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Anthropometric and Lipid Responses to 24 Week Yoga in College Women with Polycystic Ovary Syndrome

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ABSTRACT:

Background: Central adiposity and dyslipidemia are two cardiometabolic burdens of polycystic ovary syndrome (PCOS), but anthropometric and lipid abnormalities are only loosely related, and few trials measure both across a sustained intervention.

Objective: To evaluate the effect of a 24-week supervised yoga programme on waist–hip ratio (WHR) and serum total cholesterol in college women with PCOS under free-living conditions.

Methods: A single-blind, two-arm, parallel-group pragmatic randomized controlled trial was conducted at KL Deemed to be University, India. Of 310 students assessed for eligibility, 131 women aged 18–25 years were randomized to Yoga (n = 65) or Control (n = 66). WHR and serum total cholesterol were the co-primary outcomes. The Yoga group received supervised 60-minute sessions five days weekly for 24 weeks, incorporating Sukshma Vyayama, Om chanting, Surya Namaskar, asanas, mudras, pranayama, breath-watching meditation and a quick relaxation technique. Controls continued usual activity without additional intervention. Eleven withdrew (5 Yoga, 6 Control), leaving 120 for per-protocol analysis. Groups were compared at baseline and Week 24 using independent-samples t-tests.

Results: At Week 24, mean WHR was 0.76 versus 0.89 and mean total cholesterol 176.79 versus 193.40 mg/dL in the Yoga and Control groups (both $p < .001$). Relative to baseline, WHR fell 14.6% and total cholesterol 8.9% under yoga, against +1.1% and -1.0% in controls.

Conclusion: A 24-week supervised yoga programme was associated with substantially lower Week-24 WHR and total cholesterol than usual activity. Comparisons apply to group means; the magnitude of the WHR difference warrants independent replication

1. INTRODUCTION

Polycystic ovary syndrome (PCOS) is a common endocrine and metabolic disorder affecting women during the reproductive years, although prevalence estimates vary with the diagnostic criteria and population studied (Escobar-Morreale, 2018; Neven et al., 2024; Teede et al., 2018, 2023). Its clinical presentation is reproductive as well as metabolic. In addition to ovulatory dysfunction, hyperandrogenism, and polycystic ovarian morphology, many women with PCOS have insulin resistance, compensatory hyperinsulinemia, low-grade inflammation, and other metabolic disturbances (Moran and Teede, 2009; Moran et al., 2010; Teede et al., 2010).

Two of these metabolic burdens are addressed in the present trial. The first is central adiposity. Women with PCOS are more likely than comparison women to carry fat in an abdominal distribution, with a pooled relative risk for central obesity of 1.73 (95% CI 1.31–2.30) across 35 studies and more than fifteen thousand women (Lim et al., 2012). Waist-hip ratio (WHR) is the simplest field measure of that distribution, requires no laboratory, and carries independent prognostic weight: in a case-control study of 27,000 participants across 52 countries, WHR showed a graded association with myocardial infarction that persisted after adjustment for body mass index (Yusuf et al., 2005). A WHR of 0.85 or above is the threshold identified by the World Health Organization as marking substantially increased metabolic risk in women, and is used throughout this report as the interpretive anchor for central obesity (World Health Organization, 2011).

The second is dyslipidemia. Women with PCOS may have lower HDL-C and higher LDL-C and triglyceride concentrations, although the pattern varies across populations (Escobar-Morreale, 2018; Teede et al., 2018). Serum total cholesterol is the summary measure of circulating cholesterol across all lipoprotein fractions, remains the most widely available lipid measure in routine practice, and is the value against which conventional desirable, borderline-high, and high categories are set.

These two burdens are often discussed together, and are sometimes treated as interchangeable indicators of a single underlying metabolic disturbance. The evidence does not support that assumption. Where anthropometric and lipid measures have been examined side by side in women with PCOS, WHR correlates appreciably with triglycerides and HDL-C but weakly or not at all with total cholesterol (Jabczyk et al., 2024; Saghaei-Asl et al., 2013). That pattern has a physiological basis. Visceral adipose tissue delivers free fatty acids to the liver and promotes hepatic very-low-density lipoprotein output while reducing lipoprotein lipase activity, which raises triglycerides and lowers HDL-C. Total cholesterol is a composite in which a rise in LDL-C and a fall in HDL-C partially offset one another, and it is therefore the lipid measure least sensitive to where body fat is carried. Central adiposity and total cholesterol consequently behave as two related but distinct dimensions of cardiometabolic burden, and an intervention may plausibly move one more than the other.

This matters for how lifestyle trials are designed and read. If the two dimensions were interchangeable, measuring either would suffice. If they are not, a trial that measures only anthropometry cannot speak to lipid benefit, and a trial that measures only lipids cannot speak to central adiposity. Yet trials in PCOS commonly report one and not the other, which makes it difficult to judge how broadly a lifestyle intervention acts.

University students are a relevant population for lifestyle research because diet, sleep, academic demands, and sedentary time can vary substantially across the academic year. Stress and changes in daily routine may influence metabolic health, making it useful to study interventions under ordinary university conditions rather than only under tightly controlled circumstances (Rao et al., 2024).

Lifestyle modification remains central to PCOS management, while pharmacological treatments are used according to the individual's reproductive, metabolic, and symptom profile (Forslund et al., 2023; Rashid et al., 2022; Teede et al., 2023). Yoga

is of interest as a structured lifestyle intervention because it combines physical activity with breathing practices and meditation within a single programme. Previous studies have reported improvements in selected metabolic, hormonal, and quality-of-life outcomes, although the evidence remains heterogeneous (Mishra et al., 2023; Patil et al., 2023; Rao et al., 2024).

The present trial therefore examined whether a 24-week, structured, multi-component yoga programme could improve WHR and serum total cholesterol in young adult women with PCOS while participants continued their usual university lives, and to describe the relative pattern of change in the two outcomes. Attrition was recorded throughout the study and reported by treatment arm. Serum HDL-C and LDL-C were measured in the same cohort and are reported separately in a companion manuscript currently under consideration at another journal.

1.1 Study Objectives

The primary aim of this study was to evaluate the effect of a 24-week structured, supervised yoga intervention on WHR and serum total cholesterol in college women diagnosed with PCOS. WHR and total cholesterol were treated as co-primary outcomes of equal importance, representing central adiposity and circulating cholesterol respectively.

1. To assess the effect of a 24-week structured yoga intervention on WHR in college women with PCOS.
2. To assess the effect of a 24-week structured yoga intervention on serum total cholesterol in college women with PCOS.
3. To compare the yoga and control groups on WHR and total cholesterol at Week 24.

Secondary objectives

1. To describe the magnitude and direction of change in each outcome, and the relative pattern of change across the two outcomes, without formal statistical comparison of their responsiveness.
2. To assess the feasibility of delivering a five-day-per-week, supervised, multi-component yoga protocol among young women with PCOS in a university setting.
3. To document attrition patterns, their timing, and their contributing factors across the intervention period under free-living conditions, together with any reported adverse events.

1.2 Central Adiposity as a Cardiometabolic Burden in PCOS

Lim et al. (2012) provide the most substantial quantitative estimate of adiposity in PCOS. Pooling 35 studies and 15,129 women, they reported relative risks of 1.95 (95% CI 1.52–2.50) for overweight, 2.77 (95% CI 1.88–4.10) for obesity, and 1.73 (95% CI 1.31–2.30) for central obesity specifically. Heterogeneity was substantial and varied by ethnicity, with the relative risk for obesity considerably higher in Caucasian than in Asian cohorts.

Whether that central excess is intrinsic to PCOS or a consequence of accompanying overweight is less settled than it is often presented. Li et al. (2021) meta-analysed imaging-based measures of fat distribution and found increased visceral fat in PCOS compared with BMI-matched controls when all imaging modalities were pooled (SMD 0.41; 95% CI 0.23–0.59), but no significant difference when analysis was restricted to MRI and CT, the gold-standard methods (SMD 0.19; 95% CI –0.04 to 0.41). Their conclusion, that central obesity may be independent of PCOS rather than caused by it, provides an important qualification. For the purposes of a lifestyle trial the distinction is secondary: whatever its origin, central adiposity is present, it is measurable, and it is modifiable.

WHR remains a defensible choice of measure. It requires only a tape measure, is reproducible in field conditions, and retains prognostic value independent of BMI (Yusuf et al., 2005). The WHO threshold of 0.85 in women provides an interpretable clinical anchor (World Health Organization, 2011).

