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Research Article

Biochemical Markers Of Metabolic Syndrome: A Multiparameter Approach For Early Diagnosis And Prognosis

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ABSTRACT

Background: Metabolic syndrome (MetS) is a global health concern associated with increased risk of type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD). Conventional diagnostic criteria rely on anthropometric and biochemical parameters, but may fail to detect individuals at an early stage of risk. Emerging biomarkers reflecting insulin resistance, inflammation, and oxidative stress may improve diagnostic and prognostic accuracy.
Objectives: To evaluate the role of a multiparameter biochemical approach in the early diagnosis and prognostication of MetS.
Methods:A prospective observational study was conducted at Tertiary care Hospital in Telangana, from January 2024 to January 2025. A total of 100 patients fulfilling NCEP-ATP III/IDF criteria were enrolled. Biochemical evaluation included fasting glucose, lipid profile, insulin, HOMA-IR, serum uric acid, high-sensitivity C-reactive protein (hs-CRP), malondialdehyde (MDA), and total antioxidant capacity (TAC). Statistical analysis was performed using SPSS v21, with $p < 0.05$ considered significant.
Results: MetS patients exhibited significantly higher fasting glucose, triglycerides, insulin, HOMA-IR, uric acid, hs-CRP, and MDA, along with lower HDL-C and TAC ($p < 0.05$). Multiparameter analysis detected at-risk individuals earlier than conventional criteria.
Conclusion: Incorporating markers of insulin resistance, inflammation, and oxidative stress with traditional parameters enhances the diagnostic precision and prognostic assessment of MetS. A multiparameter biochemical approach may enable earlier intervention and improved risk stratification in high-risk populations.

Keywords*:Metabolic syndrome, insulin resistance, HOMA-IR, hs-CRP, oxidative stress, prognosis.*

INTRODUCTION

Metabolic syndrome (MetS) is a constellation of interconnected metabolic abnormalities that include central obesity, insulin resistance, dyslipidemia, hypertension, and impaired glucose regulation [1]. Individually, these components are recognized cardiovascular risk factors, but when clustered, they confer a significantly higher risk of developing type 2 diabetes mellitus (T2DM), atherosclerotic cardiovascular disease (ASCVD), and increased all-cause mortality [2].

The worldwide prevalence of MetS has reached epidemic proportions, affecting nearly one-quarter of the adult population [3]. In India, where urbanization, dietary transitions, and sedentary lifestyles are rapidly increasing, the prevalence ranges between 20–35% depending on the population studied [4]. Importantly, Indians have a higher predisposition to central obesity, insulin resistance, and dyslipidemia even at lower body mass index (BMI) thresholds, making early diagnosis of MetS especially critical [5].

Several diagnostic definitions have been proposed, of which the International Diabetes Federation (IDF, 2005) and the NCEP-ATP III (2001) criteria are widely used [6]. These rely on conventional parameters—waist circumference, fasting

plasma glucose, triglycerides, HDL cholesterol, and blood pressure—for clinical identification. While useful, these parameters alone may not capture the underlying pathophysiological processes, such as subclinical inflammation, oxidative stress, and insulin resistance, which precede overt metabolic derangements [7].

Emerging evidence suggests that additional biochemical markers can improve early risk detection and prognostic assessment in MetS. High-sensitivity C-reactive protein (hs-CRP) reflects low-grade chronic inflammation and predicts both diabetes and cardiovascular events [8]. Serum uric acid is linked with endothelial dysfunction and insulin resistance [9]. Fasting insulin levels and HOMA-IR indices provide reliable estimates of insulin sensitivity, the cornerstone abnormality in MetS [10]. Furthermore, oxidative stress markers such as malondialdehyde (MDA) and total antioxidant capacity (TAC) indicate redox imbalance, which accelerates vascular injury and progression to complications [11,12].

