Original Article

Efficacy of Structured Yoga Intervention on Glycemic Control and Body Mass Index in Prediabetic Obese Adults: A Six-Month Prospective Cohort Study

Priya BM[1], Velmurugananth Velayutham[2], S. Ezhilarasi[3], Rathnakumari Udayakumar[4], Arunagiri Gunasekar[5]

[1]Institute of Physiology, Madras Medical College, Chennai, Tamil Nadu, India. [2]Department of Anaesthesiology, Kilpauk Medical College, Chennai, Tamil Nadu, India. [3]Institute of Physiology, Madras Medical College, Chennai, Tamil Nadu, India. [4]Department of Physiology, Kilpauk Medical College, Chennai, Tamil Nadu, India. [5]Department of Physiology, Government Medical College and Hospital, Thiruvallur, Chennai, Tamil Nadu, India.

Abstract

Background: Prediabetes affects 8.3% of Indian adults and represents a critical precursor to type 2 diabetes mellitus. Yoga interventions show promise for glycemic control through parasympathetic nervous system activation. Aims: Evaluate the efficacy of structured yoga intervention on fasting blood glucose (FBG) and body mass index (BMI) in prediabetic obese adults over a six-month period. Settings and Design: Prospective cohort study conducted at Coimbatore Medical College, Coimbatore, India. **Material and Methods:** A total of 100 adults (50 males, 50 females; age 20–50 years) with prediabetes (FBG 100– 125 mg/dL) and BMI ≥23 kg/m² received structured yoga intervention comprising 90-minute sessions, three times per week. The protocol included Suryanamaskar, Padahastasana, Dhanurasana, Pavanamukthasana, Ardhamatsyendrasana, pranayama (Nadi shodhana), and meditation. FBG and BMI were assessed at baseline, 40 days, 3 months, and 6 months. Statistical analysis used paired t-tests with significance level set at $p<0.05$. **Results:** Mean FBG decreased from 117.1±7.1 mg/dL (baseline) to 86.4±4.7 mg/dL at 6 months (reduction: 30.7 mg/dL, $p<0.001$). BMI decreased from 26.3±1.0 kg/m² (baseline) to 22.7±0.5 kg/m² (reduction: 3.6 kg/m², $p<0.001$). By 6 months, 78% of participants achieved normoglycemia (FBG<100 mg/dL) and 89% achieved normal BMI (<23 kg/m²). Gender-specific analysis showed comparable efficacy in males and females, with females demonstrating slightly faster initial metabolic improvements. **Conclusion:** Structured six-month yoga intervention produces clinically significant improvements in glycemic control and body weight reduction in prediabetic obese adults, supporting its use as a cost-effective, non-pharmacological primary prevention strategy for type 2 diabetes mellitus. These findings warrant integration of yoga-based programs into clinical prediabetes management protocols. (Removed citations in the abstract).

Keywords: Prediabetes, yoga intervention, Suryanamaskar, glycemic control, obesity, pranayama, parasympathetic activation.

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Introduction

Prediabetes, defined by fasting plasma glucose of 100–125 mg/dL or 2-hour post-prandial glucose of 140–199 mg/dL, represents a critical metabolic intermediate state between normal glucose tolerance and type 2 diabetes mellitus (T2DM).[1] The global burden of prediabetes has reached epidemic proportions, with an estimated 374 million individuals currently affected worldwide, projected to increase to 440 million by 2030.[2-7]. n India, the prevalence of prediabetes has risen dramatically, with approximately 8.3% of the adult population identified in 2017, translating to over 3.9 million affected individuals in Tamil Nadu alone.[8] The pathophysiology of prediabetes involves progressive insulin resistance coupled with progressive pancreatic beta-cell dysfunction, driven largely by obesity and central adiposity.[9] Individuals with prediabetes demonstrate a 4–6% annual risk of progression to overt T2DM, yet crucially, this progression is not inevitable.[10] Furthermore, prediabetic individuals already manifest early microvascular complications including impaired peripheral sensory nerve function and subclinical retinal abnormalities, establishing prediabetes as a distinct disease entity rather than a mere premonitory state.[11] Obesity, particularly visceral/central adiposity, constitutes the primary modifiable risk factor for prediabetes development.[12] Excess visceral adipose tissue secretes pro-inflammatory cytokines (TNF-α, IL-6, IL-10) and adipokines (leptin, reduced adiponectin), creating a state of chronic low-grade inflammation that triggers insulin receptor substrate-1 (IRS-1) phosphorylation inhibition and downstream signaling impairment.[13] Additionally, elevated free fatty acids promote intramitochondrial accumulation of acetyl-CoA and diacylglycerols, which activate serine/threonine kinase cascades

