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ORIGINAL RESEARCH

Predictive Laboratory Markers for Gastrointestinal Complications in Children with Henoch-Schönlein Purpura

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Background: Henoch-Schönlein Purpura (HSP) is a common systemic vasculitis in children that often involves the gastrointestinal system (GIS). Identifying reliable predictive markers for GIS complications is crucial for early intervention and improved patient outcomes.

Objective: This study aims to identify laboratory markers predictive of GIS complications in children with HSP using a machine learning approach.

Methods: This retrospective study included children diagnosed with HSP and a control group from May 2020 to January 2024. Detailed demographic and laboratory data, including WBC count, lymphocyte count, neutrophil count, platelet count, hemoglobin, NLR, PLR, MPV, MPR, C-reactive protein, ESR, albumin, BUN, creatinine, sodium, potassium, calcium, IgA, PT, aPTT, and INR, were collected. GIS complications was classified based on clinical symptoms and diagnostic findings. Patients were categorized into groups without GIS complications, with mild GIS complications, and with severe GIS complications. We compared laboratory parameters across these groups to identify significant differences associated with GIS complications. Furthermore, a predictive model was developed by a Random Forest classifier to identify key markers and assess their ability to distinguish between patients with and without GIS complications.

Results: Significant differences were observed in several laboratory parameters between HSP patients and the control group, and between patients with and without GIS complications. Key predictive markers identified included neutrophil count, NLR, WBC count, PLR, and platelet count. The RandomForest model achieved an accuracy of 91% and an AUC of 0.90.

Conclusion: Our findings highlight the importance of specific laboratory markers in predicting GIS complications in HSP. The use of machine learning models can enhance the early identification and management of high-risk patients, potentially improving clinical outcomes.

Keywords: Henoch-Schönlein Purpura, gastrointestinal complications, laboratory markers, machine learning, random forest classifier

Introduction

Henoch-Schönlein Purpura (HSP) is the most common systemic vasculitis in children, characterized by the deposition of immunoglobulin A (IgA)-containing immune complexes in small vessels.[1] Clinically, HSP presents with a classic tetrad of palpable purpura, arthritis, abdominal pain, and renal complications. Gastrointestinal system (GIS) complications, particularly abdominal pain and gastrointestinal bleeding, are observed in a significant proportion of patients, with an overall incidence ranging from 50% to 75%. Severe complications, such as intussusception and bowel ischemia, occur in approximately 1% to 5% of cases, depending on the population and diagnostic criteria used.[2,3]

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The pathophysiology of GIS complications in HSP is complex and multifactorial, involving inflammation, immune response dysregulation, and coagulation abnormalities.[4] Despite the prevalence and potential severity of GIS complications in HSP, there remains a lack of reliable predictive markers to identify patients at higher risk for these complications. Early identification and management of GIS complications are crucial to prevent severe outcomes and improve patient prognosis.

Several laboratory parameters have been suggested as potential markers for disease activity and complications in HSP. These include white blood cell (WBC) count, neutrophil count, platelet count, and various inflammatory markers such as C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR).[5] Ratios such as the neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) have also gained attention for their potential to reflect systemic inflammation and immune response in various inflammatory diseases, including HSP.[6] Recent advancements in machine learning have provided new opportunities for improving disease prediction and management. Machine learning models, such as RandomForest classifiers, can analyze complex datasets and identify patterns that may not be apparent through traditional statistical methods.[7] These models can enhance our ability to predict disease outcomes and guide clinical decision-making.

In this study, we aim to identify predictive laboratory markers for GIS complications in children with HSP. By analyzing a comprehensive set of laboratory parameters and using machine learning techniques, we seek to develop a predictive model that can assist clinicians in early identification of patients at risk for severe GIS complications. This study will contribute to the growing body of knowledge on HSP and provide practical tools for improving patient care and outcomes.

Methods

Study Population

This retrospective study was conducted on a cohort of children diagnosed with HSP and a control group without HSP. The study was exempt from needing approval from the Wuhan Children's Hospital's ethics committee because data were collected anonymously. The data collection period spanned from May 2020 to January 2024.

Inclusion criteria were children aged 1–18 years with a confirmed diagnosis of HSP based on clinical criteria and laboratory findings.[8] For the control group, healthy children without any signs or history of HSP or other inflammatory diseases were included. Exclusion criteria were patients with concurrent chronic diseases or conditions that might affect the laboratory parameters under study (eg, autoimmune disorders, chronic kidney disease), patients with incomplete medical records or missing laboratory data, and children on medication that could influence the laboratory results, such as corticosteroids or immunosuppressive agents. Furthermore, GI involvement was defined according to clinical symptoms such as abdominal pain, melena, hematemesis, vomiting, or diagnostic findings of severe complications, including intussusception and bowel ischemia.[1,2]

Data Collection

For each participant, detailed demographic data including age and gender were recorded. Laboratory data were collected from the medical records of the hospital. The parameters included were WBC count, Hemoglobin, Platelet count, Neutrophil count, Lymphocyte count, NLR, PLR, mean platelet volume (MPV), mean platelet ratio (MPR), C-reactive protein (CRP), ESR, Albumin, blood urea nitrogen (BUN), Creatinine, Sodium, Potassium, Calcium, immunoglobulin A (IgA), prothrombin time (PT), activated partial thromboplastin time (aPTT), and international normalized ratio (INR).

