RESEARCH PAPER

Comparative Evaluation of TyG Index and TyG-Derived Indices for Hypertension Staging According to ESH 2023 Criteria: A Cross-Sectional Study from Northern India

Dr Aman Ansari[1], Dr Rudra Dutt Kaushik[2], Dr Deepak Sharma[3*], Dr Lavish Singla[4], Dr Vipul Goyal[5]

[1]Post Graduate Resident, Department of medicine, School of Medical Sciences and Research (SMS&R), Sharda University, Greater Noida, Uttar Pradesh, India
[2]Post Graduate Resident, Department of medicine, School of Medical Sciences and Research (SMS&R), Sharda University, Greater Noida, Uttar Pradesh, India
[3]Professor & Head, Department of Medicine, School of Medical Sciences and Research (SMS&R), Sharda University, Greater Noida, Uttar Pradesh, India*
[4]Post Graduate Resident Department of Medicine, School of Medical Sciences and Research (SMS&R), Sharda University, Greater Noida, Uttar Pradesh, India
[5]Post graduate Resident Department of General Medicine, School of Medical Sciences and Research (SMS&R), Sharda University, Greater Noida, Uttar Pradesh, India

ABSTRACT

Background: Hypertension remains a leading contributor to cardiovascular morbidity and mortality worldwide. The Triglyceride-Glucose (TyG) index has emerged as a practical surrogate marker for insulin resistance, with growing evidence linking elevated TyG values to hypertension risk. However, data evaluating TyG and its anthropometric derivatives across hypertension stages defined by the European Society of Hypertension (ESH) 2023 guidelines remain limited, particularly in South Asian populations.

Objectives: To evaluate the association of TyG index and TyG-derived indices (TyG-BMI, TyG-WC, TyG-WHR, TyG-WHtR) with hypertension staging according to ESH 2023 criteria in newly detected, treatment-naive hypertensive patients.

Methods: This cross-sectional observational study enrolled 200 participants (100 newly diagnosed hypertensive cases and 100 age- and sex-matched normotensive controls) at a tertiary care hospital in Northern India. TyG index was calculated as Ln[TG(mg/dL) × FPG(mg/dL)/2]. TyG-derived indices incorporating BMI, waist circumference, waist-hip ratio, and waist-height ratio were computed. Cases were staged per ESH 2023 criteria. Statistical analyses included Welch's t-test, one-way ANOVA, and Pearson correlation.

Results: Hypertensive cases demonstrated significantly higher TyG index compared with controls (9.366 ± 0.274 vs 8.504 ± 0.252; $p < 0.001$). TyG index increased progressively across
ESH grades: Grade 1 (9.169 ± 0.152), Grade 2 (9.364 ± 0.116), and Grade 3 (9.517 ± 0.107);
ANOVA $p < 0.001$. All TyG-derived indices were significantly elevated in cases ($p < 0.01$ to $p < 0.001$). TyG correlated strongly with systolic ($r = 0.783$) and diastolic blood pressure ($r = 0.741$), both $p < 0.001$.

Conclusion: TyG index and its derived parameters are significantly elevated in newly diagnosed hypertensive patients and demonstrate a graded increase across ESH 2023 hypertension stages. These accessible, cost-effective markers may serve as useful adjuncts for cardiovascular risk stratification.

Keywords: Triglyceride-glucose index; TyG index; Hypertension staging; ESH 2023 guidelines; Insulin resistance; Cardiovascular risk

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INTRODUCTION

Hypertension constitutes one of the most significant modifiable risk factors for cardiovascular disease, stroke, and chronic kidney disease globally.[1] According to the World Health Organization, over 1.28 billion adults aged 30–79 years are affected by hypertension worldwide, with nearly two-thirds residing in low- and middle-income countries.[2] The burden is particularly substantial in India, where national surveys indicate prevalence rates approaching 30% among adults, with considerable variation between urban and rural populations.[1,2] The European Society of Hypertension (ESH) 2023 guidelines provide a

**Author for Correspondence:* Dr Deepak Sharma

contemporary classification system that stratifies blood pressure into optimal, normal, high-normal, and three grades of hypertension, each associated with incrementally higher cardiovascular risk and requiring appropriately escalated management.[3]

