The therapeutic potential of yoga in prediabetes: a systematic review and meta-analysis

El potencial terapéutico del yoga en la prediabetes: una revisión sistemática y un metaanálisis

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Abstract

Introduction: Prediabetes, characterized by elevated blood glucose, increases the risk of type II diabetes. Accessible interventions like yoga offer a holistic approach to improve metabolic health and delay disease onset.
Objective: This systematic review and meta-analysis evaluated yoga's effects on primary outcomes; fasting blood glucose, postprandial blood glucose, glycated hemoglobin, and secondary outcome: body mass index in individuals with prediabetes.
Methods: Following PRISMA guidelines and PROSPERO registration (CRD420251017200), a search (2013–2023) identified five randomized control trail. Fasting blood glucose, postprandial blood glucose, glycated hemoglobin, and body mass index were analyzed using mean differences. Subgroup and sensitivity analyses assessed robustness. Certainty of evidence was evaluated via GRADE.
Results**:** Five randomized controlled trials involving 501 participants were included. The meta-analysis showed no significant effect of yoga on fasting blood glucose, with considerable heterogeneity and very low certainty evidence. No significant effects were observed for postprandial blood glucose or glycated hemoglobin, with negligible heterogeneity and low-certainty evidence. Effects on body mass index in individuals with prediabetes were non-significant with low-certainty evidence.
Discussion: Yoga did not have any clinical significance regarding Fasting blood glucose, postprandial blood glucose, glycated hemoglobin, and body mass index in individuals with prediabetes. Limited trial, small sample size, and low to very low certainty of evidence reduced confidence. Sensitivity analyses and subgroup analyses further strengthen the robustness of the findings.
Conclusion: Yoga interventions did not significantly improve primary outcomes: fasting blood glucose, postprandial blood glucose, and glycated hemoglobin, and secondary outcome body mass index.

Keywords

Body mass index; fasting blood glucose; glycated haemoglobin; postprandial blood glucose; prediabetes; yoga.

Resumen

Introducción: La prediabetes, caracterizada por niveles elevados de glucosa en sangre, incrementa el riesgo de desarrollar diabetes tipo II. Intervenciones accesibles como el yoga ofrecen un enfoque holístico para mejorar la salud metabólica y retrasar la aparición de la enfermedad.
Objetivo: Esta revisión sistemática y metanálisis evaluó los efectos del yoga sobre los desenlaces primarios: glucosa en ayunas, glucosa posprandial y hemoglobina glucosilada, y el desenlace secundario: índice de masa corporal, en personas con prediabetes.
Métodos: Siguiendo las directrices PRISMA y con registro en PROSPERO (CRD420251017200), se realizó una búsqueda (2013–2023) que identificó cinco ensayos controlados aleatorizados. La glucosa en ayunas, la glucosa posprandial, la hemoglobina glucosilada y el índice de masa corporal se analizaron mediante diferencias de medias. Se realizaron análisis de subgrupos y de sensibilidad para evaluar la robustez de los resultados. La certeza de la evidencia se evaluó mediante el enfoque GRADE.
Resultados: Se incluyeron cinco ensayos controlados aleatorizados con un total de 501 participantes. El metanálisis no mostró un efecto significativo del yoga sobre la glucosa en ayunas, con heterogeneidad considerable y evidencia de certeza muy baja. No se observaron efectos significativos sobre la glucosa posprandial ni sobre la hemoglobina glucosilada, con heterogeneidad mínima y evidencia de baja certeza. Los efectos sobre el índice de masa corporal en personas con prediabetes tampoco fueron significativos, con evidencia de baja certeza.
Discusión: El yoga no mostró relevancia clínica en relación con la glucosa en ayunas, la glucosa posprandial, la hemoglobina glucosilada ni el índice de masa corporal en personas con prediabetes. El número limitado de ensayos, el tamaño muestral pequeño y la baja o muy baja certeza de la evidencia reducen la confianza en los resultados. Los análisis de sensibilidad y de subgrupos reforzaron la robustez de los hallazgos.
Conclusión: Las intervenciones de yoga no mejoraron de forma significativa los desenlaces primarios —glucosa en ayunas, glucosa posprandial y hemoglobina glucosilada— ni el desenlace secundario del índice de masa corporal en personas con prediabetes.

Palabras clave

Índice de masa corporal; glucosa en ayunas; hemoglobina glucosilada; glucosa posprandial; prediabetes; yoga.

Introduction

Prediabetes is a severe metabolic disorder in which the glucose content of the blood is high but not so high to be classified as type 2 diabetes mellitus (T2DM) (Saboo & Kacker, 2023). It is a serious red flag warning because individuals with prediabetes are at risk of developing T2DM and cardiovascular-related complications (Vijayakumar et al., 2021). In 2022, it was estimated that approximately one in thirteen adults aged 20–79 years, corresponding to 374 million individuals worldwide, were living with prediabetes, with the vast majority remaining undiagnosed. This burden is expected to increase markedly, as the International Diabetes Federation projects that 587 million people, representing 8.3% of the adult population, will be living with prediabetes by 2045 (Kirthi et al., 2022). As a consequence, more healthcare systems, along with major health organizations, have developed grading systems that label individuals as having normal, prediabetes, or diabetes. The American Diabetes Association (ADA) describes prediabetes as having a fasting plasma glucose (FPG) concentration of 100-125 mg/dL (5.6-6.9mmol/L), as well as two-hour oral glucose tolerance test (OGTT) results of 140-199 mg/dL, and glycated hemoglobin (HbA1c) levels of between 5.7-6.4% (Zhu et al., 2022). The Madras Diabetes Research Foundation (MDRF) developed the Indian Diabetes Risk Score (IDRS), a population-specific health instrument which combines age, waist circumference, physical activity, and family history of diabetes to categorize individuals as low-risk, moderate-risk, and high-risk for T2DM, a valuable scoring system which identifies individuals with a score of ≥60 as significantly more likely to develop T2DM (Maniyara & Kodali, 2025). Limited randomized controlled trials evaluating the impact of yoga specifically to address prediabetes formed the basis of this review's inclusion strategy, which integrated studies that used either the ADA or IDRS criteria to identify prediabetes.

Including the Indian Diabetes Risk Score (IDRS) was necessary because a considerable number of yoga focused RCTs are conducted in India where the IDRS tool is well known. At the same time, to ensure worldwide relevance for this review, the American Diabetes Association standards were also considered alongside IDRS, as these are globally recognized standards. Indian yoga, which consists of yoga asanas, pranayama, meditation, and relaxation, is gaining acceptance as a non-medical intervention. It is also affordable, easily adaptable, and can be practiced by people across the age spectrum (Jyotsna, 2014).

Yoga, an ancient system of knowledge practiced for over 5,000 years, is now recognized as a leading mind–body therapy due to its cost-effectiveness and the growing body of evidence demonstrating its therapeutic benefits (Kurian et al., 2022). Consequently, yoga may serve as a valuable component of lifestyle interventions recommended for individuals at high risk of T2DM to aid in its prevention (Chattopadhyay et al., 2023). Yoga interventions are traditional practices believed to support multiple aspects of health and may serve as effective non-pharmacological strategies to prevent the progression of prediabetes to type 2 diabetes (T2D) and its associated complications (Gong et al., 2015). Yoga-based lifestyle intervention is an emerging integrative healthcare practice comprised of asanas (physical exercises), pranayama (breathing techniques), and meditation for short- and long-term regulation of prediabetes and its complications (Yau et al., 2020). Although in the past, yoga was primarily considered a spiritual practice, today, it is widely accepted as a complementary therapeutic practice for various health issues. Recent studies indicate the potential of yoga as a non-invasive intervention for the prevention and management of prediabetes (Chattopadhyay et al., 2020). Lately, the holistic benefits of yoga are contributing to its rising acceptance as an alternative to the more traditional pharmacological treatments.