1.3 Total Cholesterol in PCOS

Dyslipidemia is a recognised component of the PCOS metabolic phenotype, and the international guideline development groups treat lipid assessment as part of routine cardiometabolic screening in this population (Teede et al., 2018, 2023). Total cholesterol occupies a particular position within the lipid panel. It is the most widely measured lipid value, the one most often available in routine clinical records, and the value against which patients are categorised as having desirable (<200 mg/dL), borderline-high

(200–239 mg/dL), or high (≥ 240 mg/dL) cholesterol. It is also, by construction, the least specific: it aggregates atherogenic and protective fractions into a single number.

1.4 The Two Dimensions Are Only Loosely Coupled

The third strand is the one that shapes the present design. Two studies have examined anthropometric and lipid measures side by side in women with PCOS, and both report the same pattern.

Jabczyk et al. (2024) studied 49 women with PCOS and correlated anthropometric indices against the lipid panel. WHR correlated strongly with triglycerides ($r = 0.50$, $p < .01$) and inversely with HDL-C ($r = -0.51$, $p < .01$), moderately with LDL-C ($r = 0.37$, $p = .01$), and not at all with total cholesterol ($r = 0.13$, $p = .37$). Their conclusion was that anthropometric indices are poor predictors of dyslipidemia in PCOS.

Saghafi-Asl et al. (2013) reached a compatible conclusion in 63 overweight women with PCOS, reporting that WHR showed no significant correlations with any lipid parameter. Correlations between WHR and total cholesterol were 0.35 in the insulin-resistant subgroup and 0.03 in the non-insulin-resistant subgroup, neither reaching significance.

Intervention data point the same way. Nidhi et al. (2012) reported that the lipid benefit observed in their yoga trial in adolescents with PCOS was independent of anthropometric change, which is the longitudinal counterpart of the cross-sectional dissociation described above.

These findings suggest that central adiposity and total cholesterol are not proxies for one another in PCOS, and that a lifestyle trial should measure both rather than infer one from the other.

1.5 Intervention Evidence on Each Dimension

Anthropometric outcomes. The Cochrane review of lifestyle intervention in PCOS (Lim et al., 2019) pooled 15 randomized trials and 498 women. Against minimal treatment, lifestyle intervention reduced weight by 1.68 kg (95% CI -2.66 to -0.70), BMI by 0.34 kg/m^2 (95% CI -0.68 to -0.01), waist circumference by 0.97 cm (95% CI -1.80 to -0.14), and WHR by 0.04 (95% CI -0.07 to -0.01 ; 4 trials, $n = 135$). The evidence was graded as low quality, and the WHR estimate in particular rests on a small number of trials. Yoga specifically has been associated with reduced waist circumference in metabolic syndrome (SMD -0.35 ; 95% CI -0.57 to -0.13 ; 7 RCTs, $n = 794$), although the same synthesis found no significant effect on triglycerides, HDL-C, or fasting glucose (Cramer et al., 2016). Within PCOS, Mohseni et al. (2021) examined anthropometric indices during infertility treatment, and Selvaraj-type school and community studies have examined broader risk profiles, but WHR has rarely been a pre-specified primary outcome.

Lipid outcomes. The largest quantitative estimate of yoga's lipid effect comes from outside PCOS. Ghazvineh et al. (2022) pooled 53 randomized clinical trials comprising 13,191 participants and found total cholesterol reduced by 10.31 mg/dL (95% CI -14.16 to -6.45), LDL-C by 8.64 mg/dL (95% CI -12.03 to -5.25), triglycerides by 13.50 mg/dL (95% CI -20.09 to -6.92), and VLDL-C by 3.94 mg/dL (95% CI -6.31 to -1.56), with HDL-C raised by 1.98 mg/dL (95% CI 0.81 to 3.14). Heterogeneity was high across all outcomes, and intervention duration was identified as a principal contributor, implying that pooled averages drawn largely from shorter protocols may understate what longer interventions achieve. Within PCOS, Nidhi et al. (2012) remains the main source of direct lipid evidence, reporting significant improvement across most lipid values after a twelve-week programme in adolescents.

1.6 Broader PCOS Evidence

Two recent syntheses characterise the wider evidence base. Verma et al. (2023) systematically reviewed 11 interventional studies representing 515 participants, of which two randomized controlled trials proved suitable for meta-analysis, and reported benefit across menstrual irregularity, clinical hyperandrogenism, fasting blood glucose, fasting insulin, and HOMA-IR, while grading the strength of that evidence as low and calling explicitly for well-designed trials. Zhao et al. (2024) pooled 12 randomized controlled trials of mind-body interventions and reported significant improvement across PCOSQ quality-of-life subscales and reduced depression scores, with high GRADE certainty for two subscales. Neither review reports pooled anthropometric or total cholesterol outcomes, so neither serves as a benchmark here; their contribution is to document benefit in psychological and quality-of-life domains alongside the metabolic outcomes considered in the present trial. Supporting work has examined yoga alongside mindfulness-based approaches (Patel et al., 2020; Rao et al., 2024), integrative naturopathy and Ayurvedic

protocols (Anitha et al., 2025; Shetty et al., 2024; Shrivastava et al., 2022), and yoga nidra (Vanita et al., 2018); narrative and systematic reviews report favourable but heterogeneous effects (Kumari et al., 2023; Mirase et al., 2023; Thakur et al., 2021), and the most recent syntheses continue to identify small samples and short protocols as the principal constraints on inference (Chauhan et al., 2026; Gautam et al., 2026).

1.7 Synthesis of Identified Gaps

Four gaps follow. First, central adiposity in PCOS is well characterised descriptively but rarely treated as a pre-specified primary endpoint in intervention trials, and the pooled WHR estimate available rests on four small trials. Second, total cholesterol is widely measured in practice but seldom reported as a primary outcome in PCOS trials, with effect estimates borrowed from general populations whose dyslipidemia has a different origin. Third, and most importantly, the two dimensions are known to be loosely coupled in this population, yet almost no trial measures both across a sustained intervention in a way that allows their responses to be compared. Fourth, young adult women in educational settings are largely absent from the literature, despite being a group in which lifestyle intervention could be introduced early in the course of the condition. To these must be added a methodological gap: attrition is frequently unreported, which limits what can be inferred about real-world feasibility. Table 1 sets the present trial against the studies discussed above on design, protocol, outcome measures, and attrition reporting.

Table 1. Methodological and clinical comparison with published interventions

Author & Year	Design & Cohort	Protocol & Duration	Outcome Measures	Attrition	Key Findings & Gaps
Lim et al. (2012)	Systematic review & meta-analysis (35 studies; N = 15,129); PCOS vs. controls	Observational; no intervention	Overweight, obesity, central obesity	Not applicable	Central obesity RR 1.73 (1.31–2.30); obesity RR 2.77; overweight RR 1.95. Establishes the burden but not its modifiability.
Lim et al. (2019)	Cochrane systematic review (15 RCTs; N = 498); PCOS	Heterogeneous lifestyle interventions	Weight, BMI, waist circumference, WHR, androgens	Not uniformly reported	WHR MD –0.04 (–0.07 to –0.01; 4 trials, n=135); waist circumference MD –0.97 cm; BMI MD –0.34. Evidence graded low . No lipid outcomes pooled.
Cramer et al. (2016)	Meta-analysis (7 RCTs; N = 794); metabolic syndrome	Heterogeneous yoga modules	Waist circumference, blood pressure, lipids, glucose	Not uniformly reported	Waist circumference SMD –0.35 (–0.57 to –0.13); no significant effect on triglycerides, HDL-C or glucose. Not PCOS-specific.
Ghazvineh et al. (2022)	Systematic review & meta-analysis (53 RCTs; N = 13,191); general populations	Heterogeneous yoga modules, variable duration	Full lipid panel including total cholesterol	Not uniformly reported	Total cholesterol –10.31 mg/dL (–14.16 to –6.45); LDL-C –8.64; TG –13.50; HDL-C +1.98. Duration a principal source of heterogeneity. Not PCOS-specific.
Nidhi et al. (2012)	Prospective RCT (N = 90; ages 15–18); PCOS	Yoga vs. conventional physical exercise; 12 weeks, 60 min/day	Blood lipids, fasting insulin, glucose, HOMA-IR	Not systematically reported	Significant improvement across lipid values except HDL-C; benefit reported as independent of anthropometric change. Adolescent cohort; active comparator; short duration.

