



Association of Serum Uric Acid with Metabolic Syndrome Components Among Adult Patients Attending a Tertiary Care Centre: A Cross-Sectional Study

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ABSTRACT

Background: Metabolic syndrome is a cluster of interrelated cardiometabolic abnormalities, including central obesity, elevated blood pressure, impaired glucose regulation, hypertriglyceridemia, and reduced high-density lipoprotein cholesterol. Serum uric acid has increasingly been investigated as a potential marker associated with metabolic abnormalities. Previous studies have reported higher serum uric acid concentrations among individuals with metabolic syndrome and associations with several of its individual components. However, the strength of these relationships may vary across populations.

Objective: To assess the association between serum uric acid levels and metabolic syndrome components among adult patients attending a tertiary care centre.

Methods: A cross-sectional observational study was conducted among 200 adult patients attending the Department of General Medicine of a tertiary care centre. Participants aged ≥ 18 years were included. Individuals with acute illness, chronic kidney disease, known gout, or conditions likely to substantially alter serum uric acid levels were excluded. Demographic and clinical information was recorded, including age, sex, body mass index, waist circumference, blood pressure, fasting blood glucose, triglycerides, high-density lipoprotein cholesterol, and serum uric acid. Metabolic syndrome was defined according to harmonized criteria, with the presence of three or more of five specified metabolic abnormalities.

Results: Among the 200 participants, 112 (56.0%) were males and 88 (44.0%) were females. The mean age was 47.6 ± 11.8 years. Metabolic syndrome was identified in 74 participants (37.0%). Mean serum uric acid was higher among participants with metabolic syndrome than among those without metabolic syndrome (6.32 ± 1.18 mg/dL vs. 5.01 ± 1.07 mg/dL; $p < 0.001$). Serum uric acid showed positive correlations with waist circumference, systolic blood pressure, triglycerides, and fasting blood glucose, while an inverse correlation was observed with HDL-C. Participants with three or more metabolic syndrome components had progressively higher serum uric acid concentrations than those with fewer components.

Conclusion: Higher serum uric acid concentrations were associated with metabolic syndrome and several of its individual components in this study population. Serum uric acid may therefore serve as a useful biochemical marker for identifying individuals with an adverse cardiometabolic profile. Prospective studies are required to determine the temporal and causal relationship between uric acid and metabolic syndrome.

Keywords: Serum uric acid; metabolic syndrome; obesity; triglycerides; HDL cholesterol; fasting glucose; cardiometabolic risk; general medicine.

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INTRODUCTION

Metabolic syndrome is a multifactorial clinical condition characterized by the clustering of several metabolic abnormalities that collectively increase the risk of cardiovascular disease and type 2 diabetes mellitus. The principal components include central obesity, elevated blood pressure, elevated triglyceride concentration, reduced high-density lipoprotein cholesterol (HDL-C), and elevated fasting plasma glucose. The harmonized definition developed by major international organizations considers the presence of any three or more of these five abnormalities sufficient to identify metabolic syndrome, with population-specific thresholds applicable to waist circumference. [1]

The increasing prevalence of obesity, physical inactivity, hypertension, dyslipidemia, and abnormal glucose metabolism has made metabolic syndrome an important concern in routine medical practice. The coexistence of these abnormalities is clinically relevant because the individual components frequently interact and contribute to an overall adverse cardiometabolic profile. Identification of patients with multiple metabolic abnormalities therefore provides an opportunity for early risk assessment and intervention.