The unique psycho-physical benefits of yoga, including lower levels of anxiety and an enhanced mood, promote better compliance with lifestyle modifications over the long term (Vicks et al., 2022). Integrating the physical, metabolic, and psychological elements of yoga provides a unique approach to the prevention and management of prediabetes (Formagini et al., 2023).

To date, no meta-analysis has specifically synthesized randomized controlled trials conducted exclusively in prediabetic populations. Our comprehensive literature search identified only five randomized controlled trials that directly compared yoga-based interventions with control conditions in adults with prediabetes, underscoring the limited and fragmented nature of the available evidence. These trials have varied findings that have not been previously quantitatively pooled to estimate the overall effect of yoga on glycaemic and anthropometric control at the prediabetes stage, where preventive interventions are most clinically relevant.

Therefore, the present systematic review and meta-analysis is the first to quantitatively synthesize randomized controlled trial evidence comparing yoga-based interventions with control conditions in adults with prediabetes. This review aimed to evaluate the effects of yoga-based interventions, compared with control conditions, on glycaemic and anthropometric outcomes in this population. The primary outcomes were changes in fasting blood glucose (FBG), postprandial blood glucose (PPBG), and glycated haemoglobin (HbA1c), and the secondary outcome was body mass index (BMI), assessed between the yoga and control groups.

Method

Study protocol

The review protocol was developed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines (Page et al., 2021). The study was registered in the International Prospective Register of Systematic Reviews (PROSPERO) with the registration number CRD420251017200.

Search Strategy

Two authors (GCS, SM) searched in different large databases, including PubMed, Scopus, and Web of Science, to be as comprehensive as possible. A combined methodology was used to employ keywords (free-text terms) and Medical Subject Headings (MeSH). Terms associated with the Population, Intervention, and Outcomes (PIO framework) were combined using Boolean operators (OR, AND). Table 1 demonstrates the specific search strategy for each database. The search was confined to publications between September 2013 and May 2023 and limited to full-text articles in the English language to avoid inconsistency and manage data extraction.

In order to optimize the sensitivity and specificity, a careful search strategy was created based on a combination of MeSH terms, keywords, and Boolean operators.

A total of 407 records were retrieved across databases: PubMed (200), Scopus (121), and Web of Science (86)

Table 1. Databases, search terms, and search strategies

Database	Search Terms	Search Strategies
PubMed	“Yoga”, "Meditation", "Breathing Exercises", “yoga”, “pranayama”, "Prediabetic State", “prediabetes”, “impaired glucose tolerance”, “Metabolic Syndrome”, “prediabetic”, “high risk for diabetes”	(("Yoga"[MeSH] OR "Meditation"[MeSH] OR "Breathing Exercises"[MeSH] OR yoga[TIAB] OR pranayama[TIAB])) AND (("Prediabetic State"[MeSH] OR prediabetes[TIAB] OR "Impaired Glucose Tolerance"[MeSH] OR "Metabolic Syndrome"[MeSH] OR prediabetic[TIAB] OR "high risk for diabetes"[TIAB]))
Scopus	“yoga”, “prediabetes”, “impaired glucose tolerance”, "impaired fasting glucose", “fasting blood glucose”, “HbA1c”, “glycemic control”, “insulin resistance”	(TITLE-ABS-KEY("yoga")) AND (TITLE-ABS-KEY("prediabetes") OR TITLE-ABS-KEY("impaired glucose tolerance") OR TITLE-ABS-KEY("impaired fasting glucose")) AND (TITLE-ABS-KEY("fasting blood glucose") OR TITLE-ABS-KEY("HbA1c") OR TITLE-ABS-KEY("glycemic control") OR TITLE-ABS-KEY("insulin resistance"))
Web of Science	“Yoga”, “prediabetes”, “impaired glucose tolerance”, "Impaired Fasting Glucose", “fasting blood glucose”, “HbA1c”, “glycemic control”, “insulin resistance”	((TS=("Yoga")) AND (TS=("Prediabetes") OR TS=("Impaired Glucose Tolerance") OR TS=("Impaired Fasting Glucose"))) AND (ALL=("fasting blood glucose") OR ALL=("HbA1c") OR ALL=("glycemic control") OR ALL=("insulin resistance"))

[TIAB] — Title/Abstract, TITLE-ABS-KEY — Title, Abstract, and Keywords, *TS= Topic* Search, *ALL= All* Fields.

Selection criteria

The eligibility criteria for study selection were based on the Population, Intervention, Comparison, Outcomes, and Study design (PICOS) framework. Studies were screened according to the following inclusion and exclusion criteria, as demonstrated in Table 2.

Table 2. Inclusion and exclusion criteria of study selection process for the systematic review and meta-analysis on the therapeutic potential of yoga in prediabetes.

Criteria	Inclusion	Exclusion
Population	Studies in which individual with prediabetes was diagnosed using either ADA or IDRS standards. Age – 29 to 60 years. Sex – Male & Female.	Exclusion criteria were a diagnosis of diabetes mellitus, cancer, pulmonary tuberculosis, rheumatoid arthritis, osteoporosis, infectious diseases, cardiovascular disease, neuromuscular disorders, or pregnancy.
Intervention	Yoga-based interventions included practices such as Surya Namaskar, asanas, pranayama, meditation, or integrated yoga modules.	Interventions involving other forms of physical exercise besides yoga.
Comparison	Control Group (no intervention)	
Outcomes	Primary outcomes: Fasting blood glucose, postprandial blood glucose, and glycated hemoglobin. Secondary outcome: Body Mass Index,	Studies not reporting mean and standard deviation (pre/post values or change scores).
Study Design	Randomized Controlled Trials.	Non-randomized, observational, or qualitative studies.
Study Access	Studies published in the English language, freely accessible (open access), and conducted on human participants.	Studies with unclear age group, ambiguous sample size, or unpublished/unavailable full text.
Publication Type	Peer-reviewed original research articles.	Duplicates, reviews, case reports, book chapters, conference proceedings, abstracts, commentaries, editorials.

Data extraction and synthesis

Independent reviewers (GCS and SM), using blinded study selection with the Rayyan platform, screened titles, abstracts, and full texts according to set eligibility criteria. The selection of studies was carried out in two steps: First, titles and abstracts were screened, and then, for potentially qualified studies, full texts were assessed. The reviewer's inter-rater agreement was calculated using Cohen's kappa (κ), which quantifies agreement. The formula for kappa is: $\kappa = (Po - Pe) / (1 - Pe)$, where Po is the measure of observed agreement, and Pe is the expected agreement by chance (Higgins et al., 2024). Both reviewers independently assessed all studies and reached 100% observed agreement, reflecting perfect inter-rater reliability ($\kappa = 1.00$). With no disagreements, the reported observed agreement percentage is 100. Given the absence of disagreement, the observed agreement percentage was also reported for transparency. To reflect good practices, possible disagreements that were to be discussed and resolved by the reviewers. This process indicates that the review was completed in a manner that kept bias and adherence to the review criteria in check. A standardized data extraction form was used to systematically collect the relevant information from the included studies. The data extraction form was designed to be uniform to avoid errors and bias, as much as possible (Higgins et al., 2024). The main data that were extracted were author and year of publication, country, study design, sample characteristics, intervention and control conditions, and key outcome measures. The mean and SD of the intervention and control groups were obtained. If change scores were unreported, the mean and SD of the pre- and post-intervention were obtained. Data extraction was done by one reviewer (GCS), and to enhance the data's precision, the second reviewer (SM) performed a check. There was no need to communicate with the study authors, since all pertinent information was accessible in the published articles.

