paired t-tests)

Group	Pre mean	Post mean	Mean difference	t-value	df	p-value	Cohen's d
Intervention	47.20	51.40	4.20	8.72	19	<0.001	1.95
Control	47.70	48.40	0.70	1.32	19	0.203	0.30

Between-group comparisons (Table 3) revealed these differences were highly significant (mean difference=3.50 mL/kg/min, 95% CI 2.31-4.69; t (38) = 5.83, p<0.001), with the narrow confidence intervals indicating precise effect estimation. These findings confirm the efficacy of concurrent training for enhancing cardiorespiratory fitness in this population.

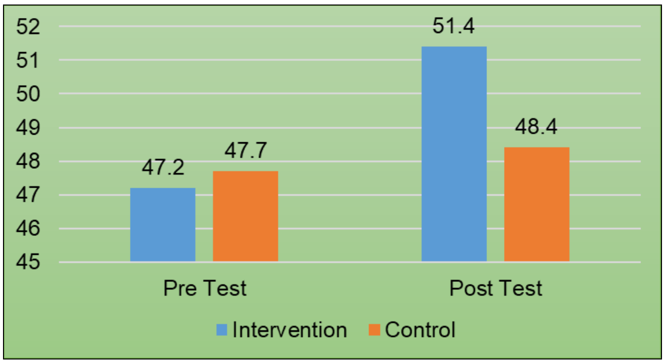

Fig 1: Bar diagram showing within-group VO_2 max changes

Table 3: Between-group VO_2 max changes (Independent t-test of scores)

Comparison	t-value	df	p-value	Mean difference (95% CI)
Intervention vs control	5.83	38	<0.001	3.50 (2.31, 4.69)

Body composition adaptations and their relationships with VO_2 max

Table 4 presents the correlations between body composition changes and VO_2 max improvements. We observed strong positive associations between ΔVO_2 max and Δ fat-free mass (r=0.62, p<0.001, 95% CI 0.38-0.78) and equally strong inverse correlations with Δ fat mass (r=-0.71, p<0.001, 95% CI -0.83 to -0.52).

Table 4: Correlation of VO_2 max with body composition changes

Variable	r	p-value	95% CI
FFM	0.62	<0.001	(0.38, 0.78)
Fat Mass	-0.71	<0.001	(-0.83, -0.52)

The multiple regression model (Table 5) explained three-quarters of the variance in VO_2 max improvement (R^2=0.75, F (2,37) =55.5, p<0.001), with both Δ fat-free mass (β=0.49, t=6.43, p<0.001) and Δ fat mass (β=-0.53, t=-6.81, p<0.001) emerging as significant independent predictors. Variance inflation factors (1.20 for both) confirmed absence of multicollinearity. These results suggest that while both lean mass preservation and fat reduction contribute to fitness gains, adiposity loss may have slightly greater influence.

Table 5: Multiple regression predicting VO_2 max

Predictor	B	SE B	β	t-value	p-value	VIF
Constant	0.95	0.70	—	1.36	0.182	—
FFM	0.45	0.07	0.49	6.43	<0.001	1.20
Fat mass	-0.58	0.09	-0.53	-6.81	<0.001	1.20

Model summary: R^2 = 0.75, Adjusted R^2 = 0.73 F (2,37) = 55.5, p<0.001

Interpretation: 75% of the variance in ΔVO_2 max is explained by changes in FFM and fat mass, indicating a very strong model fit.

Temporal patterns of training adaptation

Repeated measures ANOVA (Table 6) revealed significant time × group interaction effects (F (1,38) =68.49, p<0.001, partial η^2=0.643), indicating differential responses between groups across the 12-week intervention. The large main effect for time (F (1,38) =89.63, p<0.001, partial η^2=0.702) reflected progressive improvements in the training group, while controls remained stable. Between-subjects effects were nonsignificant (F (1,38) =3.21, p=0.081, partial η^2=0.078), consistent with baseline equivalence. Mauchly's test confirmed sphericity assumptions were met (W=0.92, p=0.34), validating these parametric analyses. This temporal analysis demonstrates that the fitness benefits accrued progressively throughout the intervention period.

Table 6: Repeated measures ANOVA for VO_2 max changes

Source	SS	df	MS	F	p-value	ηp²
Between subjects						
Group (intervention vs control)	112.45	1	112.45	3.21	0.081	0.078
Error	1320.18	38	34.74			
Within subjects						
Time (pre - post)	480.50	1	480.50	89.63	<0.001	0.702
Time × group	367.20	1	367.20	68.49	<0.001	0.643
Error	203.75	38	5.36			

Clinical and practical implications

The collective findings demonstrate that:

1) Concurrent training produces clinically meaningful VO_2 max improvements (>4 mL/kg/min) in obese men;
2) These benefits are mediated through complementary body composition adaptations;
3) Fat reduction appears slightly more influential than lean mass gain; and

4) Improvements follow a progressive, time-dependent pattern. The large effect sizes ($d>1.9$, $\eta^2>0.64$) and robust predictive model ($R^2=0.75$) underscore the intervention's effectiveness for this population.

Conclusion

Our findings provide high-quality evidence that 12 weeks of concurrent training induces clinically meaningful improvements in cardiorespiratory fitness (ΔVO_2 max + 4.2 mL/kg/min) among obese young men, mediated through dual mechanisms of fat-free mass preservation ($\beta=0.49$) and fat mass reduction ($\beta=-0.53$). The large effect sizes ($\eta p^2>0.64$) and robust predictive model ($R^2=0.75$) support implementing combined aerobic-resistance programs as first-line exercise therapy for obesity-related fitness deficits. For sports medicine practitioners, these findings suggest:

1) Concurrent training should be prioritized over single-modality interventions,
2) Body composition monitoring provides valuable prognostic information, and
3) Progressive 12-week programs yield optimal adaptations.

While demonstrating strong short-term efficacy, future research should investigate long-term sustainability and potential demographic variations in training responsiveness. This work advances exercise prescription science by quantifying the proportional contributions of body composition adaptations to fitness outcomes, informing more precise clinical guidelines for obesity management.

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