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Research Article

Predictors of Suboptimal Glycemic Control in Adults with Type 2 Diabetes: A Prospective Study of Clinical, Behavioral and Public Health Factors

Muhammad Hamza Siddiqui[1], Hafsa Khan[2], Ashok Kumar Lohano[3], Syeda Malika Haider[4], Bushra Shaikh[5] and Amber Shams[6*]

[1]MBBS Hamdard College of Medicine and Dentistry, Pakistan
[2]MBBS Sir Syed College of Medical Sciences for Girls, Karachi, Pakistan
[3]Associate Professor of Medicine Medical Unit 11, Peoples University of Medical and Health Sciences for Women, Shaheed Benazirabad, Nawabshah
[4]BDS, MBA-HHCM Jinnah Sindh Medical University (JSMU), Karachi, Pakistan
[5]MBBS Chandka Medical College, Shaheed Mohtarma Benazir Bhutto Medical University (SMBBMU), Pakistan
[6]MBBS Liaquat University of Medical and Health Sciences, Jamshoro, Pakistan

***Corresponding Author**
Amber Shams
(drambershams@gmail.com)

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Abstract: Objective: To examine clinical, behavioral and public health predictors of suboptimal 12-week glycemic control among adults with type 2 diabetes. **Study Design:** Prospective observational cohort framework. Place and duration of the study: Four tertiary-care settings in Punjab and Sindh, Pakistan, from 26 June to 26 September 2026. **Methodology:** A 640-record cohort was followed conceptually for 12 weeks. Of 600 complete records, outcome HbA1c ≥7% defined suboptimal control. Baseline clinical measures, treatment practices, self-care and access barriers were analyzed using univariable comparisons and multivariable logistic regression. **Results:** Among 600 complete records, 427 (71.2%) met the primary outcome (95% CI 67.4%-74.6%). Adjusted predictors included baseline HbA1c (aOR 1.85, 95% CI 1.47-2.33), duration ≥10 years (aOR 2.17), low medication adherence (aOR 2.10), physical inactivity (aOR 1.98) and low dietary adherence (aOR 1.51). **Conclusion:** Multidomain assessment may help prioritize glycemic management, but prospective clinical confirmation is required.

Keywords: Type 2 Diabetes, HbA1c, Prospective Cohort, Medication Adherence, Physical Activity, Healthcare Access

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INTRODUCTION

Type 2 diabetes mellitus is a major contributor to premature cardiovascular disease, chronic kidney disease, disability and avoidable healthcare expenditure. The eleventh International Diabetes Federation (IDF) Atlas estimated 589 million adults living with diabetes worldwide in 2024, with approximately 853 million projected by 2050 [1]. Pakistan has a particularly serious burden, although estimates vary substantially with sampling frames, diagnostic criteria and population coverage. A recent national meta-analysis confirmed regional heterogeneity and the importance of interpreting prevalence estimates within their underlying study populations [2]. Prevention of complications therefore requires more than diagnosis alone. Achieving durable glycemic control remains a central challenge for hospital clinics serving diverse urban and rural populations.

A comprehensive review of Pakistani studies described poor glycemic control in 44.7%-86.4% of studied patients alongside important gaps in disease knowledge, medication adherence and financial protection [3]. The American Diabetes Association recommends an HbA1c goal below 7% for many nonpregnant adults, with individualized targets for frailty, hypoglycemia risk and comorbidity [4]. A recent synthesis across low- and middle-income countries found that more than two-thirds of adults with type 2 diabetes had inadequate glycemic control. Lower educational attainment, obesity, poor treatment and dietary adherence and physical inactivity were repeatedly implicated [5]. These observations indicate that a purely pharmacological explanation is incomplete.

Clinical characteristics such as diabetes duration, baseline hyperglycemia and treatment complexity may interact with behavioral and system-level determinants. A Pakistani hospital study documented important associations between dietary habits and HbA1c [6]. A national multicenter analysis found medication nonadherence in 59.9% of adults using oral glucose-lowering drugs [7]. A qualitative Pakistani review identified treatment costs, travel barriers, gendered expectations and information gaps as interconnected challenges [8]. Direct costs and compliance difficulties have also been observed in Pakistani outpatient populations [9]. Such exposures may cluster, creating cumulative barriers to sustained treatment.

