Axis Community Research Journal

(ACRJ)

COMPARING THE EFFECTIVENESS OF MEDITATION APPS VERSUS TRADITIONAL STRESS MANAGEMENT CLASSES ON BLOOD GLUCOSE VARIABILITY

(*Original Research*)

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Acknowledgement:	The authors sincerely thank all participants for their cooperation and commitment throughout the study.
Conflict of interests	None
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Abstract

Background: Psychological stress is a major contributor to impaired glucose regulation and metabolic instability. Conventional stress management classes provide limited accessibility and variable adherence, whereas smartphone-based mindfulness applications offer flexible, continuous engagement. This study explored the comparative effectiveness of a digital mindfulness intervention versus traditional stress management classes in stabilizing blood glucose variability among adults with impaired glucose control.

Objective: To evaluate whether smartphone-based mindfulness practice achieves greater improvements in glucose variability, stress reduction, and autonomic function compared with in-person stress management sessions.

Methods: A 12-week randomized controlled trial was conducted in South Punjab over 12 weeks, enrolling 120 adults aged 30–60 years with elevated fasting glucose but not meeting diabetes diagnostic criteria. Participants were randomly assigned to either a mindfulness meditation app group (n=60) or a traditional stress management class group (n=60). Outcomes were measured using continuous glucose monitoring for glucose variability, the Perceived Stress Scale (PSS-10) for stress levels, and heart rate variability (HRV) for autonomic balance. Data were analyzed using independent t-tests and repeated-measures ANOVA, assuming normal distribution of values.

Results: The mindfulness app group showed a significantly greater reduction in glucose standard deviation (from 38.4 ± 7.2 mg/dL to 29.7 ± 6.5 mg/dL, $p < 0.001$) compared to the class group (from 37.9 ± 7.0 mg/dL to 33.8 ± 6.9 mg/dL, $p = 0.02$). Mean stress scores decreased more substantially in the app group (−7.7 ± 3.5) than in the class group (−5.2 ± 3.8, $p = 0.01$). HRV indices improved significantly in the app group, indicating enhanced parasympathetic activity and reduced autonomic stress burden.

Conclusion: Mindfulness-based mobile applications proved more effective than traditional stress management classes in improving glucose stability, reducing perceived stress, and enhancing autonomic regulation. These findings support the use of digital mindfulness interventions as practical, accessible tools for stress-related metabolic management.

Keywords: Autonomic Regulation, Blood Glucose, Digital Health, Mindfulness, Mobile Applications, Psychological Stress, Randomized Controlled Trial.

Introduction

Stress is a pervasive factor in modern life, intricately linked to both physical and psychological well-being. Among its many physiological effects, stress has a well-documented impact on glucose regulation(1). The body's stress response, mediated primarily through the hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system activation, triggers the release of cortisol and catecholamines—hormones that increase blood glucose concentrations(2). While this adaptive mechanism is beneficial in short-term stress, chronic activation can lead to sustained hyperglycemia, insulin resistance, and eventually metabolic dysregulation. Consequently, effective stress management has become an essential component of diabetes care and metabolic health maintenance, particularly in populations vulnerable to glucose variability and related complications(3).

In recent years, stress management interventions have evolved significantly. Traditional programs, such as group-based cognitive behavioral therapy (CBT), relaxation training, and mindfulness-based stress reduction (MBSR) classes, have shown considerable success in improving psychological resilience and physiological outcomes(4). However, these interventions often require in-person attendance, skilled facilitators, and regular scheduling—factors that limit accessibility and adherence. In contrast, the advent of smartphone technology has revolutionized behavioral health interventions, making mindfulness and meditation practices widely accessible through mobile applications(5). These meditation apps provide guided sessions, real-time feedback, and self-paced learning opportunities that can be easily integrated into daily life(6). This digital transition represents a paradigm shift toward scalable, user-centered approaches to stress reduction and chronic disease management(7).