The pathophysiological connection between metabolic dysfunction and hypertension has been increasingly recognized.[19,20] Insulin resistance, a hallmark of metabolic syndrome, contributes to elevated blood pressure through multiple mechanisms including endothelial dysfunction, sympathetic nervous system activation, sodium retention, and alterations in vascular smooth muscle function.[19,21] The hyperinsulinemic-euglycemic clamp remains the gold standard for assessing insulin resistance; however, its complexity, cost, and invasiveness preclude routine clinical application. Consequently, surrogate markers have gained attention. The Triglyceride- Glucose (TyG) index, calculated as the natural logarithm of the product of fasting triglycerides and fasting plasma glucose divided by two, has emerged as a practical, accessible alternative that correlates well with clamp-derived measures of insulin resistance.4,5

Multiple studies have established associations between elevated TyG index and both prevalent and incident hypertension. Cohort analyses from China, the United States, and other populations have demonstrated that higher TyG values predict new-onset hypertension and correlate with blood pressure levels.[6-9,16] Furthermore, TyG-derived indices that incorporate anthropometric parameters such as body mass index (BMI), waist circumference (WC), waist-hip ratio (WHR), and waist-height ratio (WHtR) have shown enhanced predictive capacity for metabolic and cardiovascular outcomes by integrating visceral adiposity measures with biochemical markers of insulin resistance.[7,10,23,24] Despite this growing evidence base, limited data exist evaluating TyG and its anthropometric derivatives specifically across hypertension stages as

defined by the ESH 2023 guidelines, particularly in treatment-naive South Asian populations with distinct metabolic phenotypes.[3,6]

Given this background, the present study aimed to evaluate the association of TyG index and TyG-derived indices (TyG-BMI, TyG-WC, TyG-WHR, TyG-WHtR) with hypertension staging according to ESH 2023 criteria3 in newly detected, treatment-naive hypertensive patients from Northern India, and to examine their correlations with blood pressure parameters.

MATERIALS AND METHODS

Study Design and Setting

This cross-sectional observational study was conducted at the Department of General Medicine, School of Medical Sciences and Research (SMS&R), Sharda Hospital, Sharda University, Greater Noida, Uttar Pradesh, India. Participants were recruited from both outpatient and inpatient departments.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee of SMS&R, Sharda University. Written informed consent was obtained from all participants in both English and Hindi prior to enrollment. The study was conducted in accordance with the Declaration of Helsinki.

Study Population and Sample Size

Sample size was calculated using the formula $n = Z^2P(1-P)/e^2$, where $Z = 1.96$ (95% confidence), $P = 0.31$ (hypertension prevalence in India per WHO NCD Country Profile 2023), and $e = 0.07$ (precision). This yielded $n \approx 168$, rounded to 200 participants comprising 100 newly detected hypertensive cases and 100 age- and sex-matched normotensive controls.

Inclusion criteria for cases included: age ≥18 years; newly diagnosed hypertension per ESH 2023 criteria (SBP ≥140 mmHg and/or DBP ≥90 mmHg); and treatment-naive status. Controls were normotensive individuals matched for age and sex. Exclusion criteria encompassed: prior antihypertensive treatment; diabetes mellitus; chronic kidney disease; malignancy; moderate- severe valvular heart disease; inflammatory diseases; thyroid dysfunction; pregnancy; and use of medications affecting TyG index (statins, oral hypoglycemics).

Clinical and Laboratory Measurements

Sitting blood pressure was measured after 5 minutes of rest using an automated sphygmomanometer with appropriate cuff size; three readings were averaged. Anthropometric measurements included height (cm), weight (kg), waist circumference (WC, cm), and hip circumference (HC, cm). Body mass index (BMI) was calculated as weight/height² (kg/m²). Waist- hip ratio (WHR) was computed as WC/HC, and waist-height ratio (WHtR) as WC/height.

Fasting blood samples were collected after ≥9 hours overnight fast via venipuncture. Fasting plasma glucose (FPG) was measured by hexokinase method; triglycerides (TG) by enzymatic colorimetric method; total cholesterol, HDL-cholesterol, and VLDL by standard enzymatic methods; and LDL-cholesterol calculated using the Friedewald formula.

Calculation of TyG Index and Derived Indices

The TyG index was calculated as:

$TyG = Ln[TG(mg/dL) \times FPG(mg/dL)/2]$

TyG-derived indices were computed as:

TyG-BMI = TyG × BMI; TyG-WC = TyG × WC; TyG-WHR = TyG × WHR; TyG-WHtR = TyG × WHtR.

Hypertension Staging

Hypertensive cases were classified according to ESH 2023 guidelines: Grade 1 (SBP 140– 159 and/or DBP 90–99 mmHg), Grade 2 (SBP 160–179 and/or DBP 100–109 mmHg), and Grade 3 (SBP ≥180 and/or DBP ≥110 mmHg).