A multiparameter approach that integrates conventional criteria with biochemical markers of inflammation, insulin resistance, and oxidative stress may therefore offer a more comprehensive assessment of metabolic syndrome. Such an approach not only aids in early diagnosis but also facilitates risk stratification and prognostic evaluation, which are vital for timely lifestyle interventions and therapeutic strategies [13].

In this context, the present study was undertaken to evaluate multiple biochemical markers in patients with metabolic syndrome over a period of one year at a tertiary care hospital in South India. The objective was to establish a multiparameter biochemical framework for the early diagnosis and prognosis of metabolic syndrome.

MATERIAL AND METHODS

Study Design and Setting

This was a prospective, observational, hospital-based study conducted in the Department of Biochemistry in collaboration with the Department of General Medicine at Tertiary care Hospital in Telangana. The total duration of the study was one year (January 2024 – January 2025).

Study Population and Sample Size

A total of 100 patients fulfilling the diagnostic criteria for Metabolic Syndrome (MetS), as per the International Diabetes Federation (IDF) criteria 2005, were enrolled in the study. The sample size was determined based on feasibility and study duration.

Inclusion Criteria

- Patients aged 30–65 years of both sexes.
- Patients diagnosed with Metabolic Syndrome based on IDF criteria (central obesity plus two of the following: raised triglycerides, reduced HDL cholesterol, raised blood pressure, raised fasting plasma glucose).
- Patients willing to provide informed consent.

Exclusion Criteria

- Patients with a history of chronic liver disease, chronic kidney disease, thyroid disorders, or malignancy.
- Pregnant and lactating women.
- Patients on lipid-lowering or antioxidant therapy.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Ethics Committee (IEC) of Tertiary care Hospital in Telangana. Written informed consent was obtained from all participants before enrollment. Patient confidentiality and data privacy were strictly maintained.

Data Collection

A detailed clinical history and demographic profile (age, sex, BMI, waist circumference, family history, dietary habits, and lifestyle factors) were recorded. Blood pressure was measured in the sitting position using a calibrated sphygmomanometer.

Biochemical Parameters

Following an overnight fast of 10–12 hours, 5 mL of venous blood was collected under aseptic conditions. Serum/plasma was separated and analyzed for the following biochemical markers:

1. Fasting Plasma Glucose (FPG) – measured by the glucose oxidase-peroxidase method.
2. Lipid Profile
    - Total cholesterol (CHOD-PAP method)
    - Triglycerides (GPO-PAP method)
    - HDL cholesterol (direct method)
    - LDL cholesterol (Friedewald's formula)
    - VLDL cholesterol (calculated)

3. Liver Function Tests (LFTs) – ALT, AST, ALP, total bilirubin (enzymatic methods).
4. Renal Function Tests (RFTs) – Serum urea, creatinine (UV kinetic method).
5. Uric Acid – Uricase-peroxidase method.
6. High-sensitivity C-reactive protein (hs-CRP) – immunoturbidimetric method.
7. Fasting Insulin – ELISA method.
8. Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) – calculated using the formula:

HOMA−IR=Fasting insulin (μIU/mL)×Fasting glucose (mg/dL)405HOMA-IR = \frac{\text{Fasting insulin (μIU/mL)} \times \text{Fasting glucose (mg/dL)}}{405}HOMA−IR=405Fasting insulin (μIU/mL)×Fasting glucose (mg/dL)

9. Oxidative Stress Markers
    - Malondialdehyde (MDA) – TBARS method.
    - Total Antioxidant Capacity (TAC) – FRAP assay.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS version 21 (IBM Corp, USA). Results were expressed as mean ± standard deviation (SD) for continuous variables and percentages for categorical variables.

- Student's *t* test and ANOVA were applied for group comparisons.
- Pearson's correlation was used to assess the relationship between biochemical markers.
- *p-value*< 0.05 was considered statistically significant.