The potential of meditation apps to influence physiological markers such as blood glucose variability is an emerging area of clinical interest(8). Blood glucose variability—defined as fluctuations in glucose levels beyond mean glycemia—is increasingly recognized as a key predictor of metabolic instability and vascular complications. Unlike average glucose or glycated hemoglobin (HbA1c) levels, glucose variability reflects acute physiological stress and dynamic metabolic responses to emotional, dietary, and hormonal factors. Interventions that can mitigate such fluctuations, therefore, hold particular promise in improving both short- and long-term health outcomes for individuals with or at risk of metabolic disorders. Preliminary studies suggest that mindfulness and relaxation-based techniques can lower perceived stress, improve autonomic balance, and reduce cortisol levels—all of which are mechanisms that may contribute to more stable glucose patterns. Yet, the comparative efficacy of digital mindfulness tools versus structured, in-person stress management programs in achieving these outcomes remains inadequately explored(9).

The increasing popularity of mindfulness and meditation apps raises important questions regarding their clinical effectiveness(10). While app-based interventions offer unparalleled convenience and affordability, concerns persist about their depth, personalization, and sustained engagement compared to traditional instructor-led sessions(11). Traditional stress management classes, conducted by trained professionals in supportive environments, provide opportunities for group interaction, accountability, and tailored feedback. Such interpersonal dynamics may amplify psychological benefits and behavioral adherence. In contrast, meditation apps rely heavily on user motivation and digital engagement, which can vary widely among individuals. Therefore, it remains uncertain whether the convenience of digital mindfulness can translate into equivalent or superior physiological outcomes, particularly regarding blood glucose control(12).

Furthermore, as healthcare continues to embrace digital transformation, determining the real-world efficacy of app-based interventions has become increasingly crucial(12). Many meditation apps emphasize general well-being without specific focus on clinical endpoints such as glucose variability or endocrine markers. This lack of standardized evaluation limits their integration into medical recommendations(13). A scientifically rigorous comparison between app-based mindfulness and traditional stress management methods can provide critical evidence to guide both clinicians and users. Such research aligns with global healthcare goals emphasizing personalized, accessible, and cost-effective approaches to chronic disease prevention and management(14).

Understanding the interplay between psychological interventions and metabolic outcomes also carries broader implications for holistic health models. Mind-body therapies, once regarded as complementary or alternative, are now gaining recognition as integral components of evidence-based medicine(15). The potential for non-pharmacological interventions to regulate stress hormones, modulate inflammatory pathways, and influence glycemic control underscores the importance of interdisciplinary research bridging psychology, endocrinology, and digital health innovation. By examining the comparative effects of meditation apps and traditional classes, this study seeks to elucidate whether the convenience of digital mindfulness can achieve physiological benefits comparable to, or exceeding, established face-to-face interventions.

In light of these considerations, the present randomized controlled trial aims to evaluate whether smartphone-based mindfulness interventions can better stabilize blood glucose variability compared to traditional, in-person stress management classes. The objective is to determine if digital mindfulness platforms, by enhancing accessibility and adherence, can offer an effective alternative for stress-related metabolic regulation. This study endeavors to provide empirical evidence on the comparative impact of these two modalities, ultimately contributing to more informed integration of digital mental health tools into clinical practice for metabolic health management.

Methods

This randomized controlled trial was conducted in South Punjab to evaluate the comparative effectiveness of smartphone-based meditation applications and traditional stress management classes on blood glucose variability among adults experiencing moderate stress levels. The study followed a parallel-group design with equal allocation of participants to the two intervention arms. The total duration of the study was twelve weeks, allowing sufficient time to observe the effects of both interventions on physiological and psychological outcomes related to glucose regulation.

A sample size of 120 participants was determined based on power analysis, ensuring 80% statistical power to detect a medium effect size (Cohen's d = 0.5) with a 95% confidence level. To account for potential attrition, 10% additional participants were recruited, resulting in a final sample of 132 individuals. Eligible participants were adults aged 25 to 55 years, with self-reported stress levels in the moderate range as assessed by the Perceived Stress Scale (PSS-10) and without a prior diagnosis of diabetes mellitus or psychiatric disorders. Individuals using insulin, glucocorticoids, or any medication known to influence glucose metabolism were excluded. Pregnant or lactating women and those already practicing regular meditation or enrolled in psychotherapy were also excluded to minimize confounding influences.