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation (SD) with minimum and maximum values; categorical variables as counts and percentages. Between-group comparisons (cases vs controls) used Welch's t-test for continuous variables and chi-square test for categorical variables. Among cases, differences across hypertension grades were assessed using one-way ANOVA with post-hoc analysis and linear trend testing. Correlations between TyG indices and blood pressure were evaluated using Pearson's correlation coefficient. Statistical significance was set at $p < 0.05$. All analyses were performed using appropriate statistical software.

RESULTS

Baseline Characteristics

A total of 200 participants were enrolled, comprising 100 newly detected hypertensive cases and
100 normotensive controls. The baseline demographic, anthropometric, and biochemical characteristics are presented in Table 1.

Table 1. Baseline Characteristics of Study Population

Parameter	Cases (n=100)	Controls (n=100)	p-value
Age (years)	52.91 ± 5.08	42.83 ± 8.40	< 0.001
Sex (Male/Female)	57/43	62/38	0.474
Family history of HTN (%)	48%	14%	< 0.001
SBP (mmHg)	167.86 ± 8.41	119.55 ± 6.22	< 0.001
DBP (mmHg)	98.50 ± 1.52	78.94 ± 3.07	< 0.001
Height (cm)	165.38 ± 9.02	163.83 ± 3.46	0.006
Weight (kg)	77.71 ± 4.24	57.23 ± 2.62	0.039
BMI (kg/m²)	28.40 ± 1.72	25.07 ± 0.86	0.007
Waist circumference (cm)	87.69 ± 1.95	80.75 ± 1.52	< 0.001
Hip circumference (cm)	90.64 ± 1.84	89.50 ± 2.37	< 0.001
Waist-hip ratio	0.97 ± 0.03	0.90 ± 0.02	< 0.001
Waist-height ratio	0.53 ± 0.03	0.50 ± 0.01	< 0.001
Fasting plasma glucose (mg/dL)	109.60 ± 16.60	78.98 ± 4.18	< 0.001
Total cholesterol (mg/dL)	202.57 ± 9.43	146.99 ± 7.47	< 0.001
LDL cholesterol (mg/dL)	156.94 ± 15.61	78.94 ± 3.07	< 0.001
HDL cholesterol (mg/dL)	36.62 ± 1.77	42.04 ± 2.07	< 0.001
Triglycerides (mg/dL)	212.80 ± 48.31	125.09 ± 23.69	< 0.001

Data expressed as mean ± SD or n (%). SBP: systolic blood pressure; DBP: diastolic blood pressure; BMI: body mass index; HTN: hypertension. p-values from Welch's t-test (continuous) or chi-square test (categorical).

Cases were significantly older than controls (52.91 ± 5.08 vs 42.83 ± 8.40 years; $p < 0.001$). Sex distribution was comparable between groups. Positive family history of hypertension was more prevalent among cases (48% vs 14%; $p < 0.001$). Cases demonstrated significantly higher BMI, waist circumference, and all central adiposity indices compared with controls (all $p < 0.001$). Fasting plasma glucose, total cholesterol, LDL-cholesterol, and triglycerides were significantly elevated in cases, while HDL-cholesterol was significantly lower.

Among cases, hypertension staging according to ESH 2023 criteria revealed: Grade 1 in 18 patients (18%), Grade 2 in 77 patients (77%), and Grade 3 in 5 patients (5%). Blood pressure increased significantly across grades (ANOVA $p <$ 0.001 for both SBP and DBP).