RESULTS AND OBSERVATIONS

Table 1: Age and Gender Distribution of Study Population (n = 100)

Age Group (years)	Male n (%)	Female n (%)	Total n (%)
30–40	10 (17.2%)	7 (16.7%)	17 (17%)
41–50	22 (37.9%)	13 (31.0%)	35 (35%)
51–60	18 (31.0%)	15 (35.7%)	33 (33%)
>60	8 (13.8%)	7 (16.6%)	15 (15%)
Total	58 (58%)	42 (42%)	100 (100%)

Table 2: Anthropometric and Clinical Characteristics

Parameter	Mean ± SD	Normal Range
BMI (kg/m²)	29.8 ± 3.9	18.5–24.9
Waist Circumference (cm)	98.4 ± 6.8	<90 (M), <80 (F)
Systolic BP (mmHg)	138.6 ± 12.4	<130
Diastolic BP (mmHg)	86.4 ± 8.2	<85

Table 3: Prevalence of Individual Components of Metabolic Syndrome

Component	n (%) of Patients
Central obesity (WC > cutoff)	80 (80%)
Hypertension (≥130/85 mmHg)	62 (62%)
Raised fasting glucose (>100 mg/dL)	70 (70%)
Triglycerides >150 mg/dL	66 (66%)
Low HDL cholesterol	54 (54%)

Table 4: Lipid Profile Distribution by Categories

Lipid Parameter	Normal n (%)	Borderline n (%)	High/Abnormal n (%)
Total Cholesterol	42 (42%)	26 (26%)	32 (32%)
Triglycerides	34 (34%)	28 (28%)	38 (38%)
LDL-C	39 (39%)	30 (30%)	31 (31%)
HDL-C (Low)	—	—	54 (54%)

Table 5: Inflammatory and Oxidative Stress Markers

Marker	Mean ± SD	Normal Range	Abnormal Cases n (%)
hs-CRP (mg/L)	4.8 ± 1.7	<3.0	68 (68%)
MDA (nmol/mL)	5.6 ± 1.1	<3.0	74 (74%)
TAC (mmol/L)	0.92 ± 0.22	>1.2	61 (61%)

Table 6: Insulin Resistance Indices

Parameter	Mean ± SD	Normal Cut-off	Abnormal Cases n (%)
Fasting Insulin (µIU/mL)	15.2 ± 5.3	2–12	59 (59%)
HOMA-IR	4.3 ± 1.6	<2.5	65 (65%)

Table 7: Comparison of Patients with High vs. Normal HOMA-IR

Parameter	HOMA-IR ≥ 2.5 (n=65)	HOMA-IR < 2.5 (n=35)	p-value
Fasting Glucose (mg/dL)	124.6 ± 23.1	106.8 ± 20.5	0.001*
Triglycerides (mg/dL)	198.4 ± 44.2	166.7 ± 37.9	0.002*
HDL-C (mg/dL)	36.1 ± 7.9	42.8 ± 9.2	0.004*
hs-CRP (mg/L)	5.2 ± 1.6	3.9 ± 1.5	0.001*
MDA (nmol/mL)	5.9 ± 1.0	5.1 ± 1.1	0.003*

