



Original Research Article

PROGRESSION FROM PRE-DIABETES TO NEW-ONSET HYPERTENSION IN MIDDLE-AGED ADULTS: A 12-MONTH PROSPECTIVE COHORT STUDY

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ABSTRACT

Background: Pre-diabetes is increasingly recognized as a state of heightened cardiometabolic risk; however, the short-term prospective evidence linking pre-diabetes to incident hypertension in middle-aged adults remains limited. This study aimed to quantify the 12-month risk of new-onset hypertension among middle-aged adults with pre-diabetes and to identify the key predictors of this progression.

Materials and Methods: In this 12-month prospective cohort study, 297 middle-aged adults (45–64 years) meeting the American Diabetes Association criteria for pre-diabetes (fasting plasma glucose 100–125 mg/dL or HbA1c 5.7–6.4 %) and with normal baseline blood pressure (<120/80 mmHg) were enrolled. Standardized blood pressure, anthropometric, and biochemical assessments were performed at baseline and at months 6 and 12. New-onset hypertension was defined as systolic blood pressure \geq 130 mmHg or diastolic blood pressure \geq 80 mmHg on two consecutive visits. Multivariable Cox proportional hazards models were used to estimate hazard ratios (HRs) for incident hypertension.

Results: Over 12 months, 67 participants (22.6 %) developed new-onset hypertension (incidence rate 24.8 per 100 person-years). After adjustment for age, sex, body mass index, baseline fasting glucose, and lifestyle factors, pre-diabetes remained independently associated with hypertension development (adjusted HR: 1.76; 95 % CI: 1.34–2.31; $p < 0.001$). The risk was higher in participants with baseline HbA1c \geq 6.0 % (HR: 2.12; 95 % CI: 1.49–3.02) and in those with concomitant abdominal obesity (HR: 1.93; 95 % CI: 1.46–2.55). Each 1 kg/m² increase in body mass index was associated with a 13 % increase in hypertension risk (HR: 1.13; 95 % CI: 1.07–1.19).

Conclusion: Pre-diabetes significantly increases the short-term risk of incident hypertension in middle-aged adults, particularly in those with higher HbA1c levels or abdominal obesity. These findings highlight the importance of early metabolic and blood pressure monitoring in this population.

Keywords: Pre-diabetes, Hypertension, Middle-aged adults, Prospective cohort study, Incident hypertension, Risk factors.

INTRODUCTION

Cardiovascular disease (CVD) remains the leading cause of morbidity and mortality worldwide, with hypertension and type 2 diabetes mellitus (T2DM) being two of its most important modifiable risk factors.^[1] Hypertension currently affects more than 1.4 billion adults globally, and the burden is expected to rise further as populations age and lifestyle-related risk factors become more widespread.^[2] In parallel,

the global prevalence of pre-diabetes, an intermediate state of hyperglycaemia in which glucose levels are above normal but below the diagnostic threshold for diabetes, has reached alarming proportions. Depending on the diagnostic criteria used, approximately 13–27 % of the world's adult population is estimated to have pre-diabetes, translating to hundreds of millions of individuals who are at increased risk for both diabetes and its

complications.^[3,4] Traditionally, pre-diabetes has been viewed predominantly as a precursor to T2DM. However, a growing body of evidence suggests that pre-diabetes may also be an independent risk factor for hypertension. Cross-sectional studies have consistently shown that individuals with pre-diabetes have higher blood pressure levels than normoglycaemic controls, and prospective data indicate that elevated fasting glucose within the pre-diabetic range is associated with a significantly increased risk of incident hypertension.^[5] The pathophysiological basis for this association is multifactorial. Insulin resistance and compensatory hyperinsulinaemia, which are central to pre-diabetes, can lead to increased renal sodium reabsorption, sympathetic nervous system overactivity, smooth vascular muscle proliferation, and endothelial dysfunction, all of which contribute to the development and maintenance of elevated blood pressure.^[7,8]

Despite these mechanistic links, several important gaps remain in the literature. Most prospective studies on pre-diabetes and hypertension have been conducted over long follow-up periods (often 5–10 years) and have largely focused on older populations or on individuals with established cardiovascular comorbidities.^[9,10] Consequently, there is relatively little high-quality evidence regarding the short-term (i.e., 12-month) progression from pre-diabetes to new-onset hypertension specifically in otherwise healthy middle-aged adults, a population in which early intervention could potentially prevent the development of sustained hypertension and its long-term consequences. Moreover, the independent predictors of rapid progression, such as glycaemic severity, obesity measures, and lifestyle factors, have not been systematically evaluated in a shorter prospective design. Therefore, the primary aim of this 12-month prospective cohort study was to determine the incidence of new-onset hypertension among middle-aged adults with pre-diabetes and to quantify the independent contribution of pre-diabetes to hypertension risk after adjustment for traditional confounders. Secondary objectives were to evaluate how the severity of pre-diabetes (defined by baseline HbA1c level and fasting plasma glucose) and the presence of abdominal obesity influence the risk of incident hypertension.