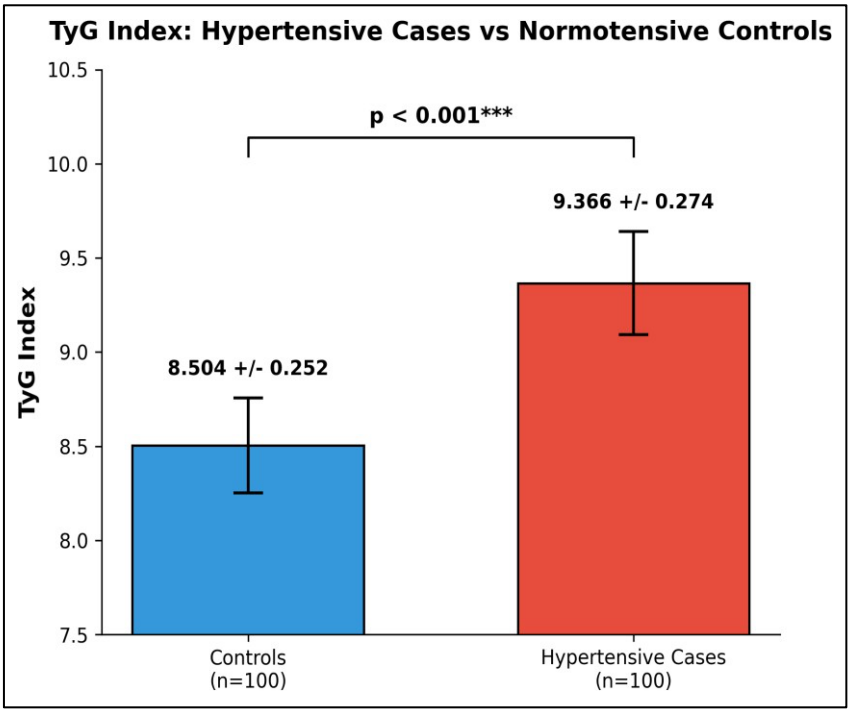


Figure 1. Comparison of TyG index between hypertensive cases and normotensive controls. Error bars represent standard deviation. ***p < 0.001

TyG Index and TyG-Derived Indices

The TyG index was significantly higher in hypertensive cases compared with normotensive controls (9.366 ± 0.274 vs 8.504 ± 0.252; p < 0.001) (Figure 1, Table 2). All TyG-derived indices were significantly elevated in cases: TyG-BMI (249.92 ± 23.06 vs 213.18 ± 8.41; p < 0.01), TyG- WC (821.34 ± 69.81 vs 686.64 ± 12.82; p < 0.001), TyG-WHR (9.07 ± 0.33 vs 7.63 ± 0.23; p <
0.001), and TyG-WHtR (4.89 ± 0.31 vs 4.21 ± 0.06; p < 0.001).

Table 2. TyG Index and TyG-Derived Indices by Group

Index	Cases (n=100)	Controls (n=100)	p-value
TyG Index	9.366 ± 0.274	8.504 ± 0.252	< 0.001
TyG-BMI	249.92 ± 23.06	213.18 ± 8.41	< 0.01
TyG-WC	821.34 ± 69.81	686.64 ± 12.82	< 0.001
TyG-WHR	9.07 ± 0.33	7.63 ± 0.23	< 0.001
TyG-WHtR	4.89 ± 0.31	4.21 ± 0.06	< 0.001

TyG: triglyceride-glucose index; BMI: body mass index; WC: waist circumference; WHR: waist-hip ratio; WHtR: waist-height ratio. p-values from Welch's t-test

TyG Index Across Hypertension Stages

Among hypertensive cases, TyG index demonstrated a progressive increase across ESH 2023 hypertension grades (Table 3, Figure 2). Mean TyG values were 9.169 ± 0.152 in Grade 1, 9.364
± 0.116 in Grade 2, and 9.517 ± 0.107 in Grade 3. One-way ANOVA revealed significant differences across stages (p < 0.001), and linear trend analysis confirmed a significant progressive increase (p < 0.001). Similar stage-wise gradients were observed for TyG-derived indices.

**Author for Correspondence:* Dr Deepak Sharma

Table 3. TyG Index and Derived Indices Across ESH 2023 Hypertension Grades

Index	Grade 1 (n=18)	Grade 2 (n=77)	Grade 3 (n=5)	p-value*
TyG Index	9.169 ± 0.152	9.364 ± 0.116	9.517 ± 0.107	< 0.001
TyG-BMI	232.15 ± 18.42	252.88 ± 22.15	268.45 ± 19.87	< 0.001
TyG-WC	782.45 ± 52.36	828.72 ± 68.45	862.18 ± 48.92	< 0.001
TyG-WHR	8.75 ± 0.28	9.12 ± 0.31	9.38 ± 0.25	< 0.001
TyG-WHtR	4.68 ± 0.24	4.93 ± 0.30	5.12 ± 0.22	< 0.001

