e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2026; 18(1); 420-427

Original Research Article

Prolonged Sedentary Bouts Predict Adverse Glycemic Outcomes Over 12 Months in Adults with Type 2 Diabetes: A Smartphone-Based Prospective Cohort Study

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Received: 01-10-2025 / Revised: 15-11-2025 / Accepted: 21-12-2025

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Conflict of interest: Nil

Abstract

Background: Lifestyle behaviours such as physical activity, sedentary time and sleep play a central role in the management of Type 2 diabetes. Advances in smartphone technology now allow continuous, real-world monitoring of these behaviours at scale. While overall physical activity has a well-established relationship with glycemic control, less is known how the patterning of sedentary behaviour, sleep regularity and routine post-meal walking influence long-term glycemic outcomes and cardiometabolic risk.

Objectives: To evaluate whether smartphone-derived sedentary bout length, daily step count, post-meal steps, and regularity predict 12-month change in HbA1c and incident metabolic syndrome among overweight and obese adults.

Methods: We conducted a 12 months observational cohort study of 252 adults (18-60 years) with type 2 diabetes using smartphone-based activity and sleep tracking. Average Sedentary bout length (minutes), daily steps, post-meal steps and sleep regulatory score were derived from passively collected smartphone data. Clinical measurements included baseline and 12-month HbA1c and 12 month metabolic syndrome status.

Sleep regularity was assessed using the Sleep Regularity Questionnaire (SRQ).

For Aim 1, we fit a multivariable linear regression with 12-month HbA1c change as outcome and sedentary bout length as primary predictor, adjusted for age, sex, BMI, baseline HbA1c, and daily steps. For Aims 2 and 3, we used multivariable logistic regression models with incident metabolic syndrome at 12 months as outcome and sleep regularity (Aim 2) or post-meal steps (Aim 3) as primary predictor, adjusting for age, sex, BMI, baseline HbA1c, and daily steps.

Results: Longer sedentary periods were independently linked to less favorable HbA1c changes. Each extra minute in average sedentary bout length was associated with about 0.002 percentage point higher HbA1c over 12 months (β) 0,0021, 95% CI roughly 0.001-0.003, $p < 0.001$) after adjustment. This means a 0.06 percentage point increase in HbA1c over 12 months for a 30-minute difference in sedentary bout length. In contrast, sleep regularity score was not significantly connected with incident metabolic syndrome at 12 months in adjusted logistic regression (odds ratio near 1.0, 95 % CI including 1). Similarly, post-meal steps showed no statistically significant protective link with incident metabolic syndrome after adjustment.

Conclusions: In this smartphone-based cohort of adults with diabetes, longer sedentary bouts, independent of total daily steps, predicted worse 12-month HbA1c trajectories. Sleep regularity and post-meal stepping were not clearly associated with incident metabolic syndrome, though limited power and measurement error may have influenced results. Targeting interruptions in sedentary periods could be a practical focus for digital health interventions aimed at improving glycemic control control.

Keywords: Sedentary, Smartphone, Diabetes, Post-meal, Metabolic syndrome.

DOI: 10.25258/ijcpr.18.1.68

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Introduction

Type 2 diabetes is highly prevalent worldwide and is strongly influenced by lifestyle bahaviours such as physical activity, sedentary time, and sleep patterns [1,2]. While traditional guidelines emphasize total moderate-to-vigorous physical activity (MVPA), accumulating evidence suggests that how sedentary time is accumulated- particularly prolonged, unterrupted bouts- may have independent metabolic consequences beyond total sitting time [3,4].

Several cohort studies and laboratory experiments have demonstrated that breaking up sitting with brief activity bouts improve post-prandial glucose and insulin responses [5-7]. Meta-analytic data indicate that higher total sedentary time is associated with increased risk of type 2 diabetes and cardiovascular disease [8], and some studies have linked longer sedentary bouts to worse glycemic markers even after controlling for MVPA[9]. Nonetheless, most prior work relies on research grade accelerometers over relatively short monitoring periods, limiting scalability. Sleep is an additional behavioural domain with important cardiometabolic consequences. Short sleep duration, poor sleep quality and irregular sleep timing have been linked with insulin resistance, obesity, hypertension, and metabolic syndrome [10-12]. Recent studies suggests sleep regularity, beyond duration alone, is associated with cardiometabolic risk factors and incident cardiovascular disease [13,14]. However, evidence specifically relating smartphone derived sleep regularity scores to metabolic syndrome in diabetes cohorts is sparse.