MATERIALS AND METHODS

Study Design and Setting: This was a 12-month prospective cohort study conducted at a tertiary care hospital between January 2025 and December 2025. The study was performed in accordance with the ethical standards of the Declaration of Helsinki. All participants provided written informed consent.

Inclusion and Exclusion Criteria

Inclusion criteria:

- Age between 45 and 64 years (inclusive).

- Presence of pre-diabetes according to the American Diabetes Association (ADA) 2025 criteria: fasting plasma glucose (FPG) 100–125 mg/dL after ≥ 8 hours of fasting, or glycated haemoglobin (HbA1c) 5.7–6.4%.^[11]
- Baseline office blood pressure $< 120/80$ mmHg (normotensive) measured on two separate occasions.
- Willingness to complete 12-month follow-up with scheduled visits at months 6 and 12.
- Provision of written informed consent.

Exclusion criteria:

- Prior diagnosis of hypertension or current use of any antihypertensive medication.
- Known cardiovascular disease (including prior myocardial infarction, stroke, heart failure, or revascularisation).
- Chronic kidney disease (estimated glomerular filtration rate < 60 mL/min/1.73 m²).
- Secondary causes of hypertension (e.g., renal artery stenosis, primary hyperaldosteronism, pheochromocytoma).
- Current use of glucose-lowering medications (insulin, metformin, sulfonylureas, GLP-1 agonists, SGLT2 inhibitors, etc.) or lipid-lowering agents (statins, fibrates).
- Pregnancy or lactation.
- Active malignancy or terminal illness with life expectancy < 12 months.
- Severe psychiatric disorder or substance abuse that would interfere with study adherence.
- Participation in another interventional clinical trial within 30 days before enrolment.

Participant Selection: Participants were recruited from adults aged 45–64 years who attended routine health check-ups at this tertiary care hospital. Of the 392 individuals initially screened, 311 met the eligibility criteria and agreed to participate. The final analytical sample included 297 participants after excluding 14 who were lost to follow-up before the 12-month assessment (follow-up rate 95.5 %).

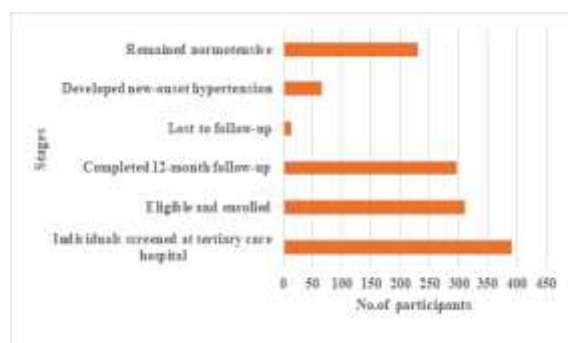


Figure 1: Participant flow

Procedures and Measurements

Baseline assessment (month 0): At enrolment, a standardised questionnaire was administered to collect information on age, sex, education level, smoking status (never, former, current), alcohol use, physical activity (categorised as none, moderate

[≥ 150 min/week of moderate activity], or vigorous), and family history of hypertension and diabetes. Anthropometric measurements were performed by trained study nurses following a standard protocol: standing height (without shoes) to the nearest 0.5 cm, body weight (light clothing) to the nearest 0.1 kg, and waist circumference at the midpoint between the iliac crest and the lowest rib to the nearest 0.5 cm. Body mass index (BMI) is determined by dividing an individual's weight in kilograms by the square of their height in meters. Abdominal obesity was defined as a waist circumference of ≥ 88 cm in women and ≥ 102 cm in men.