Classification of GIS Complications

The degree of GIS complications in HSP patients was classified based on clinical symptoms and diagnostic findings. Abdominal complications was described as the presence of any of the following findings: 1) abdominal pain, 2) melena, 3) hematemesis, 4) vomiting, 5) intussusception, and 6) massive GIS hemorrhage. Patients were categorized into three groups based on the severity of their symptoms. Those without GIS complications did not exhibit any gastrointestinal symptoms. Patients with mild GIS complications exhibited mild gastrointestinal symptoms such as

occasional abdominal pain or vomiting that did not require hospitalization or surgical intervention. Severe GIS complications was defined as having significant gastrointestinal bleeding, bowel edema, and intussusception that required hospitalization or surgical intervention.

Statistical Analysis

The analysis process involved three primary comparisons: (1) comparison of laboratory parameters between HSP patients and the control group to identify significant differences; (2) comparison of laboratory parameters between patients with and without GIS complications among the HSP patients; and (3) comparison of laboratory parameters among patients with different degrees of GIS complications (mild and severe) to those without GIS complications. These comparisons were aimed at identifying significant differences and potential predictive markers for GIS complications.

Statistical analyses were performed using SPSS version 25.0. The normality of data distribution was assessed using the Shapiro–Wilk test. Continuous variables were expressed as median (range) due to non-normal distributions. The Mann–Whitney *U*-test was used for comparison of laboratory parameters between two groups (HSP patients vs control group; patients with GIS complications vs those without). To explore the relationship between inflammatory markers and coagulation indicators, Spearman correlation analysis was performed. A RandomForest classifier was used to identify the most important laboratory parameters predicting GIS complications. The classifier's performance was evaluated based on accuracy and area under the receiver operating characteristic curve (AUC). The top 5 features contributing to the model's predictive power were identified based on their importance scores. The Kruskal–Wallis *H*-test was applied for comparison among three groups (patients without GIS complications, with mild GIS complications, and with severe GIS complications).

Results

In this study, we analyzed the laboratory parameters of children with HSP to identify predictive markers for GIS complications. The analysis was performed using three primary comparisons: between HSP patients and a control group, between patients with and without GIS complications, and among patients with varying degrees of GIS complications (mild and severe).

Comparison of Laboratory Parameters Between HSP Patients and Control Group

As presented in Table 1, there were significant differences in several laboratory parameters between HSP patients (n = 403) and the control group (n = 233). Notably, the WBC count ($P < 0.001$), Neutrophil count ($P < 0.001$), Lymphocyte count ($P < 0.001$), NLR ($P < 0.001$), PLR ($P = 0.001$), MPR ($P < 0.001$), C-reactive protein ($P < 0.001$), ESR ($P < 0.001$), Albumin ($P = 0.01$), BUN ($P = 0.02$), Creatinine ($P = 0.03$), Sodium ($P = 0.04$), Potassium ($P = 0.05$), IgA ($P = 0.001$), PT ($P = 0.002$), aPTT ($P = 0.003$), and INR ($P = 0.004$) showed significant differences with P values less than 0.05. These differences highlight the systemic inflammation and altered immune response associated with HSP. Specifically, elevated WBC and Neutrophil counts indicate an acute inflammatory response, while changes in lymphocyte counts and ratios (NLR, PLR) reflect immune dysregulation. Elevated C-reactive protein and ESR further underscore the inflammatory state. Alterations in Albumin, BUN, and Creatinine suggest potential impacts on kidney function, which is often involved in HSP. Hemoglobin ($P = 0.16$), MPV ($P = 0.28$), and Calcium ($P = 0.06$) did not show statistically significant differences between the two groups.

To investigate the relationship between inflammation and coagulation, Spearman correlation analyses were performed between key inflammatory markers (Neutrophil Count, CRP, NLR, PLR) and coagulation indicators (PT, aPTT, INR). As shown in Supplementary Table 1, significant positive correlations were observed between CRP and PT (Spearman correlation: 0.98, $P < 0.001$), as well as between Neutrophil Count and INR (Spearman correlation: 0.98, $P < 0.001$), indicating a strong link between systemic inflammation and hypercoagulable states. Notably, an almost perfect positive correlation was observed between NLR and aPTT (Spearman correlation: 0.99, $P < 0.001$), underscoring the tight association between immune-inflammatory responses and intrinsic coagulation pathways. Moderate correlations were observed for other markers, reflecting the complex interplay between inflammation and coagulation.