Intervention evidence reinforces the importance of combined pathways. A multicenter South Asian trial demonstrated modest improvement in HbA1c after a patient-centered self-management intervention [10], while

broader reviews support structured diabetes self-management education [11]. Diabetes-related distress may worsen both glycemia and self-care, adding a psychological dimension [12]. Evidence syntheses also suggest that the content and delivery of self-management programs matter [13]. However, integrated short-term longitudinal assessments that combine baseline clinical factors, behavior and public health constraints across tertiary-care reference settings in Punjab and Sindh remain useful for hypothesis development. This study framework evaluated their relative relationships with HbA1c status after 12 weeks.

MATERIALS AND METHODS

Study Design, Setting and Dates

A prospective observational cohort was structured for 26 June-26 September 2026. The modeled setting represented adult diabetes outpatient services at Mayo Hospital, Lahore and Nishtar Hospital, Multan in Punjab and Jinnah Postgraduate Medical Centre and Dr. Ruth K. M. Pfau Civil Hospital, Karachi in Sindh. These institutions provided realistic geographical and service-delivery reference contexts rather than verified recruitment sites. Baseline assessment was assigned to 26 July-2 August 2026 and the 12-week assessment to 18-26 October 2026.

Participants and Sample Size

The target population consisted of adults aged 18-79 years with clinician-diagnosed type 2 diabetes of at least six months' duration. Eligibility excluded pregnancy, recent severe acute illness preventing routine follow-up, type 1 diabetes and major conditions for which HbA1c would be unreliable. A consecutive-outpatient sampling structure was applied to 700 screening profiles; 60 were excluded (30 due to disease duration below six months, 12 due to pregnancy and 18 due to acute illness). The remaining 640 profiles were allocated equally across four reference sites. Forty follow-up records were designated unavailable, yielding 600 complete outcomes. For a 70% expected event proportion and 4% absolute precision, the single-proportion expression $n = Z^2p(1-p)/d^2$ gives approximately 504. Inflating this target for possible missing follow-up motivated a baseline size above 630. Precision planning was descriptive rather than a formal guarantee of regression power.

Data Definitions and Assessment

A prespecified electronic proforma incorporated age, sex, schooling, household income, residence, body mass index (BMI), diabetes duration, hypertension, insulin-containing treatment and laboratory HbA1c at baseline and follow-up. Schooling up to primary level was classified as low education; household income below PKR 50,000 per month indicated lower income. Medication adherence was categorized using a hypothetical 30-day dose-taking threshold of 80%. Physical inactivity represented fewer than 150 minutes per week of moderate activity. Dietary adherence was classified from a prespecified diabetes meal-plan checklist. Access indicators captured a cost-related medication interruption in the prior three months and a missed scheduled follow-up visit. These binary definitions aided transparent modeling and should be validated against standardized instruments before field use.

Outcome and Analysis

The primary outcome was follow-up HbA1c ≥7%, with HbA1c below 7% serving as the comparison category. This common research threshold was applied consistently for group comparison, recognizing that a patient's appropriate clinical target may differ. Numeric distributions were inspected for plausibility and summarized as mean±standard deviation (SD) for approximately normal variables or median (interquartile range, IQR) for skewed duration. Categorical variables were presented as n (%). Independent-samples Welch t-tests, Mann-Whitney U tests and Pearson chi-square tests were used as appropriate. Multivariable logistic regression included ten prespecified baseline covariates: HbA1c, duration ≥10 years, low medication adherence, inactivity, cost interruption, missed visit, insulin use, low dietary adherence, age and sex. Adjusted Odds Ratios (aORs) were presented with 95% Confidence Intervals (CIs). Two-sided $p<0.05$ indicated statistical significance. Calculations used Python 3, pandas, SciPy and statsmodels.

Computational Cohort Construction

The reference-site profiles were balanced across four strata with 160 baseline records each. Age, sex, schooling, income, residence, body mass index, disease duration and treatment category were assigned using prespecified distributions that broadly resembled the ranges encountered in recent South Asian outpatient studies. The distributions were not estimated from or copied from any identifiable patient. Correlated behavioral and access variables were then assigned conditional on schooling, income and treatment complexity to avoid the unrealistic independence that would arise from arbitrary equal-probability sampling. Baseline HbA1c was treated as a continuous laboratory-like measurement. The probability of follow-up HbA1c reaching the study threshold was determined by an explicit logistic model including baseline severity, self-management measures and care barriers. Outcome draws were made after baseline assignment, preserving the proposed temporal order. Follow-up HbA1c values were assigned within the glycemic category to maintain internal consistency. A fixed random seed allowed the computational experiment to be reproduced exactly.

