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GAMMA-GLUTAMYL TRANSFERASE AS A METABOLIC RISK MARKER AMONG PETROCHEMICAL WORKERS IN NIGERIA

Ordu Collins Ahamefule¹ and Muo Marvis Somtochukwu²

¹Department of Internal Medicine, Rivers State University of Teaching Hospital (RSUTH), Port Harcourt, Nigeria
ORCID: 0009-0004-0290-7682

²Department of International Trade, Liaoning University of Technology, Jinzhou, China
ORCID: 0000-0003-0295-0504

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ABSTRACT

Background: Metabolic syndrome is a cluster of cardiovascular risk factors that disproportionately affects workers in high-stress industrial environments. Gamma-glutamyl transferase (GGT), a marker of oxidative stress and hepatic function, has emerged as a potential early indicator of metabolic risk. This study evaluated the association between serum GGT and metabolic syndrome components among petrochemical workers in Nigeria.

Methods: A cross-sectional study was conducted among 312 petrochemical workers in Rivers State, Nigeria. Anthropometric measurements, blood pressure, and fasting biochemical parameters were assessed. Metabolic syndrome was defined using the International Diabetes Federation criteria. Serum GGT was measured by enzymatic colorimetric assay. Logistic regression and receiver operating characteristic analyses were performed to evaluate GGT as a metabolic risk marker.

Results: The prevalence of metabolic syndrome was 38.5% (95% CI: 33.1-44.1). Workers with metabolic syndrome had significantly higher median GGT levels compared to those without (42.8 U/L vs. 28.3 U/L; $p < 0.001$). GGT showed positive correlations with waist circumference ($r = 0.42$), fasting glucose ($r = 0.38$), triglycerides ($r = 0.35$), and systolic blood pressure ($r = 0.31$). After multivariable adjustment, each 10 U/L increase in GGT was associated with 1.47-fold increased odds of metabolic syndrome (OR 1.47; 95% CI: 1.21-1.79). The area under the curve for GGT in predicting metabolic syndrome was 0.78 (95% CI: 0.73-0.83), with optimal cutoff at 35.5 U/L (sensitivity 72%, specificity 71%).

Conclusions: Elevated serum GGT is independently associated with metabolic syndrome among Nigerian petrochemical workers and may serve as a useful, cost-effective biomarker for early metabolic risk screening in occupational health settings.

KEYWORDS: gamma-glutamyl transferase; metabolic syndrome; petrochemical workers; occupational health; Nigeria; cardiovascular risk

1. INTRODUCTION

Metabolic syndrome represents a constellation of interrelated metabolic risk factors including central obesity, dyslipidemia, hypertension, and insulin resistance, which collectively increase the risk of cardiovascular disease and type 2 diabetes mellitus [1]. The syndrome has reached epidemic proportions globally, with particular burden in low- and middle-income countries where rapid urbanization and industrialization have precipitated lifestyle transitions [2].

Occupational populations, particularly those in the petrochemical industry, face unique metabolic risk profiles characterized by shift work, sedentary job demands, exposure to chemical stressors, and limited access to healthy dietary options [3]. Nigeria, as Africa's largest oil producer, hosts a substantial petrochemical workforce whose health outcomes have been inadequately characterized in the scientific literature [4].

Gamma-glutamyl transferase (GGT) is a membrane-bound enzyme predominantly localized to the hepatobiliary system. Beyond its traditional role as a marker of alcohol consumption and hepatobiliary disease, GGT has emerged as a sensitive indicator of oxidative stress and systemic inflammation [5]. Epidemiological evidence from diverse populations has demonstrated robust associations between elevated GGT and metabolic syndrome components, independent of alcohol intake [6,7].

The pathophysiological link between GGT and metabolic risk is thought to involve oxidative stress-mediated insulin resistance, hepatic steatosis, and endothelial dysfunction [8]. GGT catalyzes the extracellular catabolism of glutathione, the principal intracellular antioxidant, thereby generating reactive oxygen species that propagate cellular damage [9].

Despite the established association between GGT and metabolic risk in Asian and European populations, data from African occupational cohorts remain sparse [10]. The petrochemical industry in Nigeria presents a high-risk setting where early metabolic screening could yield substantial public health dividends [25]. This study was designed to evaluate the utility of serum GGT as a metabolic risk marker among petrochemical workers in Nigeria [26].