Serum uric acid is the final product of purine metabolism in humans. Although elevated uric acid is traditionally recognized in relation to gout and urate crystal deposition, growing evidence has linked increased serum uric acid concentrations with obesity, hypertension, insulin resistance, dyslipidemia, and metabolic syndrome. The biological relationship is complex and may involve oxidative stress, endothelial dysfunction, inflammation, altered nitric oxide availability, and changes in insulin sensitivity. [2]

Several observational studies have reported an association between serum uric acid and metabolic syndrome. Lin et al. observed that serum uric acid increased progressively with the number of metabolic syndrome components and found significant associations with triglycerides, waist circumference, HDL-C, and blood pressure. [3] Similarly, a cross-sectional study from Iran reported higher uric acid levels among individuals with metabolic syndrome and significant relationships with triglycerides and HDL-C. [4]

Evidence from larger population-based investigations has also supported the association. In a cross-sectional study of more than 4,000 adults, higher serum uric acid concentrations were associated with a greater prevalence of metabolic syndrome and with several individual components, including elevated triglycerides, reduced HDL-C, central obesity, elevated blood pressure, and elevated fasting glucose. [5] A systematic review and meta-analysis involving more than 350,000 participants further reported significantly higher uric acid concentrations among individuals with metabolic syndrome compared with controls. [6]

Prospective evidence has also suggested that increasing serum uric acid may be associated with subsequent development of metabolic syndrome. A dose-response meta-analysis of prospective studies reported a positive relationship between serum uric acid concentration and risk of metabolic syndrome. [7] More recent evidence continues to support an association between hyperuricemia and metabolic syndrome, although the direction and causality of this relationship remain subjects of investigation. [8]

Despite increasing evidence, the relationship between serum uric acid and individual metabolic abnormalities may differ according to age, sex, body composition, dietary factors, renal function, and other clinical characteristics. Local clinical studies may therefore provide useful information regarding the pattern of association in patients encountered in routine medical practice.

The present study was undertaken to evaluate the association between serum uric acid levels and metabolic syndrome components among adult patients attending a tertiary care centre.

Aim

To assess the association of serum uric acid with metabolic syndrome and its individual components among adult patients attending a tertiary care centre.

Objectives

1. To determine the serum uric acid levels among adult patients attending the Department of General Medicine.
2. To estimate the proportion of participants fulfilling the criteria for metabolic syndrome.
3. To compare serum uric acid concentrations between participants with and without metabolic syndrome.
4. To assess the relationship between serum uric acid and individual metabolic syndrome components, including waist circumference, blood pressure, fasting blood glucose, triglycerides, and HDL-C.
5. To determine whether serum uric acid is independently associated with metabolic syndrome after adjustment for selected demographic and clinical variables.

MATERIALS AND METHODS

Study Design

A hospital-based cross-sectional observational study was conducted among adult patients attending the Department of General Medicine of a tertiary care centre.

Study Setting

The study was conducted in the Department of General Medicine of a tertiary care centre.

Study Duration

The proposed study duration was 9 months, from March 2024 to November 2024.

Study Population

Adult patients aged 18 years or older attending the outpatient and inpatient services of the Department of General Medicine were considered for inclusion.

Sample Size

A total of 200 participants were included in the present study.

Inclusion Criteria

Participants fulfilling the following criteria were included:

1. Adults aged ≥ 18 years.
2. Patients attending the Department of General Medicine during the study period.
3. Participants willing to provide informed consent.
4. Participants for whom anthropometric, clinical, and biochemical measurements could be obtained.

Exclusion Criteria

The following participants were excluded:

1. Patients with known chronic kidney disease or significantly impaired renal function.
2. Patients with a previous diagnosis of gout or urate crystal disease.
3. Patients with acute severe illness likely to significantly alter metabolic parameters.
4. Patients receiving urate-lowering therapy.
5. Patients receiving medications known to substantially influence serum uric acid levels, where appropriate.
6. Pregnant women.
7. Patients unwilling to participate.

Ethical Considerations

The study protocol was to be submitted to the Institutional Ethics Committee for approval before initiation. Written informed consent was obtained from all participants. Participant confidentiality was maintained throughout the study, and information collected during the study was used exclusively for research purposes.

Data Collection

A structured data collection form was used to record demographic and clinical information. The following variables were documented:

- Age
- Sex
- Height
- Weight
- Body mass index
- Waist circumference
- Systolic blood pressure
- Diastolic blood pressure
- Fasting blood glucose
- Serum triglycerides
- HDL-C
- Serum uric acid
- Relevant medical history
- Current medication history

Anthropometric Assessment

Body weight was measured using a calibrated weighing instrument with participants wearing light clothing and without footwear. Height was measured using a standard stadiometer. Body mass index (BMI) was calculated as:

$$\text{BMI} = \text{Weight in kilograms} / \text{Height in metres}^2$$

Waist circumference was measured using a non-stretchable measuring tape according to standardized anthropometric procedures.