**ANOVA across grades. Linear trend p < 0.001 for all indices*

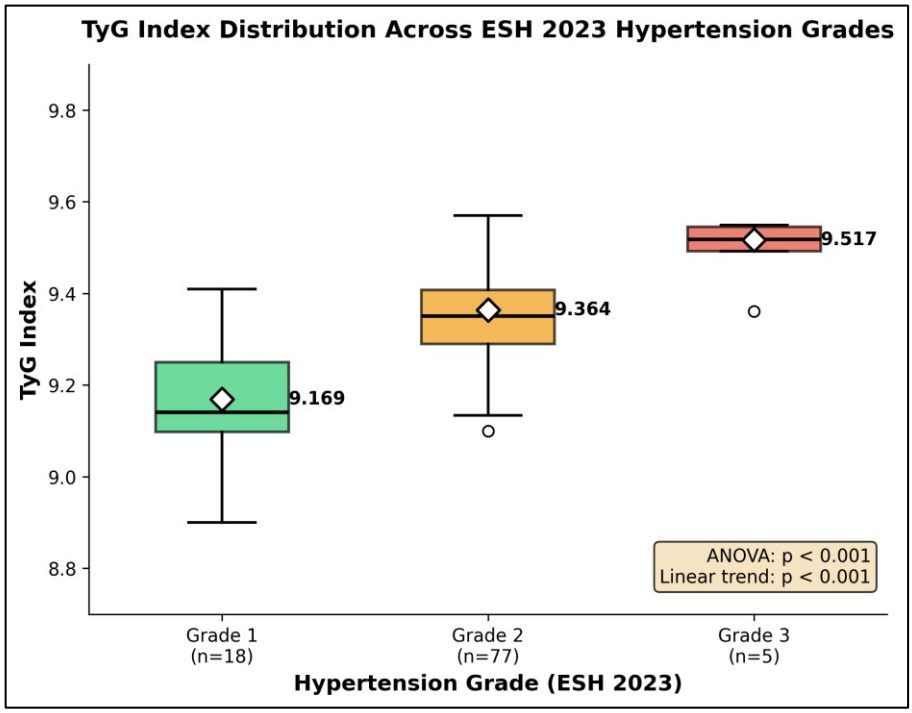


Figure 2. Distribution of TyG index across ESH 2023 hypertension grades. Box plots show median, interquartile range, and outliers. Diamond markers indicate mean values. ANOVA p < 0.001; linear trend p < 0.001.

Correlations with Blood Pressure

TyG index demonstrated strong positive correlations with blood pressure parameters in the overall sample (Table 4). The correlation coefficient for TyG with systolic blood pressure was r = 0.783 (p < 0.001), and with diastolic blood pressure was r = 0.741 (p < 0.001) (Figure 3). Within cases alone, TyG showed moderate correlation with SBP (r = 0.488; p = 0.032) and weak but significant correlation with DBP (r = 0.218; p = 0.029).

Table 4. Correlation of TyG Index with Blood Pressure Parameters

Parameter	Overall r	p-value	Cases-only r	p-value
TyG vs SBP	0.783	< 0.001	0.488	0.032
TyG vs DBP	0.741	< 0.001	0.218	0.029

r: Pearson correlation coefficient; SBP: systolic blood pressure; DBP: diastolic blood pressure

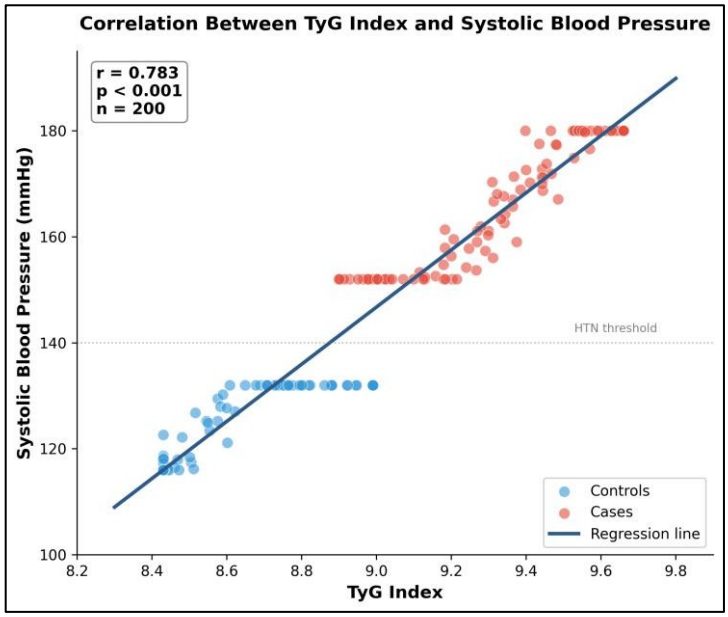


Figure 3. Scatter plot demonstrating correlation between TyG index and systolic blood pressure. Blue circles: controls; red circles: hypertensive cases. Solid line: regression line. r = 0.783, p < 0.001.