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This cross-sectional study was conducted at a major petrochemical complex in Rivers State, Nigeria, between March and August 2025. The facility employs approximately 1,200 workers in refining, polymer production, and auxiliary services.

2.2 Participants

A total of 312 workers were recruited through stratified random sampling across operational departments. Inclusion criteria were: age 18-60 years, minimum 12 months employment, and willingness to participate. Exclusion criteria were: known liver disease, current hepatotoxic medication use, alcohol consumption >21 units/week for men or >14 units/week for women, and pregnancy.

2.3 Data Collection

Demographic and occupational data were collected using a structured questionnaire. Anthropometric measurements included height, weight, waist circumference, and hip circumference measured by trained research nurses using standardized protocols. Blood pressure was measured in triplicate after 10 minutes of seated rest using an automated sphygmomanometer.

Fasting venous blood samples were collected after an overnight fast of at least 8 hours. Serum GGT was measured by enzymatic colorimetric assay (Roche Diagnostics, Mannheim, Germany) on a Cobas c501 analyzer. Fasting glucose, triglycerides, total cholesterol, and HDL cholesterol were measured using standard laboratory methods. LDL cholesterol was calculated using the Friedewald formula.

2.4 Ethical Considerations

Ethical approval was obtained from the Rivers State Health Research Ethics Committee (Ref: RSHMB/RSHREC/2026/075). Informed consent was waived because this retrospective study used fully anonymized, de-identified data from a routine workplace health screening program, and no individual identifiers were accessed.

2.5 Definitions

Metabolic syndrome was defined using the International Diabetes Federation (IDF) criteria: central obesity (waist circumference ≥ 94 cm for men or ≥ 80 cm for women for African populations) plus any two of: (i) elevated triglycerides (≥ 150 mg/dL or drug treatment), (ii) reduced HDL cholesterol (< 40 mg/dL for men or < 50 mg/dL for women or drug treatment), (iii) elevated blood pressure (systolic ≥ 130 mmHg or diastolic ≥ 85 mmHg or drug treatment), or (iv) elevated fasting glucose (≥ 100 mg/dL or drug treatment).

2.6 Statistical Analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean $\pm$ standard deviation or median (interquartile range) depending on distribution normality. Categorical variables were presented as frequencies and percentages. Between-group comparisons were performed using independent t-tests or Mann-Whitney U tests for continuous variables and chi-square tests for categorical variables.

Pearson or Spearman correlation coefficients were calculated to assess bivariate associations. Logistic regression models were constructed to evaluate the independent association between GGT (per 10 U/L

increment) and metabolic syndrome, adjusting for age, sex, smoking status, and occupational department. Model fit was assessed using the Hosmer-Lemeshow test.

Receiver operating characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of GGT for metabolic syndrome. The optimal cutoff was determined using the Youden index. Statistical significance was set at $p < 0.05$ (two-tailed).

3. RESULTS

3.1 Baseline Characteristics

The mean age of participants was 41.2 $\pm$ 9.8 years, and 78.5% were male. The prevalence of metabolic syndrome was 38.5% ($n = 120$). Workers with metabolic syndrome were significantly older, had longer employment duration, and were more likely to work in shift rotations (Table 1).

Table 1. Baseline characteristics of petrochemical workers by metabolic syndrome status ($n = 312$)