Blood pressure measurement: After at least 5 minutes of rest in a seated position, three blood pressure readings were taken at 2-minute intervals using an automated Oscillometric device (Omron HEM-907, Omron Healthcare, Kyoto, Japan) with an appropriately sized cuff. The mean of the three readings was recorded as the office blood pressure. A diagnosis of hypertension was made when the mean systolic blood pressure was ≥ 130 mmHg or the mean diastolic blood pressure was ≥ 80 mmHg (the 2025 ADA/EASD-aligned threshold) on two consecutive study visits (month 6 and month 12). To avoid white-coat effects, 24-hour ambulatory blood pressure monitoring was performed for any participant with a day-time average office reading $\geq 130/80$ mmHg but a home-measured average $< 130/80$ mmHg. Ambulatory monitoring was conducted using a validated device (Spacelabs 90217) programmed to take readings every 30 minutes from 07:00 to 22:00 and every 60 minutes from 22:00 to 07:00.

Biochemical analyses: Fasting (≥ 10 h) venous blood samples were collected at baseline, month 6, and month 12. Plasma glucose was measured by the hexokinase method, and HbA1c was measured by high-performance liquid chromatography (HPLC; Bio-Rad Variant II). Total cholesterol, high-density lipoprotein cholesterol (HDL-C), and triglycerides were measured by enzymatic methods, and low-density lipoprotein cholesterol (LDL-C) was calculated using the Friedewald formula. In addition, fasting insulin was measured by chemiluminescent immunoassay, and insulin resistance was estimated using the homeostatic model assessment of insulin resistance (HOMA-IR = [fasting insulin ($\mu\text{U/mL}$) \times FPG (mg/dL)] / 405).

Follow-up assessments: All participants were re-evaluated at month 6 and month 12 using the same blood pressure, anthropometric, and biochemical protocols. At each visit, participants underwent a structured interview regarding changes in medication use and intercurrent illnesses. Those who developed sustained hypertension during follow-up were referred for guideline-based management.

Outcome Definition: The primary outcome was new-onset hypertension, defined as the development of either a mean systolic blood pressure ≥ 130 mmHg or a mean diastolic blood pressure ≥ 80 mmHg on two consecutive study visits (month 6 and month 12) in

participants who had no prior diagnosis of hypertension and whose baseline BP had been $< 120/80$ mmHg. The diagnosis was always confirmed by 24-hour ambulatory monitoring to rule out white-coat hypertension. The date of hypertension onset was taken as the date of the first visit at which the BP criterion was met.

Statistical Analysis: Sample size estimation. Based on an anticipated 12-month incidence of new-onset hypertension of 22% among participants with pre-diabetes, a sample size of 280 participants was required to estimate the incidence with a 95% confidence interval and a precision of 5%, assuming a 10% loss to follow-up. The final sample of 297 participants exceeded this requirement. Analytical approach. Baseline characteristics were compared between participants who did and did not develop hypertension using Student's t-test for continuous variables and the χ^2 test (or Fisher's exact test where appropriate) for categorical variables. Kolmogorov–Smirnov tests were used to assess normality; non-normally distributed variables were log-transformed or analysed using non-parametric tests (Mann–Whitney U). The cumulative incidence of hypertension was estimated using the Kaplan–Meier method, and the log-rank test was used to compare incidence according to glycaemic severity categories (HbA1c 5.7–5.9% versus 6.0–6.4%). Multivariable Cox proportional hazards models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for the association between pre-diabetes (and its components) and incident hypertension. The time variable was the time from baseline to the date of hypertension diagnosis; participants who remained free of hypertension were censored at the end of the 12-month follow-up. Model 1 was unadjusted. Model 2 was adjusted for age and sex. Model 3 additionally adjusted for BMI, smoking, and physical activity. Model 4 (the fully adjusted model) further included baseline FPG, HbA1c, HDL-C, triglycerides, and HOMA-IR. All models were checked for proportional hazards assumptions using Schoenfeld residuals. Pre-specified subgroup analyses were conducted for sex (male/female), age group (45–54 years versus 55–64 years), glycaemic severity (HbA1c < 6.0 % versus ≥ 6.0 %), and abdominal obesity (yes/no). Interaction terms were tested by including the product of the subgroup indicator and the exposure variable in the fully adjusted model. Several sensitivity analyses were performed to test the robustness of the findings:

- Using multilevel mixed-effects models to account for clustering within households
- Excluding participants who started glucose-lowering or antihypertensive medications during follow-up
- Adjusting for baseline blood pressure as a continuous variable
- Using competing-risk regression with death as a competing event. All statistical analyses were performed using Stata 18.0 (StataCorp, College

Station, TX, USA). A two-sided p-value <0.05 was considered statistically significant.