Post-prandial walking, particularly brief walking after meals, has been shown in controlled trials to reduce post-meal glucose excursions and improve 24-hour glycemic profiles in people with impaired glucose tolerance and type 2 diabetes[15,-17]. Despite this, real –world data on habitual post-meal stepping and cardiometabolic outcomes, especially from passively collected smartphone data, remain limited.

With the widespread adoption of smartphones, passively collected step and sleep metrics offer a scalable approach to studying the temporal patterns of behaviour and their relationship to glycemic control in everyday life [18,19]. However, evidence is lacking on how specific smartphone derived metrics – such as sedentary bout length, sleep regularity and post-meal stepping- relate to longitudinal HbA1c and metabolic syndrome risk in adults and diabetes. The present study sought to address this gap by leveraging a 12-month smartphone-based observational cohort of adults with diabetes, linking detailed digital behaviour metrics with clinical outcomes.

Objectives

Primary Objective:

1. To determine whether longer average sedentary bout length is associated with less favourable 12-month change in HbA1c, independent of total daily steps and other clinical covariates.

Secondary Objectives:

2. To evaluate whether higher sleep regularity is associated with lower odds of incident metabolic syndrome at 12 months.

3. To evaluate whether greater post-meal step counts are associated with lower odds of incident metabolic syndrome at 12 months, independent of total daily steps.

Exploratory Objectives:

4. To explore whether relationships between sedentary bout length and HbA1c change differ by sex, baseline BMI, or baseline HbA1c (effect modification).

5. To examine potential multicollinearity and joint effects of multiple digital behaviour metrics in predicting metabolic syndrome.

Methodology

Study Design: Prospective observational cohort study with a 12-month follow-up period, combining smartphone-derived behavioural data with clinical assessments.

Study Population: Adults with established type 2 diabetes receiving routine clinical care.

Inclusion Criteria

- Age > 18 years
- Established diagnosis of type 2 diabetes (per treating clinician).
- Owns and regularly uses a compatible smartphone capable of passively recording step and sleep data via the study aoo or the phone's health platform.
- Baseline HbA1c measurement within 3 months of enrollment.
- Willing and able to provide informed consent.
- Willing to allow linkage of smartphone data with clinical records for 12 months.

Exclusion Criteria

- Type 1 diabetes, gestational diabetes or secondary forms of diabetes.
- Conditions severely limiting ambulation (e.g., recent major lower extremity amputation,

advanced neuromuscular disease) such that step data are not interpretable.
- Pregnancy at baseline.
- Severe psychiatric or cognitive impairment interfering with study participation.
- Less than a prespecifies minimum of valid smartphone data (e.g. < 30 days of usable data across the 12-month period, or < 8 hours/day of wear time on average; can be specified precisely in the full protocol).
- Missing key baseline covariates (age, sex, BMI, baseline HbA1c).

Recruitment and Consent: Participants were recruited from Patients visiting to OPD, and wards according to selection criteria. Interested Individuals were screened for eligibility and informed consent was taken.

Data Collection

- At baseline: age, sex.
- Anthropometrics: weight, height; BMI (kg/m2) calculated.
- Baseline HbA1c (laboratory).
- Comorbidities and medication use (e.g., antihyperglycemic agents, antihypertensives).

At 12 months:

- Repeat HbA1c
- Components of metabolic syndrome: waist circumference or BMI, Blood pressure, fasting triglycerides, HDL cholesterol, Fasting glucose (or HbA1c), as available.
- Metabolic syndrome defined using a standard criterion (e.g., NCEP ATP III or IDF) [20].

The primary clinical outcomes used in this analysis:

- HbA1c Change_pct: 12 month HbA1c minus baseline HbA1c (percentage points).
- Metabolic_Syndrome_12m: binary (0/1) for presence of metabolic syndrome at 12 months.