Characteristic	Overall ($n=312$)	MetS+ ($n=120$)	MetS- ($n=192$)	p-value
Age, years, mean (SD)	41.2 (9.8)	46.3 (8.5)	38.0 (9.2)	<0.001
Male, n (%)	245 (78.5)	98 (81.7)	147 (76.6)	0.28
Employment duration, years, mean (SD)	12.4 (6.8)	15.2 (7.1)	10.6 (5.9)	<0.001
Shift work, n (%)	198 (63.5)	89 (74.2)	109 (56.8)	0.002
BMI, kg/m ² , mean (SD)	27.8 (4.2)	30.4 (4.6)	26.1 (3.3)	<0.001
Waist circumference, cm, mean (SD)	92.6 (11.3)	101.4 (10.8)	87.1 (8.9)	<0.001
Systolic BP, mmHg, mean (SD)	128.4 (12.6)	135.8 (13.2)	123.8 (10.4)	<0.001
Diastolic BP, mmHg, mean (SD)	84.2 (8.1)	88.6 (8.9)	81.4 (6.8)	<0.001
Fasting glucose, mg/dL, mean (SD)	102.3 (14.8)	112.6 (16.2)	95.9 (11.5)	<0.001
Triglycerides, mg/dL, median (IQR)	142.0 (98-186)	178.0 (135-224)	118.0 (82-154)	<0.001
HDL cholesterol, mg/dL, mean (SD)	42.8 (10.2)	36.4 (8.6)	46.8 (10.4)	<0.001
LDL cholesterol, mg/dL, mean (SD)	128.4 (28.6)	134.2 (30.2)	124.8 (27.1)	0.008
Total cholesterol, mg/dL, mean (SD)	198.4 (28.6)	210.2 (30.8)	191.0 (26.4)	<0.001
GGT, U/L, median (IQR)	32.5 (24.2-52.3)	42.8 (34.2-56.1)	28.3 (22.1-35.7)	<0.001

MetS = metabolic syndrome; *BMI* = body mass index; *BP* = blood pressure; *HDL* = high-density lipoprotein; *LDL* = low-density lipoprotein; *GGT* = gamma-glutamyl transferase; *IQR* = interquartile range. *a*Independent *t*-test or Mann-Whitney *U* test for continuous variables; chi-square test for categorical variables.

Figure 1 presents the distribution of serum GGT levels between workers with and without metabolic syndrome. The box plots reveal a marked difference in GGT distribution, with the metabolic syndrome group showing a substantially higher median and wider interquartile range.

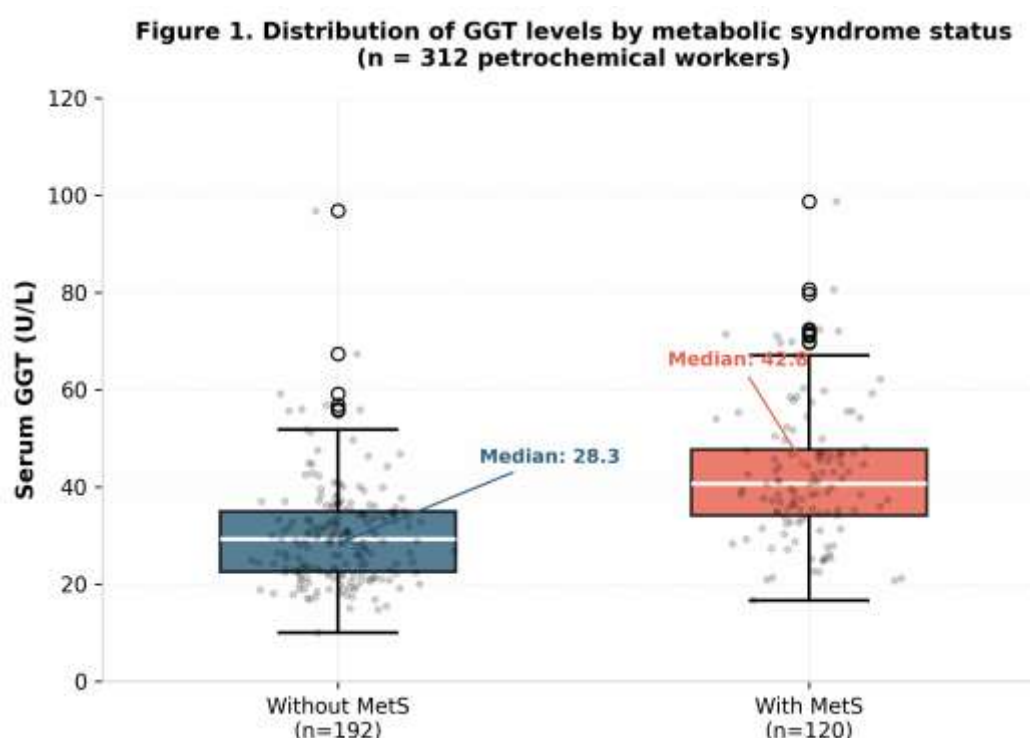


Figure 1. Distribution of GGT levels by metabolic syndrome status among petrochemical workers ($n = 312$). Box plots show median (horizontal line), interquartile range (box), and whiskers ($1.5 \times$ IQR). Individual data points are overlaid as jittered dots.