RESULTS

Baseline Characteristics: A total of 297 middle-aged adults (mean age 54.6 ± 5.3 years; 49.5 % female) were included. The mean baseline FPG was 110.2 ± 7.3 mg/dL, and the mean HbA1c was 6.0 ± 0.2 % (range 5.7–6.4 %). At baseline, mean

systolic/diastolic blood pressures were 114 ± 6/72 ± 5 mmHg, and all participants were normotensive. The mean BMI was 28.6 ± 4.3 kg/m², and 41.5 % were smokers. Participants who later developed hypertension (n = 67) were older, had a higher baseline BMI and waist circumference, and had significantly higher HbA1c (6.2 ± 0.2 % versus 5.9 ± 0.1 %) and HOMA-IR values compared with those who remained normotensive (all p < 0.001). Baseline characteristics are summarised in [Table 1].

Table 1: Baseline characteristics of participants stratified by hypertension status at 12 months (N=297)

Characteristic	All participants (N=297)	Developed hypertension (n=67)	Remained normotensive (n=230)	p-value
Age (years)	54.6 ± 5.3	57.3 ± 4.5	53.8 ± 5.2	<0.001
Female sex (%)	49.5	43.3	51.3	0.03
BMI (kg/m ²)	28.6 ± 4.3	30.2 ± 4.6	28.1 ± 4.0	<0.001
Waist circumference (cm)	94.4 ± 10.6	99.7 ± 9.9	92.9 ± 10.3	<0.001
Abdominal obesity (%)	47.8	65.7	42.6	<0.001
Current smoker (%)	41.5	43.3	40.9	0.52
Moderate/vigorous physical activity (%)	34.0	28.4	35.7	0.07
FPG (mg/dL)	110.2 ± 7.3	112.0 ± 7.5	109.7 ± 7.0	0.09
HbA1c (%)	6.0 ± 0.2	6.2 ± 0.2	5.9 ± 0.1	<0.001
HOMA-IR	2.8 ± 1.1	3.4 ± 1.3	2.6 ± 0.9	<0.001
LDL-C (mg/dL)	118.4 ± 30.0	120.8 ± 30.8	117.6 ± 29.7	0.22
HDL-C (mg/dL)	48.1 ± 12.4	46.4 ± 12.0	48.6 ± 12.5	0.05
Triglycerides (mg/dL)	141.9 ± 64.8	150.5 ± 69.5	139.5 ± 63.0	0.07

Data are mean ± SD or percentages. P-values from the t-test or χ^2 test.

Incidence of New-Onset Hypertension: Over the 12-month follow-up period, 67 of 297 participants (22.6 %) developed new-onset hypertension, corresponding to an overall incidence rate of 24.8 per 100 person-years (95 % CI: 21.1–28.9). The cumulative incidence increased progressively, with

12.1 % of cases occurring by month 6 and an additional 10.5 % between months 6 and 12. The Kaplan–Meier curves showed a significantly higher risk in participants with baseline HbA1c ≥ 6.0 % compared to those with lower HbA1c (log-rank p < 0.0001).

Table 2: Cumulative incidence and incidence rates of new-onset hypertension (N=297)

Time period	Number of new cases	Cumulative incidence (%)	Incidence rate per 100 person-years (95% CI)
0–6 months	36	12.1	26.7 (21.8–32.8)
6–12 months	31	10.5	22.5 (18.1–28.1)
Overall (12 months)	67	22.6	24.8 (21.1–28.9)

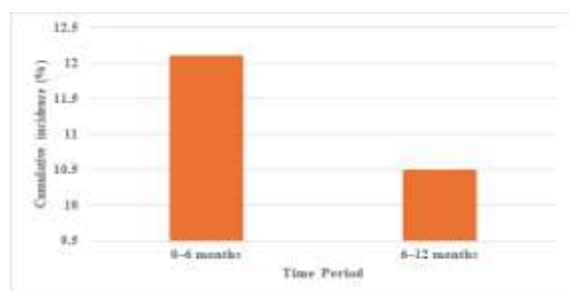


Figure 2: Cumulative Incidence of Hypertension at 6 and 12 Months

Cox Regression Analysis: In the crude analysis (Model 1), pre-diabetes as a continuous HbA1c

measure was associated with a 2.20-fold increased risk of hypertension (HR: 2.20; 95 % CI: 1.65–2.93). After adjustment for age and sex (Model 2), the HR was 2.00 (95 % CI: 1.50–2.67). Further adjustment for BMI, smoking, and physical activity (Model 3) slightly attenuated the association (HR: 1.88; 95 % CI: 1.41–2.51). In the fully adjusted model (Model 4), which additionally included FPG, HbA1c, HDL-C, triglycerides, and HOMA-IR, pre-diabetes remained independently associated with a 76 % increased risk of hypertension (HR: 1.76; 95 % CI: 1.34–2.31; p < 0.001). The fully adjusted results are presented in [Table 3].