Study quality:

The Cochrane Risk of Bias 2 tool (RoB 2) was applied to assess the methodological quality of the randomized controlled trials (Higgins et al., 2024) that evaluate five potential domains of bias, those are bias arising from the randomization process (D1), bias due to deviations from intended interventions (D2), bias due to missing outcome data (D3), bias in measurement of the outcome (D4), and bias in selection of the reported result (D5). . Each study was determined to have either a low risk of bias, a high risk of bias, or some concerns, following the RoB 2 Cochrane guidelines (Higgins et al., 2024).

Statistical analysis

Cochrane Handbook for Systematic Reviews of Interventions was used to conduct meta-analyses to compare the effect of yoga interventions and control on primary outcomes (FBG, PPBG, and HbA1c) and secondary outcome (BMI) in people with prediabetes. For the studies that did not report change scores, the mean difference was calculated as the difference of baseline and post intervention scores. The baseline and post-intervention measures were assumed to have a correlation coefficient of r=0.7, to compute the standard deviation (SD) of the change scores, per Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2024). On the other hand, SD of change scores for post and pre correlations of 0.5 and 0.9 were utilized for the sensitivity analyses of the results to assess the robustness of the results. (Higgins et al., 2024). To show single and combined effects, the results were presented using forest plots (Higgins et al., 2024). The results were standardized to units: FBG and PPBG measured in mg/dL, HbA1c measured in percentage, and BMI measured in kg/m2. Due to the anticipated diversity among the studies, a random effects model using the inverse variance method was used. The mean differences (MD) and 95% confidence intervals (CI) were computed for the continuous outcome (FBG, PPBG, HbA1c, and BMI). I^2, Tau^2, and Chi^2 statistics were used to assess heterogeneity. The level of heterogeneity was determined by the I^2 statistic, with thresholds of 25 percent, 50 percent, and 75 percent being considered, respectively, low, moderate, and high heterogeneity. When I2 values were reported as high due to having considerable heterogeneity, subgroup analyses were then performed. Subgroup analyses were performed based on the duration of single yoga sessions. Other subgroup analyses regarding the duration of the intervention, frequency of the intervention, and the characteristics of the target population could not be performed due to the limited number of studies in each subgroup. Using the R software (version 4.4.3), standard deviation scores were calculated, and meta-analyses were done using Review Manager (version 5.4.1). All analyses were conducted independently by two reviewers.

Mean Difference

The mean difference is correctly stated as:

Mean difference = Mean baseline − Mean post.

Mean baseline = Before intervention mean.

Mean post = post-intervention means (Higgins et al., 2024).

Standard Deviation of the Change:

$$\text{SD difference} = \sqrt{\text{SD}^2_{\text{baseline}} + \text{SD}^2_{\text{post}} - (2 \times \text{corr} \times \text{SD}_{\text{baseline}} \times \text{SD}_{\text{post}})}$$

Where:

SDbaseline = Standard deviation at baseline.

SDpost =Standard deviation at post-intervention.

corr = correlation coefficient, which estimates 0.7(Higgins et al., 2024).

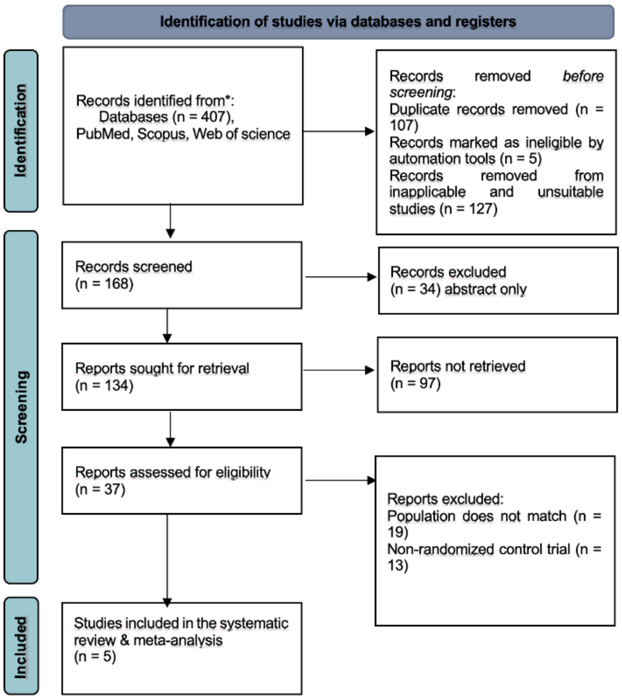
Certainty of evidence (GRADE)

The certainty of the evidence for each outcome was assessed using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach. Several areas were evaluated, including the study design, the risk of bias, inconsistency, indirectness, imprecision, the number of participants in each group, and absolute effect at 95% (CI). The “undetected” option was selected for Publication bias in GRADEpro GDT. The evidence was classified in the levels of high, moderate, low, or very low using GRADEpro GDT software (Higgins et al., 2024). High-certainty evidence points to the fact that we are highly certain that the true effect is almost equal to the estimated effect. Moderate-certainty evidence: we are moderately sure; the actual effect must be like the one which we have estimated, but can differ significantly. Evidence of low certainty indicates that there is little confidence that the effect is accurate, and it could be that the actual effect is very different. Very little confidence is represented by very low-certainty evidence, and the actual effect is likely to be significantly different than the estimated effect (Higgins et al., 2024). The certainty of evidence is described in table no 4.

Results

Records were identified through database searches of PubMed, Scopus, and Web of Science, yielding a total of 407 records. Before screening, 239 records were removed, including 107 duplicate records, 5 records marked as ineligible by automation tools, and 127 records excluded as inapplicable or unsuitable based on an initial review. Following this process, 168 records were screened at the title and abstract level. Of these, 34 records were excluded because only abstracts were available. Consequently, 134 reports were sought for full-text retrieval. However, 97 reports could not be retrieved or were excluded because they were not original research articles (e.g., review papers or book chapters). A total of 37 full-text reports were assessed for eligibility. Of these, 32 reports were excluded due to population mismatch (n = 19) or non-randomized controlled trial design (n = 13). Ultimately, five studies met all eligibility criteria and were included in the final systematic review and meta-analysis. Figure 1 demonstrates the PRISMA flow diagram of the study selection process.

Figure 1. PRISMA flow diagram of study selection process for the systematic review and meta-analysis on the therapeutic potential of yoga in prediabetes:



Participants' characteristics and research design

A comprehensive summary of intervention characteristics and outcome measures is presented in Table 3.

Study Types

All included studies employed randomized controlled trial (RCT) designs, though they differed in methodological characteristics. Keerthi et al. (2017) conducted a double-blind randomized controlled trial, while Hegde et al. (2013) implemented a multi-site randomized controlled trial. Chattopadhyay et al. (2023) used a multicentre, two-arm, parallel-group randomized controlled trial design. Kaur et al. (2021) conducted a parallel-group randomized controlled trial, and Kacker et al. (2019) employed a single-blind randomized controlled trial.

Population

Participants in the studies included adult male and female pre-diabetic patients from India aged 29 to 75 years. Keerthi et al. (2017) recruited adults aged 29 to 43 years, and Hegde et al. (2013) recruited adults aged 30 to 75 years. Chattopadhyay et al. (2023) reported participants aged 34 to 51 years, Kaur et al. (2021) reported adults aged 38 to 60 years, and Kacker et al. (2019) had individuals aged 30 to 50 years. All studies had adult participants of both sexes. This produced a mixed adult population demonstrating the increased risk for progression to type 2 diabetes for both sexes.