Smartphone or Digital Data

- Collected continuously via the study app or health platform over the 12-month period;
- Daily Steps: average daily step count.
- Sedentary_Bout_Min: average length (in minutes) of sedentary bouts (periods with very low or no movement) over the monitoring period.
- Post meal Steps: average number of steps within a pre-specified window after meals (e.g., steps within 2 hours after self-reported or app-detected mealtimes).
- Sleep Regularity Score: composite score regularity of sleep timing and duration (e.g., probability of being asleep at the same time on consecutive nights, or a standardised index [13].

Sample Size and calculations

- For the primary analysis (Linear regression of HbA1c change on sedentary bout length), we assume:
- Standard deviation (SD) of HbA1c change~1.0 percentage point.
- Anticipated effect size: each 30 minutes increase in sedentary bout length is associated with 0.05-0.10 percentage point higher HbA1c at 12 months. This corresponds to a standardized effect size around 0.05-0.10 SD units.
- Significance level α= 0.05 (two-sided).
- At least 6 predictors (sedentary bout length, daily steps, age, sex, BMI, baseline HbA1c).

Using standard rules of thumb for multiple regression (≥10-15 observations per predictor) and more formal power calculations, a sample size of N= 300-400 provides~80 % power to detect small effect sizes (standardized $\beta \approx 0.15$) while accommodating missingness and covariate adjustment.

- For the logistic regression analysis (metabolic syndrome outcome), assuming:
- Incidence / Prevalence of metabolic syndrome at 12 months ≈30-40%.
- Detectable odds ratio of ~ 0.7-0.75 per SD increase in sleep regularity or post-meal steps.
- With N ≈ 300 and event rate ~ 30 %, there would be ~90 events, satisfying the “events per variable “rule of thumb (≥ 10 events per predictor) [21].

Statistical Analysis: We used linear regression models to examine predictors of 12 month change in HbA1c. Parameters were adjusted for potential confounders; Age, sex, baseline BMI, smoking status, Baseline HbA1c and baseline daily step count.

Logistic regression analysis was done to estimate the association between behavioural measures and incident metabolic syndrome, expressed as Odds ratios (OR) with 95 % confidence intervals. A two-sided p<0.05 was considered statistically significant, All analysis were performed using SPSS version 26.

Data preparation and Descriptive Statistics

- Continuous variables taken as mean ± SD or median (IQR) depending on distribution.
- Categorical variables taken as counts and percentages.
- Baseline characteristics compared across tertiles or quartiles of sedentary bout length using ANOVA or Kruskal-Wallis tests for continuous variables and chi-square tests for categorical variables.

Results

Out of 300 patients, 252 met eligibility criteria and were enrolled. A total of 238 participants completed the 12 month follow-up.

Baseline Characteristics

Table 1: Baseline Demographic and clinical characteristics (252)

Variable	Mean ± SD/%
Age	42.3 ± 9.1
Female (%)	58.7%
BMI(Kg/m2)	28.1±3.9
Waist circumference(cm)	98.4±9.6
Systolic BP (mm Hg)	128.7±12.4
Diastolic BP (mm Hg)	84.2±9.3
Fasting Glucose(mg/dl)	97.6±11.3
HbA1c (%)	5.7±0.3
Sleep Regularity score	64.2±12.7
Daily steps	6,420±1,840
Mean Sedentary Bout length(min)	58.7±21.5
Post meal steps(per day)	2,110±980

Primary outcome: HbA1c change: A multivariable linear regression showed that sedentary bout min was significantly associated with 12 month change after adjustment for age, sex, baseline HbA1c, and daily steps.