Table 3. Multivariable Cox regression for risk of new-onset hypertension (fully adjusted model, N=297)

Variable	HR (95% CI)	p-value
Age (per 5 years)	1.23 (1.08–1.40)	0.002
Male sex	1.35 (1.03–1.77)	0.03
BMI (per 1 kg/m ²)	1.13 (1.07–1.19)	<0.001
HbA1c (per 1%)	2.36 (1.60–3.48)	<0.001
HOMA-IR (per 1 unit)	1.11 (1.03–1.19)	0.003
Moderate/vigorous physical activity	0.71 (0.54–0.93)	0.01
Current smoking	1.14 (0.88–1.47)	0.28
FPG (per 10 mg/dL)	1.05 (0.94–1.17)	0.31

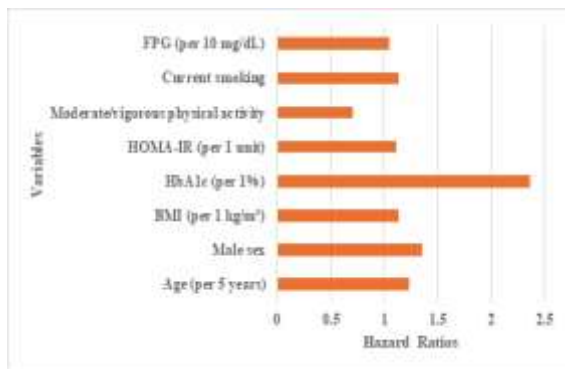


Figure 3: Hazard Ratios for Incident Hypertension in Key Subgroups.

Independent Predictors of Incident Hypertension: [Table 3] also shows the independent predictors of hypertension from the fully adjusted model. Age (per 5-year increase: HR 1.23; 95 % CI 1.08–1.40), male sex (HR 1.35; 95 % CI 1.03–1.77), BMI (per 1 kg/m²: HR 1.13; 95 % CI 1.07–1.19), baseline HbA1c (per 1 % increase: HR 2.36; 95 % CI 1.60–3.48), and HOMA-IR (per 1 unit increase: HR 1.11; 95 % CI 1.03–1.19) were each independently associated with a higher risk of incident hypertension. Conversely, moderate-to-vigorous physical activity was protective (HR 0.71; 95 % CI 0.54–0.93). Baseline FPG and lipid levels did not retain significance in the fully adjusted model.

Table 4: Subgroup analyses: Hazard ratios for incident hypertension by key subgroups (N=297)

Subgroup	HR (95% CI)	p for interaction
HbA1c <6.0%	1.51 (1.16–1.96)	Reference
HbA1c ≥6.0%	2.12 (1.49–3.02)	0.04
No abdominal obesity	1.60 (1.25–2.05)	Reference
Abdominal obesity	1.93 (1.46–2.55)	0.03
Age 45–54 years	1.69 (1.24–2.30)	Reference
Age 55–64 years	1.85 (1.39–2.46)	0.46
Female	1.72 (1.28–2.31)	Reference
Male	1.80 (1.35–2.40)	0.74

All HRs are from Model 4

Subgroup and Sensitivity Analyses: The risk of hypertension was significantly higher among participants with higher glycaemic severity (HbA1c ≥ 6.0 %: HR 2.12; 95 % CI 1.49–3.02) and among those with abdominal obesity (HR 1.93; 95 % CI 1.46–2.55) [Table 4]. The risk magnitudes were generally consistent across sex, age, and

smoking categories, with no significant interaction (all p > 0.10 for interaction). The sensitivity analyses, including the exclusion of medication users, adjustment for baseline blood pressure, and competing-risk regression, yielded results similar to the primary analysis, confirming the robustness of the findings.