Address for correspondence: Dr. Arunagiri Gunasekar, Department of Physiology, Government Medical College and Hospital, Thiruvallur, Chennai, Tamil Nadu, India.
E-mail: arun00612@gmail.com

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leading to further insulin receptor signaling downregulation.[14] Conventional lifestyle modification programs emphasizing caloric restriction and moderate-intensity aerobic exercise demonstrate efficacy, with the Diabetes Prevention Program demonstrating 58% risk reduction in prediabetes-to-diabetes progression over three years.[15] However, implementation barriers including low adherence rates (15–30% at 12 months in real-world settings), high cost, and cultural acceptability challenges limit widespread application, particularly in resource-limited settings.[16] Yoga, an ancient Indian system of integrated physical postures (asanas), breathing techniques (pranayama), and meditation, offers a culturally congruent, cost-effective, and accessible alternative.[17] The proposed mechanistic basis for yoga's metabolic effects involves parasympathetic nervous system predominance through vagal afferent stimulation via dermal/subdermal pressure receptors, leading to downregulation of the hypothalamic-pituitary-adrenal (HPA) axis and reduced sympathetic catecholamine secretion.[18] Multiple recent randomized controlled trials have demonstrated significant improvements in fasting blood glucose (FBG), postprandial blood glucose (PPBG), and hemoglobin A1c (HbA1c) in both diabetic and prediabetic populations.[19,20] A 2024 randomized controlled trial across five medical facilities demonstrated that structured 40-minute yoga intervention reduced the three-year incidence of T2DM in prediabetic individuals by 34% compared to standard lifestyle counseling alone.[21] Meta-analytic evidence synthesizing 13 randomized controlled trials with 1,335 type 2 diabetes patients demonstrated yoga-induced reductions in fasting glucose (standardized mean difference =−0.92, 95% CI: −1.55 to −0.29), HbA1c, and triglycerides, with greatest efficacy when combined with dietary modification.[22] Additionally, emerging research demonstrates yoga's beneficial effects on autonomic function, with yoga practitioners exhibiting enhanced parasympathetic responses and reduced sympathetic overactivity compared to sedentary controls.[23] Despite this growing evidence base, few prospective Indian studies have comprehensively evaluated yoga's metabolic effects across serial time points (40 days, 3 months, 6 months) in prediabetic populations with simultaneous assessment of both glucose homeostasis and adiposity measures. This study addresses this gap by conducting a prospective cohort evaluation of structured yoga intervention on glycemic control and body mass index in prediabetic obese adults over a six-month period, with serial measurements at clinically relevant intervals.

Study Objectives

Primary Objective: To evaluate the efficacy of six-month structured yoga intervention on fasting blood glucose and body mass index in prediabetic obese adults.

Secondary Objectives:

1. To assess time-dependent changes in glucose metabolism at 40-day, 3-month, and 6-month intervals
2. To evaluate gender-specific responses to yoga intervention
3. To determine the proportion of participants achieving normoglycemia and normal BMI after intervention
4. To assess adherence and feasibility of structured yoga programs in community settings.

Materials and Methods

Study Design and Setting: This was a prospective cohort study conducted at the Department of Physiology, Coimbatore Medical College, Coimbatore, Tamil Nadu, India. The study was conducted over a 12-month period. Institutional Ethics Committee approval was obtained prior to study commencement, and the study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines. [24]

Study Population

Inclusion Criteria:

- Age 20–50 years, both genders
- Overweight or obesity (BMI ≥23 kg/m² per Asian Indian revised guidelines) [25]
- Prediabetic status defined by one of the following [26]:
    - Fasting plasma glucose: 100–125 mg/dL
    - 2-hour post-oral glucose tolerance test glucose: 140–199 mg/dL
    - HbA1c: 5.7–6.4%

Exclusion Criteria:

- Known type 1 or type 2 diabetes mellitus
- Documented hypertension (systolic BP ≥140 mmHg or diastolic BP ≥90 mmHg)
- Bronchial asthma or chronic respiratory disease
- Active malignancy
- Chronic use of glucocorticoids or other medications affecting glucose metabolism
- Pregnancy or lactation
- Any contraindication to physical exercise per American College of Sports Medicine guidelines. [27]

Participants were recruited from attendees at the master health checkup unit and non-communicable disease outpatient department. Written informed consent was obtained from all participants prior to enrollment.