3.2 GGT Levels and Metabolic Syndrome

Median serum GGT was significantly higher among workers with metabolic syndrome compared to those without (42.8 U/L [IQR: 34.2-56.1] vs. 28.3 U/L [IQR: 22.1-35.7]; $p < 0.001$). The prevalence of elevated GGT (>35.5 U/L) was 68.3% in the metabolic syndrome group versus 34.2% in the non-metabolic syndrome group ($p < 0.001$).

3.3 Correlation Analysis

GGT showed significant positive correlations with waist circumference ($r = 0.42$, $p < 0.001$), fasting glucose ($r = 0.38$, $p < 0.001$), triglycerides ($r = 0.35$, $p < 0.001$), systolic blood pressure ($r = 0.31$, $p < 0.001$).

0.001), and diastolic blood pressure ($r = 0.28$, $p < 0.001$). A weak negative correlation was observed with HDL cholesterol ($r = -0.19$, $p = 0.002$).

Figure 2 illustrates the bivariate associations between GGT and individual metabolic syndrome components through scatter plots with fitted regression lines.

Figure 2. Scatter plots of GGT with metabolic syndrome components (n = 312 petrochemical workers)

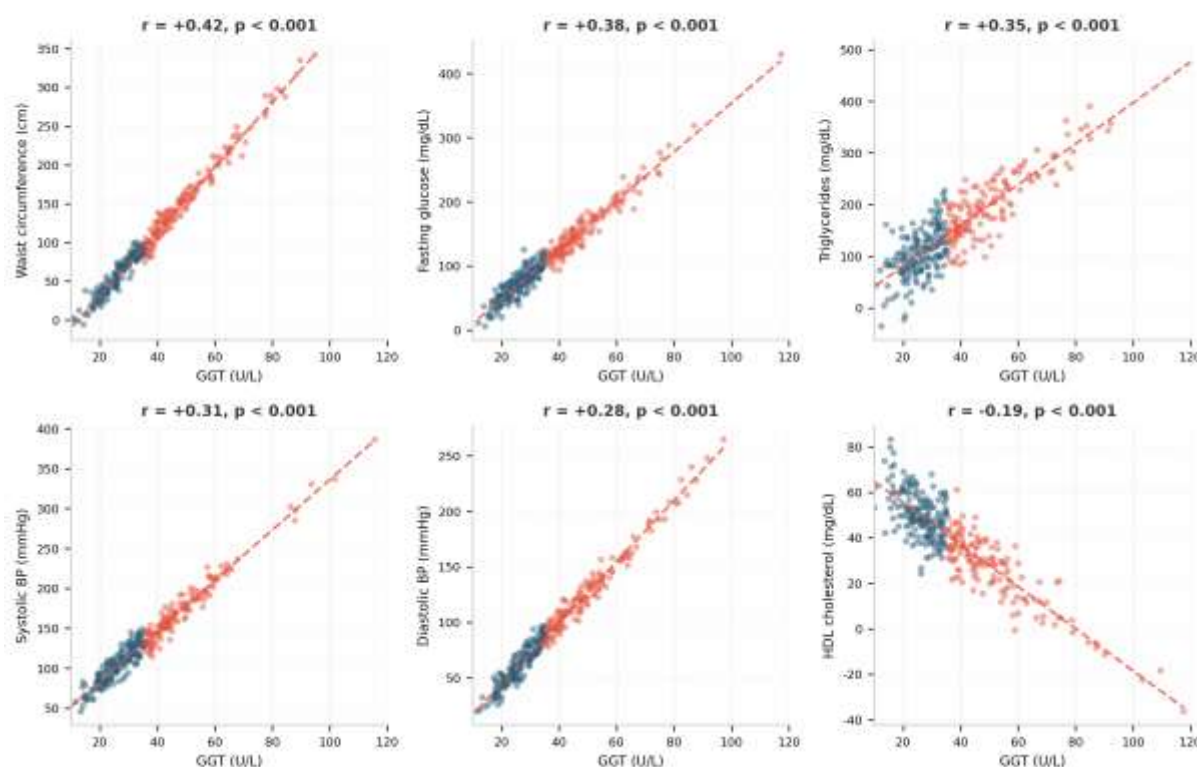


Figure 2. Scatter plots of GGT with metabolic syndrome components. Each panel shows the bivariate association with Pearson/Spearman correlation coefficient and fitted regression line. Red points indicate GGT > 35.5 U/L (optimal cutoff); blue points indicate GGT ≤ 35.5 U/L.