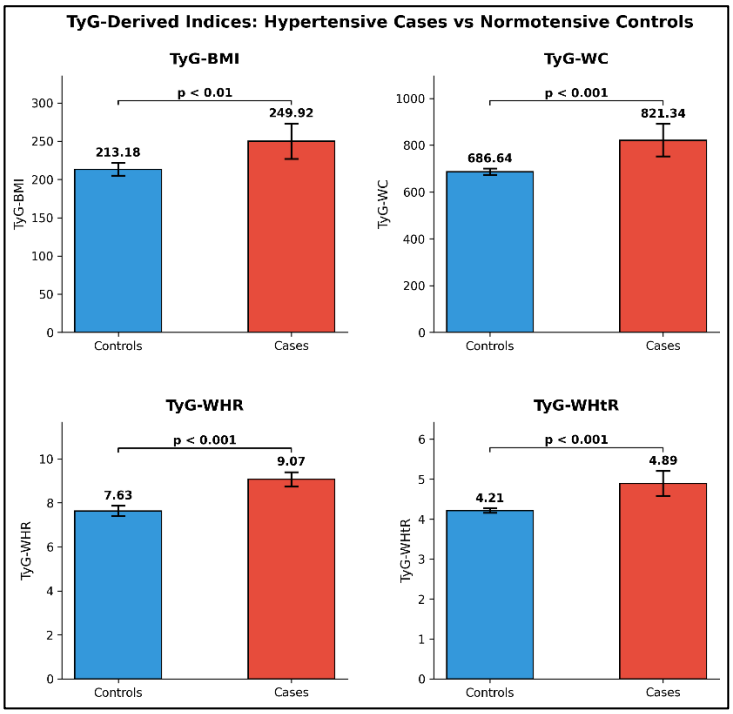


Figure 4. Comparison of TyG-derived indices (TyG-BMI, TyG-WC, TyG-WHR, TyG-WHtR) between hypertensive cases and normotensive controls. Error bars represent standard deviation. All comparisons p < 0.01 to p < 0.001.

DISCUSSION

The present study evaluated the association of TyG index and its anthropometric derivatives with hypertension staging according to ESH 2023 criteria3 in newly detected, treatment-naive patients from Northern India. Our principal findings demonstrate that TyG index and all TyG-derived indices are significantly elevated in hypertensive cases compared with normotensive controls, show a progressive increase across hypertension grades, and correlate positively with blood pressure parameters. These findings support the utility of TyG-based markers as accessible indicators of metabolic dysfunction associated with hypertension severity.[4,5,30]

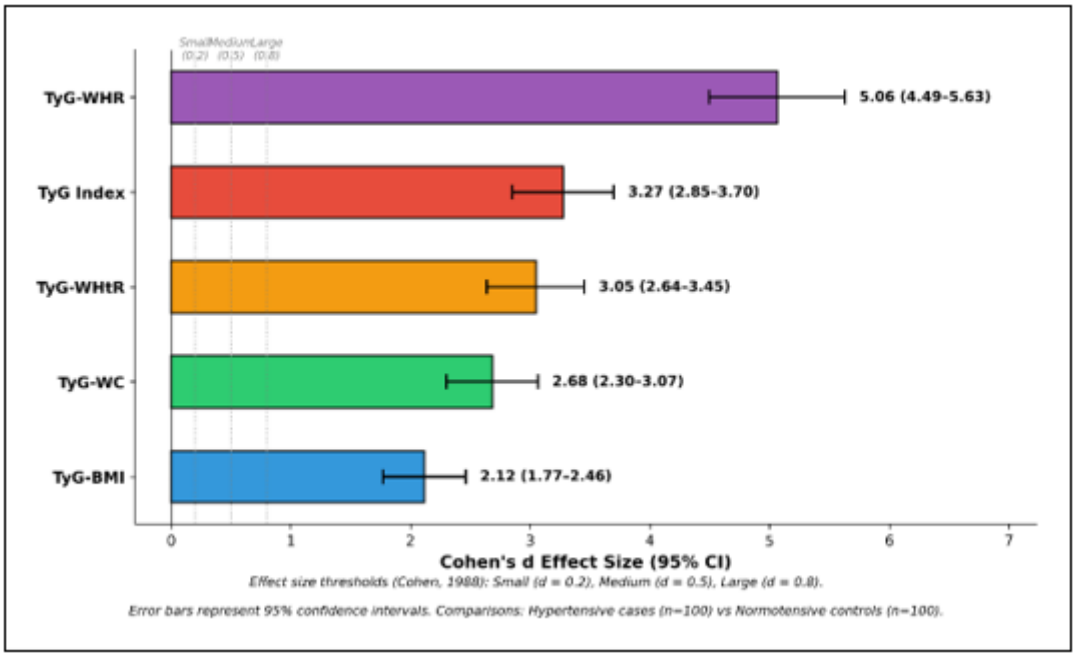
The significantly higher TyG index in hypertensive cases (9.366 ± 0.274) compared with controls (8.504 ± 0.252) aligns with multiple published studies. Zhao et al.,

