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Biochemical Predictors of Elevated Blood Pressure and Cardiometabolic Risk in School-Aged Children: A Cross-Sectional Study

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ABSTRACT

Background: Hypertension is emerging in children, mainly due to obesity and lifestyle changes. Early biochemical markers may help detect cardiometabolic risk before clinical disease appears.

Objective: To determine the association between selected biochemical markers and elevated blood pressure in school-aged children.

Methods: A cross-sectional study was conducted among 220 children aged 8–14 years from three schools. Blood pressure was categorized according to age- and height-specific percentiles. Fasting blood samples were analyzed for lipid profile, fasting glucose, fasting insulin, HOMA-IR, uric acid, high-sensitivity CRP (hs-CRP), and vitamin D levels. Anthropometry and BMI percentiles were recorded.

Results:
Pre hypertension and hypertension were found in 14.5% and 6.8% of children, respectively. Mean systolic BP was higher in children with high LDL (112.7 ± 8.5 mmHg) compared to normal LDL (105.4 ± 7.9 mmHg, $p < 0.01$). Insulin resistance (HOMA-IR > 2.5) was present in 28% of participants. Children with elevated HOMA-IR had significantly higher systolic BP (113.6 ± 9.1 mmHg) compared to those without insulin resistance (104.9 ± 7.5 mmHg, $p < 0.001$). Uric acid showed a moderate positive correlation with systolic BP (r = 0.42). Elevated hs-CRP (>3 mg/L) was detected in 18% of participants and was associated with higher BMI and BP. Vitamin D deficiency (<20 ng/mL) was common (62%) but showed a weak association with BP.

Conclusion: LDL cholesterol, insulin resistance, uric acid, and hs-CRP are strong biochemical predictors of elevated blood pressure in children. Routine screening in overweight and obese children may help identify early cardiometabolic risk.

1. INTRODUCTION

Childhood hypertension is increasingly reported in Pakistan, largely driven by rising obesity, unhealthy diet, and sedentary behaviour.[1,2] While office blood pressure is useful for screening, it may underestimate early vascular and metabolic injury,

particularly in children who already have clustered cardiometabolic risk factors but remain asymptomatic.

[3] Recent local data show a high burden of dyslipidaemia, central adiposity, vitamin D deficiency and elevated blood pressure among Pakistani children and adolescents, underscoring the need for simple risk-stratification tools that go beyond anthropometry alone.[4,5] International and regional studies further highlight that biochemical markers such as fasting lipid profile, fasting glucose, insulin-based and non–insulin-based indices of insulin resistance (e.g. HOMA-IR, triglyceride–glucose [TyG] index, METS-IR), serum uric acid and related glycaemic measures are strongly associated with elevated blood pressure and early cardiometabolic dysfunction in paediatric populations.[6,7]

In South Asian children, excess adiposity has been linked with adverse lipid patterns and insulin resistance even at relatively low BMI thresholds, suggesting an ethnic susceptibility to early metabolic derangement [8]. However, many of the available risk scores require specialized assays or complex calculations that may not be feasible in routine school health programmes or primary-care settings in Pakistan. There is, therefore, a clear need to identify a small panel of common, low-cost, and easily measurable biochemical markers that can help flag school-aged children at higher risk of elevated blood pressure and future cardiovascular disease.

The present study focuses on widely available biochemical parameters, including conventional lipid fractions, fasting glucose, simple indices of adiposity and selected metabolic markers, as potential predictors of elevated blood pressure in school-aged children in Pakistan. By examining their independent and combined associations with blood pressure categories, we aim to develop an evidence base for pragmatic, laboratory-supported screening strategies that could be integrated into existing school health and paediatric services in low-resource settings.

Methods

Study Design and Setting

This descriptive cross-sectional study was conducted from March to July 2024 in Faisalabad, Pakistan. In order to obtain a school-based sample, three schools; two private and one public, were selected through convenience sampling. Data collection was carried out within school premises under standardized conditions by trained research staff. The study focused on evaluating anthropometric, biochemical, and blood pressure parameters among school-aged children to identify early cardiometabolic risk indicators.

Sample Size

A total of 220 children aged 8–14 years were enrolled. Participants with known chronic medical conditions, congenital disorders, endocrine abnormalities, or those receiving long-term medication were excluded to minimize confounding effects on biochemical and blood pressure outcomes.

Data Collection Procedures

Anthropometric Assessment:
Body weight was measured using a calibrated digital weighing scale to the nearest 0.1 kg, and height was recorded with a standard stadiometer. Body mass index (BMI) was calculated as weight (kg) divided by height in meters squared (m^2), and values were plotted against CDC age- and sex-specific percentiles to categorize nutritional status.

Blood Pressure Measurement:
Blood pressure (BP) was measured using a validated digital sphygmomanometer following a five-minute seated rest. Two readings were obtained at an interval of two minutes, and the mean value was used for analysis. BP categories were assigned according to the American Academy of Pediatrics (AAP) 2017 reference percentiles: normal (<90th percentile), prehypertension (90th–94th percentile), and hypertension (≥95th percentile).

Laboratory Investigations:
Following an overnight fast, venous blood samples were collected using standardized kits and procedures. Fasting glucose was analyzed via the hexokinase method (reference: 70–100 mg/dL), while fasting insulin was measured using immunoassay techniques (reference: 3–20 µIU/mL). Insulin resistance was estimated using the Homeostatic Model Assessment (HOMA-IR), calculated as (glucose × insulin)/405, with values >2.5 considered indicative of insulin resistance. Lipid profile parameters were assessed through enzymatic methods using age-adjusted reference ranges. Serum uric acid levels were measured via the uricase enzymatic method (reference: 2.0–5.5 mg/dL), high-sensitivity C-reactive protein (hs-CRP) via immunoturbidimetric assay (reference: <3 mg/L), and serum 25-hydroxyvitamin D using chemiluminescent immunoassay (reference: >30 ng/mL).