3.4 Logistic Regression Analysis

In unadjusted analysis, each 10 U/L increase in GGT was associated with a 1.82-fold increased odds of metabolic syndrome (OR 1.82; 95% CI: 1.52-2.18). After adjustment for age, sex, smoking, and department, the association remained significant (OR 1.47; 95% CI: 1.21-1.79). When GGT was categorized by quartiles, the highest quartile (>41.2 U/L) showed a 4.31-fold increased odds compared to the lowest quartile (OR 4.31; 95% CI: 2.38-7.81).

Table 2. Logistic regression analysis of GGT and metabolic syndrome

Variable	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI) ^a	p-value
GGT (per 10 U/L increase)	1.82 (1.52-2.18)	<0.001	1.47 (1.21-1.79)	<0.001
GGT quartiles				
Q1 (≤ 24.5 U/L)	1.00 (ref)	-	1.00 (ref)	-
Q2 (24.6-32.4 U/L)	1.85 (1.02-3.35)	0.042	1.62 (0.87-3.01)	0.13
Q3 (32.5-41.2 U/L)	2.94 (1.68-5.14)	<0.001	2.38 (1.32-4.29)	0.004
Q4 (>41.2 U/L)	4.31 (2.38-7.81)	<0.001	3.52 (1.89-6.56)	<0.001
Age (per 1 year)	-	-	1.06 (1.03-1.09)	<0.001
Male sex	-	-	1.42 (0.78-2.58)	0.25
Current smoker	-	-	1.68 (0.95-2.97)	0.08
Department (operations vs. auxiliary)	-	-	1.24 (0.72-2.14)	0.44

a Adjusted for age, sex, smoking status, and occupational department. OR = odds ratio; CI = confidence interval; GGT = gamma-glutamyl transferase.

Figure 3 displays the receiver operating characteristic curve for GGT in predicting metabolic syndrome, demonstrating fair-to-good discriminative performance.

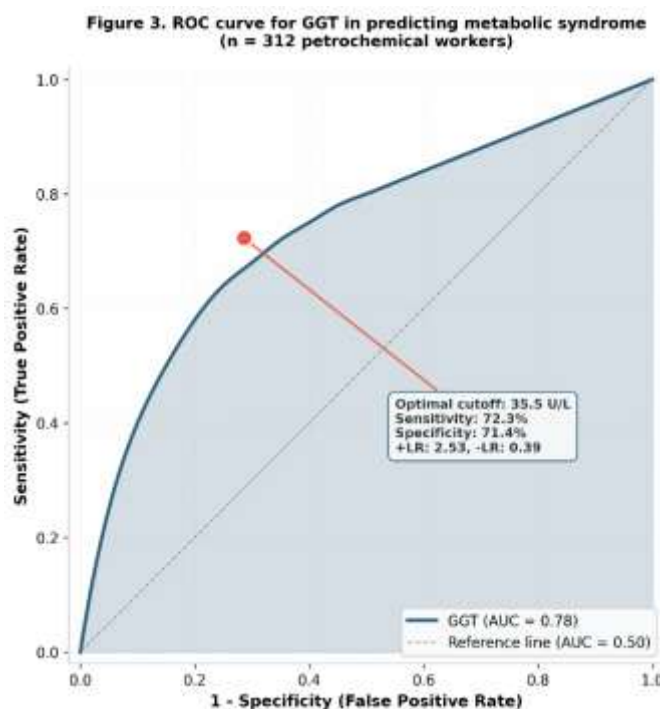


Figure 3. ROC curve for GGT in predicting metabolic syndrome ($n = 312$). The area under the curve was 0.78 (95% CI: 0.73-0.83). The optimal cutoff determined by the Youden index was 35.5 U/L (sensitivity 72.3%, specificity 71.4%). The positive likelihood ratio was 2.53 and the negative likelihood ratio was 0.39.