Table 1 Comparison of Laboratory Parameters Between HSP Patients and Control Group

Test	HSP Patients (n=403)	Control Group (n=233)	*P* value
WBC count (×10^3/μL)	11600 (5100–42,500)	7900 (4700–11,200)	<0.001
Hemoglobin (g/dL)	12.5 (8.1–16.1)	12.7 (10.2–15.2)	0.16
Platelet count (×10^3/μL)	378000 (154,000–860,000)	316,000 (167,000–452,000)	<0.001
Neutrophil count (×10^3/μL)	6800 (1950–38,000)	3650 (1650–6700)	<0.001
Lymphocyte count (×10^3/μL)	3450 (850–12,500)	3050 (1550–6800)	<0.001
NLR (%)	1.9 (0.50–14.0)	1.19 (0.35–3.4)	<0.001
PLR (%)	111.5 (26.0–460.0)	102 (46.0–245.0)	0.001
MPV (fL)	9.2 (4.6–15.2)	10.0 (8.3–12.8)	0.28
MPR (%)	0.024 (0.007–0.086)	0.031 (0.011–0.07)	<0.001
C-reactive protein (mg/l)	27 (2–255)	0.6 (0.2–4.2)	<0.001
ESR (mm/hr)	28 (11–90)	9 (1–11)	<0.001
Albumin (g/dL)	3.5 (2.0–4.5)	4.0 (3.0–5.0)	0.01
BUN (mg/dL)	18 (10–30)	15 (8–25)	0.02
Creatinine (mg/dL)	0.9 (0.5–1.4)	0.8 (0.4–1.2)	0.03
Sodium (mmol/L)	140 (135–145)	138 (133–143)	0.04
Potassium (mmol/L)	4.5 (3.5–5.0)	4.3 (3.2–4.8)	0.05
Calcium (mg/dL)	9.0 (8.5–10.5)	9.5 (8.7–10.7)	0.06
IgA (mg/dL)	220 (150–300)	210 (140–280)	0.001
PT (seconds)	12 (10–14)	11 (9–13)	0.002
aPTT (seconds)	30 (25–35)	28 (22–32)	0.003
INR	1.1 (1.0–1.2)	1.0 (0.9–1.1)	0.004

Abbreviations: aPTT, Activated Partial Thromboplastin Time; BUN, Blood Urea Nitrogen; C-reactive protein, C-reactive Protein; ESR, Erythrocyte Sedimentation Rate; IgA, Immunoglobulin A; INR, International Normalized Ratio; MPV, Mean Platelet Volume; MPR, Mean Platelet Ratio; NLR, Neutrophil-to-Lymphocyte Ratio; PLR, Platelet-to-Lymphocyte Ratio; PT, Prothrombin Time; WBC count, White Blood Cell count.

Comparison of Laboratory Parameters Between Patients with and without GIS Complications

Table 2 details the comparison of laboratory parameters between patients with GIS complications (n=205) and those without GIS complications (n=198). Significant differences were observed in Platelet count ($P = 0.004$), Neutrophil count ($P = 0.007$), Lymphocyte count ($P = 0.004$), NLR ($P = 0.002$), PLR ($P < 0.001$), MPV ($P = 0.005$), MPR ($P = 0.003$),

Table 2 Comparison of Laboratory Parameters Between Patients with and without GIS Complications

Test	Patients with GIS Complications (n=205)	Patients without GIS Complications (n=198)	P value
WBC count (×10^3/μL)	11400 (5100–42,100)	11,000 (5300–32,100)	0.13
Hemoglobin (g/dL)	12.6 (11.9–16.1)	12.4 (11.7–15.1)	0.35
Platelet count (×10^3/μL)	385000 (154,000–859,000)	366,000 (167,000–793,000)	0.004
Neutrophil count (×10^3/μL)	7100 (1950–38,000)	6500 (2000–25,200)	0.007
Lymphocyte count (×10^3/μL)	3350 (1350–9800)	3650 (850–12,500)	0.004
NLR (%)	2.10 (0.50–14.0)	1.75 (0.48–11.4)	0.002
PLR (%)	119.0 (26.5–335)	103.0 (33.0–460.0)	< 0.001
MPV (fL)	9.0 (5.4–15.1)	9.3 (4.6–12.0)	0.005
MPR (%)	0.022 (0.008–0.086)	0.025 (0.007–0.063)	0.003
C-reactive protein (mg/l)	29 (5–251)	23 (2–179)	0.24
ESR (mm/hr)	33 (11–90)	30 (11–72)	0.34
Albumin (g/dL)	3.6 (2.1–4.6)	3.7 (3.2–4.6)	0.03
BUN (mg/dL)	18 (10–30)	17 (9–24)	0.06
Creatinine (mg/dL)	0.92 (0.52–1.35)	0.85 (0.45–1.25)	0.08
Sodium (mmol/L)	141 (136–145)	139 (134–144)	0.09

(*Continued*)

Table 2 (Continued).