Author & Year	Design & Cohort	Protocol & Duration	Outcome Measures	Attrition	Key Findings & Gaps
Jabczyk et al. (2024)	Cross-sectional (N = 49); PCOS	Observational; no intervention	WHR, waist circumference, full lipid panel	Not applicable	WHR vs. TG $r = 0.50$; vs. HDL-C $r = -0.51$; vs. LDL-C $r = 0.37$; vs. total cholesterol $r = 0.13$, $p = .37$. Anthropometric indices judged poor predictors of dyslipidemia. Cross-sectional only.
Present Study	Pragmatic single-blind RCT (N = 131 randomized; 120 analysed); PCOS, ages 18–25	Multi-component yoga; 24 weeks, 60 min/day, 5 days/week, free-living conditions	WHR and serum total cholesterol as co-primary outcomes	8.4%	Week-24 between-group differences of -0.130 in WHR and -16.61 mg/dL in total cholesterol, both $p < .001$; relative changes of -14.6% and -8.9% respectively under yoga. Both dimensions measured across a sustained intervention in the same cohort.

2. MATERIALS AND METHODS

2.1 Study Design and Ethical Approval

This single-blind, two-arm, parallel-group pragmatic randomized controlled trial (blinding of outcome assessors, laboratory personnel and data analysts, but not of participants or the instructor; see below) was conducted over 24 weeks under the academic supervision of the Faculty of Yoga Science and Therapy, Meenakshi Academy of Higher Education and Research (MAHER), Chennai, India, and implemented at KL Deemed to be University, Green Fields, Vaddeswaram, Guntur District, Andhra Pradesh, India. Recruitment, screening, intervention delivery, and outcome assessment were undertaken at the university campus. Participants were enrolled between 8 and 21 July 2025. The intervention began on 28 July 2025 and continued for 24 weeks, with the final assessment completed in January 2026.

The pragmatic design was intentional. The study asked whether a structured yoga programme could improve waist–hip ratio and total cholesterol while participants continued their usual student lives, rather than under tightly controlled laboratory conditions. Accordingly, normal diet, sleep, academic routine, daily activities, and physical activity outside the intervention were not restricted or otherwise modified.

The study followed the 2003 Rotterdam ESHRE/ASRM diagnostic criteria, consistent with the framework used when the protocol was developed and approved. Ethical approval was obtained from the Institutional Human Ethics Committee of MAHER, Chennai (Study Ref. No. MAHER/IEC/PHD/15/JAN 24; DHR Reg. No. EC/NEW/INST/2023/3553; CDSCO Reg. No. ECR/1906/INST/TN/2023; approved 23 April 2024). Written institutional permission was obtained from KL Deemed to be University before recruitment. The trial was prospectively registered with the Clinical Trials Registry—India on 25 October 2024 (CTRI/2024/10/075924), before enrolment of the first participant. All procedures were conducted in accordance with the Declaration of Helsinki, and reporting followed the CONSORT 2025 statement (Hopewell et al., 2025). A completed CONSORT 2025 checklist is provided as supplementary material.

2.2 Relationship to the Companion Report

This trial measured a panel of anthropometric and biochemical outcomes in a single cohort, and two manuscripts have been prepared from it. The present manuscript reports waist–hip ratio and serum total cholesterol. A companion manuscript reports serum HDL-C and LDL-C. Because both arise from the same randomized trial cohort, they share the trial design, randomization procedure, intervention protocol, participant flow, and attrition information, which are described in full in each manuscript for

the reader's convenience. The primary outcome sets are non-overlapping; neither outcome reported here is reported in the companion manuscript, and neither lipid fraction reported there is reported here.

All participants underwent fasting lipid assessment at baseline and at Week 24. The same fasting and sample-collection procedure, the same external laboratory, and the same assay methodology were used for the lipid measurements underlying both manuscripts. The companion manuscript describes its own biochemical assessment as limited to HDL-C and LDL-C; that statement identifies the fractions reported in that manuscript rather than the full content of the lipid assessment performed.

The companion manuscript is currently under consideration at another journal. It has not been accepted and has not been published, and it is therefore not cited as a published reference in this manuscript.

2.3 Open Science

Trial registration. The trial was registered with the Clinical Trials Registry—India (CTRI/2024/10/075924) on 25 October 2024. Registration preceded enrolment of the first participant on 8 July 2025 and was therefore prospective.

Protocol and statistical analysis plan. The registered protocol specifies the eligibility criteria, intervention schedule, and primary outcomes. No separate statistical analysis plan was prepared; the statistical approach and primary outcomes were specified within the registered trial protocol.

Data sharing. De-identified individual participant data underlying the reported analyses are available from the corresponding author on reasonable request. The data are not deposited in a public repository because participant confidentiality must be maintained in accordance with the institutional ethics approval.

Funding and conflicts of interest. The trial received no external grant funding and was self-funded by the authors, with institutional facilities provided by KL Deemed to be University. The authors declare no financial or other conflicts of interest. Full statements are provided under Declarations.

2.4 Sample Size Determination

Sample size was calculated a priori using G*Power (Version 3.1.9.7). A single calculation governed the whole trial. It was anchored to previously reported mean HDL-C differences in yoga trials ($\Delta = 4.2$ mg/dL; pooled SD = 6.8 mg/dL), corresponding to an anticipated Cohen's $d = 0.62$. With $\alpha = 0.05$ (two-tailed) and power $(1-\beta) = 0.85$, the minimum required sample was 98 participants (49 per arm). HDL-C was used as the anchor outcome because it was expected to be the most difficult of the measured outcomes to change and therefore provided the most conservative basis for sample-size estimation. Allowing for an anticipated attrition of 15–20%, the recruitment target was increased to 131 participants. No separate power calculation was performed for waist–hip ratio or total cholesterol; the 120 participants analysed here exceed the prespecified sample-size target for the trial.

2.5 Patient and Public Involvement

Participants were not involved in setting the research question, designing the trial, or interpreting the findings. During orientation, prospective participants were shown the yoga protocol and informed about the time commitment and practical requirements of participation. Feedback about session timing and scheduling was considered when arranging delivery within the academic timetable.

2.6 Participant Recruitment and Screening

The source population comprised approximately 8,000 female students enrolled at the university. Recruitment was conducted in three stages. First, awareness seminars provided information about PCOS and its associated health implications, and students completed screening questionnaires. Second, interested students received an orientation describing the 24-week study commitment, safety procedures, and session schedule, together with a demonstration of the yoga programme. Third, previous medical records documenting PCOS were reviewed against the prespecified diagnostic and eligibility criteria.

Eligibility was determined by the first author (V.V.S.) from the screening questionnaires and the medical records reviewed at the third stage, and V.V.S. also enrolled the eligible participants. Written informed consent was obtained before enrolment and before any baseline measurement. Of the 310 students assessed for eligibility, 179 were excluded because they did not satisfy one or more of the inclusion criteria or met one or more of the exclusion criteria listed under Eligibility Criteria; no student

was excluded for any other reason, and no eligible student declined to participate. The remaining 131 eligible participants completed baseline assessment and were then randomized, and all commenced their allocated condition. Eleven participants subsequently withdrew during the 24-week study period, leaving 120 participants for analysis. Participant flow is presented in Figure 1.

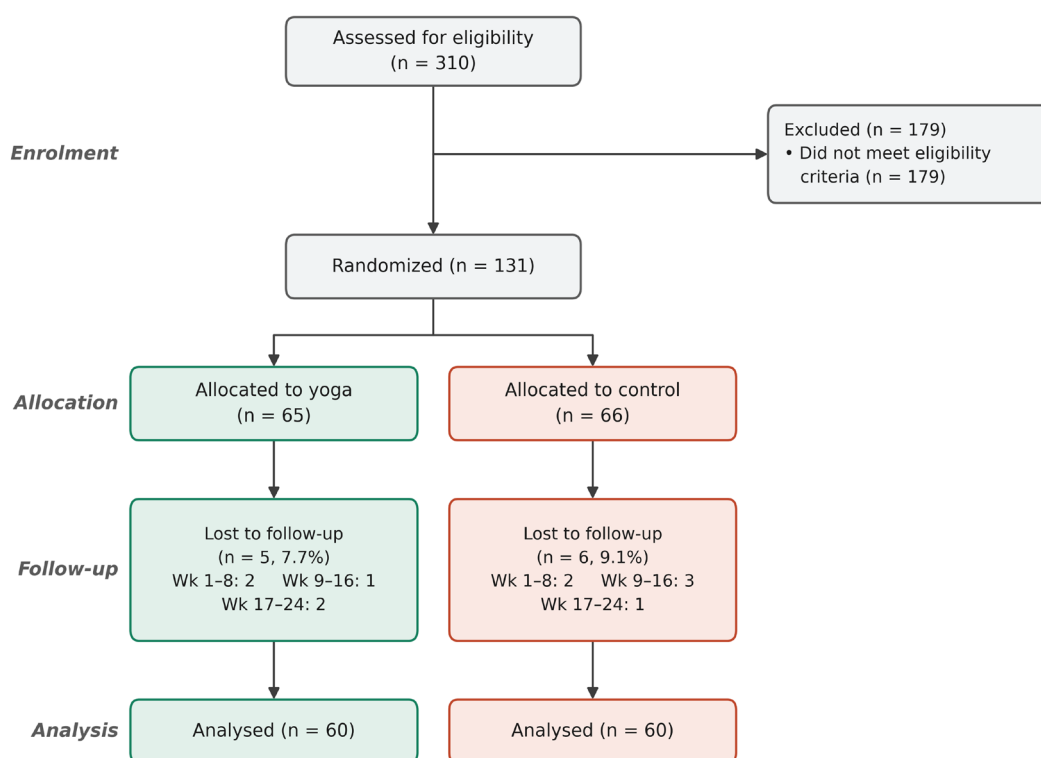


Figure 1. CONSORT 2025 participant flow diagram showing eligibility assessment, exclusions, randomization, loss to follow-up by study arm, and the final analysed cohort.