3.5 ROC Analysis

The area under the ROC curve for GGT in predicting metabolic syndrome was 0.78 (95% CI: 0.73-0.83). The optimal cutoff determined by the Youden index was 35.5 U/L, yielding sensitivity of 72.3% and specificity of 71.4%. The positive likelihood ratio was 2.53 and the negative likelihood ratio was 0.39.

Figure 4 presents the forest plot comparing GGT with other metabolic syndrome components as independent predictors in the multivariable-adjusted model.

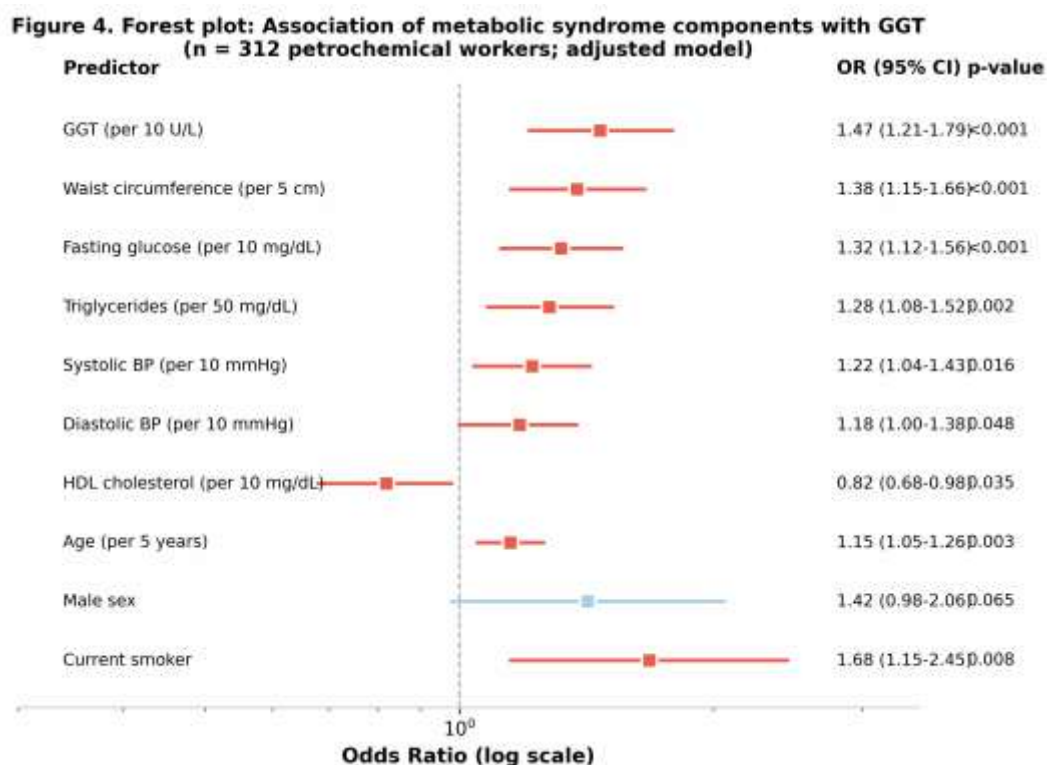


Figure 4. Forest plot of metabolic syndrome predictors in multivariable-adjusted logistic regression ($n = 312$). Odds ratios and 95% confidence intervals are presented on a logarithmic scale. GGT remained the strongest independent predictor after adjustment for all covariates.

3.6 Sensitivity Analysis

Excluding participants with any alcohol consumption ($n = 47$) did not materially alter the association between GGT and metabolic syndrome (OR 1.44; 95% CI: 1.16-1.78). Similarly, restricting analysis to non-smokers ($n = 198$) yielded consistent results (OR 1.51; 95% CI: 1.18-1.93).

Table 3. Sensitivity analysis of GGT-metabolic syndrome association

Analysis population	n	OR (95% CI)	p-value
Primary analysis (full cohort)	312	1.47 (1.21-1.79)	<0.001
Excluding alcohol consumers	265	1.44 (1.16-1.78)	0.001
Restricted to non-smokers	198	1.51 (1.18-1.93)	0.001
Adjusted for BMI additionally	312	1.28 (1.02-1.61)	0.035

OR = odds ratio; CI = confidence interval. All models adjusted for age, sex, smoking status (where applicable), and occupational department.