Intervention

Yoga Interventions, while having different structures, frequency, and durations, shared the same components for all of the included randomized controlled studies. For example, Keerthi et al. (2017) had a 12-week program where participants attended 45-minute sessions three times a week for 12 weeks. The intervention programme included sukshma vyayama, surya namaskara, asanas, pranayama, and meditation. Hegde et al. (2013) had a more intensive intervention with their participants having 75 to 90 minute sessions five times a week for 12 weeks, including asanas, pranayama, and Shavasana. In the multicentre trial by Chattopadhyay et al. (2023), the participants completed the Yoga Programme for Diabetes Prevention (YOGA-DP), which included 75–90 minute sessions conducted once a week, plus additional home practice assignments for 24 weeks, which included surya namaskar, various asanas, pranayama, and meditation. Kaur et al. (2021) used the Diabetes Yoga Protocol (DYP), which included as part of the protocol, prayer, asanas, pranayama, and meditation, and was 60 minutes in duration, 3 times per week for 12 weeks. Kacker et al. (2019). Similarly, they completed a yoga intervention of 12 weeks duration with 45-minute sessions conducted 6 times per week, and it included prayer, Omkar recitation, various asanas, pranayama, meditation, and Shavasana.

Outcome Measurement

Several of the included studies measured various glycemic and anthropometric parameters as a means of assessing the effects of the yoga interventions. Fasting blood glucose was assessed in four studies with a cumulative sample of 399 participants (Keerthi et al., 2017; Hegde et al., 2013; Chattopadhyay et al., 2023; Kaur et al., 2021). Two studies measured postprandial blood glucose and had a total of 213 participants (Hegde et al., 2013; Kaur et al., 2021), while three studies reported glycated hemoglobin with 278 participants (Hegde et al., 2013; Chattopadhyay et al., 2023; Kaur et al., 2021). Body mass index was measured in four studies with a total sample of 380 participants (Hegde et al., 2013; Chattopadhyay et al., 2023; Kaur et al., 2021; Kacker et al., 2019). These outcomes illustrated various metabolic and anthropometric changes associated with yoga practice in adults with prediabetes.

Table 3. Characteristics of Included Studies

Author(s)	Age & Sex of Participants	Age & Sex of Participants	Study Design	Intervention (Yoga Group)	Comparison	Duration	Outcomes Measured
(Keerthi et al., 2017)	India	29–43 years, both genders	RCT	Yoga intervention – 45-min sessions, 3 days/week; included Sukshma Vyayama, Surya Namaskara, asanas, pranayama, meditation	Control Group	12 weeks	FBG
(Hegde et al., 2013)	India	30–75 years, both genders	RCT	Yoga intervention – 75–90 min sessions, 5 days/week; included asanas, pranayama, Shavasana	Control Group	12 weeks	FBG, HbA1c, PPBG, BMI
(Chattopadhyay et al., 2023)	India	34–51 years, both genders	RCT	Yoga intervention: Yoga Program for Diabetes Prevention (YOGA-DP)75–90 min sessions, 1 day/week with self-Practice of Yoga at home included Surya Namaskar, asanas, pranayama, and meditation	Control Group	24 weeks	FBG, HbA1c, BMI
(Kaur et al., 2021)	India		RCT	Yoga intervention: Diabetes Yoga Protocol	Control Group	12 weeks	HbA1c, FBG, PPBG, BMI

		38–60 years, both genders		(DYP), 60-minute sessions; 3 days/week; included prayer, asanas, pranayama, meditation			
(Kacker et al., 2019)	India	30–50 years, both genders	RCT	Yoga intervention – 45-min sessions, 6 days/week; included prayer, Omkar recitation, asanas, pranayama, meditation, Shavasana	Control Group	12 weeks	BMI

Abbreviations: RCT: Randomized controlled trial; FBG: fasting blood glucose; PPBG: postprandial blood glucose; HbA1c: glycated hemoglobin; BMI: body mass index.

Risk of bias assessment

As illustrated in Figures 2 and 3, the risk of bias assessment using the RoB 2 tool indicated that all included studies (Chattopadhyay et al., 2023; Hegde et al., 2013; Kacker et al., 2019; Kaur et al., 2021; Keerthi et al., 2017) had a low risk of bias arising from the randomization process (D1), reflecting appropriate sequence generation and absence of baseline imbalances. However, all studies were judged to have a high risk of bias due to deviations from intended interventions (D2), as blinding of participants and personnel was not feasible because of the nature of yoga-based interventions, and deviations from assigned interventions could not be excluded. Bias due to missing outcome data (D3) was considered low across all studies, as outcome data were largely complete and attrition was minimal or adequately addressed. Regarding bias in outcome measurement (D4), Hegde et al. (2013) were assessed as having a high risk due to insufficient reporting of blinded outcome assessment, whereas the remaining studies were judged to be at low risk, supported by the use of standardized blinding outcome measures. All studies demonstrated a low risk of bias in the selection of the reported results (D5), with no evidence of selective outcome reporting. Despite low-risk judgments in most domains, the consistent high risk in D2 in all studies and D4 in Hegde et al. (2013) resulted in an overall high risk of bias classification for all included trials, in accordance with RoB 2 guidance.

Figure 2. Traffic light plot of risk of bias assessment

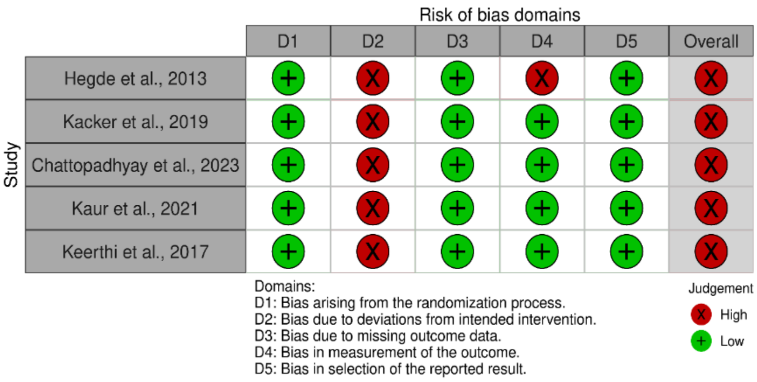
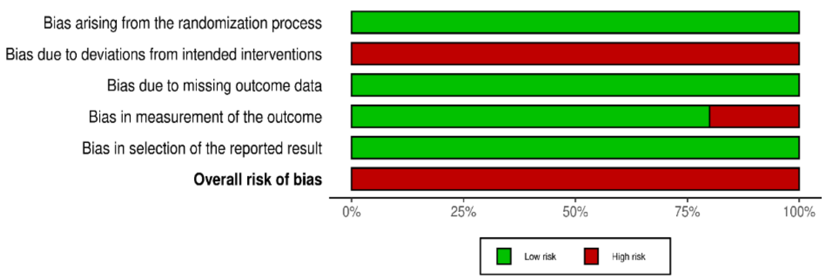