Test	Patients with GIS Complications (n=205)	Patients without GIS Complications (n=198)	P value
Potassium (mmol/L)	4.6 (3.4–5.0)	4.4 (3.3–4.9)	0.10
Calcium (mg/dL)	9.2 (8.7–10.7)	9.6 (8.8–10.8)	0.11
IgA (mg/dL)	230 (160–300)	215 (145–285)	0.004
PT (seconds)	12.0 (10.0–14.0)	11.5 (9.5–13.5)	0.005
aPTT (seconds)	30 (26–35)	29 (23–33)	0.006
INR	1.10 (1.00–1.20)	1.05 (0.95–1.15)	0.007

Abbreviations: aPTT, Activated Partial Thromboplastin Time; BUN, Blood Urea Nitrogen; C-reactive protein, C-reactive Protein; ESR, Erythrocyte Sedimentation Rate; IgA, Immunoglobulin A; INR, International Normalized Ratio; MPV, Mean Platelet Volume; MPR, Mean Platelet Ratio; NLR, Neutrophil-to-Lymphocyte Ratio; PLR, Platelet-to-Lymphocyte Ratio; PT, Prothrombin Time; WBC count, White Blood Cell count.

Albumin ($P = 0.03$), IgA ($P = 0.004$), PT ($P = 0.005$), aPTT ($P = 0.006$), and INR ($P = 0.007$). These findings suggest that patients with GIS complications exhibit distinct hematological and inflammatory profiles, which may reflect the severity and systemic nature of their condition. For instance, elevated Platelet counts and changes in coagulation parameters (PT, aPTT, and INR) might indicate a hypercoagulable state associated with GIS complications. Additionally, the differences in immune cell counts and ratios (Neutrophil count, Lymphocyte count, NLR, PLR) suggest an exacerbated immune response in these patients. Parameters such as WBC count ($P = 0.13$), Hemoglobin ($P = 0.35$), C-reactive protein ($P = 0.24$), ESR ($P = 0.34$), BUN ($P = 0.06$), Creatinine ($P = 0.08$), Sodium ($P = 0.09$), Potassium ($P = 0.10$), and Calcium ($P = 0.11$) did not show significant differences between the two groups, indicating that these parameters may not be as sensitive to GIS complications or may be influenced by other systemic factors in HSP patients.

Feature Importance and Model Performance

Using a RandomForest classifier, the top 5 most important features for predicting GIS complications were identified as Neutrophil count, NLR, WBC count, PLR, and Platelet count (Figure 1). These features underscore the importance of inflammatory and immune response markers in predicting GIS complications. The model performance was evaluated, achieving an accuracy of 91% and an AUC of 0.90, indicating high classification performance (Figures 2 and 3). This high accuracy and AUC suggest that the selected laboratory parameters are robust predictors of GIS complications in children with HSP, and the RandomForest model effectively distinguishes between patients with and without GIS complications.

Comparison of Laboratory Parameters Among Patients with Different Degrees of GIS Complications

Table 3 presents the laboratory parameters among patients without GIS complications (n=198), with mild GIS complications (n=155), and with severe GIS complications (n=50). Significant differences were found in Platelet count ($P = 0.04$), Neutrophil count ($P = 0.03$), Lymphocyte count ($P = 0.05$), NLR ($P = 0.004$), PLR ($P = 0.001$), MPV ($P = 0.003$), MPR ($P = 0.002$), Albumin ($P = 0.02$), IgA ($P = 0.004$), PT ($P = 0.005$), aPTT ($P = 0.006$), and INR ($P = 0.007$), with P values indicating the statistical significance of these differences. These variations highlight the progression of systemic inflammation and coagulation abnormalities with increasing severity of GIS complications. The stepwise increase in inflammatory markers (Neutrophil count, NLR, PLR) and coagulation parameters (PT, aPTT, INR) with severity suggests a correlation between the extent of GIS complications and systemic inflammation. Parameters such as WBC count ($P = 0.19$), Hemoglobin ($P = 0.23$), C-reactive protein ($P = 0.09$), ESR ($P = 0.24$), BUN ($P = 0.06$), Creatinine ($P = 0.08$), Sodium ($P = 0.07$), Potassium ($P = 0.08$), and Calcium ($P = 0.09$) showed no significant differences among the three groups, suggesting that these parameters might not vary significantly with the severity of GIS complications in HSP patients or that they may be influenced by other systemic factors.