2.7 PCOS Diagnosis and Eligibility Verification

Female university students aged 18–25 years with a previously established diagnosis of PCOS were eligible for screening. Participants were required to provide previous medical records documenting the diagnosis. These records were reviewed by the study instructor (V.V.S.) with reference to the Rotterdam ESHRE/ASRM criteria (Rotterdam ESHRE/ASRM-Sponsored PCOS Consensus Workshop Group, 2004), which require at least two of the following three features after exclusion of other relevant causes: oligo- or anovulation, clinical or biochemical hyperandrogenism, and polycystic ovarian morphology.

Menstrual dysfunction was identified from participant history and available medical records, with oligomenorrhoea defined as cycles longer than 35 days or fewer than eight cycles per year. Clinical or biochemical hyperandrogenism was accepted when documented in previous medical records; no androgen assay was performed specifically for this trial. Polycystic ovarian morphology was assessed by transabdominal ultrasonography and documented by the attending gynaecologist on the basis of follicle count and morphology. All enrolled participants had documentation supporting fulfilment of at least two Rotterdam criteria.

2.8 Eligibility Criteria

Inclusion criteria

- Female university students aged 18–25 years
- Previously established PCOS diagnosis verified against the Rotterdam ESHRE/ASRM criteria

- Physical capacity to perform the prescribed yoga practices safely
- Written informed consent

Exclusion criteria

- Concurrent endocrine or metabolic disorders, including thyroid dysfunction, congenital adrenal hyperplasia, or Cushing's syndrome
- Type 1 diabetes mellitus or diagnosed cardiovascular disease
- Current or recent (within three months) use of hormonal contraceptives, anti-androgens, lipid-lowering agents, or insulin sensitizers
- Participation in structured exercise or yoga within the preceding six months
- Any medical condition contraindicating physical exercise

A student was enrolled only if all four inclusion criteria were met and none of the exclusion criteria applied. The exclusions relating to medications and recent structured exercise were applied to reduce potential interference with the anthropometric and lipid outcomes and to establish a comparable activity background at study entry.

Pragmatic variable framework. Diet, sleep, daily routine, academic workload, physical activity outside the study sessions, and other usual lifestyle factors were not controlled. Participants were therefore able to continue their normal routines throughout the trial.

2.9 Randomization, Allocation Concealment, and Blinding

Randomization took place after enrolment and baseline assessment. The allocation sequence was generated by computer in R (version 4.2.1) by an independent research assistant who was not involved in recruitment, intervention delivery, or outcome assessment. Participants were allocated to the Yoga and Control groups in a 1:1 ratio using permuted blocks of four, without stratification. Because 131 is not a multiple of four, the final block was only partly used, which accounts for the allocation of 65 participants to the Yoga group and 66 to the Control group.

Allocation was concealed using sequentially numbered, opaque, sealed envelopes prepared by the same research assistant, who retained the sequence. Participants were enrolled by the first author (V.V.S.), who therefore could not foresee or influence the next assignment. Once a participant's baseline assessment was complete, the research assistant opened the next envelope in the sequence and assigned the participant to the group it contained. Because the intervention could not be concealed from participants or the instructor, participant and instructor blinding was not feasible. Outcome assessors, anthropometrists, phlebotomists, laboratory personnel, and data analysts remained blinded to group assignment.

2.10 Intervention Protocol

The Yoga group participated in 60-minute supervised sessions five days per week for 24 weeks. All sessions were conducted indoors in person at the university and were delivered by the same instructor throughout the intervention. The instructor (V.V.S.), the first author, held an MSc in Yoga and formal yoga teacher training and had more than 20 years of teaching experience.

The intervention followed a predefined written protocol and session checklist. The sequence, duration, repetitions and holds, and breathing cycles were standardized and remained unchanged throughout the 24-week intervention. The programme comprised Sukshma Vyayama, Om chanting, Surya Namaskar, targeted asanas, therapeutic mudras, pranayama, breath-watching meditation, and a quick relaxation technique (Table 2). Session performance was supervised directly by the instructor, with intensity and progression adjusted according to instructor judgement while the prescribed session structure was kept constant.

Adherence. The programme comprised 120 scheduled sessions (five per week for 24 weeks), each delivered and supervised in person by the instructor. Attendance was recorded for each participant at every session. Participants who missed a scheduled session were offered an opportunity to complete it at an available after-hours or nearby time slot. A 95% attendance threshold, equivalent to at least 114 of the 120 sessions, was prespecified for monitoring adherence during the intervention. The threshold

was a monitoring standard and not a criterion for analysis: participants below it were not excluded, and inclusion in the analysis depended on retention to Week 24 rather than on the number of sessions attended (see Statistical Analysis). Attendance was not analysed in relation to the outcomes.

Table 2. Yoga intervention protocol

Seq	Component	Specific Practices	Time	Intended Physiological Rationale
1	Loosening and Centering	Sukshma Vyayama, Om chanting	12 min	Joint mobilisation and preparatory relaxation
2	Dynamic Warm-Up	Surya Namaskar	8 min	Dynamic whole-body movement and metabolic activation
3	Targeted Postures	Prasarita Padottanasana, Utkata Konasana, Malasana, Vakrasana, Mandukasana, Baddha Konasana, Upavistha Konasana, Janu Sirsasana, Setu Bandhasana, Supta Konasana, Bhujangasana, Dhanurasana	20 min	Pelvic, abdominal and general musculoskeletal engagement
4	Mudras	Viparita Karani, Yoni Mudra	5 min	Relaxation and postural practice
5	Pranayama	Bhramari, Nadi Shodhana	8 min	Regulated breathing and relaxation
6	Meditation and Rest	Breath-watching meditation, Quick Relaxation Technique	7 min	Relaxation and recovery

Control participants were instructed to continue their usual academic and personal activities. They were not given an additional exercise programme, PCOS-specific advice, counselling, or another study-related intervention.

2.11 Harms

Harms were defined as musculoskeletal injury, syncope, cardiovascular events, or other adverse physical or psychological effects occurring during or considered attributable to a supervised session. Adverse events were monitored through participant self-report and questionnaire-based assessment, with reports recorded during the intervention. No intervention-related adverse events were reported, and no participant withdrew for a reason attributed to the intervention.

2.12 Attrition Tracking

Of the 131 randomized participants, 11 withdrew during the 24-week study, giving an overall attrition rate of 8.4%. Five participants withdrew from the Yoga group (7.7%) and six from the Control group (9.1%). A participant was classified as having withdrawn if they discontinued participation before the Week-24 assessment and therefore provided no Week-24 measurements. Reasons for withdrawal were recorded at the time of withdrawal and summarized by study phase and treatment arm (Table 3). No withdrawal was attributed to the yoga intervention. Participants who withdrew were excluded from the analysis and their Week-24 values were not imputed; the baseline values in Table 4 therefore describe the 120 analysed participants rather than all 131 randomized (see Statistical Analysis).