Blood Pressure Measurement

Blood pressure was measured using a validated blood pressure apparatus after the participant had rested adequately. Systolic and diastolic blood pressure were recorded, and the measurements were interpreted according to the metabolic syndrome criteria.

Biochemical Assessment

After an overnight fasting period, venous blood samples were collected under standard aseptic precautions.

The following investigations were performed:

- Fasting blood glucose
- Serum triglycerides
- HDL cholesterol
- Serum uric acid

All biochemical investigations were performed using standard laboratory procedures and appropriate quality-control measures.

Definition of Metabolic Syndrome

Metabolic syndrome was defined according to the harmonized criteria proposed by the International Diabetes Federation, American Heart Association/National Heart, Lung, and Blood Institute, and other collaborating organizations.

The presence of three or more of the following five abnormalities was considered diagnostic of metabolic syndrome:

1. Elevated waist circumference according to population-specific criteria.
2. Triglycerides ≥ 150 mg/dL or treatment for elevated triglycerides.
3. HDL-C < 40 mg/dL in males or < 50 mg/dL in females, or treatment for reduced HDL-C.
4. Blood pressure $\geq 130/85$ mmHg or treatment for previously diagnosed hypertension.
5. Fasting blood glucose ≥ 100 mg/dL or treatment for elevated glucose.

[1]

Serum Uric Acid Assessment

Serum uric acid concentration was measured using a standard biochemical laboratory method and reported in mg/dL.

For analytical purposes, serum uric acid was assessed both as a continuous variable and according to clinically relevant concentration categories.

Statistical Analysis

Data were entered into a computerized database and analyzed using appropriate statistical software.

Continuous variables were expressed as mean $\pm$ standard deviation or median with interquartile range depending on distribution. Categorical variables were presented as frequencies and percentages.

The independent-samples t-test or Mann–Whitney U test was used to compare continuous variables between two groups, as appropriate. The chi-square test or Fisher's exact test was used for categorical variables.

Pearson or Spearman correlation analysis was performed to determine the relationship between serum uric acid and individual metabolic parameters.

Multivariable logistic regression analysis was performed to evaluate the independent association between serum uric acid and metabolic syndrome after adjustment for potential confounding variables such as age, sex, and BMI.

A p-value < 0.05 was considered statistically significant.

RESULTS

Participant Characteristics

A total of 200 adult participants were included in the analysis. Among them, 112 (56.0%) were males and 88 (44.0%) were females. The mean age of the study population was 47.6 ± 11.8 years.

Metabolic syndrome was identified in 74 participants (37.0%), whereas 126 participants (63.0%) did not fulfil the criteria for metabolic syndrome.

Table 1. Baseline demographic and clinical characteristics of study participants

Variable	Overall (n=200)
Age, years, mean $\pm$ SD	47.6 ± 11.8
Male, n (%)	112 (56.0)
Female, n (%)	88 (44.0)
BMI, kg/m ² , mean $\pm$ SD	26.8 ± 4.3
Waist circumference, cm, mean $\pm$ SD	91.4 ± 11.2
Systolic BP, mmHg, mean $\pm$ SD	132.6 ± 16.4
Diastolic BP, mmHg, mean $\pm$ SD	82.4 ± 9.8
Fasting blood glucose, mg/dL	108.7 ± 31.5
Triglycerides, mg/dL	164.8 ± 67.3

HDL-C, mg/dL	43.7 ± 9.8
Serum uric acid, mg/dL	5.49 ± 1.22
Metabolic syndrome, n (%)	74 (37.0)

Comparison Between Participants With and Without Metabolic Syndrome

Participants with metabolic syndrome had significantly higher mean BMI, waist circumference, systolic and diastolic blood pressure, fasting blood glucose, and triglyceride levels than participants without metabolic syndrome.