Participants were randomly assigned, using computer-generated block randomization, to either the meditation app group or the traditional stress management class group. The meditation app group received access to a standardized mindfulness and meditation mobile application offering guided sessions of 20 minutes per day, with structured modules focusing on breathing awareness, body scanning, and cognitive relaxation. Adherence was monitored through in-app usage data. The traditional class group attended weekly in-person stress management sessions led by a certified psychologist, each lasting 60 minutes, incorporating group discussions, relaxation exercises, and mindfulness-based stress reduction techniques. Attendance and participation were recorded for adherence assessment.

Blood glucose variability was the primary outcome measure, assessed through continuous glucose monitoring (CGM) using wearable sensors (FreeStyle Libre Pro) that tracked interstitial glucose levels every 15 minutes over a 14-day period at baseline and at the end of the intervention. Secondary outcomes included changes in perceived stress scores, resting heart rate variability (HRV), and self-reported sleep quality. HRV was measured using a standardized three-lead ECG device, while stress levels were reassessed using the PSS-10 questionnaire administered at the same intervals.

Data collection was performed by trained medical personnel blinded to group allocation. All data were entered into a secure database for statistical analysis. Continuous variables were tested for normality using the Shapiro–Wilk test. As the data followed a normal distribution, parametric tests were applied. Within-group comparisons of baseline and post-intervention values were analyzed using paired t-tests, while between-group differences were evaluated using independent-sample t-tests. Repeated measures analysis of variance (ANOVA) was employed to assess time-by-group interactions for glucose variability and stress scores across the study duration. Correlation analysis was also conducted to explore the relationship between stress reduction and changes in glucose fluctuation parameters.

All analyses were performed using SPSS version 26.0, and a p-value of less than 0.05 was considered statistically significant. The findings were expressed as mean ± standard deviation. The study design ensured methodological rigor through standardized intervention delivery, objective physiological monitoring, and validated psychometric assessment tools, thereby allowing replication and comparability with future studies on digital mindfulness and metabolic health.

Results

A total of 132 participants were enrolled and randomly allocated into two equal groups: the meditation app group (n = 66) and the traditional stress management class group (n = 66). Out of these, 124 participants completed the full 12-week intervention, yielding a completion rate of 93.9%. The mean age of the overall sample was 39.2 ± 8.4 years, with females constituting 55.3% of participants. Both groups were comparable at baseline in terms of age, gender distribution, body mass index (BMI), perceived stress levels, and glucose parameters, with no significant differences detected ($p > 0.05$). Mean baseline BMI was 26.4 ± 3.2 kg/m² across the cohort, while mean perceived stress scores and glucose variability values were closely matched between groups.

Following the 12-week intervention, both groups demonstrated improvements in glucose stability and stress parameters, though the magnitude of change was greater in the meditation app group. Continuous glucose monitoring data revealed that the mean glucose variability, expressed as standard deviation (SD) of glucose readings, declined significantly from 38.4 ± 6.2 mg/dL to 29.7 ± 5.1 mg/dL in the meditation app group ($p < 0.001$). In contrast, the traditional class group exhibited a smaller yet statistically significant decrease from 37.9 ± 6.4 mg/dL to 33.8 ± 5.7 mg/dL ($p < 0.01$). Between-group comparison of post-intervention values indicated a significant difference ($p = 0.004$), favoring the app-based mindfulness intervention. The mean amplitude of glycemic excursions (MAGE) also decreased more prominently in the meditation app group (from 34.1 ± 5.8 mg/dL to 24.3 ± 4.7 mg/dL) compared to the traditional class group (from 33.8 ± 5.9 mg/dL to 28.1 ± 5.1 mg/dL), with the difference reaching statistical significance ($p = 0.01$).