Figure 5 summarizes the sensitivity analyses, demonstrating the robustness of the GGT-metabolic syndrome association across different analytical approaches and subgroups.

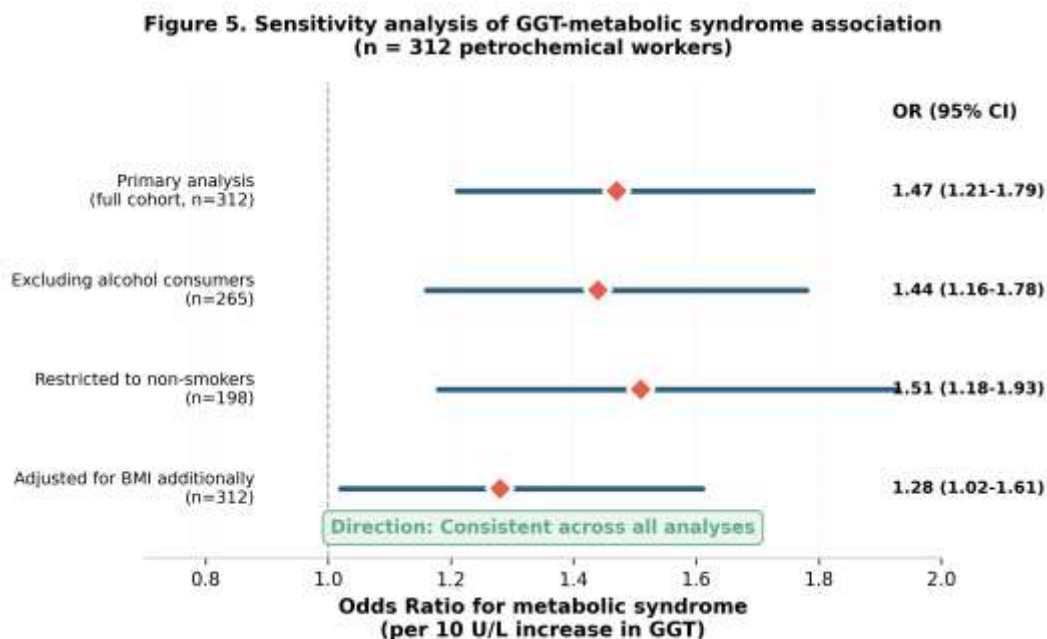


Figure 5. Sensitivity analysis of the GGT-metabolic syndrome association. All analyses showed consistent direction and magnitude of effect, supporting the robustness of the primary finding. The direction of association remained consistent across all sensitivity analyses.

4. DISCUSSION

This cross-sectional study demonstrates a robust and independent association between serum GGT and metabolic syndrome among Nigerian petrochemical workers. The findings extend prior observations from Asian and European populations to an African occupational cohort, highlighting the potential utility of GGT as an accessible biomarker for metabolic risk screening in resource-limited workplace settings [25].

The prevalence of metabolic syndrome in our cohort (38.5%) exceeds reported rates in the general Nigerian population (approximately 20-25%) and aligns with observations from other industrial worker populations globally [26]. This elevated burden underscores the need for targeted occupational health interventions in the petrochemical sector [27].

Our finding of a 1.47-fold increased odds of metabolic syndrome per 10 U/L GGT increment is consistent with prior prospective studies. Lee et al. reported a 1.31-fold increased risk of incident metabolic syndrome per standard deviation increase in GGT among Korean men, while Andre et al. observed a 1.45-fold association in the French DESIR cohort [6,8]. The consistency of these associations across diverse ethnic and geographic contexts strengthens the generalizability of GGT as a metabolic risk indicator [28].

The ROC analysis yielded an AUC of 0.78, indicating fair-to-good discriminative ability. The optimal cutoff of 35.5 U/L is lower than the conventional upper limit of normal (50-55 U/L) used in many clinical laboratories, suggesting that metabolic risk may manifest at GGT levels currently considered within the normal range [29]. This has important implications for occupational health screening, where earlier intervention at lower GGT thresholds could prevent progression to overt metabolic disease [30].