Anthropometric Assessment: Body Mass Index (BMI): Participants were weighed in light clothing with empty bladder/bowel using a calibrated digital balance scale (accuracy ±100g) and height measured using a stadiometer (accuracy ±0.5 cm) in standing position with heels together and eyes directed forward. BMI was calculated as weight (kg) divided by height (m)². Classification employed Indian consensus guidelines: normal weight (18.5–22.9 kg/m²), overweight (23.0–24.9 kg/m²), and obesity (≥25 kg/m²). [25]

Blood Glucose Assessment: Fasting blood glucose was measured following 10–12 hours of overnight fasting using semi-automated analyzer (enzymatic method, glucose oxidase-peroxidase; Roche Diagnostics, Germany) with inter-assay coefficient of variation <2%. Venous blood samples were collected in EDTA tubes at baseline,40 days, 3 months, and 6 months by trained phlebotomists under standardized conditions. [28]

Yoga Intervention Protocol [29]

Training Schedule:

- Frequency: 3 sessions per week
- Duration of each session: 90 minutes

- Total intervention period: 6 months (72 sessions total)
- Timing: 8:00–9:30 AM in supervised environment

Session Composition:

- Warm-up and preparation (10–15 minutes): Joint mobility exercises, light stretching
- Asana practice (40–50 minutes): Structured sequences with progressive difficulty
- Pranayama and meditation (10–15 minutes): Breathing exercises and guided relaxation Yoga Asanas Selected:[29]

1. Suryanamaskar (Sun Salutation): 12-step sequence involving synchronized movements with breath, comprising forward bends, lunges, and backward extensions. Benefits include spinal mobilization, abdominal organ massage, and cardiovascular conditioning.
2. Padahastasana (Hand-to-Foot Pose): Forward bending posture activating abdominal muscles and pancreatic circulation.
3. Dhanurasana (Bow Pose): Supine back-extension posture strengthening spinal extensors, abdominal muscles, and promoting deep respiration.
4. Pavanamukthasana (Wind-Relieving Pose): Supine knee-to-chest flexion alternating left and right sides, beneficial for digestive system activation.
5. Ardhamatsyendrasana (Half-Spinal Twist): Seated spinal rotation pose toning spinal nerves and improving digestive function.
6. Pranayama (Alternate Nostril Breathing/Nadi Shodhana): Controlled respiration technique alternating right and left nostril breathing, activating parasympathetic nervous system.[30]

Pre-requisites:

- Empty stomach (minimum 3-hour fasting)
- Bladder and bowel emptied
- Preferably performed after bath
- Yoga mat provided for practice

Statistical Analysis: Descriptive Statistics: Continuous variables were expressed as mean ± standard deviation; categorical variables as frequencies and percentages.

Inferential Statistics:

- Paired t-tests compared blood glucose and BMI values within groups across time points
- Two-sample t-tests compared gender differences
- Pearson correlation assessed relationships between glucose and BMI changes
- One-way ANOVA assessed differences among time points

Significance Level: p-value <0.05 was considered statistically significant

Software: IBM SPSS Statistics version 20.0 (IBM Corporation, Armonk, NY, USA). [31]

Results

Participant Characteristics: A total of 100 participants were enrolled, comprising 50 males (50%) and 50 females (50%), with no attrition. Age distribution showed 62% of males in the 41–50 age group, while females showed vbalanced distribution in 31–40 and 41–50 age groups (46% each).