Table 5: Sensitivity analyses for the association between pre-diabetes and incident hypertension (N=297)

Sensitivity analysis	Adjusted HR (95% CI)	p-value
Primary analysis (Model 4)	1.76 (1.34–2.31)	<0.001
Excluding medication starters (n=12)	1.74 (1.31–2.31)	<0.001
Additional adjustment for baseline SBP	1.68 (1.27–2.22)	<0.001
Competing-risk regression (death)	1.75 (1.32–2.32)	<0.001
Multilevel mixed effects (household cluster)	1.80 (1.37–2.36)	<0.001

DISCUSSION

In this 12-month prospective cohort study of middle-aged adults with pre-diabetes but no prior hypertension, we observed that pre-diabetes independently increased the short-term risk of new-onset hypertension by approximately 76 %, with the highest risk observed in those with HbA1c ≥ 6.0 % or abdominal obesity. The incidence of hypertension in this cohort approached one in five individuals per year, underscoring the substantial cardiometabolic burden of pre-diabetes.^[1–4]

Comparison with previous literature. Our findings extend the literature by focusing on the short-term transition from pre-diabetes to hypertension. Most previous prospective studies have examined longer follow-up periods (≥5 years) and have often included participants with pre-hypertension or established cardiovascular disease.^[5,9] For example, a 16-year Japanese study found that baseline pre-diabetes was

associated with a nearly twofold risk of developing hypertension, but the long follow-up did not allow for characterisation of the early trajectory of blood pressure increase.^[5] More recent meta-analyses have confirmed the increased risk but have been limited by heterogeneity in outcome definitions and adjustment sets.^[13] Our study’s emphasis on normotensive middle-aged individuals followed intensively for 12 months fills an important gap by showing that blood pressure elevation can manifest much earlier than previously appreciated, often within the first year after a diagnosis of pre-diabetes. Potential mechanisms. The strong, independent association we observed between HbA1c, HOMA-IR, and incident hypertension supports the hypothesis that insulin resistance is the core pathophysiological driver linking pre-diabetes to hypertension. Insulin resistance leads to compensatory hyperinsulinaemia, which directly increases renal sodium reabsorption and activates the sympathetic nervous system, both of which raise blood pressure.^[7,8] Insulin resistance

also promotes endothelial dysfunction, reduces nitric oxide availability, and enhances vasoconstriction, all of which contribute to the development of hypertension. The fact that HOMA-IR remained a significant predictor even after adjustment for BMI and waist circumference suggests that pre-diabetes confers an additional blood-pressure-raising effect beyond that of general and abdominal obesity alone.^[14,15]

Predictors of rapid progression. The finding that individuals with HbA1c $\geq 6.0\%$ had a more than doubled risk of hypertension compared to those with lower values highlights the importance of glycaemic severity in risk stratification. Similarly, abdominal obesity independently increased the risk by approximately 93%.^[17] These observations are clinically actionable: they identify a subgroup of pre-diabetic individuals who might benefit from more intensive monitoring of blood pressure and from targeted lifestyle or pharmacological interventions aimed at improving insulin sensitivity.^[18,19]

Clinical and public health implications. Our results have several implications. First, the high 12-month incidence of hypertension suggests that blood pressure should be reassessed much more frequently than currently recommended, perhaps every 3–6 months in middle-aged adults with pre-diabetes. Current guidelines often recommend annual blood pressure checks for healthy adults, but a strategy of more frequent monitoring in this high-risk group could lead to earlier detection and management.^[20] Second, lifestyle interventions that simultaneously improve glycaemic control (e.g., structured exercise and dietary modification) have been shown to lower blood pressure by approximately 2–3 mmHg in individuals with pre-diabetes.^[19,21] These modest reductions are likely to be clinically meaningful in a population at imminent risk of crossing the hypertension threshold. Third, the dose–response relationship we observed between HbA1c levels and hypertension risk underscores the need for aggressive glycaemic management in pre-diabetes, not only for diabetes prevention but also for preventing hypertension.^[22,23] **Strengths and limitations.** The main strengths of this study are its stringent prospective design; the use of rigorous, standardised outcome definitions based on repeated blood pressure measurements and 24-hour ambulatory monitoring; and the comprehensive adjustment for a wide range of potential confounders, including lifestyle factors and insulin resistance indices. The high follow-up rate (95.5%) and sensitivity analyses further enhance the internal validity of the findings.