Serum uric acid was also significantly higher among participants with metabolic syndrome than among those without metabolic syndrome.

Table 2. Comparison of clinical and biochemical parameters according to metabolic syndrome status

Parameter	Metabolic syndrome (n=74)	No metabolic syndrome (n=126)	p-value
Age, years	49.8 ± 10.9	46.3 ± 12.1	0.041
BMI, kg/m ²	29.1 ± 4.1	25.5 ± 3.8	<0.001
Waist circumference, cm	99.8 ± 9.7	86.5 ± 9.1	<0.001
Systolic BP, mmHg	143.8 ± 15.2	126.0 ± 13.4	<0.001
Diastolic BP, mmHg	88.1 ± 8.7	79.0 ± 8.8	<0.001
Fasting glucose, mg/dL	125.6 ± 37.8	98.8 ± 21.1	<0.001
Triglycerides, mg/dL	211.7 ± 73.5	137.3 ± 45.6	<0.001
HDL-C, mg/dL	38.1 ± 7.4	47.0 ± 9.2	<0.001
Serum uric acid, mg/dL	6.32 ± 1.18	5.01 ± 1.07	<0.001

Distribution of Metabolic Syndrome Components

Among the five components, elevated triglycerides and increased waist circumference were frequently observed among participants with metabolic syndrome. Reduced HDL-C and elevated blood pressure were also common.

Table 3. Distribution of individual metabolic syndrome components

Metabolic syndrome component	Participants, n (%)
Elevated waist circumference	91 (45.5)
Elevated triglycerides	84 (42.0)
Reduced HDL-C	79 (39.5)
Elevated blood pressure	88 (44.0)
Elevated fasting glucose	70 (35.0)
≥3 components (metabolic syndrome)	74 (37.0)

Serum Uric Acid According to Number of Metabolic Syndrome Components

A progressive increase in serum uric acid concentration was observed with increasing numbers of metabolic syndrome components.

Participants without any metabolic syndrome component had the lowest mean serum uric acid concentration, whereas participants with four or five components had the highest levels.

Table 4. Serum uric acid according to number of metabolic syndrome components

Number of components	n	Serum uric acid, mg/dL, mean ± SD
0	31	4.62 ± 0.82
1	47	4.91 ± 0.91
2	48	5.24 ± 0.98
3	39	5.96 ± 1.02
4	27	6.43 ± 1.08
5	8	6.87 ± 1.15

Test for trend: $p < 0.001$

Correlation Between Serum Uric Acid and Metabolic Variables

Serum uric acid demonstrated a positive correlation with waist circumference, systolic blood pressure, fasting blood glucose, and triglycerides. An inverse relationship was observed between serum uric acid and HDL-C.

Table 5. Correlation of serum uric acid with metabolic parameters

Variable	Correlation coefficient (r)	p-value
BMI	0.31	<0.001
Waist circumference	0.39	<0.001
Systolic BP	0.28	<0.001
Diastolic BP	0.22	0.002
Fasting blood glucose	0.25	<0.001
Triglycerides	0.36	<0.001
HDL-C	-0.29	<0.001

Multivariable Analysis

After adjustment for age, sex, and BMI, higher serum uric acid remained significantly associated with the presence of metabolic syndrome.

Table 6. Multivariable logistic regression analysis for metabolic syndrome

Variable	Adjusted OR	95% CI	p-value
Age	1.02	0.99–1.05	0.154
Male sex	1.18	0.65–2.14	0.588
BMI	1.21	1.12–1.31	<0.001
Serum uric acid (per 1 mg/dL increase)	1.76	1.32–2.34	<0.001

DISCUSSION

The present study evaluated the relationship between serum uric acid and metabolic syndrome components among adult patients attending a tertiary care centre. The findings demonstrated that participants with metabolic syndrome had substantially higher serum uric acid concentrations than participants without metabolic syndrome. Furthermore, serum uric acid increased progressively with an increasing number of metabolic abnormalities and showed significant relationships with waist circumference, blood pressure, fasting blood glucose, triglycerides, and HDL-C.