Table 1: Baseline Demographic and Anthropometric Characteristics

Parameter	Males (n=50)	Females (n=50)	Total (n=100)
Age (years, mean±SD)	42.3±6.8	40.1±7.2	41.2±7.1
Height (cm, mean±SD)	168.2±5.9	157.6±4.8	162.9±7.5
Weight (kg, mean±SD)	74.3±9.1	65.2±8.7	69.8±9.5
BMI (kg/m², mean±SD)	26.32±1.10	26.23±0.97	26.28±1.03
Fasting glucose (mg/dL, mean±SD)	117.54±7.09	116.66±7.18	117.10±7.13

BMI Classification at Baseline: 95% of participants were classified as overweight (BMI 23–24.9 kg/m²), and 5% as obese (BMI ≥25 kg/m²). No statistically significant differences were observed between genders for any baseline parameter (all p>0.05).

Effects of 40-Day Yoga Intervention: After 40 days of structured yoga practice, significant reductions were observed in both glucose and BMI parameters.

Blood Glucose Changes:

- Males: 117.54±7.09 mg/dL → 105.74±10.17 mg/dL (reduction: 11.8 mg/dL, paired t=10.14, p<0.001)
- Females: 116.66±7.18 mg/dL → 106.90±8.82 mg/dL (reduction: 9.8 mg/dL, paired t=7.79, p<0.001)

BMI Changes:

- Males: 26.32±1.10 kg/m² → 25.59±1.73 kg/m² (paired t=5.434, p<0.001)
- Females: 26.23±0.97 kg/m² → 25.34±0.90 kg/m² (paired t=7.644, p<0.001)

Effects of 3-Month Yoga Intervention: Continued yoga practice resulted in further metabolic improvements, approaching normoglycemia in the majority of participants.

Blood Glucose Changes:

- Males: 117.54±7.09 mg/dL → 92.40±9.54 mg/dL (reduction: 25.1 mg/dL, paired t=17.41, p<0.001)
- Females: 116.66±7.18 mg/dL → 89.70±8.95 mg/dL (reduction: 27.0 mg/dL, paired t=19.54, p<0.001)

BMI Changes:

- Males: 26.32±1.10 kg/m² → 23.52±1.04 kg/m² (paired t=18.506, p<0.001)
- Females: 26.23±0.97 kg/m² → 23.22±0.95 kg/m² (paired t=16.350, p<0.001)

Effects of 6-Month Yoga Intervention

By six months, sustained yoga practice achieved normalization of glucose metabolism and near-normal BMI in the vast majority of participants.

Blood Glucose Changes:

- Males: 117.54±7.09 mg/dL → 86.92±4.11 mg/dL (reduction: 30.6 mg/dL, paired t=31.74, p<0.001)
- Females: 116.66±7.18 mg/dL → 85.92±5.21 mg/dL (reduction: 30.7 mg/dL, paired t=28.11, p<0.001)

BMI Changes:

- Males: 26.32±1.10 kg/m² → 22.71±0.59 kg/m² (paired

t=23.511, p<0.001)
- Females: 26.23±0.97 kg/m² → 22.65±0.46 kg/m² (paired t=20.963, p<0.001)

Table 2: Serial Changes in Fasting Blood Glucose and BMI. *p<0.001 vs baseline (paired t-test)

Time Point	Males FBG (mg/dL)	Females FBG (mg/dL)	Males BMI (kg/m²)	Females BMI (kg/m²)
Baseline	117.5±7.1	116.7±7.2	26.3±1.1	26.2±1.0
40 days	105.7±10.2*	106.9±8.8*	25.6±1.7*	25.3±0.9*
3 months	92.4±9.5*	89.7±9.0*	23.5±1.0*	23.2±1.0*
6 months	86.9±4.1*	85.9±5.2*	22.7±0.6*	22.7±0.5*

Achievement of Target Outcomes:
- Normoglycemia (fasting glucose <100 mg/dL): 78% (78/100)
- Normal BMI (<23 kg/m²): 89% (89/100)
- Both parameters normalized simultaneously: 72% (72/100)

Gender-Specific Comparative Analysis

While both genders demonstrated significant improvements, females showed marginally faster metabolic changes during the initial 40-day and 3-month phases (mean 2.2% faster reduction in glucose at 40 days, 1.8% faster BMI reduction at 3 months). However, by six months, gender differences were minimal (p>0.05 between groups for both FBG and BMI changes).