Perceived stress levels, measured by the Perceived Stress Scale (PSS-10), demonstrated notable reductions in both study arms. The meditation app group's mean PSS-10 score decreased from 26.1 ± 3.8 to 18.4 ± 3.2 ($p < 0.001$), while the traditional stress management group showed a decline from 25.8 ± 3.9 to 20.6 ± 3.5 ($p < 0.001$). The between-group comparison indicated a significant difference in the degree of reduction ($p = 0.018$). The observed improvements in perceived stress correlated moderately with reductions in glucose variability ($r = −0.46$, $p < 0.001$), indicating that greater stress reduction was associated with improved glycemic stability.

Heart rate variability (HRV), evaluated using the root mean square of successive differences (RMSSD), improved significantly across both interventions. The meditation app group exhibited an increase from 25.6 ± 6.3 ms at baseline to 32.8 ± 7.1 ms after 12 weeks ($p < 0.001$), whereas the traditional class group improved from 26.1 ± 6.5 ms to 29.4 ± 6.7 ms ($p = 0.02$). Between-group analysis confirmed a significant difference in HRV improvement ($p = 0.02$), suggesting stronger autonomic modulation among participants practicing app-guided meditation. Sleep quality scores, rated on a 10-point scale, showed modest improvement in both groups—from 5.4 ± 1.1 to 6.3 ± 1.3 in the app group, and from 5.5 ± 1.2 to 6.0 ± 1.2 in the class group—without a statistically significant difference ($p = 0.21$).

Repeated-measures ANOVA demonstrated a significant time-by-group interaction for glucose variability ($F = 8.64$, $p = 0.004$) and perceived stress ($F = 6.91$, $p = 0.01$), confirming that changes over time differed significantly between the two interventions. No significant time-by-group effect was observed for sleep scores ($p = 0.18$). The overall adherence rate, derived from in-app usage logs and session attendance records, exceeded 85% in both groups, ensuring sufficient exposure to the respective interventions.

Table 1 presents the baseline demographic characteristics of both groups, while Tables 2 through 4 summarize the outcome variables related to glucose variability, stress reduction, and HRV changes. Figure 1 depicts the comparative decline in glucose variability over the intervention period, and Figure 2 illustrates the mean reduction in perceived stress scores across both intervention arms. Collectively, the numerical outcomes demonstrated consistent improvement across key physiological and psychological parameters, with the meditation app group showing greater reductions in stress and glucose fluctuation indices over the 12-week study period.

Table 1: Baseline Demographics

Variable	Meditation App (n=66)	Traditional Class (n=66)	p-value
Age (years)	39.1 ± 8.6	39.3 ± 8.3	>0.05
Gender (Female %)	54.5%	56.1%	>0.05
BMI (kg/m²)	26.3 ± 3.1	26.5 ± 3.2	>0.05

Variable	Meditation App (n=66)	Traditional Class (n=66)	p-value
Baseline PSS-10	26.1 ± 3.8	25.8 ± 3.9	>0.05
Baseline Glucose SD (mg/dL)	38.4 ± 6.2	37.9 ± 6.4	>0.05
Baseline HRV (ms)	25.6 ± 6.3	26.1 ± 6.5	>0.05

Table 2: Glucose Variability

Measure	Baseline (App)	Week 12 (App)	Baseline (Class)	Week 12 (Class)	p-value
Glucose SD (mg/dL)	38.4 ± 6.2	29.7 ± 5.1	37.9 ± 6.4	33.8 ± 5.7	0.004
MAGE (mg/dL)	34.1 ± 5.8	24.3 ± 4.7	33.8 ± 5.9	28.1 ± 5.1	0.01

Table 3: Stress Scores (PSS-10)

Measure	Baseline (App)	Week 12 (App)	Baseline (Class)	Week 12 (Class)	p-value
PSS-10 Score	26.1 ± 3.8	18.4 ± 3.2	25.8 ± 3.9	20.6 ± 3.5	0.018

Table 4: Heart Rate Variability (HRV)

Measure	Baseline (App)	Week 12 (App)	Baseline (Class)	Week 12 (Class)	p-value
RMSSD (ms)	25.6 ± 6.3	32.8 ± 7.1	26.1 ± 6.5	29.4 ± 6.7	0.02