Figure 3. Summary plot of risk of bias assessment



Primary Outcome

Fasting blood glucose

This study included four randomized controlled trials with a total of 399 subjects (yoga: n = 199; control: n = 200) to evaluate the impact of yoga interventions on fasting blood glucose levels. Due to considerable variations among the studies, a random effects model was utilized. Assuming a correlation coefficient (r) of 0.7 for SD calculation, analysis showed that there was no significant difference between the fasting blood glucose levels of the yoga group, compared to the control group, with a mean difference (MD) of -6.91 (95% CI -16.92 to 3.11) and a p value of 0.18 with very low certainty evidence. The analysis showed considerable heterogeneity (Tau^2 of 102.35; Chi^2 = 252.02, df = 3, p < 0.00001), and I^2 of 99% as shown in the forest plot (Figure 4). In order to test the correlation coefficient used for SD calculation, sensitivity analyses were performed. Adjusting the assumed correlation to a lower figure (r = 0.5), the sensitivity analysis maintains the statistically non-significant effect (MD = -6.95, 95% CI = -18.59 to 4.69; p = 0.24), despite the considerable heterogeneity (Tau^2 = 138.22; Chi^2 = 252.35, df = 3, p < 0.00001; I^2 = 99%) as shown in the forest plot in Figure 5. Analyzing results under the assumption of a higher correlation (r = 0.9) also yielded consistent results (MD = -6.95, 95% CI = -17.35 to 3.46; p = 0.19) with a similar degree of heterogeneity (Tau^2 = 111.82; Chi^2 = 727.37, df = 3, p < 0.00001; I^2 = 100%) as shown in the forest plot in Figure 6. Overall, the stability of effect estimates across r = 0.5, 0.7, and 0.9 indicates that the findings were robust to different assumptions regarding the correlation between baseline and post-intervention measurements, despite persistently high heterogeneity.

A subgroup analysis was performed regarding the impact of the length of a single yoga session per day. The studies were divided into 2 subgroup such as 45–60 minute yoga sessions per day and 75–90 minute yoga sessions per day. As seen in the forest plot (Figure 7), yoga did not yield any notable positive outcomes in comparison to the control conditions. The aggregated data from studies involving 45 to 60 minute/sessions showed that the result was not statistically significant (MD = −12.40 mg/dL, 95% CI: −39.56 to 14.77; p = 0.37), yet the studies also reported extremely high heterogeneity (I^2 = 99%), indicating a considerable level of inconsistency in the findings. Similarly, studies involving 75 to 90 minute/sessions showed an insignificant reduction of FBG (MD = -0.77 mg/dL, 95% CI: -3.33 to 1.80; p = 0.56), which indicates moderate heterogeneity (I^2 = 50%). No significant subgroup differences were detected between session durations (p for subgroup differences = 0.40), indicating that the length of a single daily yoga session did not significantly modify the intervention effect

Postprandial blood glucose

There were two randomized controlled trials with 213 total participants (Yoga: n = 105; Control: n = 108) included in the meta-analysis examining the impact of yoga interventions on Postprandial blood glucose. A random-effects model was used. The forest plot (Figure 8) illustrates the analysis with an assumed correlation coefficient of r = 0.7 for SD calculation. The analysis found no statistically significant differences among the yoga and control groups (MD= −0.61, 95% CI: −0.06 to 1.28; Z = 1.78, p = 0.07) with low certainty evidence. The absence of significant heterogeneity across the studies (Tau^2 = 0.00; Chi^2 = 0.35, df = 1, p = 0.56; I^2 = 0%) suggests studies were quite consistent.

As a further means to evaluate the accuracy of the results, alternative assumed correlation coefficients were used for the sensitivity analyses.

The effect estimates in the forest plot (Figure 9) still stayed non-significant (MD = -0.31, 95% CI: -1.16 to 0.54; Z = 0.71, p = 0.47; I^2 = 0%) even with lower correlation (r = 0.5). This was also the case for the higher correlation (r = 0.9), which gave the same results (MD = -0.31, 95% CI: -0.73 to 0.11; Z = 1.45, p = 0.15; I^2 = 0%) as seen in the forest plot (Figure 10). The consistent findings associated with the effect estimates across r = 0.5, 0.7, and 0.9, and the data showing consistently negligible levels of heterogeneity, suggest that the findings related to PPBG were consistent across the various methods utilized to estimate the correlation between the baseline and post-intervention measures.

Glycated hemoglobin

The effect of yoga interventions on HbA1c has been studied in three randomized controlled trials with a total of 278 participants (Yoga: n = 138; Control: n = 140). A random-effects model has been used in this study. In figure 11, we used a presumed correlation coefficient of r = 0.7. In our analysis, we found no statistically significant difference between the yoga and control groups (MD = −0.02 with a 95% (CI) of −0.10 to 0.05; Z = 0.67 and p = 0.50). The heterogeneity between studies was low (Tau^2 = 0.00; Chi^2 = 0.56, df = 2, p = 0.76; I^2 = 0%), which means that the studies were very similar to one another.

In order to test the correlation coefficient used for SD calculation, sensitivity analyses were performed. With r = 0.5, the effect was pooled non-significant (MD = −0.02, 95% CI: −0.12 to 0.07; Z = 0.52, p = 0.60; I^2 = 0%), as shown in Figure 12. With r = 0.9, we obtained similar results, with the MD = −0.02, 95% CI: −0.07 to 0.02; Z = 1.09, p = 0.27; I^2 = 0%), which are shown in Figure 13.

The consistent findings associated with the effect estimates across r = 0.5, 0.7, and 0.9, and the data showing consistently negligible levels of heterogeneity, suggest that the findings related to HbA1c were consistent across the various methods utilized to estimate the correlation between the baseline and post-intervention measures.

Secondary outcome

Body mass index

Assuming correlation coefficient r = 0.7 for SD calculation, the pooled analysis indicated there was no statistically significant difference between the yoga and control groups (MD = −0.63, 95% CI −1.44 to 0.17; Z=1.53; p = 0.12) and no heterogeneity was observed (Tau^2 = 0.00; Chi^2 = 0.53, df = 3, p = 0.91; I^2 = 0%) as shown in the forest plot (Figure 14). Using a lower assumed correlation (r = 0.5) in the sensitivity analysis also resulted in a non-significant difference (MD = −0.66, 95% CI −1.66 to 0.35; p = 0.20; I^2 = 0%), which is shown in the forest plot (Figure 15). In contrast, using a higher assumed correlation (r = 0.9) the pooled effect was statistically significant (MD = −0.58 kg/m^2, 95% CI −1.08 to −0.07; p = 0.02; I^2 = 0%) as shown in the forest plot (Figure 16), but this effect was clinically negligible. Despite this, the magnitude and direction of the effect remained consistent across all analyses, indicating that statistical significance was sensitive to assumptions regarding the correlation between baseline and post-intervention measurements, while between-study heterogeneity remained negligible.

A total of four randomized controlled trials were analyzed for the effect of yoga interventions on body mass index, yielding a total of 380 participants (yoga: n = 189; control: n = 191). A random-effects model was utilized.