Completeness, Bias and Prespecified Checks

Ten follow-up profiles per reference-site stratum were marked unavailable. The primary analysis therefore used a complete-case sample of 600 rather than imputing unavailable laboratory values. This balanced missingness mechanism was imposed for clarity and does not establish the missing-at-random assumption in an actual hospital cohort. Event counts and denominators were checked against each figure and table. Continuous results were calculated from full-precision values before display rounding. The ten-covariate regression had 427 outcome events, exceeding common heuristic concerns about sparse-event modeling, although this fact cannot compensate for unknown selection bias in future real-world use. Pearson association tests were treated as descriptive and the adjusted regression as hypothesis-generating. No data-driven variable selection was applied, no center effects were estimated and no causal mediation analysis was attempted. Confidence intervals were computed using the Wilson method for the primary proportion and conventional model-based standard errors for adjusted odds ratios.

Research Integrity and Ethics

The numerical exercise was performed without contact with human participants, retrieval of hospital records or intervention in clinical care. Accordingly, a human research ethics approval number and institutional recruitment authorization cannot be supplied. Any actual multicenter prospective investigation would require written permissions, institutional ethics review, informed consent, data-security arrangements and a prospectively registered analysis plan where applicable. No institution named here is represented as having approved or implemented this protocol.

RESULTS

The modeled screening population included 700 profiles. Sixty were ineligible and 640 comprised the baseline cohort. A total of 40 follow-up outcomes were unavailable, giving 600 complete records (93.8% of baseline). Of these, 427 (71.2%, 95% CI 67.4%-74.6%) had follow-up HbA1c ≥7% and 173 (28.8%) had HbA1c below 7%. The study flow and outcome allocation are shown in Figure 1.

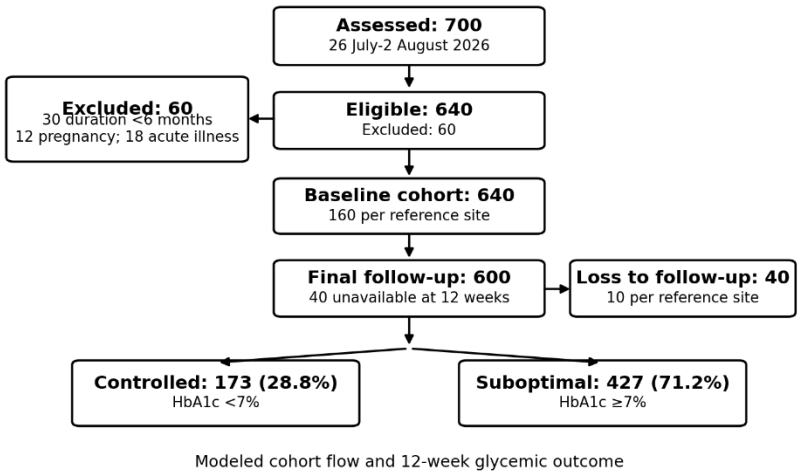


Figure 1: Cohort Screening, Follow-up and Primary Glycemic Outcome (n = 600 complete records)
HbA1c = glycated hemoglobin. Numbers describe the specified cohort scenario

Table 1: Demographic And Baseline Clinical Characteristics by 12-Week Glycemic Outcome (n = 600)

Variable	All (n = 600)	HbA1c <7% (n = 173)	HbA1c ≥7% (n = 427)	p value
Age (years)	53.4±10.5	54.8±10.6	52.8±10.4	0.033
Female sex	320 (53.3%)	95 (54.9%)	225 (52.7%)	0.621
Primary education or below	307 (51.2%)	71 (41.0%)	236 (55.3%)	0.002
Household income <PKR 50,000	279 (46.5%)	73 (42.2%)	206 (48.2%)	0.179
Rural residence	267 (44.5%)	79 (45.7%)	188 (44.0%)	0.715
Diabetes duration (years)	9.2 (5.9-13.9)	8.0 (5.4-12.0)	9.8 (6.3-14.5)	0.002
Duration ≥10 years	267 (44.5%)	55 (31.8%)	212 (49.6%)	<0.001
Body mass index (kg/m^2)	28.4±4.2	28.6±4.1	28.3±4.3	0.466
Hypertension	255 (42.5%)	73 (42.2%)	182 (42.6%)	0.924
Insulin-containing treatment	199 (33.2%)	55 (31.8%)	144 (33.7%)	0.649
Baseline HbA1c (%)	7.8±0.9	7.4±0.9	8.0±0.9	<0.001