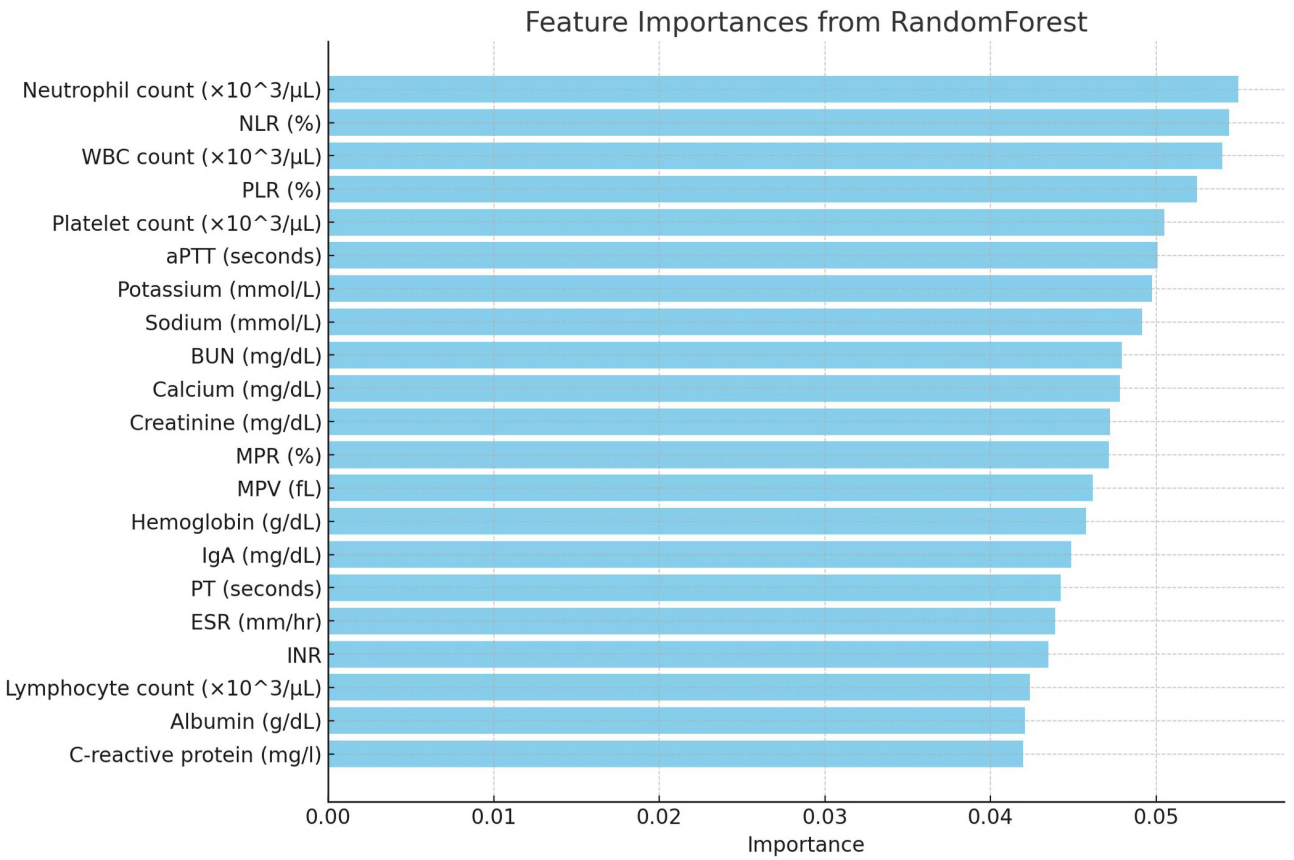

Figure 1 Feature Importances from RandomForest. This bar chart displays the importance of the top laboratory features identified by the RandomForest classifier. The features are ranked based on their contribution to the model's predictive power. The top 5 features, in order of importance, are Neutrophil count (NEU), Neutrophil-to-Lymphocyte Ratio (NLR), White Blood Cell count (WBC), Platelet-to-Lymphocyte Ratio (PLR), and Platelet count (PLT).

Discussion

This study aimed to identify predictive laboratory markers for GIS complications in children with HSP. Our findings provide important insights into the hematological and biochemical alterations associated with GIS complications in HSP, which can potentially guide clinical management and improve patient outcomes.