Primary Outcomes

FBG

Figure 4. Forest plot of the meta-analysis for FBG (Assuming *r* = 0.7 for SD calculation)

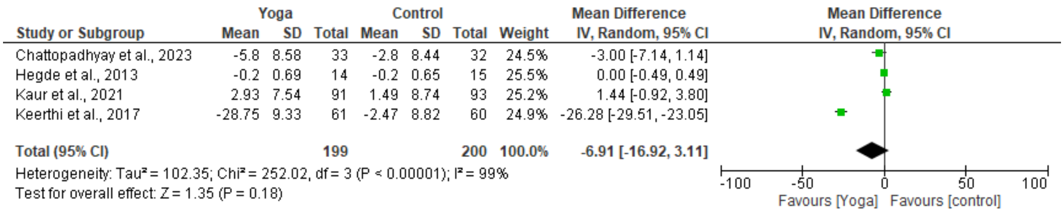


Figure 5. Forest plot of the Sensitivity Analysis for FBG (Assuming r = 0.5 for SD Calculation)

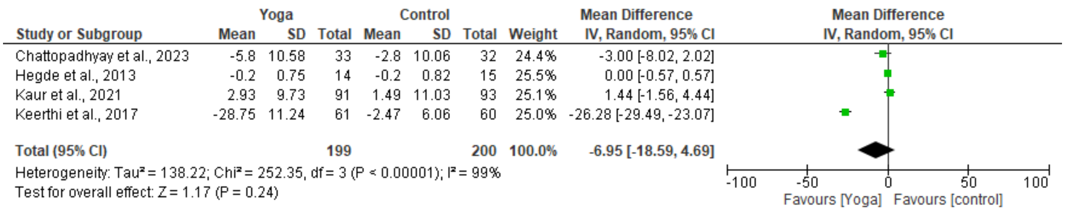


Figure 6. Forest plot of the Sensitivity Analysis for FBG (Assuming r = 0.9 for SD Calculation)

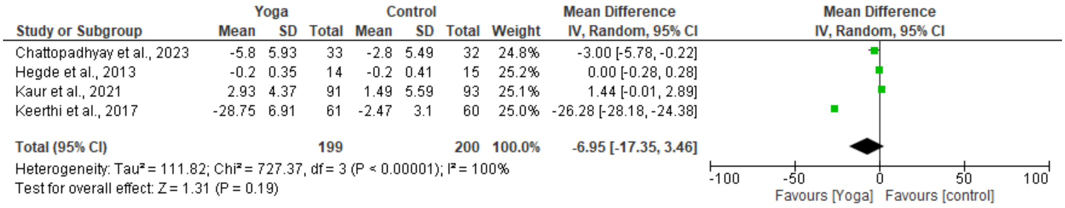
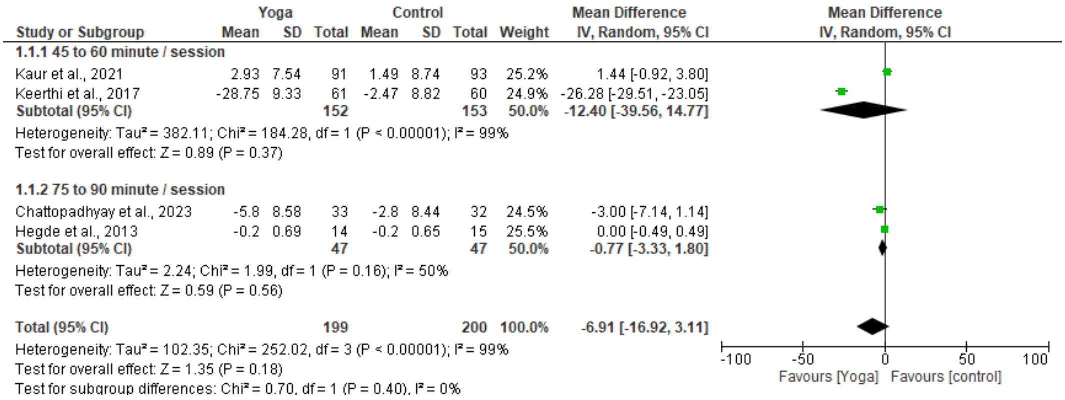


Figure 7. Forest plot of the subgroup analysis for FBG



PPBG

Figure 8. Forest plot of the meta-analysis for PPBG (Assuming *r* = 0.7 for SD calculation)

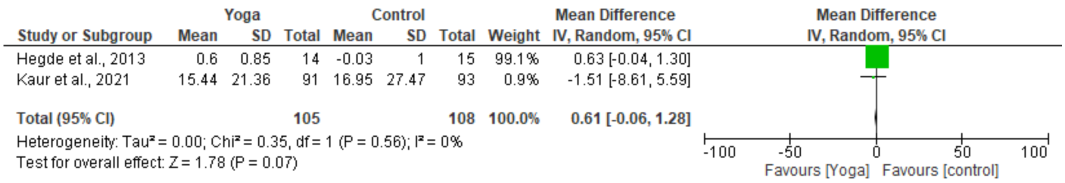


Figure 9. Forest plot of Sensitivity Analysis for PPBG (Assuming r = 0.5 for SD Calculation)

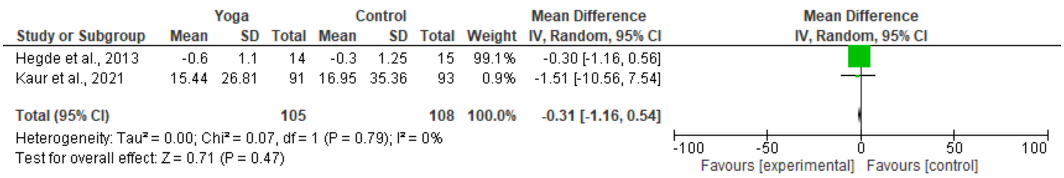
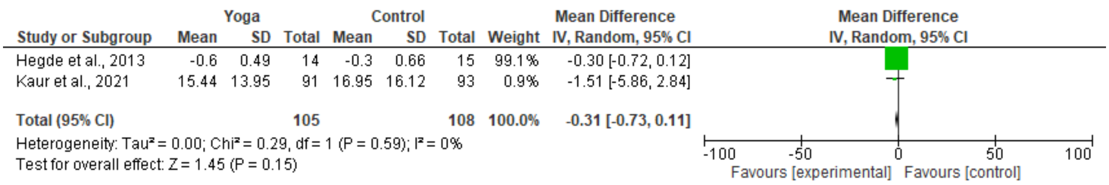


Figure 10. Forest plot of Sensitivity Analysis for PPBG (Assuming r = 0.9 for SD Calculation)



HBA1C

Figure 11. Forest plot of the meta-analysis for HBA1c, (Assuming *r* = 0.7 for SD calculation)

Study or Subgroup	Yoga Mean	Yoga SD	Yoga Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Chattopadhyay et al., 2023	-0.3	0.29	33	-0.3	0.36	32	19.9%	0.00 [-0.16, 0.16]
Hegde et al., 2013	-0.1	0.31	14	0	0.29	15	10.6%	-0.10 [-0.32, 0.12]
Kaur et al., 2021	0	0.3	91	0.02	0.29	93	69.5%	-0.02 [-0.11, 0.07]
Total (95% CI)			**138**			**140**	**100.0%**	**-0.02 [-0.10, 0.05]**

Heterogeneity: Tau² = 0.00; Chi² = 0.56, df = 2 (P = 0.76); I² = 0%
Test for overall effect: Z = 0.67 (P = 0.50)

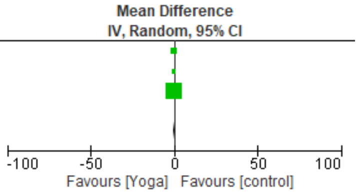


Figure 12. Forest plot of Sensitivity Analysis for HBA1c, (Assuming r = 0.5 for SD Calculation)

Study or Subgroup	Yoga Mean	Yoga SD	Yoga Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Chattopadhyay et al., 2023	-0.3	0.36	33	-0.3	0.46	32	20.9%	0.00 [-0.20, 0.20]
Hegde et al., 2013	-0.1	0.4	14	0	0.36	15	11.0%	-0.10 [-0.38, 0.18]
Kaur et al., 2021	0	0.39	91	0.02	0.38	93	68.2%	-0.02 [-0.13, 0.09]
Total (95% CI)			**138**			**140**	**100.0%**	**-0.02 [-0.12, 0.07]**