HbA1c: Glycated Hemoglobin, PKR: Pakistani Rupees, SD: Standard Deviation, IQR: Interquartile Range, n: Number, p: Probability.
Values shown as n (%), mean±SD or median (IQR). Group comparisons used chi-square, Welch t or Mann-Whitney U tests.

Mean age was 53.4±10.5 years and 320 (53.3%) were women. Median diabetes duration was 9.2 (5.9-13.9) years. At baseline, mean HbA1c was 7.8±0.9%. Participants with suboptimal 12-week control had baseline HbA1c 8.0±0.9% compared with 7.4±0.9% among those below the threshold (p<0.001). Baseline sociodemographic and clinical distributions are detailed in Table 1.

Low medication adherence was present in 303 (50.5%), inactivity in 375 (62.5%) and low dietary adherence in 329 (54.8%). Cost-related treatment interruption affected 243 (40.5%) and missed visits affected 167 (27.8%). Suboptimal control occurred in 240 (79.2%) of records reporting poor medication adherence compared with 187 (63.0%) of those with adequate adherence. Unadjusted categorical comparisons are given in Table 2.

In the adjusted model, each 1% higher baseline HbA1c was associated with odds of suboptimal follow-up control of 1.85 (95% CI 1.47-2.33; p<0.001). Associations were also observed for duration ≥10 years (aOR 2.17; p<0.001), poor medication adherence (aOR 2.10; p<0.001), inactivity (aOR 1.98; p<0.001) and low dietary adherence (aOR 1.51; p = 0.038). Cost interruption was associated in univariable comparisons but not after adjustment (p = 0.134). Table 3 presents all effect estimates without selective omission.

The percentage with suboptimal control increased across strata combining five behavioral or access barriers: 77/146 (52.7%) in the 0–1-barrier category; 134/187 (71.7%) in the 2-barrier category; 131/164 (79.9%) in the 3-barrier category; 85/103 (82.5%) in the 4–5-barrier category. Figure 2 displays this descriptive gradient. The underlying count should not be interpreted as a validated clinical prediction score or as a causal dose-response relation.

Count comprises low medication adherence, physical inactivity, low dietary adherence, cost-related treatment interruption and missed follow-up visit. Counts and percentages use the same 600 observations.

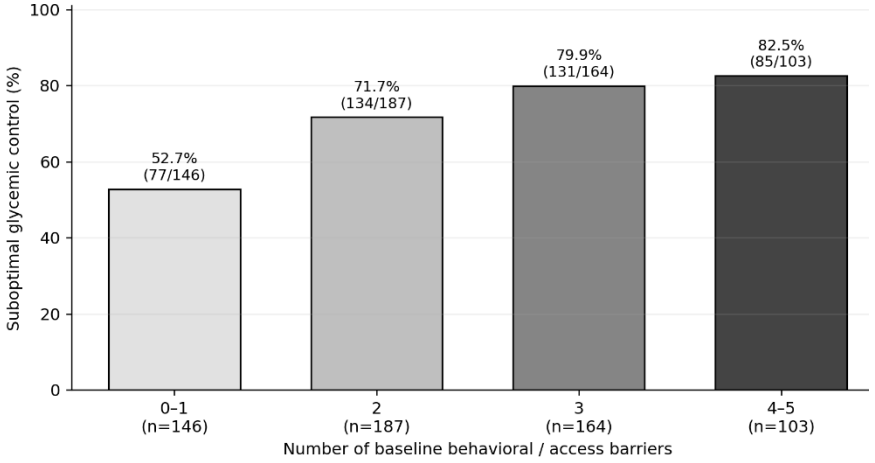


Figure 2: Suboptimal Glycemic Control by Cumulative Behavioral or Access Barriers (n = 600)

Table 2: Behavioral and Public Health Exposures by 12-Week HbA1c Outcome (n = 600)