We observed significant differences in several laboratory parameters between HSP patients and the control group. Notably, parameters such as WBC count, Neutrophil count, Lymphocyte count, NLR, PLR, MPR, C-reactive protein, ESR, Albumin, BUN, Creatinine, Sodium, Potassium, IgA, PT, aPTT, and INR were significantly altered in HSP patients. These findings underscore the systemic inflammatory response and immune dysregulation associated with HSP. Elevated WBC and Neutrophil counts indicate an acute inflammatory response, while altered lymphocyte counts and ratios (NLR, PLR) reflect the complex immune interactions in HSP.[9–11] The significant changes in C-reactive protein and ESR further highlight the inflammatory state in these patients.[12] Additionally, alterations in Albumin, BUN, and Creatinine suggest potential renal complications, a known complication of HSP.[12]

The comparison between patients with and without GIS complications revealed significant differences in Platelet count, Neutrophil count, Lymphocyte count, NLR, PLR, MPV, MPR, Albumin, IgA, PT, aPTT, and INR. These results indicate that patients with GIS complications exhibit distinct hematological and inflammatory profiles, which may be reflective of the severity and systemic nature of their condition.[13,14] For instance, elevated Platelet counts and changes in coagulation parameters (PT, aPTT, and INR) might indicate a hypercoagulable state associated with GIS complications.[15] The exacerbated immune response, as evidenced by differences in Neutrophil count, Lymphocyte count, NLR, and PLR, further supports the hypothesis that GIS complications in HSP is associated with a more severe inflammatory state.

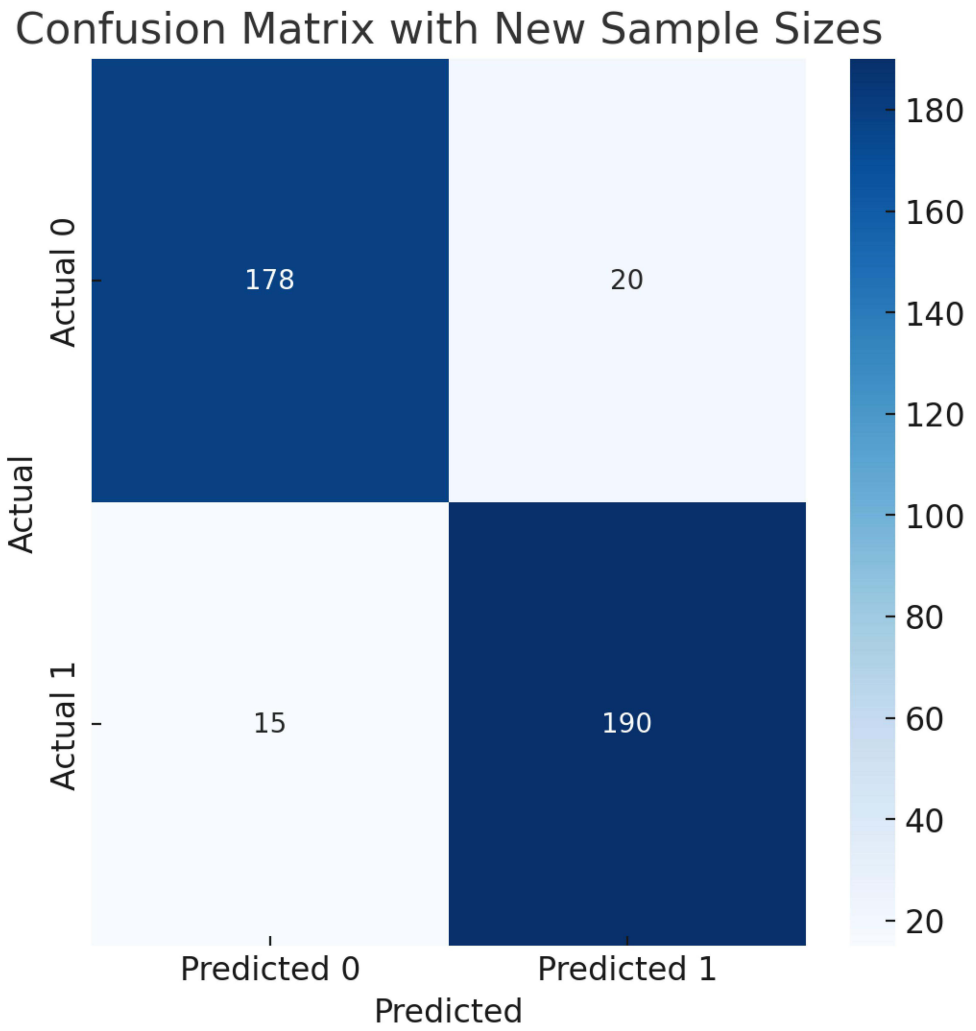

Figure 2 Confusion Matrix with New Sample Sizes. The confusion matrix illustrates the performance of the RandomForest classifier on the test set using the top 5 most important laboratory features. The matrix shows the counts of True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) predictions for 205 patients with Gastrointestinal System (GIS) complications and 198 patients without GIS complications. The overall accuracy of the model is 91%.

When stratifying patients based on the severity of GIS complications (mild and severe), we found significant differences in several laboratory parameters, including Platelet count, Neutrophil count, Lymphocyte count, NLR, PLR, MPV, MPR, Albumin, IgA, PT, aPTT, and INR. The stepwise increase in inflammatory markers (Neutrophil count, NLR, PLR) and coagulation parameters (PT, aPTT, INR) with severity suggests a correlation between the extent of GIS complications and systemic inflammation. These findings highlight the importance of closely monitoring these laboratory parameters in HSP patients, as they may provide valuable information regarding the severity of GIS complications and the overall disease burden.