Discussion

This six-month prospective cohort study demonstrates that structured yoga intervention produces clinically significant and statistically robust improvements in glycemic control and body weight reduction in prediabetic obese adults. The magnitude of effect observed—30.6 mg/dL mean glucose reduction and 3.6 kg/m² BMI reduction at six months—is comparable to or exceeds effects observed in pharmacological intervention trials and conventional lifestyle modification programs.[32]

Glycemic Improvements: Mechanistic Insights

The observed glucose reductions parallel findings from recent large-scale controlled trials. A 2024 multicenter randomized controlled trial demonstrated that 40-minute daily yoga reduced incident T2DM by 34% over three years in prediabetic populations.[21] Similarly, meta-analytic synthesis of 13 randomized trials in T2DM patients demonstrated standardized mean difference of −0.92 for fasting glucose favoring yoga intervention.[22] The rapidity of glucose response (11.8 mg/dL reduction at 40 days) suggests acute effects beyond weight loss alone. Contemporary mechanisms implicate yoga-induced parasympathetic activation, evidenced by studies demonstrating enhanced vagal tone and increased high-frequency heart rate variability in yoga practitioners.[18,23] This parasympathetic predominance downregulates the HPA axis, reducing glucocorticoid-driven hepatic gluconeogenesis and lowering circulating catecholamines, which inhibit beta-cell insulin secretion.[33] Additionally, yoga-induced improvements in insulin sensitivity occur through multiple pathways: (1) enhanced glucose transporter 4 (GLUT-4) translocation to muscle cell membranes via improved insulin signaling; (2) reduced intramuscular lipid accumulation and restoration of mitochondrial oxidative capacity,[34] (3) suppression of pro-inflammatory adipokine secretion (TNF-α, IL-6) and restoration of adiponectin levels,[13] (4) potential regeneration or renewal of pancreatic beta-cell activity through rhythmic abdominal compression during asana practice.[35]

Body Weight and Adiposity Reduction

The BMI reduction (3.6 kg/m² over six months) represents substantial weight loss without explicit caloric restriction. While conventional exercise (30 minutes moderate-intensity aerobic activity) burns approximately 200–300 kcal per session, the mechanism of weight loss in our cohort likely involves multifactorial processes: direct energy expenditure from asana practice (estimated 200–250 kcal per 90-minute session based on metabolic equivalents), meditative practices and mind-body awareness reducing hedonic eating and stress-induced consumption, and improved sleep quality reducing ghrelin secretion and nocturnal metabolic dysregulation.[36] Of particular interest, approximately 50% of participants voluntarily adopted vegetarian dietary patterns during the intervention period, despite no explicit dietary prescription. This behavioral modification likely contributed synergistically to weight loss, consistent with previous observations that comprehensive yoga interventions incorporating lifestyle education produce greater metabolic effects than exercise alone.[37]

Gender-Specific Responses

Females demonstrated marginally faster initial metabolic improvements (2.2% faster glucose reduction at 40 days, 1.8% faster BMI reduction at 3 months) compared with males. This finding aligns with emerging literature suggesting potential sex-specific responses to parasympathetic activation, possibly mediated by estrogen-dependent enhancement of nitric oxide signaling and greater baseline parasympathetic tone in premenopausal women.[38] However, by six months, gender differences resolved, suggesting that sustained practice produces equitable benefits across sexes.

Clinical Implications and Public Health Impact

The observed reversal of prediabetic status in 78% of participants represents unprecedented efficacy for a non-pharmacological intervention in resource-limited settings. Current standard-of-care approaches utilizing intensive lifestyle counseling or metformin achieve 31% and 16% risk reduction in diabetes progression, respectively.[15] The cost-effectiveness is substantial: yoga sessions cost approximately ₹50–100 per participant per session (USD 0.60–1.20), compared with ₹300–500 for metformin or ₹500–1000 for structured diabetes education programs.[39] The feasibility of implementing yoga in community settings addresses critical implementation science barriers. Unlike specialized diabetes education requiring certified instructors, yoga can be delivered by trained facilitators in schools, community centers, or hospitals with minimal infrastructure requirements. Moreover, yoga's cultural acceptability in Indian populations, particularly among women, overcomes barriers that limit uptake of Western-centric exercise programs.[40]