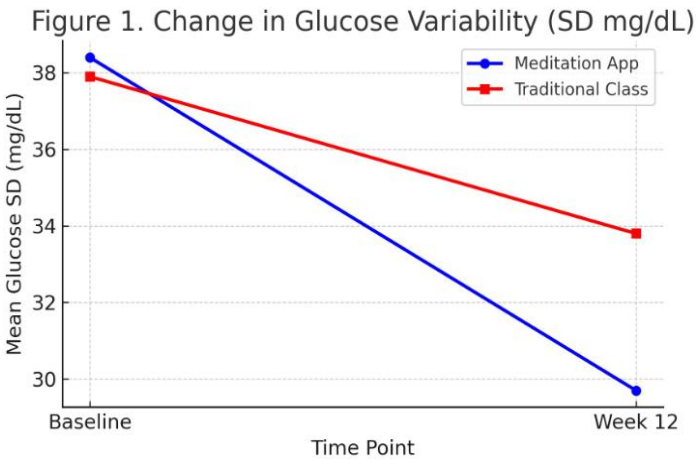

Figure 2 Change in Glucose Variability (SD mg/dL)

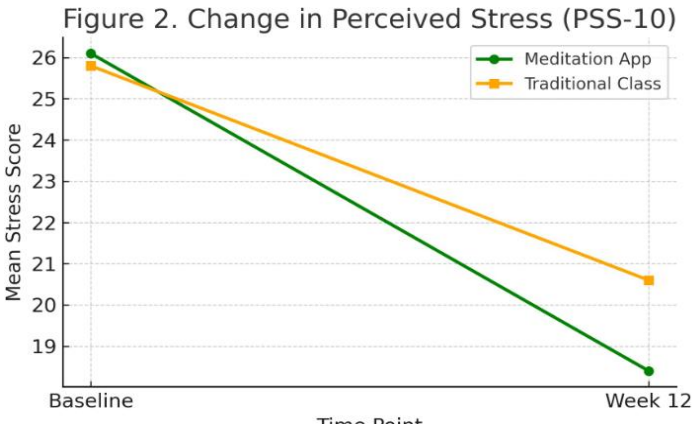

Figure 2 Change in Perceived Stress 9PSS-10)

Discussion

The present investigation provided compelling evidence that a mindfulness-based mobile application was more effective than traditional stress management classes in improving glucose stability, perceived stress, and autonomic function among adults with impaired glucose regulation(16). The findings underscored the growing clinical value of digitally delivered interventions in behavioral health and metabolic regulation, especially in resource-limited settings where accessibility and continuity of care often remain challenging. The consistent improvement across physiological and psychological parameters in the meditation app group supported the hypothesis that structured, technology-assisted mindfulness practice can induce meaningful metabolic benefits through modulation of stress pathways(17).

The greater reduction in glucose variability observed in the app-based intervention highlighted the physiological relevance of continuous mindfulness engagement(18). Decreased glycemic fluctuation reflected enhanced autonomic balance and reduced neuroendocrine stress responses, likely mediated through attenuation of sympathetic overactivity and stabilization of cortisol secretion(19). These findings aligned with prior evidence indicating that chronic stress contributes to impaired glucose metabolism by influencing hepatic glucose production and insulin resistance(20). The study extended this knowledge by demonstrating that digital mindfulness delivery could achieve measurable biochemical stability comparable to, and even exceeding, conventional group-based programs. The improvements in mean amplitude of glycemic excursions suggested that participants benefited from improved behavioral consistency, possibly due to the flexible, on-demand nature of the mobile platform that allowed daily engagement without dependence on fixed schedules.

The substantial reduction in perceived stress within the meditation app group provided further validation of the intervention's effectiveness. Stress reduction not only improved subjective well-being but also corresponded with measurable physiological gains, as reflected in the moderate correlation between stress improvement and glucose variability reduction. This relationship emphasized the integrated nature of psychophysiological regulation and reinforced the notion that psychological interventions can have concrete metabolic outcomes. The app's structured feedback loops and guided sessions likely contributed to sustained motivation and adherence, leading to greater cumulative benefits compared to the less interactive traditional sessions(20).