Table 3. Attrition tracking

Trial Phase	Weeks	Yoga	Ctrl	Tot	Primary Reasons for Withdrawal
Phase I (Early)	1–8	2	2	4	Timetable conflicts with lectures; initial scheduling difficulty
Phase II (Mid)	9–16	1	3	4	Mid-semester examinations; inter-semester travel; project deadlines

Trial Phase	Weeks	Yoga	Ctrl	Tot	Primary Reasons for Withdrawal
Phase III (Late)	17–24	2	1	3	Non-study-related health issues; final-year internship relocation
Total	1–24	5	6	11	Cumulative attrition = 8.4%

2.13 Outcome Measurement

Waist–hip ratio. Waist and hip circumferences were measured at baseline (Week 0) and at Week 24 by a trained assessor blinded to group allocation, using a non-elastic anthropometric tape with the participant standing, feet together, arms relaxed at the sides, and at the end of a normal expiration. Waist circumference was taken at the midpoint between the lowest rib and the iliac crest, and hip circumference at the widest point over the greater trochanters, following the WHO measurement protocol (World Health Organization, 2011). Measurements were recorded to the nearest 0.1 cm and WHR was calculated as waist divided by hip circumference. A WHR of 0.85 or above was used as the interpretive threshold for central obesity in women, following the same WHO consultation.

Serum total cholesterol. Venous blood samples (5 mL) were collected on the KL Deemed to be University campus after a 12-hour overnight fast at baseline and at Week 24. Samples were transported to Lalitha Super Speciality Hospital, Guntur, an external ISO-certified clinical pathology laboratory, where a single fasting lipid profile was assayed from each sample by automated enzymatic colorimetric methods. Serum total cholesterol, the outcome reported here, was measured within that profile; HDL-C and LDL-C from the same lipid assessment are reported in the companion manuscript. No additional venepuncture or separate blood sample was required for the present outcome. The same fasting procedure, collection protocol, assay methodology, and laboratory were used at both assessment points and for both study arms. Values were interpreted against conventional adult categories: desirable below 200 mg/dL, borderline-high 200–239 mg/dL, and high at or above 240 mg/dL.

2.14 Statistical Analysis

Data were analysed using SPSS (Version 28.0). Continuous variables were summarized as mean $\pm$ standard deviation. Normality was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests.

Analysis population. The analysis included the 120 participants (60 per group) who remained in the trial to Week 24 and provided both baseline and Week-24 measurements. This population is described as per-protocol; inclusion depended on retention to Week 24, not on the number of sessions attended. The 11 participants who withdrew before Week 24 provided no Week-24 measurements; they were excluded from the analysis, and no imputation was performed. There were no missing outcome values among analysed participants. An intention-to-treat analysis of all randomized participants was not undertaken and is acknowledged as a study limitation.

Baseline comparison. Baseline age, WHR, and total cholesterol are summarized for the analysed participants (Table 4), and baseline WHR and total cholesterol were compared between groups using independent-samples *t*-tests (Table 5). Because withdrawals occurred after randomization and the analysis is restricted to retained participants, these comparisons describe how similar the two analysed groups were at the start of the trial. They were not treated as a test of whether randomization had succeeded, and no analysis was adjusted on the basis of them.

Week-24 comparison. The primary inferential analysis compared the two groups on each co-primary outcome at Week 24 using independent-samples (Student's) *t*-tests with pooled variance ($df = 118$), without adjustment for baseline values. Results are reported as the between-group mean difference (Yoga minus Control) with its 95% confidence interval, the *t* statistic with its degrees of freedom, and the *p* value. Cohen's *d* was computed as the mean difference divided by the pooled standard deviation. Because the two groups were of equal size, the pooled-variance *t* statistic is numerically identical to the unequal-variance (Welch) statistic, so the choice between them does not change the *t* values reported. All tests were two-tailed, with statistical significance set at $p < .05$. WHR and total cholesterol were analysed as two co-primary outcomes without adjustment for multiplicity; both Week-24 *p* values ($< .001$) also lie below the Bonferroni-adjusted threshold of .025 for two outcomes. The companion manuscript reporting the lipid-fraction outcomes from this trial uses the between-group difference in change

scores as its primary comparison; the two manuscripts therefore differ in analytic approach, and the present analysis should be read as the Week-24 contrast it describes.

Within-group change. Within-group change is reported descriptively as the difference between group means at Week 24 and at baseline, together with change expressed as a percentage of the baseline group mean. These descriptive quantities characterise the magnitude and direction of movement in each arm and permit the relative movement of the two outcomes to be described; they are not accompanied by inferential tests, and paired within-group testing was not performed. The inferential basis for the treatment contrast is therefore the Week-24 between-group comparison.

3. RESULTS AND DISCUSSION

3.1 Participant Flow and Baseline Characteristics

Participants were enrolled between 8 and 21 July 2025. Of the 131 participants randomized (Yoga $n = 65$; Control $n = 66$), 120 completed the 24-week trial and were included in the per-protocol analysis (Yoga $n = 60$; Control $n = 60$), giving an overall attrition rate of 8.4%. No participant was excluded from analysis for reasons other than withdrawal, and no outcome data were missing among participants who completed the trial.

The baseline values reported below and in Table 4 refer to the 120 analysed participants. The mean age was 20.95 ± 2.10 years in the Yoga group and 21.20 ± 2.18 years in the Control group. Baseline values for both co-primary outcomes were closely similar between groups (Table 4). Mean baseline WHR was 0.89 ± 0.05 in the Yoga group and 0.88 ± 0.05 in the Control group, a difference of $+0.010$ (95% CI -0.008 to $+0.028$; $t(118) = 1.10$, $p = .276$; Cohen's $d = 0.20$). Mean baseline total cholesterol was 193.97 ± 13.42 mg/dL and 195.32 ± 13.80 mg/dL respectively, a difference of -1.35 mg/dL (95% CI -6.27 to $+3.57$; $t(118) = -0.54$, $p = .588$; Cohen's $d = -0.10$).

Both groups entered the trial above the WHO threshold for central obesity in women, with mean WHR of 0.89 and 0.88 against a threshold of 0.85. Mean total cholesterol in both groups was within the desirable range at baseline, below but close to the 200 mg/dL boundary of that range.

Table 4. Baseline characteristics and co-primary outcome values

Variable	Yoga (n = 60)	Control (n = 60)
Age (years)	20.95 ± 2.10	21.20 ± 2.18
Waist-hip ratio	0.89 ± 0.05	0.88 ± 0.05
Total cholesterol (mg/dL)	193.97 ± 13.42	195.32 ± 13.80

Values are mean $\pm$ SD.

3.2 Primary Between-Group Comparison at Week 24

At Week 24 the two groups differed substantially on both co-primary outcomes (Table 5; Figure 2).

Waist-hip ratio. Mean WHR was 0.76 ± 0.03 in the Yoga group and 0.89 ± 0.04 in the Control group. The between-group difference was -0.130 (95% CI -0.143 to -0.117 ; $t(118) = -20.14$, $p < .001$; Cohen's $d = -3.68$).

Total cholesterol. Mean total cholesterol was 176.79 ± 13.55 mg/dL in the Yoga group and 193.40 ± 13.93 mg/dL in the Control group. The between-group difference was -16.61 mg/dL (95% CI -21.58 to -11.64 ; $t(118) = -6.62$, $p < .001$; Cohen's $d = -1.21$).

For both outcomes the 95% confidence interval excluded zero, and in both cases the direction favoured the Yoga group. The Week-24 separation therefore represents the between-group difference observed after the 24-week intervention period; causal interpretation should take into account the per-protocol analysis and the other limitations of the trial.

Table 5. Between-group comparison of co-primary outcomes at baseline and at Week 24

Outcome	Time point	Yoga (n = 60)	Control (n = 60)	Difference (95% CI)	t(118)	p	Cohen's d
Waist-hip ratio	Baseline	0.89 ± 0.05	0.88 ± 0.05	+0.010 (−0.008 to +0.028)	1.10	.276 ^a	0.20
	Week 24	0.76 ± 0.03	0.89 ± 0.04	−0.130 (−0.143 to −0.117)	−20.14	<.001***	−3.68
Total cholesterol (mg/dL)	Baseline	193.97 ± 13.42	195.32 ± 13.80	−1.35 (−6.27 to +3.57)	−0.54	.588 ^a	−0.10
	Week 24	176.79 ± 13.55	193.40 ± 13.93	−16.61 (−21.58 to −11.64)	−6.62	<.001***	−1.21

Values are mean ± SD. Differences are Yoga minus Control, from independent-samples *t*-tests with pooled variance. ^a Baseline rows describe the starting distribution of each outcome; they are not tests of whether randomization succeeded and are not interpreted as such. *** *p* < .001.