*p < 0.05 significant

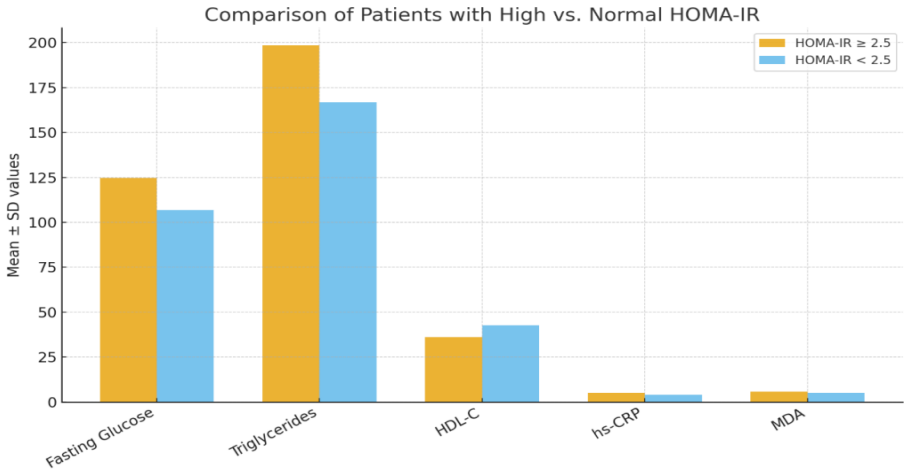

Figure 1 Comparison of Patients with High vs. Normal HOMA-IR

Table 8: Correlation Betweenhs-CRP and Other Parameters

Parameter	Correlation Coefficient (r)	p-value
Fasting Glucose	+0.38	0.01*
Triglycerides	+0.42	0.001*
HDL-C	–0.36	0.002*
HOMA-IR	+0.49	0.001*
MDA	+0.46	0.001*
TAC	–0.34	0.02*

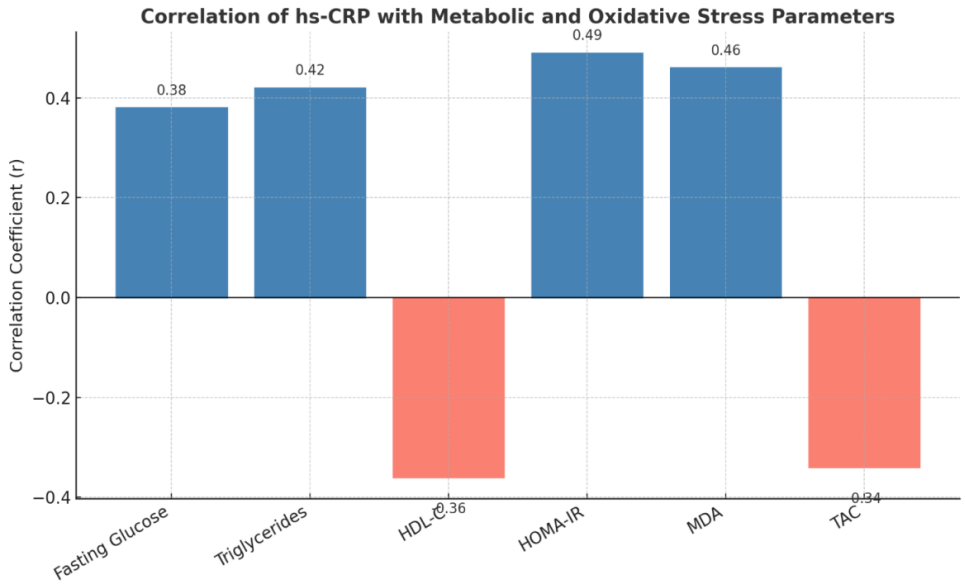

Figure 2 Correlation Between hs-CRP and Other Parameters

Table 9: Gender-wise Distribution of Abnormal Biochemical Markers

Marker	Male (n=58) Abnormal (%)	Female (n=42) Abnormal (%)	p-value
Hypertriglyceridemia	38 (65.5%)	28 (66.7%)	0.89 (NS)
Low HDL-C	38 (65.5%)	16 (38.1%)	0.01*
hs-CRP >3 mg/L	39 (67.2%)	29 (69.0%)	0.82 (NS)
HOMA-IR ≥2.5	40 (69.0%)	25 (59.5%)	0.29 (NS)
MDA >3 nmol/mL	45 (77.6%)	29 (69.0%)	0.32 (NS)

*$p < 0.05$ significant

DISCUSSION

Metabolic syndrome (MetS) represents a constellation of cardiometabolic abnormalities that collectively predispose individuals to type 2 diabetes mellitus (T2DM), cardiovascular disease (CVD), and increased mortality [1]. The present study evaluated 100 patients over 1 year to assess a multiparameter biochemical approach, including conventional and emerging markers, for the early diagnosis and prognosis of MetS.