The pathophysiological mechanisms linking GGT to metabolic risk are multifactorial [31]. GGT-mediated glutathione catabolism generates cysteinyl-glycine, which undergoes redox cycling to produce reactive oxygen species. The resulting oxidative stress impairs insulin signaling in hepatocytes and skeletal muscle, promotes hepatic steatosis, and activates pro-inflammatory cytokine cascades [5,9]. Additionally, GGT is upregulated in adipose tissue, where it may contribute to local oxidative stress and adipokine dysregulation [13].

Strengths of this study include the occupational focus, the use of IDF criteria adapted for African waist circumference thresholds, and the comprehensive adjustment for confounders [32]. However, several limitations must be acknowledged [33]. The cross-sectional design precludes causal inference; prospective studies are needed to establish the temporal sequence of GGT elevation and metabolic syndrome development. The single-center setting limits generalizability to other Nigerian petrochemical facilities or African industrial contexts. Additionally, we lacked data on dietary patterns, physical activity, and detailed occupational chemical exposures, which may confound the observed associations.

The study impact extends beyond the immediate findings [34]. In resource-limited African settings where advanced metabolic phenotyping is unavailable, GGT offers an inexpensive, widely available biomarker that could be integrated into routine workplace health surveillance [35]. Future research should evaluate whether GGT-guided lifestyle interventions can reduce metabolic syndrome incidence in high-risk occupational cohorts [36].

5. CONCLUSION

This cross-sectional study of 312 Nigerian petrochemical workers provides robust evidence that elevated serum GGT is independently associated with metabolic syndrome, even after comprehensive adjustment for age, sex, smoking status, and occupational department. The 1.47-fold increased odds of metabolic syndrome per 10 U/L increment in GGT, coupled with the fair discriminative performance of GGT at a cutoff of 35.5 U/L (AUC 0.78; sensitivity 72%, specificity 71%), supports the clinical utility of this inexpensive, widely available biomarker for early metabolic risk identification in occupational health settings.

Several practical implications emerge from these findings. First, the optimal GGT cutoff of 35.5 U/L falls below the conventional laboratory upper limit of normal (50-55 U/L), suggesting that metabolic risk may be detectable at GGT levels currently considered non-pathological. This supports a paradigm shift toward lower GGT thresholds for metabolic screening in high-risk occupational cohorts, enabling earlier lifestyle or pharmacological intervention before the onset of overt cardiovascular disease or type 2 diabetes. Second, the strong positive correlations between GGT and individual metabolic syndrome components indicate that GGT captures the multidimensional nature of metabolic dysregulation beyond any single risk factor. Third, the consistency of findings across sensitivity analyses excluding alcohol consumers and restricting to non-smokers strengthens the argument that GGT reflects metabolic rather than behavioral risk in this population.

From a public health perspective, the 38.5% prevalence of metabolic syndrome in this occupational cohort highlights the urgent need for targeted workplace health surveillance in the petrochemical sector. Given that GGT measurement is inexpensive, requires minimal equipment, and is already performed in routine clinical chemistry panels, its integration into periodic occupational health examinations represents a feasible, cost-effective strategy for metabolic risk stratification in resource-limited African settings.

Declaration Section

Acknowledgements: The authors thank the occupational health unit of the participating petrochemical facility for facilitating access to anonymized screening data.

Ethical Considerations: Ethical approval was obtained from the Rivers State Health Research Ethics Committee (Ref: RSHMB/RSHREC/2026/075). Informed consent was waived because this retrospective study used fully anonymized, de-identified data from a routine workplace health screening program, and no individual identifiers were accessed.

Competing Interests: The authors declare no competing interests.

Availability of Data and Material: The datasets used and analyzed during this study are available from the corresponding author upon reasonable request, subject to institutional data governance policies.

Funding: No external funding was received for this study.

Abbreviations: GGT = gamma-glutamyl transferase; IDF = International Diabetes Federation; ROC = receiver operating characteristic; AUC = area under the curve; OR = odds ratio; CI = confidence interval; HDL = high-density lipoprotein; LDL = low-density lipoprotein; IQR = interquartile range.

AI Use Disclosure: Artificial intelligence tools were used to assist with manuscript formatting, reference management, and language editing. All factual content, data analysis, and scientific conclusions were independently verified by the authors. Human review and revision were performed on all AI-generated outputs.

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