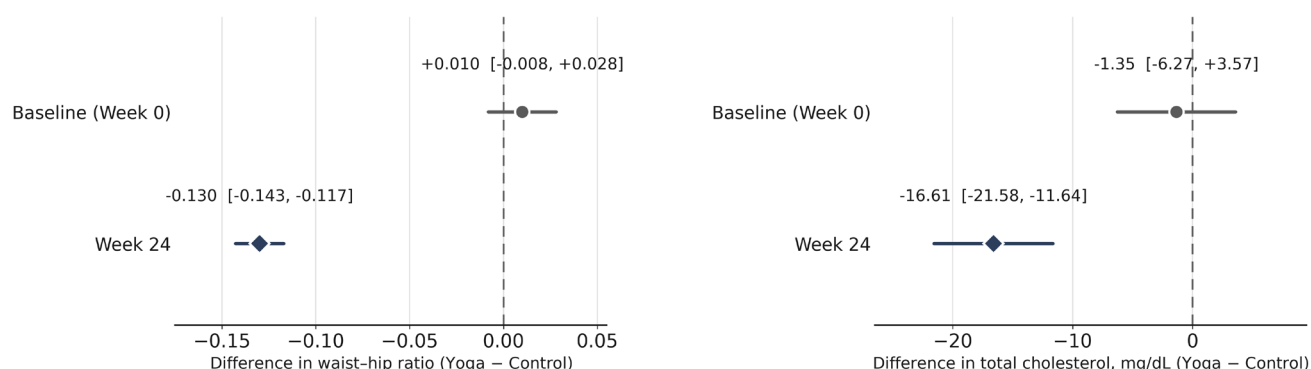


Figure 2. Between-group differences (Yoga minus Control) in waist-hip ratio and serum total cholesterol at baseline and at Week 24, with 95% confidence intervals. Circles denote baseline comparisons and diamonds denote Week-24 comparisons; the dashed line marks no between-group difference.

3.3 Descriptive Change Within Each Group

Change within each arm, expressed as the difference between group means at the two assessment points, is summarized in Table 6 and shown in Figure 3.

Mean WHR in the Yoga group moved from 0.89 to 0.76, a reduction of 0.13, while the Control group moved from 0.88 to 0.89, an increase of 0.01. The difference between these two movements was 0.14 in favour of the Yoga group. Mean total cholesterol in the Yoga group moved from 193.97 to 176.79 mg/dL, a reduction of 17.18 mg/dL, while the Control group moved from 195.32 to 193.40 mg/dL, a reduction of 1.92 mg/dL; the difference between the two movements was 15.26 mg/dL in favour of the Yoga group.

These quantities are descriptive. They follow arithmetically from the group means and are presented to characterise the magnitude and direction of movement in each arm; they are not accompanied by paired inferential tests, and the formal treatment contrast rests on the Week-24 comparison reported above.

Table 6. Descriptive change in group means from baseline to Week 24

Outcome	Group	Change	Relative change
Waist–hip ratio	Yoga	−0.13	−14.6%
	Control	+0.01	+1.1%
Total cholesterol (mg/dL)	Yoga	−17.18	−8.9%
	Control	−1.92	−1.0%

Change is the Week-24 group mean minus the baseline group mean. Relative change is expressed as a percentage of the baseline group mean. Descriptive only; no inferential test is attached to these values.

3.4 Descriptive Relative Change in the Two Outcomes

In the Yoga group, WHR fell by 14.6% and total cholesterol by 8.9% (Figure 4); these descriptive changes indicate that the two outcomes moved to different relative extents, but they should not be interpreted as a formal comparison of responsiveness. In the Control group the two outcomes also behaved differently from one another, WHR rising by 1.1% while total cholesterol fell by 1.0%.

These comparisons rest on percentage change in group means rather than on any participant-level association, which the present analysis does not evaluate. They are nonetheless consistent with the cross-sectional evidence that anthropometric and total cholesterol measures are only loosely coupled in PCOS (Jabczyk et al., 2024; Saghaei-Asl et al., 2013).

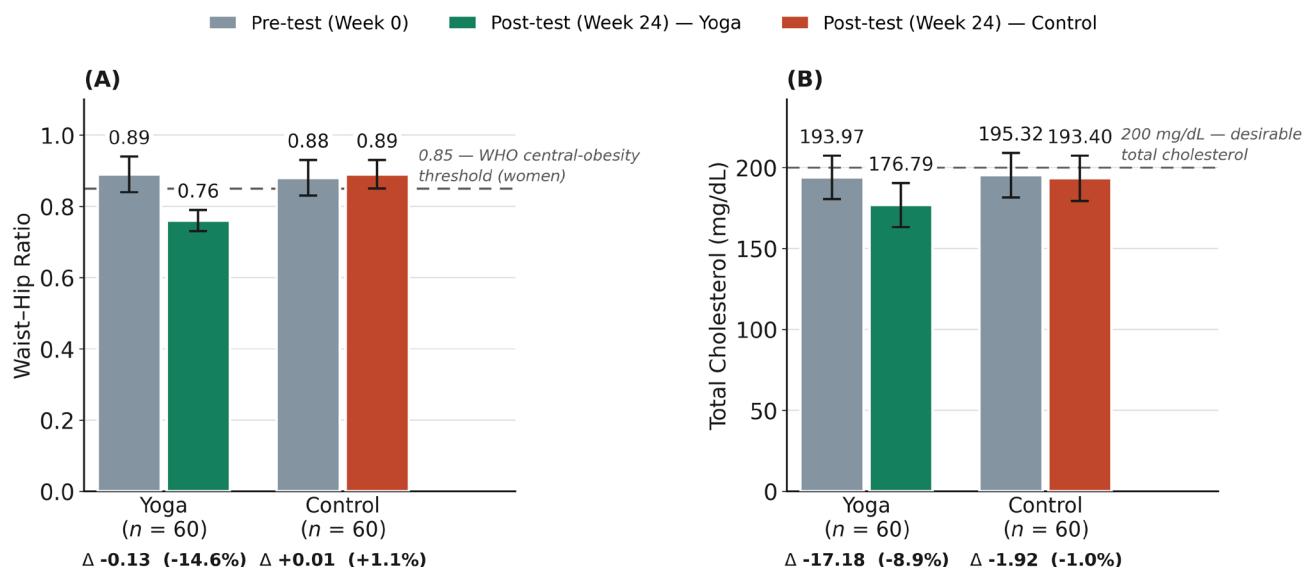


Figure 3. The two co-primary outcomes before and after 24 weeks, by group. **(A)** Waist–hip ratio; the dashed line marks the WHO threshold of 0.85 for central obesity in women. **(B)** Serum total cholesterol; the dashed line marks the conventional threshold of 200 mg/dL for desirable total cholesterol. Bars show group means with standard deviation whiskers, and Δ values below each pair give the change in the group mean with the corresponding relative change.

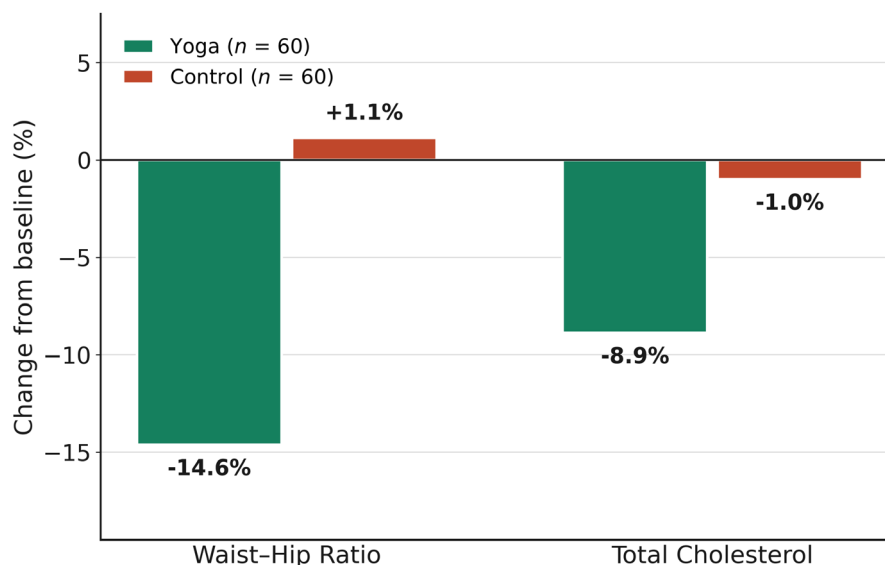


Figure 4. Relative change from baseline in waist-hip ratio and serum total cholesterol, by group. Values are percentage change in the group mean from baseline to Week 24.