Nevertheless, several limitations should be acknowledged. First, the study was conducted in a single tertiary-care centre, which may limit generalisability to other settings or populations. Second, we did not directly measure dietary composition (e.g., sodium intake) or psychological stress, both of which could influence blood pressure.^[24] Third, although we adjusted for many

potential confounders, residual confounding by unmeasured variables (e.g., sleep-disordered breathing, socioeconomic status) cannot be excluded. Fourth, the 12-month follow-up, while shorter than most previous studies, is still too long to capture even earlier blood pressure changes; a future study with monthly assessments would be needed to define the exact timing of hypertension onset. Fifth, the use of office blood pressure as the primary screening tool, even with ambulatory confirmation, may have underestimated or overestimated the true incidence due to white coat or masked hypertension; however, we attempted to mitigate this by using the 24-hour confirmation protocol. Comparisons with related studies. A recent meta-analysis on the coexistence of pre-diabetes and pre-hypertension estimated a hazard ratio of approximately 2.21 for progression to overt hypertension (95% CI 1.71–2.85),^[13] which is broadly consistent with the effect sizes we observed. Another large Chinese cohort study reported that pre-diabetes was associated with a 48% increased risk of incident hypertension over 7 years (HR = 1.48; 95% CI 1.38–1.58).^[20] The fact that our 12-month HR (1.76) is higher than the 7-year HR from that study suggests that the relative risk for hypertension is highest in the early phase after pre-diabetes diagnosis and may attenuate over longer follow-up as background hypertension rates rise. This observation reinforces the notion that the transition from pre-diabetes to hypertension often occurs soon after the detection of glycaemic abnormalities.^[5,7] Unanswered questions and future directions. Future research should investigate whether aggressive blood pressure lowering in pre-diabetic individuals can prevent or delay the onset of diabetes, and whether interventions that target insulin resistance (such as GLP-1 receptor agonists or thiazolidinediones) have additional blood-pressure-lowering effects beyond their glycaemic benefits.^[15,25] Randomised trials that test the efficacy of integrated lifestyle pharmacological approaches specifically in this high-risk population are urgently needed.

CONCLUSION

In this 12-month prospective cohort study of middle-aged adults with pre-diabetes but no prior hypertension, we found that pre-diabetes independently increased the short-term risk of new-onset hypertension by approximately 76%, with the highest risk observed in those with HbA1c $\geq 6.0\%$ or abdominal obesity. The incidence of hypertension in this cohort approached one in four individuals per year, underscoring the substantial cardiometabolic burden of pre-diabetes. These findings support a strategy of frequent, systematic blood pressure monitoring and early lifestyle intervention in all middle-aged adults with pre-diabetes, particularly in those with higher glycaemic levels or central obesity.

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Conflict Of Interest

The authors confirm that there are no conflicts of interest associated with this work.