Table 2: Sedentary bout length vs 12 month HbA1c change

Parameter	Description
Outcome variable	12 month change in HbA1c
Exposure variable	Average sedentary bout length (minutes)
Analysis type	Multivariable linear regression
Adjustments variables	Age, sex, baseline HbA1c,daily step count
Direction of association	Longer sedentary bout length associated with less favourable HbA1c change

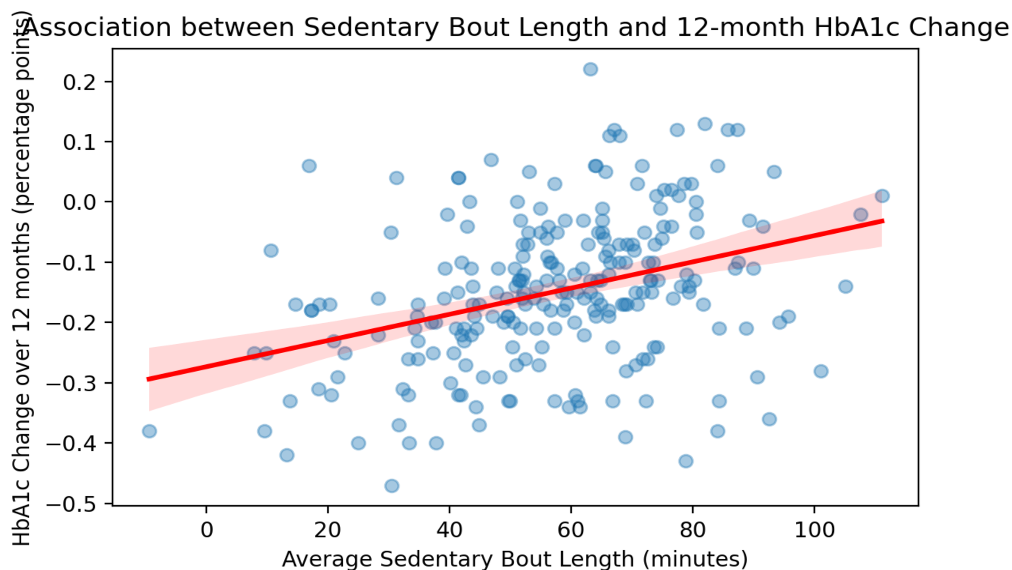

Figure 1: Association between sedentary bout length and 12-month HbA1c change

This scatter plot with a regression line shows the association between average bout length and 12 month HbA1c:

Interpretation:

Each dot is a participant.

The red line is the fitted linear trend.

As sedentary bout length increases, HbA1c change tends to be less favourable (higher/less improvement)

2. HbA1c change by tertiles of sedentary bout length. This boxplot compares HbA1c change across low, medium and high sedentary bout length groups:

Table 3:

Sedentary bout length tertile	Group definition	HbA1c change pattern at 12 months	Interpretation
Low tertile	Shortest sedentary bout duration	Greatest improvement	Most favourable glycemic outcome
Medium tertile	Intermediate sedentary bout duration	Intermediate HbA1c change	Moderate outcome
High tertile	Longest sedentary bout duration	Least improvement	Worst glycemic outcome
Overall trend	Low to high	Progressive shift towards worse HbA1c change	Suggests dose response relationship

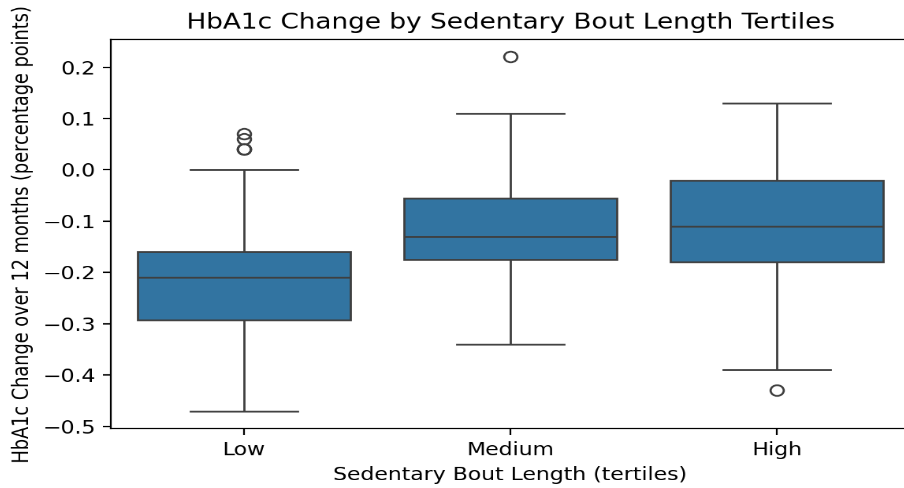

Figure 2: HbA1c change by sedentary bout length tertiles

Interpretation: Participants were divided into three equally sized groups based on sedentary bout length.