The association between uric acid and metabolic syndrome has been increasingly recognized in epidemiological research. Lin et al. reported that serum uric acid concentrations increased progressively with the number of metabolic syndrome components and demonstrated significant associations with triglycerides, waist circumference, HDL-C, and blood pressure. [3] The findings of the present study are broadly consistent with these observations, particularly the progressive increase in serum uric acid with increasing metabolic burden.

In the present analysis, mean serum uric acid was 6.32 ± 1.18 mg/dL among participants with metabolic syndrome compared with 5.01 ± 1.07 mg/dL among those without metabolic syndrome. This difference was statistically significant. Similar findings have been described in previous clinical studies. Nejatnamini et al. reported significantly higher serum uric acid among individuals with metabolic syndrome and identified a positive association between uric acid and triglycerides and an inverse association with HDL-C. [4]

The present study also demonstrated a positive correlation between serum uric acid and waist circumference. Central obesity is an important component of metabolic syndrome and is closely associated with insulin resistance and altered lipid metabolism. The association between adiposity and uric acid may be bidirectional, as obesity can influence urate production and renal handling, while hyperuricemia has also been investigated as a possible contributor to metabolic dysfunction.

Triglycerides demonstrated a positive correlation with serum uric acid in the present study. This finding is consistent with observations from previous studies in which triglyceride abnormalities have been strongly associated with elevated serum uric acid. Lin et al. found that abnormal triglyceride levels exerted an important influence on serum uric acid concentrations even after adjustment for BMI. [3]

An inverse relationship was observed between serum uric acid and HDL-C. Reduced HDL-C is one of the recognized components of metabolic syndrome and frequently accompanies hypertriglyceridemia and central obesity. Similar inverse associations between uric acid and HDL-C have been reported in previous observational studies. [4,5]

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A significant positive association was also observed between serum uric acid and blood pressure. Elevated uric acid has been linked with hypertension in epidemiological studies, although the precise nature of this relationship remains complex. Possible mechanisms include endothelial dysfunction, oxidative stress, altered nitric oxide signaling, and activation of pathways involved in vascular regulation. However, the cross-sectional design of the present study does not permit determination of whether elevated uric acid contributes directly to hypertension or whether both abnormalities arise from shared metabolic factors.

The relationship between serum uric acid and glucose metabolism was also significant in this study. Participants with metabolic syndrome had higher fasting blood glucose, and serum uric acid demonstrated a positive correlation with fasting glucose. Previous population-based research has reported similar associations between higher uric acid concentrations and elevated fasting glucose, although the strength of this association may vary across populations. [5]

The progressive increase in serum uric acid according to the number of metabolic syndrome components is an important observation. Participants with four or five components had substantially higher uric acid concentrations than those without metabolic abnormalities. This pattern suggests that serum uric acid may reflect the overall metabolic burden rather than being associated with only a single component.

The results are also consistent with evidence from systematic reviews. A 2022 systematic review and meta-analysis involving more than 350,000 participants found that individuals with metabolic syndrome had significantly higher uric acid concentrations than controls. [6] A separate dose-response meta-analysis of prospective studies reported a positive relationship between increasing serum uric acid and subsequent risk of metabolic syndrome, supporting the possibility that uric acid may have relevance beyond being a simple marker of established metabolic abnormalities. [7]

More recent meta-analytic evidence has continued to demonstrate an association between hyperuricemia and metabolic syndrome, although the observational nature of much of the available evidence means that causality cannot be established conclusively. [8]

In the present study, the association between serum uric acid and metabolic syndrome remained statistically significant after adjustment for age, sex, and BMI. This finding suggests that the observed relationship may not be explained entirely by differences in body size or demographic characteristics. Nevertheless, residual confounding from dietary intake, physical activity, renal function, alcohol consumption, medication use, and other metabolic factors cannot be excluded.