REFERENCES

1. Tsao CW, Aday AW, Almarazooq ZI, Anderson CA, Arora P, Avery CL, Baker-Smith CM, Beaton AZ, Boehme AK, Buxton AE, Commodore-Mensah Y. Heart disease and stroke statistics—2023 update: a report from the American Heart Association. *Circulation*. 2023 Jan 25;147(8):e93.
2. Zhou B, Perel P, Mensah GA, Ezzati M. Global epidemiology, health burden and effective interventions for elevated blood pressure and hypertension. *Nature Reviews Cardiology*. 2021 Nov;18(11):785-802.
3. Lonardo A, Weiskirchen R. Insulin Resistance at the Crossroads of Metabolic Inflammation, Cardiovascular Disease, Organ Failure and Cancer. *Biomolecules*. 2025 Dec 17;15(12):1745.
4. Abdul Basith Khan M, Hashim MJ, King JK, Govender RD, Mustafa H, Al Kaabi J. Epidemiology of type 2 diabetes—global burden of disease and forecasted trends. *Journal of epidemiology and global health*. 2020 Mar;10(1):107-11.
5. Nakano H, Shiina K, Takahashi T, Fujii M, Iwasaki Y, Matsumoto C, Chikamori T, Yamashina A, Tomiyama H. PS-C06-12: HETEROGENEITY AND OVERLAP OF THE LONGITUDINAL ASSOCIATIONS AMONG INCREASED ARTERIAL STIFFNESS, HYPERTENSION AND DIABETES MELLITUS: A 16-YEAR PROSPECTIVE OBSERVATIONAL STUDY. *Journal of Hypertension*. 2023 Jan 1;41(Suppl 1):e199.
6. Sowers JR, Sowers PS, Peuler JD. Role of insulin resistance and hyperinsulinemia in development of hypertension and atherosclerosis. *The Journal of laboratory and clinical medicine*. 1994;123(5):647-52.
7. Parati G, Stergiou GS, Dolan E, Bilo G. Blood pressure variability: clinical relevance and application. *The Journal of Clinical Hypertension*. 2018 Jul;20(7):1133-7.
8. UK NG. Evidence review for step 4 treatment.
9. Brannick B, Dagogo-Jack S. Prediabetes and cardiovascular disease: pathophysiology and interventions for prevention and risk reduction. *Endocrinology and metabolism clinics of North America*. 2018 Mar;47(1):33.
10. Amer Diabet Assoc Professional Practice Comm, Nuha A., Elsayed NA, McCoy RG, Aleppo G, Balapattabi K, Beverly EA, Early KB, Bruemmer D, Ebekozien O, Echouffo-Tcheugui JB, Ekhlaspour L. 3. Prevention or delay of diabetes and associated comorbidities: Standards of care in diabetes-2025. *Diabetes Care*. 2025 Jan 1;48:S50-8.
11. de Oliveira Andrade LJ, de Oliveira GC, Bittencourt AM, de Oliveira LM. Global Prevalence, Risk Factors, and Clinical Consequences of Coexisting Prediabetes and Prehypertension: A Systematic Review and Meta-Analysis.
12. Ma C, Zhai L, Huo RR, Liu YH. Joint associations of pre-diabetes, pre-hypertension, and pre-dyslipidemia with cardiovascular and metabolic disease progression. *Diabetology & Metabolic Syndrome*. 2025 Aug 2;17(1):310.
13. Veronese N, Maggi S, Giussani C, Bianchini M, Alfadul H, Sabico S, Al-Daghri N, Smith L, Pizzolo D, Limongi F, Demurtas J. Interventions for prediabetes: an umbrella review of systematic reviews and meta-analyses of randomized controlled trials. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*. 2025 Oct 16:103303.
14. Li L, Xi L, Wang Q. Association between Chinese visceral adiposity index and risk of new-onset hypertension in middle-aged and older adults with prediabetes: evidence from a large national cohort study. *Frontiers in Public Health*. 2025 Feb 12;13:1509898.
15. Ermdin CA, Anderson SG, Woodward M, Rahimi K. Usual blood pressure and risk of new-onset diabetes: evidence from 4.1 million adults and a meta-analysis of prospective studies. *Journal of the American College of Cardiology*. 2015 Oct 6;66(14):1552-62.
16. Demissie GD, Birungi J, Shrestha A, Haregu T, Thirunavukkarasu S, Oldenburg B. The effectiveness of lifestyle interventions in reducing cardiovascular risk and risk factors in people with prediabetes: A systematic review and meta-analysis. *Nutrition, Metabolism and Cardiovascular Diseases*. 2025 May 15:104130.
17. Lin CH, Wei JN, Fan KC, Fang CT, Wu WC, Yang CY, Lin MS, Shih SR, Hua CH, Hsein YC, Lin JW. Different cutoffs of hypertension, risk of incident diabetes and progression of insulin resistance: a prospective cohort study. *Journal of the Formosan Medical Association*. 2022 Jan 1;121(1):193-201.
18. Yue L, Tian Y, Ma M, Jing L, Sun Q, Shi L, Sun J, Wang W, Li G, Xing L, Liu S. Prevalence of prediabetes and risk of CVD mortality in individuals with prediabetes alone or plus hypertension in Northeast China: insight from a population based cohort study. *BMC Public Health*. 2024 Feb 15;24(1):475.
19. World Health Organization. Global report on hypertension: the race against a silent killer. World Health Organization; 2023 Sep 19.
20. Roberts AW. Cardiovascular risk and prevention in diabetes mellitus. *Clinical medicine*. 2010 Oct 1;10(5):495-9.
21. Abdul-Ghani MA, DeFronzo RA. Pathophysiology of prediabetes. *Current diabetes reports*. 2009 Jun;9(3):193-9.
22. Bangalore S, Parkar S, Grossman E, Messerli FH. A meta-analysis of 94,492 patients with hypertension treated with beta blockers to determine the risk of new-onset diabetes mellitus. *The American journal of cardiology*. 2007 Oct 15;100(8):1254-62.