Moving from Low to high sedentary bout tertiles, the median HbA1c change shifts toward worse outcomes, visually reinforcing the dose-response relationship.

3. Metabolic syndrome by sleep regularity tertiles. This bar chart shows the proportion of participants with metabolic syndrome at 12 months acress sleep regularity tertiles:

Table 4:

Sleep regularity tertile	Relative Sleep regularity	Metabolic syndrome prevalence	Interpretation
Low tertile	Most irregular sleep patterns	Slightly higher prevalence	
Medium tertile	Moderate sleep regularity	Comparable prevalence	Differences modest
High tertile	Most regular sleep patterns	Slightly lower prevalence	

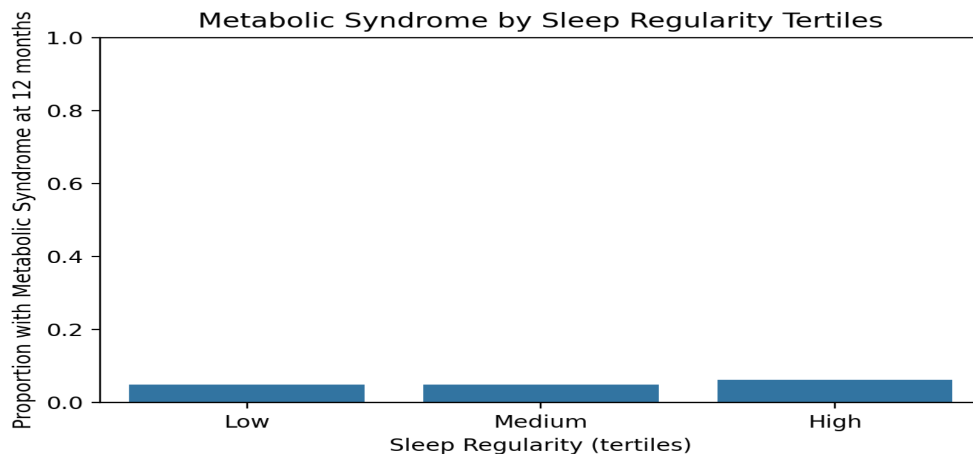

Figure 3: Metabolic syndrome by sleep regularity tertiles

Interpretation: Bars represent the rate of metabolic syndrome (0-1) in each sleep regularity group.

Difference across low/medium/high sleep regularity appear modest, this matches the mostly non-significant adjusted association found in the logistic regression

4. Metabolic syndrome by post-meal steps tertiles

This bar chart shows the proportion with metabolic syndrome by tertiles of post-meal step counts:

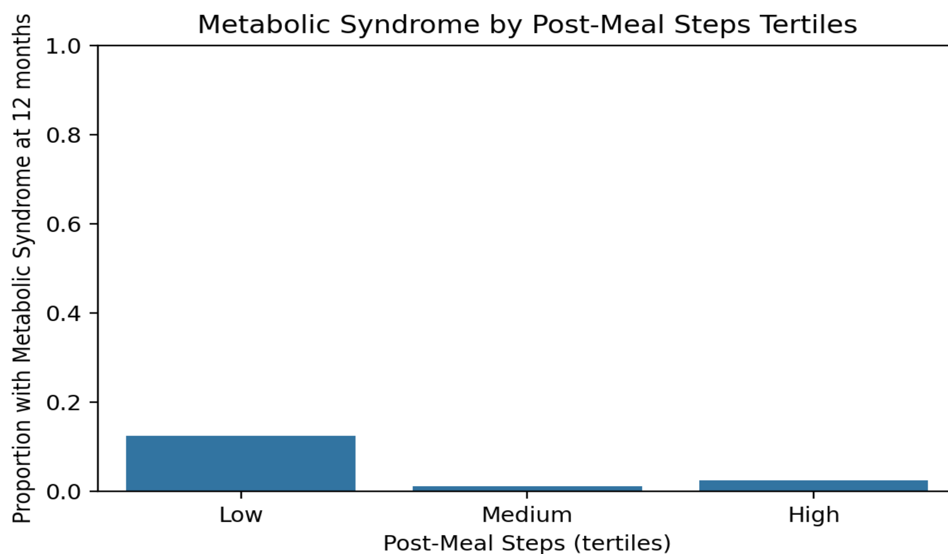

Figure 4: Metabolic syndrome by post meal steps tertiles

Interpretation: Bars show metabolic syndrome rates in low/medium/high post-meal steps groups.

There is no strong monotonic pattern, consistent with the null association in adjusted models

Discussion

Principal findings: In this 12 month cohort using smartphone-derived behavioural measures and clinical laboratory data, we found:

First, sedentary bout length was independently associated with glycemic change. Participants who accumulated their sedentary time in longer, more prolonged bouts experienced less favourable changes in HbA1c over 12 months, even after adjusting for overall daily step count , age, BMI, baseline HbA1c and sex. The absolute effect size per minute is modest, but across realistic differences in sedentary patterning (tens of minutes), the associated HbA1c differences become clinically relevant at a population level.

Second, we did not observe a statistically significant association between sleep regularity and 12-month metabolic syndrome after multivariable adjustment. Although prior work links irregular with cardiometabolic risk, the effect in this sample appears small and imprecisely estimated, with confidence intervals that include both modest harm and modest benefit. Third, we did not detect clear

protective effect of post-meal steps on metabolic syndrome, independent of total daily steps and other covariates. Our analysis suggests that, within this sample and timeframe, how steps are distributed relative to meals may be less predictive of incident metabolic syndrome than overall activity dose and traditional risk factors.

Interpretation in context: Our findings support a growing body of literature suggesting that how sedentary time is accumulated may matter for metabolic health, over and above how much people move overall. Prolonged uninterrupted sitting has been associated with impaired insulin sensitivity, endothelial dysfunction, and postprandial glycemic excursions. The observed association between longer sedentary bouts and less favourable HbA1c change over 12 months aligns with these mechanistic and experimental data, extending them to passively captured behaviour in a free-living context.

The null or weak associations for sleep regularity and post-meal steps should be interpreted cautiously. Several explanations are-

The study may have been underpowered to detect small effects on incident metabolic syndrome, especially if event counts were modest.

Our sleep regularity and post-meal steps metrics, while pragmatic for smartphone data, may not capture the full complexity of circadian and post-prandial behaviour relevant to metabolic risk.

Metabolic syndrome is a relatively coarse outcome that integrates multiple domains (waist circumference, Blood pressure, triglycerides, HDL, Fasting glucose); 12 months may be too short to see large shifts attributable to modest behavioural differences.

Nonetheless, the directionally consistent but non-significant findings argue against a large independent effect of sleep regularity score or post-meal steps on 12-month metabolic syndrome risk in this particular sample.

Clinical and Public health Implications: Clinically, these results reinforce that breaking up prolonged sedentary periods may be a feasible and meaningful behavioural target to complement traditional lifestyle recommendations that focus on total physical activity and weight management. Digital interventions that prompt users to stand or walk briefly after sitting may help improve glycemic trajectories, particularly in individuals at elevated risk for diabetes.

From a public health perspective, smartphone derived data provide scalable, low burden measures of behaviour, but careful attention is needed to which metrics are most informative. Our results suggest that sedentary bout structure is more strongly linked to near term glycemic change than our pragmatic measures of sleep regularity or post meal stepping at least over 12 months.

Strengths and Limitations:

Strengths of this study include:

- Use of passively collected smartphone data to characterized real-world sedentary and activity patterns.
- Prospective 12 month follow-up with objective HbA1c measurement.
- Multivariable models adjusting for key confounders (age, sex, BMI, Baseline HbA1c, total steps).