analyzing 3,069 adults from NHANES 2017–2020, reported mean TyG of 8.99 ± 0.53 in hypertensives versus 8.56 ± 0.52 in normotensives, with TyG-BMI showing significant association with hypertension risk.[6] Yang et al., in a prospective study of 4,866 Chinese adults followed for six years, found baseline TyG of 8.77 ± 0.49 in those who developed hypertension versus 8.54 ± 0.44 in those who remained normotensive.[7] Shan et al., analyzing 8,209 participants from the China Health and Retirement Longitudinal Study, demonstrated median TyG of 8.74 in hypertensives versus 8.52 in normotensives.[8] Our findings extend this evidence to a South Asian population with distinct metabolic characteristics.

A notable finding of our study is the graded increase in TyG index across ESH 2023 hypertension stages,3 with values progressing from 9.169 in Grade 1 to 9.364 in Grade 2 to 9.517 in Grade 3. This stage-wise gradient has been less systematically evaluated in prior literature. Shan et al. reported similar patterns using Chinese guidelines, with adjusted odds ratios for higher TyG quartiles increasing across hypertension phenotypes.[8] Gao et al., in a prospective cohort of 4,600 Chinese adults, demonstrated that hypertension incidence increased from 18.1% in the lowest TyG quartile to 33.5% in the highest quartile over six-year follow-up.[9] The linear trend observed in our study ($p < 0.001$) supports a dose-response relationship between TyG index and hypertension severity.

The significant elevation of all TyG-derived indices in hypertensive cases provides additional clinical value. TyG-WC showed the largest absolute difference between groups (821.34 vs 686.64), consistent with the well-established role of visceral adiposity in hypertension pathogenesis.[14,28] Zhao et al. specifically evaluated TyG-BMI and found it to be an independent predictor of hypertension after multivariable adjustment.6 wet al. examined all four composite indices and reported that TyG-WHtR demonstrated superior predictive capacity for incident hypertension among Chinese adults.[7] The integration of anthropometric measures with TyG index likely captures complementary aspects of metabolic risk—biochemical insulin resistance combined with adipose tissue distribution.[10,23]

Comparative Utility of TyG Index Versus TyG-Derived Indices: A key objective of this study was to compare the relative utility of the basic TyG index against its anthropometric derivatives. All indices demonstrated significant elevation in hypertensive cases and progressive increases across ESH 2023 grades. But notable differences were seen in their discriminatory patterns. TyG-WC exhibited the largest absolute difference between cases and controls (134.70 units), followed by TyG-BMI (36.74 units); whereas the basic TyG index showed a difference of 0.862 units. When expressed as percentage elevation, TyG-WHR demonstrated a 18.9% increase in cases relative to controls, compared with 16.2% for TyG-WHtR, 17.2% for TyG-BMI, 19.6% for TyG-WC, and 10.1% for the basic TyG index. These findings suggest that TyG-derived indices with central adiposity measures e.g., TyG-WC and TyG-WHR provided enhanced sensitivity for detecting metabolic derangement associated with hypertension compared with the basic TyG index alone. This aligns with Yang et al., who reported TyG-WHtR as the strongest predictor of incident hypertension,[7] and Zhao et al., who found TyG-BMI independently associated with hypertension risk.[6] The integration of anthropometric parameters may be able to capture the additive contribution of visceral adiposity to insulin resistance-mediated vascular dysfunction; this coild provide a more comprehensive metabolic risk assessment than biochemical markers alone.



TyG-WHR demonstrated the largest effect size (d = 5.06), followed by TyG Index (d = 3.28), TyG-WHtR (d = 3.05), TyG-WC (d = 2.68), and TyG-BMI (d = 2.12). All indices exceeded the threshold for large effects (d > 0.8).