3.5 Clinical Categorisation

Using the WHO threshold of 0.85 for women, the Yoga group's mean WHR moved from 0.89 to 0.76, crossing from above to below the threshold over 24 weeks. The Control group's mean WHR remained above the threshold (0.88 to 0.89). This comparison applies the threshold to group means and does not indicate that every participant crossed the threshold.

Under the conventional adult lipid categories used in this manuscript, mean total cholesterol in the Yoga group was already within the desirable range at baseline (193.97 mg/dL) and decreased to 176.79 mg/dL at Week 24, increasing the margin below the 200 mg/dL borderline-high boundary from approximately 6 mg/dL to approximately 23 mg/dL. The Control group mean remained close to the boundary throughout (195.32 to 193.40 mg/dL). These classifications describe group means and are interpretive rather than inferential; the trial did not measure cardiovascular events or long-term cardiovascular risk.

3.6 Principal Findings

This 24-week randomized trial found substantially better Week-24 values in the Yoga group than in the usual-activity group for both co-primary outcomes. Mean WHR at Week 24 was 0.130 lower in the Yoga group (95% CI 0.117 to 0.143 lower; $p < .001$), and mean total cholesterol was 16.61 mg/dL lower (95% CI 11.64 to 21.58 mg/dL lower; $p < .001$). The Week-24 separation was observed after the 24-week intervention period.

Four features of the result deserve emphasis. First, both co-primary outcomes showed statistically significant between-group differences at Week 24. Second, the mean WHR crossed the WHO threshold of 0.85 in the Yoga group, whereas the Control-group mean remained above it. Third, the control arm changed only modestly and in different directions across the two outcomes: mean WHR rose slightly while mean total cholesterol fell slightly. Fourth, the two outcomes showed different relative movement under yoga, with a 14.6% reduction in WHR and an 8.9% reduction in total cholesterol. These percentage changes are descriptive group-level summaries rather than evidence of a participant-level relationship between the outcomes.

3.7 Central Adiposity and Total Cholesterol as Distinct Targets

The trial was designed on the premise that central adiposity and total cholesterol are related but distinct cardiometabolic dimensions in PCOS rather than interchangeable indicators of a single disturbance. As set out in the review above, the cross-sectional literature supports that premise: WHR tracks the triglyceride-HDL axis but not total cholesterol in PCOS (Jabczyk et al., 2024; Saghafi-Asl et al., 2013), and lipid benefit in a PCOS yoga trial has been described as independent of anthropometric change (Nidhi et al., 2012).

There is a plausible physiological reason. Visceral adipose tissue influences the lipid panel principally through the triglyceride–HDL axis, by way of hepatic free fatty acid delivery, very-low-density lipoprotein output, and lipoprotein lipase activity. Total cholesterol aggregates an atherogenic fraction that tends to rise with metabolic stress and a protective fraction that tends to fall, so the two movements partly cancel within the summary measure. Total cholesterol is therefore expected on mechanistic grounds to be the lipid value least tightly coupled to where body fat is carried.

The present results are consistent with that expectation. Both outcomes improved, but by different relative amounts, and the control arm moved in opposite directions on the two measures. The practical implication for trial design is that neither measure substitutes for the other: a PCOS lifestyle trial reporting only anthropometry cannot claim lipid benefit, and one reporting only lipids cannot claim benefit for central adiposity.

Two limits on this interpretation must be stated plainly. The comparison rests on percentage change in group means, not on any participant-level association; the present analysis does not estimate a correlation between the two outcomes and cannot do so. And percentage change in a bounded ratio such as WHR is not directly commensurable with percentage change in a concentration, so the comparison of relative magnitudes is indicative rather than a formal test of differential responsiveness.

3.8 Comparison with Existing Literature

Anthropometric outcomes. The Cochrane review of lifestyle intervention in PCOS reported a pooled WHR reduction of 0.04 (95% CI -0.07 to -0.01) from four trials in 135 women, with the evidence graded as low quality (Lim et al., 2019). The between-group difference observed here, 0.130, is substantially larger, and the discrepancy warrants cautious interpretation. The pooled estimate derives from heterogeneous interventions of varying duration and intensity, several considerably shorter and less frequent than a supervised five-day-per-week programme sustained for 24 weeks, which may account for part of the gap. It nonetheless remains the case that the present estimate lies well outside the range of the pooled literature, and independent replication would be needed before the magnitude reported here could be regarded as established. In metabolic syndrome, yoga has been associated with reduced waist circumference (SMD -0.35) but with no significant effect on triglycerides, HDL-C, or fasting glucose (Cramer et al., 2016) — itself an instance of anthropometric and lipid outcomes responding differently within one synthesis.

Lipid outcomes. Ghazvinch et al. (2022) pooled 53 randomized trials and reported a mean total cholesterol reduction of 10.31 mg/dL (95% CI -14.16 to -6.45). The descriptive within-group reduction of 17.18 mg/dL in the present Yoga group is larger, and the Week-24 between-group difference of 16.61 mg/dL larger still, although the comparison is indirect: that meta-analysis combined different populations and yoga protocols, none of them PCOS-specific, and identified intervention duration as a principal source of heterogeneity. The present trial contributes a relatively long exposure period to that literature. Whether the longer practice period contributed to the lipid change cannot be determined from these data: the results do not establish a duration threshold, and the present design cannot separate duration from the other characteristics of the intervention.

PCOS-specific evidence. Nidhi et al. (2012) remains the principal comparator within PCOS, reporting improvement across most lipid values after twelve weeks in adolescents. The present study included a somewhat older group, doubled the intervention duration, and added a pre-specified anthropometric co-primary outcome. The control condition also differed: Nidhi et al. used conventional physical exercise as the comparator, whereas the present trial used usual activity. The effect estimates reported here therefore describe benefit relative to usual activity, not relative to another structured exercise programme.

3.9 Interpreting the Control-Group Result

The control arm did not behave uniformly. Mean total cholesterol fell by 1.92 mg/dL, a small movement in the favourable direction, while mean WHR rose by 0.01. Mean WHR therefore did not improve under usual activity over the 24-week period, while mean total cholesterol showed a small reduction. The trial did not collect data capable of explaining why the two outcomes behaved differently in this arm.

Controls were not given an additional exercise programme, PCOS-specific advice, counselling, or another study-related intervention during follow-up. They did take part in the wider study process, including the pre-randomisation awareness activities and the two assessment visits. Whether those experiences influenced behaviour, whether some participants changed

their habits independently, or whether part of the movement reflects normal biological and measurement variation cannot be determined from this design.

3.10 Magnitude of Effect and the Question of Plausibility

The standardized between-group differences observed here are very large: Cohen's $d = -3.68$ for WHR and -1.21 for total cholesterol. Because each comparison was calculated as Yoga minus Control, the negative sign denotes direction only, indicating that the Yoga-group mean was the lower of the two. The absolute magnitude, $|d| = 3.68$, states that the difference between the two group means at Week 24 corresponds to approximately 3.68 pooled within-group standard deviations.

That quantity describes the two observed distributions: at Week 24 the mean WHR of the Yoga group was 0.13 units lower than that of the Control group, corresponding to a standardized between-group difference of 3.68 pooled standard deviations, which indicates substantial separation between the two observed group distributions relative to their within-group variability. Participants allocated to yoga had a lower mean WHR with relatively tight variability around it (0.76 ± 0.03), and those allocated to usual activity a higher mean WHR with similarly small variability (0.89 ± 0.04), giving a pooled within-group standard deviation of approximately 0.035. The standardized effect therefore arises from the 0.13 mean separation in combination with that narrow dispersion, rather than from the mean separation alone.

This describes the observed sample distributions, not individuals. It does not mean that every participant allocated to yoga had a WHR 3.68 standard deviations below every participant allocated to usual activity; it does not describe the change experienced by any individual participant; and it is not a ratio, the Yoga-group mean being 0.13 units lower rather than lower by a factor of 3.68.

Effects of this size are uncommon in behavioural intervention research, and the WHR estimate in particular is substantially larger than estimates reported in the pooled lifestyle literature for this population. The magnitude therefore deserves particular scrutiny rather than being interpreted as an expected effect size. Three considerations are relevant.

First, the intervention was intensive by the standards of the literature: 60 minutes, five days per week, supervised in person by a single experienced instructor, and sustained for 24 weeks. Few trials contributing to the pooled estimates delivered anything comparable. Second, within-group variability in WHR at Week 24 was narrow in both arms, as set out above; whether dispersion of that width is characteristic of WHR measurement in this population, or reflects the homogeneity of a single-campus student sample, cannot be determined from these data. Third, the trial was conducted at a single centre with a single instructor and a single anthropometrist. That consistency is a strength for protocol delivery, but it also means that the unusual magnitude of the WHR result needs confirmation by independent assessors and centres.