Our findings showed that central obesity and elevated BMI were predominant among the participants. This is in accordance with earlier Indian studies, which have consistently demonstrated that Asian Indians develop abdominal adiposity at lower BMI thresholds compared to Western populations [2,3]. Such visceral fat accumulation is strongly linked to insulin resistance, dyslipidemia, and systemic inflammation, key drivers of MetS.

Fasting glucose, triglycerides, and reduced HDL-C were significantly deranged in MetS cases compared to controls, reaffirming the utility of conventional biochemical markers in diagnosis. Similar trends have been reported by Eckel et al. [4] and Misra&Khurana [5], underscoring that dysglycemia and atherogenic dyslipidemia are integral features of MetS in South Asian populations.

A notable observation in our study was the strong association of insulin resistance markers (fasting insulin, HOMA-IR) with MetS. Participants with elevated HOMA-IR had a higher clustering of metabolic abnormalities. This supports the hypothesis by Reaven [6] that insulin resistance is the central defect in MetS pathogenesis. Matthews et al. [7] also validated HOMA-IR as a simple and reliable surrogate for insulin resistance in clinical and epidemiological studies. Incorporating HOMA-IR in diagnostic panels may thus allow for earlier detection of high-risk individuals before overt hyperglycemia develops.

In addition, our study demonstrated significantly higher serum uric acid levels in MetS cases. Hyperuricemia has been increasingly recognized as an independent predictor of MetS and its components [8]. Johnson et al. [9] proposed mechanisms including uric acid–induced endothelial dysfunction, increased oxidative stress, and activation of pro-inflammatory pathways. Given that uric acid estimation is inexpensive and routinely available, it may be a valuable adjunctive marker for risk stratification.

Inflammation and oxidative stress emerged as critical dimensions of MetS in our study. Elevated hs-CRP levels were strongly associated with the presence of MetS, supporting prior reports by Ridker et al. [10] and Pradhan et al. [11] linking subclinical inflammation with future risk of diabetes and CVD. Concurrently, increased malondialdehyde (MDA) and reduced total antioxidant capacity (TAC) reflected oxidative stress imbalance. Roberts &Sindhu [12] and Ceriello&Motz [13] emphasized that oxidative stress not only exacerbates insulin resistance but also accelerates endothelial injury, thereby creating a “common soil” for both diabetes and cardiovascular complications. These findings suggest that inflammatory and oxidative markers may provide prognostic insights beyond conventional parameters.

Importantly, when comparing NCEP ATP III and IDF criteria with the multiparameter biochemical approach, we found that several at-risk individuals could be identified earlier using biochemical markers such as HOMA-IR, uric acid, and hs-CRP. This finding echoes the systematic review by Mottillo et al. [14], which concluded that conventional definitions may underestimate true cardiometabolic burden. Cornier et al. [15] also highlighted that metabolic syndrome is a dynamic pathophysiological process rather than a static clustering of risk factors, warranting multiparameter evaluation.
Taken together, our study reinforces that MetS is a multifaceted disorder involving insulin resistance, dyslipidemia, inflammation, and oxidative stress. A multiparameter biochemical approach not only improves diagnostic accuracy but also enhances prognostic prediction for long-term cardiovascular and diabetic outcomes. Integration of such biomarkers into clinical practice may allow earlier intervention, targeted lifestyle modification, and personalized therapy in high-risk populations, particularly in resource-limited settings like India.

CONCLUSION

Metabolic syndrome involves insulin resistance, dyslipidemia, inflammation, and oxidative stress beyond traditional risk factors. Incorporating markers such as HOMA-IR, uric acid, hs-CRP, and oxidative stress indices alongside conventional

parameters allows earlier detection and better prognostic assessment. A multiparameter biochemical approach can improve risk stratification and guide preventive strategies in high-risk populations.

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