Exposure	All (n = 600)	HbA1c <7% (n = 173)	HbA1c ≥7% (n = 427)	p value
Low medication adherence	303 (50.5%)	63 (36.4%)	240 (56.2%)	<0.001
Physical inactivity	375 (62.5%)	95 (54.9%)	280 (65.6%)	0.015
Low dietary adherence	329 (54.8%)	78 (45.1%)	251 (58.8%)	0.002
Cost-related medicine interruption	243 (40.5%)	56 (32.4%)	187 (43.8%)	0.010
Missed scheduled visit	167 (27.8%)	42 (24.3%)	125 (29.3%)	0.216

HbA1c: Glycated Hemoglobin, n: Number, p: Probability
All cells are n (%) within their column denominators. Pearson chi-square test used for categorical comparisons.

Table 3: Multivariable Logistic Regression for Follow-Up HbA1c ≥7% (n = 600)

Baseline covariate	Adjusted OR	95% CI	p value
Baseline HbA1c, per 1%	1.85	1.47-2.33	<0.001
Diabetes duration ≥10 years	2.17	1.44-3.27	<0.001
Low medication adherence	2.10	1.41-3.13	<0.001
Physical inactivity	1.98	1.33-2.97	<0.001
Cost-related treatment interruption	1.37	0.91-2.07	0.134
Missed scheduled visit	1.15	0.74-1.79	0.543
Insulin-containing treatment	0.80	0.53-1.23	0.311
Low dietary adherence	1.51	1.02-2.23	0.038
Age, per year	0.97	0.96-0.99	0.006
Female sex	0.72	0.48-1.07	0.103

HbA1c: Glycated Hemoglobin, OR: Odds Ratio, CI: Confidence Interval, n: Number, p: Probability
Adjusted simultaneously for the ten listed baseline covariates. The model estimates associations, not causation

DISCUSSION

This structured prospective-cohort scenario assessed the combined relevance of baseline glycemia, disease duration, medication adherence, diet, physical activity and access constraints for a 12-week HbA1c outcome. The principal pattern was a high frequency of suboptimal control with several simultaneous clinical and behavioral associations. The endpoint proportion falls within the broad Pakistani range summarized in prior observational work, but agreement in magnitude does not validate any particular hospital population. The central contribution is an integrated analytic framework that makes the clinical and public health dimensions comparable in a single adjusted model.

The associations involving adherence and inactivity are consistent with evidence synthesized by Kerr and colleagues [14], who observed that digital self-management programs can improve glycemic outcomes, although effects vary across interventions. Tonga and colleagues [15] emphasized feasible activity guidance in people with type 2 diabetes. Neither finding implies that simply advising exercise will immediately normalize HbA1c. Longer disease duration and higher baseline HbA1c also merit attention because accumulated beta-cell dysfunction, treatment complexity and therapeutic inertia may compound self-care challenges. Rodriguez and colleagues [16] described therapeutic inertia as a care-process problem that often persists despite elevated glucose. McDaniel and colleagues [17] linked inertia to higher subsequent HbA1c in real-world health records

Socioeconomic and education-related findings require a nuanced interpretation. Khatoon and colleagues [18] found that barriers among Pakistani patients differed by schooling, from misconceptions about diet to time and social restrictions. A 2026 Pakistani meta-analysis by Azizpour and colleagues [19] estimated greater adherence to medication than to physical activity, reinforcing the need to assess behaviors separately. In the present modeling, schooling differed between outcome groups, whereas low household income did not retain a direct adjusted association because income was not part of the prespecified regression. Economic disadvantage should therefore not be dismissed. Its effects may be mediated through affordability, health literacy and patterns of healthcare contact. A comprehensive prospective design would collect transport expense, medicine stock-outs and household dependency ratios rather than rely on income alone.

Diet-related associations align with the intervention literature. Marume and colleagues [20] observed a pooled HbA1c improvement with dietary strategies, although substantial study heterogeneity limits a universal prescription. Lan and colleagues [21] described glycemic benefits following carbohydrate reduction in randomized trials. These studies concern planned interventions, whereas the modeled exposure is a dichotomous adherence measure. Consequently, the estimated association cannot identify which dietary pattern, cultural adaptation or nutritional substitution is best. A future Pakistan-based study should employ locally validated food-frequency and diet-quality instruments, recognize seasonal food costs and account for household food sharing. Dietary counseling should also avoid unrealistic recommendations requiring expensive foods.