Heterogeneity: Tau² = 0.00; Chi² = 0.35, df = 2 (P = 0.84); I² = 0%
Test for overall effect: Z = 0.52 (P = 0.60)

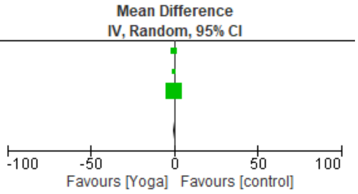
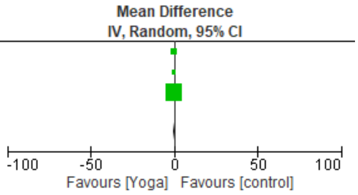


Figure 13. Forest plot of Sensitivity Analysis for HBA1c (Assuming r = 0.9 for SD Calculation)

Study or Subgroup	Yoga Mean	Yoga SD	Yoga Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Chattopadhyay et al., 2023	-0.3	0.19	33	-0.3	0.22	32	18.4%	0.00 [-0.10, 0.10]
Hegde et al., 2013	-0.1	0.2	14	0	0.18	15	9.6%	-0.10 [-0.24, 0.04]
Kaur et al., 2021	0	0.17	91	0.02	0.18	93	72.0%	-0.02 [-0.07, 0.03]
Total (95% CI)			**138**			**140**	**100.0%**	**-0.02 [-0.07, 0.02]**

Heterogeneity: Tau² = 0.00; Chi² = 1.40, df = 2 (P = 0.50); I² = 0%
Test for overall effect: Z = 1.09 (P = 0.27)



Secondary outcome

BMI

Figure 14. Forest plot of the meta-analysis for BMI (Assuming *r* = 0.7 for SD calculation)

Study or Subgroup	Yoga Mean	Yoga SD	Yoga Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Chattopadhyay et al., 2023	-0.4	4.14	33	0.1	3.3	32	19.7%	-0.50 [-2.32, 1.32]
Hegde et al., 2013	-0.4	2.79	14	0.1	3.37	15	12.9%	-0.50 [-2.75, 1.75]
Kacker et al., 2019	-1	5.08	51	0.1	2.14	51	28.4%	-1.10 [-2.61, 0.41]
Kaur et al., 2021	-0.59	4.98	91	-0.19	3.87	93	39.0%	-0.40 [-1.69, 0.89]
Total (95% CI)			**189**			**191**	**100.0%**	**-0.63 [-1.44, 0.17]**

Heterogeneity: Tau² = 0.00; Chi² = 0.53, df = 3 (P = 0.91); I² = 0%
Test for overall effect: Z = 1.53 (P = 0.12)

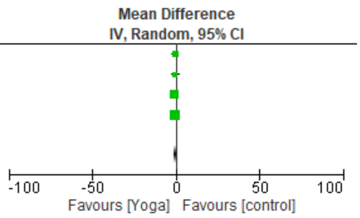


Figure 15. Forest plot of Sensitivity Analysis for BMI (Assuming r = 0.5 for SD Calculation)

Study or Subgroup	Yoga Mean	Yoga SD	Yoga Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Chattopadhyay et al., 2023	-0.4	5.33	33	0.1	4.26	32	18.5%	-0.50 [-2.84, 1.84]
Hegde et al., 2013	-0.4	3.6	14	0.1	4.25	15	12.4%	-0.50 [-3.36, 2.36]
Kacker et al., 2019	-1	6.08	51	0.1	2.25	51	32.1%	-1.10 [-2.88, 0.68]
Kaur et al., 2021	-0.59	6.37	91	-0.19	5	93	37.0%	-0.40 [-2.06, 1.26]
Total (95% CI)			**189**			**191**	**100.0%**	**-0.66 [-1.66, 0.35]**

Heterogeneity: Tau² = 0.00; Chi² = 0.36, df = 3 (P = 0.95); I² = 0%
Test for overall effect: Z = 1.27 (P = 0.20)

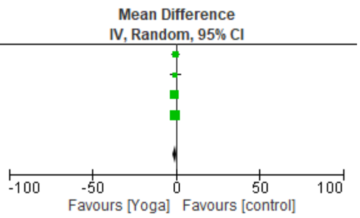


Figure 16. Forest plot of Sensitivity Analysis for BMI (Assuming r = 0.9 for SD Calculation)

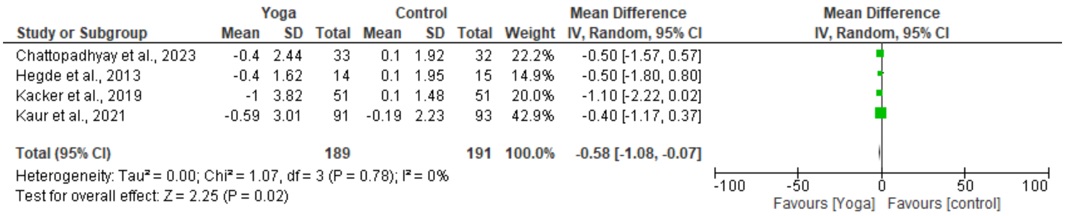


Table 4. Certainty of evidence (GRADE) table:

№ of studies	Risk of bias	Inconsistency	Indirectness	Imprecision	Other consideration	Yoga n	Control n	Absolute effect (95% CI)	Certainty	Importance
FBG (n=4)	serious[a]	serious[b]	not serious[e]	serious[c]	none	200	119	MD 6.91 lower (16.92 lower to 3.11 higher)	⊕◯◯◯ Very low[a,b,c]	IMPORTANT
PPBG (n=2)	serious[a]	not serious[d]	not serious[e]	serious[c]	none	105	108	MD 0.61 higher (0.06 lower to 1.28 higher)	⊕⊕◯◯ low[a,c]	IMPORTANT
HbA1c (n=3)	serious[a]	not serious[d]	not serious[e]	serious[c]	none	138	140	MD 0.02 lower (0.10 lower to 0.05 higher)	⊕⊕◯◯ low[a,c]	IMPORTANT
BMI (n=4)	serious[a]	not serious[d]	not serious[e]	serious[c]	none	189	191	MD 0.63 lower (1.44 lower to 0.17 higher)	⊕⊕◯◯ low[a,c]	IMPORTANT

CI: confidence interval; MD: mean difference
Explanations
a. All studies had a high risk of bias. Downgraded.
b. Serious inconsistency since I^2= 99%. Downgraded.
c. 95% CI is wide and crosses no effect. Downgraded.
d. Not serious inconsistency since I^2 = 0. Not downgraded.
e. Evidence is directly relevant. Not downgraded.

Discussion

This systematic review and meta-analysis are the first to examine the effects of yoga interventions on glycaemic and anthropometric outcomes in individuals with prediabetes. Overall, yoga did not result in statistically significant improvements in primary outcomes, including fasting blood glucose, postprandial blood glucose, glycated hemoglobin, and secondary outcome body mass index, when compared with control conditions.