We therefore present the direction and statistical significance of these findings with confidence and their absolute magnitude with reservation. Replication in an independent centre, with more than one assessor and ideally with an objective imaging measure of central fat alongside the tape measure, is required before an effect of this size should be regarded as the expected result of such a programme.

3.11 Attrition and Feasibility

Eleven of the 131 randomized participants withdrew, leaving 120 for analysis and an overall attrition rate of 8.4%. Withdrawals were distributed similarly across the two arms (5 Yoga, 6 Control), although the per-protocol analysis means that bias from withdrawal cannot be excluded. The findings describe the effect observed among participants who completed the 24-week assessment rather than an intention-to-treat estimate for all randomized participants. The overall attrition of 8.4% provides a descriptive indication of retention over the 24-week intervention. No formal feasibility endpoint or prespecified retention criterion was defined.

3.12 Mechanistic Interpretation

The observed changes are biologically plausible, but the underlying mechanisms were not measured in this trial. The explanations below should be read as possible pathways rather than demonstrated mechanisms.

Movement, energy expenditure and fat distribution. The Surya Namaskar and asana components represent sustained whole-body activity five days per week. Regular activity of this kind can reduce visceral and abdominal subcutaneous fat, which

would be reflected in waist circumference and hence WHR. Neither body composition nor energy intake was measured, so the contribution of fat loss as against changes in posture, abdominal muscle tone, or measurement conditions cannot be separated.

Autonomic and stress-related pathways. The programme included pranayama and breath-watching meditation, which may influence autonomic and hypothalamic–pituitary–adrenal regulation. Cortisol is implicated both in central fat deposition and in hepatic lipid handling, which offers one pathway by which a single intervention could act on both outcomes. Autonomic indices, cortisol, and related intermediates were not assessed, so this remains inferential.

Insulin sensitivity and lipid handling. The movement-based components may have improved insulin sensitivity and lipoprotein handling, processes relevant to circulating cholesterol. Insulin resistance, apolipoproteins, and lipoprotein lipase activity were not assessed.

Multi-component effects. Because the intervention combined movement, breathing practices, meditation, and other traditional yoga practices, no single component can be identified as responsible for either outcome. The study was designed to evaluate the package as delivered in practice, not to dismantle it into components.

3.13 Strengths and Limitations

Strengths. The trial was prospectively registered, used randomized allocation with explicit allocation concealment, maintained blinded outcome assessment where feasible, applied a standardized fasting protocol and a single external ISO-certified laboratory, followed a clearly defined 24-week intervention delivered to a written protocol, and reported attrition by treatment arm. It measured an anthropometric and a lipid outcome as pre-specified co-primary endpoints in the same cohort, which is uncommon in this literature and is what allows their responses to be compared at all.

Limitations. First, the analysis was per-protocol, restricted to the 120 participants retained to Week 24, and did not include an intention-to-treat analysis; because no Week-24 measurements were obtained from the 11 participants who withdrew, the direction of any resulting bias cannot be assessed. Second, the inferential analysis uses the Week-24 between-group comparison without adjustment for baseline values; within-group change is reported descriptively without paired testing, so the trial does not provide inferential estimates of within-arm change or a separate inferential test of the between-group difference in change. Third, the pragmatic design left diet, sleep, daily activities, and outside physical activity unmodified, so changes in these factors may have contributed to the observed outcomes. Fourth, participants and the instructor could not be blinded, leaving room for expectancy or behavioural effects. Fifth, the intervention was delivered by a single instructor at a single centre, which aids consistency but limits generalisability and provides no safeguard against a systematic measurement tendency, as discussed above. Sixth, the passive control condition does not show whether yoga is better than another structured exercise programme matched for time and attention. Seventh, PCOS status was established by verification of existing clinical records against the Rotterdam criteria rather than by a new standardized diagnostic work-up, and no androgen assays were performed within the trial. Eighth, WHR was measured by tape rather than by imaging, and total cholesterol was measured without the accompanying fractions that would allow the composite to be decomposed. Finally, session attendance was monitored but not analysed in relation to the outcomes, mechanistic intermediates were not measured, and the 24-week follow-up leaves the durability of the observed changes unknown.

3.14 Future Research Directions

The most informative next step would be an active-comparator trial in which yoga is matched with a structured aerobic or resistance programme for time and supervision, which would clarify how much of the observed benefit is specific to yoga rather than to regular supervised activity. The replication priorities for the anthropometric result are set out above.

Trials in this area should report anthropometric and lipid outcomes together as a matter of routine, and where participant-level data permit, should estimate directly whether change in central adiposity predicts change in the lipid panel within individuals. That analysis, which the present study was not designed to support, is what would convert the loose coupling described in cross-sectional work into a mechanistic claim about how lifestyle intervention acts. Longer follow-up after supervised sessions stop, and measurement of lipid and metabolic intermediates including apolipoproteins A-I and B, insulin-resistance markers, and autonomic indices, would address the remaining questions of durability and mechanism.

4. CONCLUSIONS

In this 24-week single-blind pragmatic randomized controlled trial, the Yoga group had lower mean WHR and total cholesterol than the usual-activity group at Week 24. Mean WHR was 0.76 in the Yoga group versus 0.89 in the Control group, a difference of -0.130 (95% CI -0.143 to -0.117 ; $p < .001$), and mean total cholesterol was 176.79 mg/dL versus 193.40 mg/dL, a difference of -16.61 mg/dL (95% CI -21.58 to -11.64 ; $p < .001$).

The Yoga group's mean WHR crossed the WHO threshold of 0.85, moving from 0.89 at baseline to 0.76 at Week 24, while the Control-group mean remained above the threshold. Mean total cholesterol decreased from 193.97 mg/dL at baseline to 176.79 mg/dL; both values were within the desirable range defined in this manuscript. Relative to baseline, the Yoga group showed a 14.6% reduction in WHR and an 8.9% reduction in total cholesterol, while the Control group showed a 1.1% increase and a 1.0% reduction, respectively. These are group-mean changes and should not be interpreted as participant-level response rates.

The HDL-C and LDL-C outcomes from this cohort are reported in a companion manuscript currently under consideration at another journal, and are therefore not drawn on here as established evidence. Within the present report, the results are consistent with change in two cardiometabolic measures over the 24-week programme. They do not establish that changes in WHR caused the lipid changes, because participant-level associations between outcomes were not analysed. The distinct movement of WHR and total cholesterol also supports treating anthropometric and lipid outcomes as separate endpoints in PCOS lifestyle trials rather than using either as a proxy for the other.

The absolute magnitude of the anthropometric effect is larger than estimates reported in the existing pooled literature and should be regarded as provisional pending independent replication. The present design cannot establish whether an effect of this magnitude would be expected in other populations or at other centres. The trial did not assess cardiovascular events, long-term risk, participant-level associations between the two outcomes, or the mechanisms underlying the observed changes, and these questions remain for future research.

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AUTHOR CONTRIBUTIONS

Voleti Venkatasucharita: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Resources, and Writing — original draft.

G. Raghuram: Supervision, Methodology, and Writing — review and editing.

S. Vidhya Shankari: Validation and Investigation.

K. Subbulakshmi: Validation and Resources.

V. Subbu Lakshmi: Project administration and Resources.

All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICS STATEMENT

The study protocol was approved on 23 April 2024 by the Institutional Human Ethics Committee of Meenakshi Academy of Higher Education and Research, Chennai (Study Ref. No: MAHER/IEC/PHD/15/JAN 24; DHR Reg. No: EC/NEW/INST/2023/3553; CDSCO Reg. No: ECR/1906/INST/TN/2023). Written institutional permission to conduct

the trial at KL Deemed to be University was obtained before recruitment. The trial was prospectively registered with the Clinical Trials Registry—India on 25 October 2024 (CTRI/2024/10/075924). Written informed consent was obtained from all participants before enrolment, and participation was voluntary.

DATA AVAILABILITY STATEMENT

The datasets generated and analysed during the current study are not publicly available because participant confidentiality must be protected under the terms of the institutional ethics approval. De-identified data are available from the corresponding author on reasonable request.

RELATED MANUSCRIPT

A companion manuscript reporting serum HDL-C and LDL-C from the same randomized trial cohort is currently under consideration at another journal; it has not been accepted and has not been published. The two manuscripts report non-overlapping outcome sets; their relationship is described in full in the Materials and Methods.

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