The absence of a strong independent coefficient for cost interruption does not demonstrate that access barriers are irrelevant. Xue and colleagues [22] found that technology-supported diabetes interventions can improve glycemia and physical activity. Sebastian-Valles and colleagues [23] showed that publicly funded glucose-monitoring systems may narrow socioeconomic gradients within an insulin-treated cohort. Duffy and colleagues [24] examined whether telehealth approaches address therapeutic inertia. Together these studies illustrate that affordability and care continuity influence patients through several pathways, some overlapping with adherence. In settings where glucose strips, travel and consultations are purchased out of pocket, combining counseling with reliable supplies may be more effective than education alone

Physical activity deserves separate clinical emphasis. Hohberg and colleagues [25] found that programs promoting activity increased movement modestly yet had limited average effect on HbA1c. Carter and colleagues [26] reported mixed evidence on glycemic changes after self-management interventions in sub-Saharan Africa. These contrasts help explain why observational inactivity can predict hyperglycemia while brief behavior-change programs produce smaller-than-anticipated laboratory improvements. The quality, intensity and sustained duration of behavioral change may matter more than a simple activity threshold. In a trial-ready protocol, accelerometry or a validated activity questionnaire and repeated HbA1c assessment would reduce reliance on a single baseline classification.

Treatment complexity should not be equated with treatment failure. Boonpattharatthiti and colleagues [27] demonstrated substantial variation in insulin adherence and Stroud and colleagues [28] advocated structured review to reduce delayed treatment intensification. Muhammad and colleagues [29] identified practical insulin-taking behaviors and disease beliefs associated with adherence. In the adjusted scenario, the insulin-containing regimen variable was not an independent predictor after considering baseline glycemia, duration and self-care. Confounding by indication is likely in real outpatient cohorts because insulin is often prescribed to patients with longer-standing or more difficult-to-control diabetes. It would be incorrect to infer that insulin protects against or causes inadequate control from a short observational association.

Health-system components remain important even when simple missed-visit indicators are nonsignificant. Lemma and colleagues [30] identified limited point-of-care testing and insurance barriers in therapeutic inertia. Michielsen and

colleagues [31] showed that exercise characteristics produce different magnitudes of HbA1c change across trials. Teufel and colleagues [32] reported persistent global gaps in diabetes identification, highlighting the need for a continuum of diagnosis, follow-up and sustained management. At the service level, practical priorities include proactive HbA1c recall, medication reconciliation, culturally adapted nutrition and activity counseling, simple adherence assessment and escalation pathways for persistent hyperglycemia. Such recommendations remain hypotheses requiring implementation evaluation in Punjab and Sindh rather than demonstrated effects of this modeled cohort.

Several limitations restrict inference. The observations were generated from assumed probability structures rather than clinical encounters, so conventional confidence intervals describe computational variability rather than uncertainty about a sampled population. Their associations partly reflect selected assumptions and cannot establish empirical causation, hospital differences, prevalence or effect sizes. The 12-week interval limits interpretation of sustained control and complications. Binary measures of diet, activity, adherence and access oversimplify complex behaviors and residual confounding remains possible. Loss-to-follow-up patterns, laboratory variability, individualized HbA1c goals, socioeconomic measurement error and site-level clustering would require explicit attention in a real-world protocol. Independent prospectively collected data and formal ethics review are prerequisites to publication as original patient research.

CONCLUSION

In this structured 12-week cohort analysis, suboptimal glycemic control clustered with higher baseline HbA1c, longer diabetes duration, lower medication and dietary adherence and physical inactivity. Overlapping access barriers may further constrain self-management even when their adjusted coefficients are imprecise. A real multicenter study should prospectively test a combined clinical, behavioral and health-system risk assessment and evaluate low-cost adherence support, sustained lifestyle care and reliable HbA1c follow-up.

Ethics and Consent

Institutional approval and consent would be mandatory before any actual participant recruitment. No approval or participant contact is claimed in this manuscript.

Data Analysis Transparency

The analytic dataset was generated using fixed random seed 20261026. All tables and figures were calculated from the same 600 complete records. The reproducible analysis dataset may be made available as a companion computational supplement.

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