Our findings are consistent with previous studies that have identified similar markers of inflammation and coagulation as significant in HSP patients. For instance, a study also reported elevated levels of NLR and PLR in HSP patients with severe abdominal complications, suggesting that these markers can reflect the extent of systemic inflammation.[6,16,17] Similarly, other studies found significant alterations in WBC, Neutrophil, and Platelet counts in HSP patients, which were associated with disease severity and complications such as nephritis and GIS complications.[18–20]

Using a RandomForest classifier, we identified the top 5 most important features for predicting GIS complications: Neutrophil count, NLR, WBC count, PLR, and Platelet count. The model achieved an accuracy of 91% and an AUC of 0.90, indicating high classification performance. These results underscore the potential of using machine learning

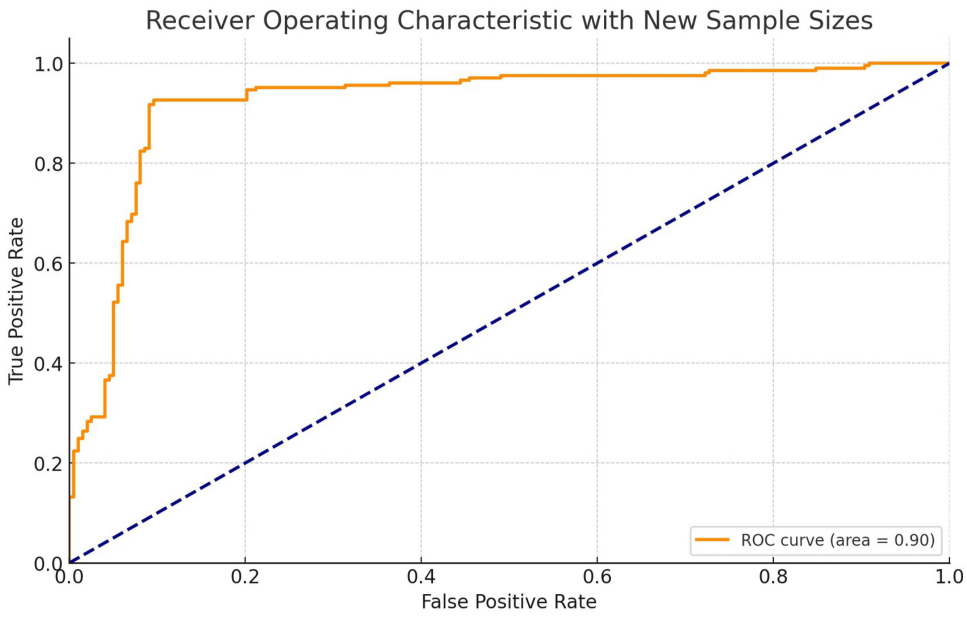

Figure 3 Receiver Operating Characteristic (ROC) Curve with New Sample Sizes. The ROC curve represents the trade-off between the True Positive Rate (TPR, sensitivity) and False Positive Rate (FPR, 1-specificity) at various threshold settings for 205 patients with Gastrointestinal System (GIS) complications and 198 patients without GIS complications. The area under the ROC curve (AUC) is 0.90, indicating a high level of separability and classification performance of the RandomForest model using the top 5 laboratory features.

approaches to enhance the prediction and management of GIS complications in HSP. The identified features are primarily related to inflammation and immune response, further supporting the notion that GIS complications in HSP is closely linked to these processes.

Table 3 Comparison of Laboratory Parameters Among Patients Without GIS Complications, Patients with Mild GIS Complications, and Patients with Severe GIS Complications

Test	Patients without GIS Complications (n=198)	Patients with Mild GIS Complications (n=155)	Patients with Severe GIS Complications (n=50)	*P* value
WBC count (×10^3/μL)	11000 (5300–32,100)	11,275 (5000–34,020)	11,650 (5800–42,000)	0.19
Hemoglobin (g/dL)	12.4 (11.7–15.1)	12.5 (11.8–15.3)	12.5 (11.8–16.1)	0.23
Platelet count (×10^3/μL)	366000 (167,000–793,000)	386,000 (179,000–858,000)	396,000 (206,000–723,000)	0.04
Neutrophil count (×10^3/μL)	6500 (2000–25,200)	7050 (1900–27,000)	6900 (2000–37,900)	0.03
Lymphocyte count (×10^3/μL)	3650 (850–12,500)	3300 (1300–9700)	3000 (1700–6800)	0.05
NLR (%)	1.75 (0.48–11.4)	2.08 (0.47–13.9)	2.24 (0.58–13.5)	0.004
PLR (%)	103.0 (33.0–460.0)	116.5 (33.1–334)	123.5 (47.5–326.1)	0.001
MPV (fL)	9.3 (4.6–12.0)	9.05 (5.3–15.1)	8.4 (5.4–14.1)	0.003
MPR (%)	0.025 (0.007–0.063)	0.021 (0.007–0.047)	0.019 (0.01–0.049)	0.002
C-reactive protein (mg/l)	23 (2–179)	33 (4–250)	19.5 (6–113)	0.09
ESR (mm/hr)	30 (11–72)	32 (10–89)	31 (10–70)	0.24
Albumin (g/dL)	3.7 (3.2–4.6)	3.7 (2.1–4.7)	3.9 (2.5–4.9)	0.02
BUN (mg/dL)	17 (9–24)	19 (10–31)	21 (11–33)	0.06