Ethical Approval

Parents provided written consent. Approval was taken from institutional review board.

Results

A total of 220 school-aged children were included in the analysis, with a mean age of 11.2 ± 2.1 years. The sample comprised 54% boys and 46% girls. Overall, 32% of participants were classified as overweight or obese based on BMI values above the 85th percentile.

Blood pressure assessment showed that 173 children (78.6%) had normal values, while 32 (14.5%) were categorized as pre hypertensive and 15 (6.8%) met criteria for hypertension. The mean systolic blood pressure (SBP) for the entire cohort was 107.8 ± 9.1 mmHg.

Biochemical analyses demonstrated mean fasting glucose of 88 ± 9 mg/dL and fasting insulin of 15.1 ± 6.4 µIU/mL, yielding a mean HOMA-IR value of 2.87 ± 1.1. Lipid parameters included LDL-C 118 ± 28 mg/dL, HDL-C 41 ± 8 mg/dL and triglycerides 122 ± 34 mg/dL. Mean serum uric acid was 4.6 ± 1.0 mg/dL, while hs-CRP averaged 2.8 ± 1.7 mg/L. Vitamin D levels were low overall, with a mean of 18.5 ± 9.2 ng/mL.

Children with LDL-C ≥130 mg/dL exhibited higher SBP values (112.7 ± 8.5 mmHg) compared with those below this threshold (105.4 ± 7.9 mmHg; $p < 0.01$). Elevated HOMA-IR (>2.5) was observed in 28% of participants, and these children had higher mean SBP (113.6 ± 9.1 mmHg) compared with their peers (104.9 ± 7.5 mmHg; $p < 0.001$). Serum uric acid demonstrated a moderate positive correlation with SBP ($r = 0.42$; $p < 0.001$), and children with levels above 5.5 mg/dL had a mean SBP of 115.2 ± 8.0 mmHg. Elevated hs-CRP (>3 mg/L; $n = 40$) was associated with higher BMI and higher systolic blood pressure ($p < 0.05$). Vitamin D deficiency, present in 62% of the sample, showed a mild but non-significant association with SBP ($p = 0.09$), with deficient children exhibiting slightly higher mean SBP values (109.1 vs. 105.7 mmHg).

Marker / Category	Comparison	SBP (Mean ± SD)	Statistical Note
LDL-C	<130 mg/dL	105.4 ± 7.9	$p < 0.01$
	≥130 mg/dL	112.7 ± 8.5	
HOMA-IR	≤2.5	104.9 ± 7.5	$p < 0.001$
	>2.5	113.6 ± 9.1	
Uric acid	Correlation with SBP	$r = 0.42$	$p < 0.001$
	>5.5 mg/dL	115.2 ± 8.0	—
hs-CRP	>3 mg/L	Higher SBP & BMI	$p < 0.05$
Vitamin D	Deficient vs. normal	109.1 vs 105.7	$p = 0.09$

2. DISCUSSION

In this cross-sectional study of school-aged children, we observed substantial clustering of cardiometabolic abnormalities, particularly among those with overweight or obesity. Elevated LDL-C and insulin resistance were significantly associated with higher systolic blood pressure (SBP), consistent with evidence showing that lipid abnormalities and impaired insulin sensitivity contribute to early elevations in blood pressure in pediatric populations [9,10]. Similar studies have demonstrated that cardiometabolic risk factors cluster early in life and track into adolescence and adulthood, increasing the likelihood of sustained hypertension and vascular dysfunction [11,12].

A moderate positive correlation between uric acid and SBP observed in this study aligns with previous findings reporting hyperuricemia as a significant metabolic correlate of elevated blood pressure in children [12,13]. Uric acid has been associated with endothelial dysfunction, oxidative stress, and inflammatory activation, all of which may contribute to heightened cardiovascular risk in youth [14]. Consistent with this pathway, elevated hs-CRP levels in our study were linked to both higher BMI and higher SBP, reflecting the presence of low-grade inflammation. Prior work similarly supports the role of hs-CRP as a key inflammatory marker in pediatric populations exhibiting features of metabolic syndrome and blood pressure elevation [15,16].

Vitamin D deficiency was highly prevalent in the cohort and showed a trend toward higher SBP, although statistical significance was not reached. Several studies have suggested that low vitamin D status may influence cardiometabolic health through pathways involving inflammation, lipid metabolism, and insulin signaling [17,18]. Other research indicates that vitamin D insufficiency is common among overweight and obese children and may be linked with adverse metabolic profiles, including hypertension and insulin resistance [19–21].

Overall, the observed associations among lipid levels, insulin resistance, uric acid, hs-CRP, and SBP highlight the multifaceted nature of early cardiometabolic dysfunction. These findings support recommendations that pediatric hypertension screening should incorporate biochemical profiling rather than relying on blood pressure measurements alone.

3. CONCLUSION

LDL cholesterol, insulin resistance (HOMA-IR), uric acid, and hs-CRP are strong biochemical predictors of elevated blood pressure in children. Routine screening of these markers in overweight and obese children can help identify early

cardiometabolic risk and guide preventive interventions.

Authors' Contribution:

Concept & Design of Study: Sidra Anwar, Asma Hussain

Drafting: Khurram Munir, Maryam Ejaz

Data Analysis: Saboohi Saeed, Farzana Rahim Memon

Critical Review: Farzana Rahim Memon, Saboohi Saeed

Final Approval of Version: All authors approved the final version

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