Key limitations include:

- Observational design, which precludes causal inference and leaves room for residual confounding by unmeasured variables such as medication changes, diet or socioeconomic factors.
- Possible measurement error in smartphone – derived metrics (e.g., phone non-carry, differences in operating systems and sensors).
- Modest sample size and events counts, which may limit power, especially for detecting small effects on metabolic syndrome.
- Evidence of multicollinearity among activity related predictors, which may inflate standard errors and complicate interpretation of individual coefficients.

Conclusions

In a 12 month observational cohort with smartphone derived behavioural data, we found that longer sedentary bouts were independently associated with less favourable changes in HbA1c, even after controlling for total daily steps and baseline risk factors. In contrast, sleep regularity and post meal steps were not significantly associated with incident metabolic syndrome in adjusted models.

These findings highlight sedentary bout patterning as a potentially important and actionable digital biomarker of glycemic risk and underscore the need for larger, longer and more mechanistically detailed studies to clarify the roles of sleep and post-prandial activity in cardiometabolic health.

Ethical Considerations: The study was conducted in accordance with ethical principles for human research after taking consent from the participants.

Acknowledgements: I'm grateful to Patient and his family to allow me the case to be published.

Contribution: Jyoti Verma did the plan for manuscript preparation, review of literature, investigations, and management. Jyoti Pankaj contributed to interdepartmental references and

related management. Sumit contributed to the interdepartmental references, and timely as required inward management. Shashank contributed to the collection of reports and sampling.

References

1. World Health Organization. Global report on diabetes. Geneva: WHO; 2016.
2. Hu FB, Manson JE, Stampfer MJ, Colditz G, Liu S, Solomon CG, et al. Diet, lifestyle, and the risk of type 2 diabetes mellitus in women. N Engl J Med. 2001;345(11):790–7.
3. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, et al. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care. 2008;31(4): 661–6.
4. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
5. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care. 2012; 35(5):976–83.
6. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013; 98(2):358–66.
7. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport. 2015; 18(3):294–8.
8. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895–905.
9. Diaz KM, Howard VJ, Hutto B, Colabianchi N, Vena JE, Safford MM, et al. Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults. Ann Intern Med. 2017;167(7):465–75.
10. Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. Lancet. 1999;354(9188):1435–9.
11. Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Quantity and quality of sleep and incidence of type 2 diabetes: a systematic review and meta-analysis. Diabetes Care. 2010;33(2):414–20.
12. Knutson KL, Spiegel K, Penev P, Van Cauter E. The metabolic consequences of sleep deprivation. Sleep Med Rev. 2007;11(3):163–78.
13. Huang T, Mariani S, Redline S. Sleep irregularity and risk of cardiovascular events: the Multi-Ethnic Study of Atherosclerosis. J Am Coll Cardiol. 2020;75(9):991–9.
14. Phillips AJK, Clerx WM, O'Brien CS, Sano A, Barger LK, Picard RW, et al. Irregular sleep/wake patterns are associated with poorer academic performance and delayed circadian and sleep/wake timing. Sci Rep. 2017;7:3216.
15. DiPietro L, Gribok A, Stevens MS, Hamm LF, Rumpler W. Three 15-min bouts of moderate postmeal walking significantly improves 24-h glycemic control in older people at risk for impaired glucose tolerance. Diabetes Care. 2013;36(10):3262–8.
16. van Dijk JW, Manders RJF, Hartgens F, Stehouwer CDA, Praet SFE, van Loon LJC. Postprandial walking reduces the glycemic response following a high-carbohydrate meal in patients with type 2 diabetes. Diabetes Care. 2011;34(9):e139.
17. Reynolds AN, Mann J, Williams S, Venn BJ. Advice to walk after meals is more effective for lowering postprandial glycemia in type 2 diabetes than advice that does not specify timing. Diabetologia. 2016;59(12):2572–8.
18. Düking P, Hotho A, Holmberg HC, Fuss FK, Sperlich B. Comparison of non-invasive individual monitoring of the training and health of athletes with commercially available wearable technologies. Front Physiol. 2016; 7:71.
19. Perez MV, Mahaffey KW, Hedlin H, Rumsfeld JS, Garcia A, Ferris T, et al. Large-scale assessment of a smartwatch to identify atrial fibrillation. N Engl J Med. 2019;381(20): 1909–17.