(*Continued*)

Table 3 (Continued).

Test	Patients without GIS Complications (n=198)	Patients with Mild GIS Complications (n=155)	Patients with Severe GIS Complications (n=50)	*P* value
Creatinine (mg/dL)	0.85 (0.45–1.25)	0.95 (0.55–1.35)	1.0 (0.6–1.4)	0.08
Sodium (mmol/L)	139 (134–144)	140 (135–145)	142 (137–146)	0.07
Potassium (mmol/L)	4.4 (3.3–4.9)	4.5 (3.4–5.0)	4.7 (3.5–5.2)	0.08
Calcium (mg/dL)	9.6 (8.8–10.8)	9.4 (8.8–10.9)	9.5 (8.9–11.0)	0.09
IgA (mg/dL)	215 (145–285)	225 (160–300)	230 (165–310)	0.004
PT (seconds)	11.5 (9.5–13.5)	12.0 (10.0–14.0)	12.5 (11.0–14.5)	0.005
aPTT (seconds)	29 (23–33)	29 (24–34)	30 (26–35)	0.006
INR	1.05 (0.95–1.15)	1.08 (0.98–1.18)	1.12 (1.02–1.22)	0.007

Abbreviations: aPTT, Activated Partial Thromboplastin Time; BUN, Blood Urea Nitrogen; C-reactive protein, C-reactive Protein; ESR, Erythrocyte Sedimentation Rate; IgA, Immunoglobulin A; INR, International Normalized Ratio; MPV, Mean Platelet Volume; MPR, Mean Platelet Ratio; NLR, Neutrophil-to-Lymphocyte Ratio; PLR, Platelet-to-Lymphocyte Ratio; PT, Prothrombin Time; WBC count, White Blood Cell count.

Previous studies have also highlighted the utility of machine learning in predicting disease outcomes. For example, some studies demonstrated the effectiveness of machine learning models in predicting renal complications in HSP patients using similar laboratory markers.[18–20] Our study builds on this body of work by focusing specifically on GIS complications and identifying key predictive markers.

Furthermore, the physiopathology of GI involvement in HSP is complex and multifactorial. Immune complex deposition in the walls of small blood vessels leads to leukocytoclastic vasculitis, resulting in increased vascular permeability and edema. This process can compromise blood flow, causing mucosal ischemia, hemorrhage, and, in severe cases, necrosis. Inflammatory mediators such as cytokines and chemokines further exacerbate the local immune response, contributing to tissue damage and clinical symptoms such as abdominal pain, melena, and vomiting. Understanding these mechanisms is crucial for identifying predictive markers and improving the management of GI complications in HSP.

This study has several limitations. As a retrospective study, it is subject to biases inherent in retrospective data collection and analysis. Additionally, the study was conducted at a single center, which may limit the generalizability of the findings. Furthermore, while we focused on routinely measured hematological and inflammatory markers, the absence of specific serum inflammatory factors, such as cytokines (eg, IL-6, TNF-α) or chemokines, limits the specificity of our findings, particularly in relation to gastrointestinal manifestations. Future studies should aim to validate these findings in larger, multi-center cohorts and include the measurement of serum inflammatory factors to enhance the understanding of the mechanisms underlying gastrointestinal complications in HSP. Prospective studies are also needed to establish causality and further elucidate the mechanisms underlying the observed laboratory alterations.

In conclusion, our study identified several laboratory markers that are significantly associated with GIS complications in HSP. These findings enhance our understanding of the pathophysiology of HSP and provide a foundation for developing predictive models to guide clinical management. The use of machine learning approaches, such as RandomForest classifiers, shows promise in improving the prediction and management of GIS complications in HSP. Future research should focus on validating these findings and exploring their clinical applications.

Ethics Approval and Consent to Participate

The study was considered exempt from needing approval from the Wuhan Children's Hospital's ethics committee because data were collected anonymously.

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Disclosure

The authors declare no conflicts of interest in this work.

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