Figure 5. Forest plot comparing discriminatory performance (Cohen's d effect size with 95% confidence intervals) of TyG index and TyG-derived indices for distinguishing hypertensive cases from normotensive controls

The strong correlations between TyG index and blood pressure in the overall sample (r = 0.783 for SBP, r = 0.741 for DBP) reflect the combined contribution of group differences and within-group associations. The attenuated but still significant correlations within cases alone (r = 0.488 for SBP) are consistent with expectations, as the restricted range of blood pressure values among hypertensives reduces correlation magnitude. Wang et al., in a longitudinal study of 17,977 Chinese adults, reported that each unit increase in TyG index was associated with 1.93 mmHg increase in SBP and 1.41 mmHg increase in DBP, supporting a quantitative relationship between TyG and blood pressure elevation.[16]

The mechanistic basis for the TyG-hypertension association is well-described.[19,20,30] Insulin resistance promotes hypertension through several pathways: endothelial dysfunction with reduced nitric oxide bioavailability, activation of the sympathetic nervous system, enhanced sodium reabsorption in renal tubules, and stimulation of vascular smooth muscle proliferation.[19,21] Elevated triglycerides contribute to atherogenesis and arterial stiffness,[17] while hyperglycemia promotes oxidative stress and advanced glycation end-products that impair vascular function.[20,22] The TyG index, by integrating fasting triglycerides and glucose, provides a composite marker capturing multiple dimensions of this metabolic-vascular axis.[4,5,30]

Clinical Implications

Our findings carry several clinical implications. The TyG index and its derivatives are calculated from routine laboratory parameters and basic anthropometric measurements, making them accessible in resource-limited settings where insulin assays are unavailable.[4,5] The observed stage-wise gradient suggests potential utility for risk stratification beyond blood pressure measurement alone.[3] Patients with higher TyG values within a given hypertension grade may warrant more aggressive lifestyle intervention or closer monitoring for metabolic complications.[9,30] Additionally, TyG index may identify normotensive individuals at elevated risk for future hypertension, enabling preventive strategies.[7,16]

Strengths

Strengths of this study include the focus on treatment-naive, newly detected hypertensive patients, eliminating confounding from antihypertensive medications that may affect metabolic parameters. The use of ESH 2023 criteria ensures contemporary relevance.[3] The comprehensive evaluation of multiple TyG-derived indices allows comparison of their relative utility.[6,7] The inclusion of an Indian population addresses a gap in literature predominantly derived from Chinese and Western cohorts.[6-9]

Limitations

Several limitations warrant acknowledgment. The cross-sectional design precludes causal inference; longitudinal studies are needed to establish whether TyG indices predict hypertension progression.[30] The single-centre design could have played a part in limited generalizability. Sample size, while adequate for primary comparisons, limited statistical power for subgroup analyses, particularly for Grade 3 hypertension (n = 5). The exclusion of diabetic patients, while appropriate for isolating hypertension-specific associations, limits applicability to the substantial population with comorbid diabetes and hypertension.[11,13] Finally - we did not perform receiver operating characteristic analysis or calculate optimal cut-off values; this would enhance clinical applicability.[23,29]

Future Directions

Future research should include prospective cohort studies to evaluate the predictive utility of TyG indices for hypertension progression and cardiovascular outcomes.[12,13] Intervention studies examining whether TyG index responds to lifestyle modifications or pharmacotherapy would clarify its utility as a treatment target.[30] Multicentre studies across diverse Indian populations would establish generalizable reference ranges and optimal cut-off values.[26]

CONCLUSION

The present study demonstrates that TyG index and TyG-derived indices (TyG-BMI, TyG- WC, TyG-WHR, TyG-WHtR) are significantly elevated in newly diagnosed, treatment-naive hypertensive patients compared with normotensive controls, and show a graded increase across ESH 2023 hypertension stages. TyG index correlates strongly with both systolic and diastolic blood pressure. These accessible, cost-effective markers integrating metabolic and anthropometric parameters may serve as useful adjuncts for cardiovascular risk stratification in hypertensive individuals, particularly in settings where comprehensive metabolic assessment is limited. Longitudinal studies are warranted to establish the predictive utility of TyG indices for hypertension progression and cardiovascular outcomes.

Out of the indices that we evaluated, the TyG-derived parameters incorporating central adiposity measures i.e., TyG-WC and TyG-WHR demonstrated greater percentage elevation in hypertensive cases compared with the basic TyG index. This suggests enhanced utility for detecting metabolic dysfunction associated with hypertension severity. Future studies incorporating receiver operating characteristic analysis are needed to formally compare the diagnostic performance of these indices.

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