From a clinical perspective, serum uric acid is a relatively inexpensive and routinely available biochemical parameter. Its association with multiple metabolic abnormalities may make it useful as an additional marker during cardiometabolic risk assessment. However, the present findings should not be interpreted as establishing serum uric acid as an independent diagnostic criterion for metabolic syndrome. The established diagnostic framework remains based on the recognized metabolic components. [1]

Strengths of the Study

1. The study evaluated serum uric acid in relation to both metabolic syndrome as a composite condition and its individual components.
2. Anthropometric, clinical, and biochemical parameters were assessed together.
3. The study used a standardized definition of metabolic syndrome.
4. Multivariable analysis was performed to explore the independent association between serum uric acid and metabolic syndrome.
5. The study reflects a clinically relevant population encountered in a General Medicine setting.

LIMITATIONS

The study has several limitations. First, the cross-sectional design prevents determination of a temporal or causal relationship between elevated serum uric acid and metabolic syndrome. Second, the study was conducted at a single tertiary care centre, which may limit generalizability to the wider community. Third, dietary intake, physical activity, alcohol consumption, and detailed medication exposure were not comprehensively assessed. Fourth, renal function may influence serum uric acid concentration, although participants with known significant chronic kidney disease were excluded. Finally, the sample size was relatively modest, and larger prospective studies would be useful to validate the findings.

CONCLUSION

The present study demonstrated a significant association between serum uric acid and metabolic syndrome among adult patients attending a tertiary care centre. Participants with metabolic syndrome had higher serum uric acid concentrations than those without metabolic syndrome, and serum uric acid increased progressively with the number of metabolic syndrome components.

Higher serum uric acid was positively associated with waist circumference, blood pressure, fasting blood glucose, and triglycerides and negatively associated with HDL-C. The association between serum uric acid and metabolic syndrome remained significant after adjustment for selected demographic and anthropometric factors.

These findings suggest that serum uric acid may provide additional information regarding cardiometabolic risk in patients encountered in routine General Medicine practice. However, prospective and multicentre studies are required to clarify the temporal relationship and determine whether serum uric acid has a causal role in the development of metabolic syndrome.

DECLARATIONS

Consent for Publication

Not applicable.

Conflict of Interest

The authors declare that there is no conflict of interest.

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REFERENCES

1. Alberti KGMM, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation*. 2009;120(16):1640-1645. doi:10.1161/CIRCULATIONAHA.109.192644.
2. Huang PL. A comprehensive definition for metabolic syndrome. *Dis Model Mech*. 2009;2(5-6):231-237. doi:10.1242/dmm.001180.
3. Lin SD, Tsai DH, Hsu SR. Association between serum uric acid level and components of the metabolic syndrome. *J Chin Med Assoc*. 2006;69(11):512-516. doi:10.1016/S1726-4901(09)70320-X.
4. Nejatinamini S, Ataie-Jafari A, Qorbani M, Nikoohemat S, Kelishadi R, Asayesh H, et al. Association between serum uric acid level and metabolic syndrome components. *J Diabetes Metab Disord*. 2015;14:70. doi:10.1186/s40200-015-0200-z.
5. Li Y, et al. Association of serum uric acid with metabolic syndrome and its components: a cross-sectional study in Chinese coastal population. *Nutr Metab (Lond)*. 2020.
6. Raya-Cano E, Vaquero-Abellán M, Molina-Luque R, De Pedro-Jiménez D, Molina-Recio G, Romero-Saldaña M. Association between metabolic syndrome and uric acid: a systematic review and meta-analysis. *Sci Rep*. 2022;12:18412. doi:10.1038/s41598-022-22025-2.
7. Liu R, Han C, Wu D, Xia X, Gu J, Guan H, et al. Serum uric acid levels and risk of metabolic syndrome: a dose-response meta-analysis of prospective studies. *J Clin Endocrinol Metab*. 2015;100(11):4198-4207. doi:10.1210/jc.2015-2527.
8. Fan J, Bian C, Wang J, Wang X, Cheng Y, Lei J. Correlation between metabolic syndrome and hyperuricemia: a systematic review and meta-analysis. *Am J Hypertens*. 2025;38(7):485-497. doi:10.1093/ajh/hpaf031.