FBG levels provide vital information regarding a person's glycaemic control, as well as complications arising from the transition from prediabetes to type 2 diabetes. The current synthesis did not demonstrate significant changes in FBG following yoga interventions, suggesting that yoga is not likely to produce clinically significant changes in FBG in prediabetes patient. While the majority of studies reported reductions in FBG (especially in studies of Chattopadhyay et al, 2023; Hegde et al, 2013; Keerthi et al, 2017), the study of Kaur et al. (2021) reported no such change after the intervention. The main analysis, in which a pre-post correlation coefficient of 0.7 was assumed to derive the standard deviation for change scores, resulted in a non-significant pooled FBG reduction and was based on low-certainty evidence combined with a considerable heterogeneity (I2=98), which greatly undermines confidence regarding the estimate. As such, results should be viewed with appropriate caution. Sensitivity analyses conducted under varying assumed correlation coefficients (0.5, 0.9) for calculating pre–post change score standard deviations yielded consistently non-significant results with high heterogeneity, thereby supporting the robustness of the primary findings. The inconsistency in findings may be attributed to substantial heterogeneity across studies with respect to participant age, intervention characteristics, and methodological quality. These factors may explain why the findings were inconsistent. Because of the limited availability of studies on the selected factors, the planned subgroup analyses based on yoga type, intervention frequency, intervention total duration, and participant characteristics were not possible. In most instances, subgroups included only three studies in one category and only one study in another category; therefore, meaningful and statistically valid comparisons were not feasible. Because of these restrictions, the only attribute available for meaningful subgroup analyses was the duration of the single yoga session per day. yoga sessions duration was the only attribute that had adequate studies for analysis. Analyses indicated that the two studies with shorter sessions 45–60 minutes of yoga per session (Kaur et al., 2021; Keerthi et al., 2017) had higher heterogeneity and the other two studies with longer sessions 75–90 minutes of yoga per session (Chattopadhyay et al., 2023; Hegde et al., 2013) had with moderate heterogeneity. Statistically, higher heterogeneity is most often viewed to be less desirable. Subgroup difference test was not statistically significant based on the single yoga session duration; therefore, a session did not significantly impact the overall outcomes. It should be noted that each subgroup contained only two studies, which require such a cautious interpretation.

In this meta-analysis, which included two studies, yoga was found to have a non-significant effect on postprandial blood glucose. Both studies (Hegde et al., 2013; Kaur et al., 2021) reported no statistically significant change in PPBG after the intervention. Using an assumed pre–post correlation coefficient of 0.7, the main analysis showed that the pooled reductions in PPBG were non-significant and supported with low certainty evidence and characterized with no heterogeneity (I^2 = 0%), which indicated that the studies had consistent results. When pre-post change score standard deviation correlation was estimated at 0.5 and 0.9 for the sensitivity analysis, the results were still statistically insignificant, which indicates that the findings were not materially influenced by the choice of correlation assumption. Based on the evidence currently available, it would appear that yoga may not have a statistically significant effect on PPBG in individuals with pre diabetic. The limited number of studies restricts the certainty of this conclusion. In this meta-analysis, which included three studies, yoga was found to have no statistically significant effect on glycated hemoglobin. Using an assumed pre–post correlation coefficient of 0.7, the main analysis showed that the pooled reductions in HbA1c were non-significant with low certainty of evidence. This was attributed to the negligible heterogeneity (I^2 = 0%), which implies that the studies showed consistent results. The primary findings were supported by the sensitivity analyses, under the assumed correlation coefficients of 0.5 and 0.9 for the calculation of SD change, which yielded non-significant results. Among the studies included in the review, the effect of yoga on HbA1c was rather heterogeneous, with Hegde et al. (2013) and Kaur et al. (2021) reporting no significant improvement and Chattopadhyay et al. (2023) reporting a significant reduction. Overall, given the limited number of studies available, we conclude that yoga is not likely to have a meaningful effect and influence on HbA1c control among the prediabetes patient. In this meta-analysis with four studies, using an assumed pre–post correlation coefficient of 0.7, the main analysis showed the effect of yoga was also found to be non-significant in terms of effect on BMI. The absence of statistical heterogeneity (I^2 = 0%) shows that the studies were consistent in their findings. Among the individual studies, 3 studies (Chattopadhyay et al., 2023; Hegde et al., 2013; Kacker et al., 2019) reported significant decreases in BMI after yoga interventions for prediabetic individuals. On the other hand, Kaur et al. (2021) reported no significant change. The assumption of alternative correlations ($r = 0.5$ and $r = 0.9$) in sensitivity analyses revealed that some of the statistical significances were r-dependent. More specifically, the pooled effect was statistically non-significant at $r = 0.5$ and $r = 0.7$, and statistically significant only with $r = 0.9$. This pattern is explained by the fact that higher assumed correlations reduce the estimated standard deviation of change scores, resulting in smaller standard errors and narrower confidence intervals, which may yield statistical significance even when the underlying effect magnitude is small. Importantly, despite achieving statistical significance at $r = 0.9$, the observed effect size was clinically negligible as it does not meet minimal clinically important difference threshold. At present, despite the fact that the available evidence appears to indicate that yoga does not significantly reduce BMI in prediabetic individuals, the limited number of studies reduces the certainty of this conclusion.

Limitations

This systematic review and meta-analysis have several important limitations that should be considered when interpreting the findings. All included studies were judged to be at an overall high risk of bias according to the Cochrane Risk of Bias 2 (RoB 2) tool. Although most studies demonstrated a low risk of bias in the randomization process, missing outcome data, and selective reporting, four of the five studies were assessed as having a low risk of bias in outcome measurement, except Hegde et al. (2013). All studies were consistently rated as high risk in the blinding of participants. This domain-level concern was sufficient to result in a high overall risk of bias judgment for every included trial and may have influenced the estimated effects of yoga interventions. The overall certainty of evidence for all outcomes was rated as low to very low, reflecting serious concerns related to risk of bias, imprecision, and inconsistency across studies. Most pooled analyses included a small number of trials with relatively small sample sizes, resulting in wide confidence intervals and limited statistical power to detect modest but potentially clinically relevant effects.

There was considerable statistical heterogeneity for the key outcome, especially for fasting blood glucose. This shows considerable variability in effect estimates across studies. This heterogeneity is likely attributable to differences in participant characteristics, as well as the differing protocols used in the yoga interventions, the conditions under which the studies were carried out, and the methodological quality of the studies. Even though heterogeneity was noted, the planned subgroup analyses were constrained by the limited number of studies available for each subgroup. All studies were conducted in India, which also results in a pronounced geographic concentration of evidence. Although India is the home of yoga, focusing the evidence on a single nation (India) is a limiting approach and undermines the generalizability of the available evidence. The differences in the dietary patterns, physical activity levels, healthcare access, and sociocultural attitudes toward yoga influence intervention adherence and effectiveness. As such, the findings of this study should be interpreted with caution in explaining or justifying the use of yoga interventions in non-Indian populations. The limited number of studies available for each outcome impedes the possibility of employing a robust meta-analysis, assessing publication bias, and performing comprehensive subgroup analyses and meta-regressions. Consequently, the possible effect modifiers could not be examined systematically.

This limitation should be overcome by future studies that involve larger, multicenter randomized trials with unified intervention strategies and appropriately extended post-intervention follow-up periods. Research needs to focus on the influence of yoga type, frequency, and longer intervention duration on glycaemic and anthropometric outcomes. Furthermore, studies conducted in diverse geographical and demographic locations will enhance the findings generalizability.

Conclusions

This systematic review and meta-analysis suggest that yoga interventions do not yield clinically relevant improvements in the primary outcomes, fasting blood glucose, postprandial blood glucose, and glycated haemoglobin, and in the secondary outcome, the body mass index in individuals diagnosed with prediabetes. None of the measured outcomes showed a statistically relevant advantage, and the total certainty of the evidence ranged from low to very low, concluding that yoga does not warrant recommendation as a primary intervention for the management of prediabetes. The limited number of studies, coupled with the notable heterogeneity and methodological restrictions, highlights the need for cautious interpretation of the findings.

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