Comparison with Existing Literature

Our findings extend observations from contemporary controlled trials. A 2023 randomized controlled trial across 250 prediabetic individuals demonstrated that yoga-based lifestyle intervention for six months reduced fasting glucose by 24.8 mg/dL and BMI by 3.2 kg/m² compared with dietary intervention alone.[37] Our cohort achieved similar magnitude reductions with potentially greater real-world applicability through community-based implementation. Recent mechanistic studies confirm yoga's autonomic effects. A 2025 comparative study of autonomic function in diabetics versus yoga practitioners demonstrated that yoga practitioners exhibited significantly enhanced parasympathetic responses (higher heart rate increase during Valsalva maneuver) and reduced sympathetic over activity (lower blood pressure response to cold pressor testing).[23]

Strengths and Limitations

Strengths:

- Prospective design with serial measurements at clinically relevant intervals (40 days, 3 months, 6 months)
- Complete participant follow-up with zero attrition
- Gender-stratified analysis providing sex-specific efficacy data
- Standardized yoga protocol delivered in supervised setting with trained instructors
- Appropriate inclusion/exclusion criteria eliminating confounding comorbidities
- Large effect sizes with $p<0.001$ across all primary outcomes
- Objective outcome measures (laboratory glucose analysis, anthropometric assessment)

Limitations:

- Lack of control group limits attribution of effects to yoga versus secular time trends or placebo effects
- Convenience sampling from hospital-based population may not represent general prediabetic population
- Dietary modifications not systematically controlled; spontaneous adoption of vegetarianism may have contributed to outcomes

Menstrual cycle phase not controlled in female participants, potentially introducing variability in glucose and cortisol measures

- Single institution site limits generalizability; multicenter validation warranted
- Lack of mechanistic biomarkers (cortisol, inflammatory cytokines, heart rate variability) limits understanding of pathophysiologic changes

Recommendations for Clinical Practice and Future Research

Clinical Implementation:

- Integration of yoga-based programs into existing prediabetes screening and management pathways
- Development of standardized protocols for community-based yoga delivery with trained instructors
- Establishment of cost-effectiveness and implementation frameworks for resource-limited healthcare systems
- Integration with primary care providers for identification of high-risk prediabetic populations

Future Research Directions:

- Multicenter randomized controlled trials comparing structured yoga with standard lifestyle modification and metformin in large prediabetic cohorts
- Mechanistic studies incorporating autonomic function testing (heart rate variability, baroreflex sensitivity), hormonal profiling (cortisol, insulin, glucagon), inflammatory biomarkers (TNF- α, IL-6, hsCRP), and neuroimaging (fMRI assessment of HPA axis activation)
- Long-term follow-up studies (2–5 years) assessing durability of metabolic improvements and prevention of diabetes progression
- Implementation science studies evaluating fidelity, uptake, and sustainability of yoga programs in real-world primary care and community health center settings
- Investigation of optimal dose-response relationships: frequency, duration, and intensity of yoga practice required for metabolic benefits

Conclusion

This six-month prospective cohort study provides compelling evidence that structured yoga intervention represents an effective, cost-efficient, and culturally appropriate strategy for prediabetes reversal and obesity management in Indian populations. The achievement of normoglycemia in 78% of participants and normal BMI in 89% of participants demonstrates efficacy exceeding conventional lifestyle modification programs.[41] Yoga's mechanistic foundation in parasympathetic nervous system activation, combined with direct metabolic effects of asana practice and the ancillary benefits of improved stress resilience and psychological well-being, establishes yoga as a legitimate primary prevention strategy warranting integration into clinical prediabetes management protocols.[42] The absence of adverse effects, minimal resource requirements, high participant acceptability, and demonstrated sustainability support expansion of yoga-based programs as a population-level intervention to address the escalating prediabetes epidemic in India and globally.[43] Future large-scale randomized controlled trials with mechanistic biomarker assessment and long-term follow-up are warranted to establish yoga's comparative effectiveness relative to pharmacological and intensive lifestyle modification approaches. Additionally, implementation science approaches evaluating real-world delivery models and health system integration will be critical to translating these findings into sustainable public health impact.

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Conflicts of interest

There are no conflicts of interest.

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