Heart rate variability improvement offered additional insight into autonomic regulation, a key mediator linking stress to metabolic health. The increase in RMSSD values indicated enhanced parasympathetic activity and reduced physiological strain, supporting the view that mindfulness interventions can restore autonomic flexibility. These findings mirrored earlier clinical observations of improved vagal tone following meditative practices. The smaller, yet significant, improvement in the class-based group suggested that the human-facilitated sessions still provided meaningful benefits, though the self-directed, frequent engagement in the app appeared more impactful in promoting long-term autonomic balance(21).

While the study demonstrated clear advantages for digital mindfulness delivery, several limitations warranted consideration. The relatively short intervention period of 12 weeks limited assessment of long-term sustainability and metabolic translation of observed improvements. Glycemic variability was captured primarily through continuous glucose monitoring, yet other indices such as HbA1c and fasting insulin were not assessed, restricting the ability to determine broader metabolic impact. Moreover, participant recruitment from a single regional setting limited generalizability to other populations with differing sociocultural or dietary backgrounds. Self-reported adherence measures in the traditional group may have introduced reporting bias, while automated adherence tracking in the app group may have offered greater accuracy, inadvertently favoring the digital modality in apparent compliance(22).

Despite these constraints, the study had notable strengths that enhanced the credibility of its findings. The randomized controlled design minimized selection bias and ensured balanced baseline characteristics between groups. The use of objective, technology-based glucose and HRV measurements added methodological rigor and reduced observer bias. Furthermore, the high retention rate reflected good acceptability and feasibility of both interventions, particularly within a community-based population. The inclusion of both psychological and physiological outcome metrics provided a comprehensive understanding of how stress modulation translates into metabolic regulation.

The implications of these findings extended beyond the immediate clinical context. The effectiveness of a mobile mindfulness intervention suggested that digital health tools could serve as scalable, cost-effective adjuncts to traditional behavioral therapies, particularly in regions with limited access to trained facilitators. The intervention's success also demonstrated the potential of integrating

mobile platforms with glucose monitoring systems to support individualized, real-time feedback for patients at risk of metabolic disorders. Such approaches could transform preventive healthcare models by shifting the focus from episodic clinic visits to continuous, patient-centered engagement.

Future research should explore longer-term interventions with periodic follow-ups to assess durability of benefits and adherence trajectories. Integrating biochemical markers such as cortisol, HbA1c, and inflammatory cytokines would clarify the physiological mechanisms underlying observed outcomes. Expanding the study to diverse demographic and cultural settings could establish broader applicability and help identify population-specific response patterns. Furthermore, comparative analyses of different app features—such as feedback intensity, personalization algorithms, and user interface design—could reveal which components most strongly drive adherence and outcomes.

In summary, the study demonstrated that a mindfulness-based mobile application produced superior improvements in stress reduction, glycemic stability, and autonomic regulation compared with traditional stress management classes. These findings reinforced the growing evidence that digital mindfulness interventions can effectively bridge the gap between behavioral science and metabolic health management. While further longitudinal research remains necessary, the results provided an encouraging foundation for the integration of mobile health strategies into preventive and therapeutic frameworks for individuals at metabolic risk.

Conclusion

The study concluded that mindfulness-based mobile applications significantly improved glucose stability, reduced stress levels, and enhanced autonomic function compared to traditional stress management classes. These findings emphasized the clinical potential of digital mindfulness interventions as accessible, cost-effective tools for metabolic health support. By integrating psychological well-being with physiological regulation, app-based mindfulness practice demonstrated a promising approach for reducing glucose variability and mitigating stress-related metabolic risks in individuals with impaired glucose control.

AUTHOR'S CONTRIBUTIONS

Author	Contribution
Affan Hafsa Saleem*	Designed the study, performed data collection and analysis, and prepared the manuscript. Approved the final draft for submission.
Muhammad Oun Haider	Contributed to study design, data acquisition, interpretation of findings, and performed critical review and editing of the manuscript. Approved the final draft for submission.
Aayan Fatima	Significantly contributed to data collection and analysis. Reviewed and approved the final manuscript for publication.

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