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RESEARCH PAPER

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Early Detection of Biliary Atresia through Quantitative Ultrasound Imaging: A Retrospective Analysis of Key Diagnostic Features

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ABSTRACT

Biliary atresia (BA) is a progressive fibroinflammatory obstruction of the intra- and extrahepatic bile ducts, accounting for approximately 25–30% of neonatal cholestasis cases worldwide. Delayed diagnosis significantly increases the risk of liver failure and the need for transplantation. This study aimed to evaluate the diagnostic value of specific ultrasonographic parameters triangular cord sign, hepatic artery to portal vein (HAD/PV) ratio, and hepatic subcapsular flow (HSF) in the early detection of BA. A retrospective observational analytic study was conducted at Dr. Soetomo General Academic Hospital, involving 82 neonates with cholestasis between January 2019 and December 2023. Ultrasound images acquired using the GE LOGIQ Series E9 XDClear 2.0 were reviewed by blinded pediatric radiology consultants via the HOROS DICOM viewer. Statistical analysis revealed that both the triangular cord sign ($p = 0.024$; OR = 3.158) and hepatic subcapsular flow ($p = 0.003$; OR = 5.635) showed significant association with BA, while the HAD/PV ratio did not reach statistical significance ($p = 0.087$). Triangular cord sign and hepatic subcapsular flow are reliable sonographic markers that support early diagnosis of biliary atresia, whereas the HAD/PV ratio showed limited diagnostic relevance in this cohort. These findings reinforce the utility of non-invasive ultrasound imaging in differentiating BA from other causes of neonatal cholestasis. Incorporating these parameters into routine neonatal screening protocols may facilitate earlier surgical intervention and improve long-term outcomes

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I. INTRODUCTION

Biliary atresia (BA) is a rare but life-threatening hepatobiliary disorder in neonates characterized by fibroinflammatory obliteration of intra- and extrahepatic bile ducts [1], [2]. Early detection is critical to ensure timely surgical intervention, which significantly affects prognosis. In the era of precision medicine and advancing medical imaging, ultrasonography (USG) remains the primary non-invasive diagnostic modality due to its real-time imaging, absence of ionizing radiation, and broad availability [3].

Several studies have highlighted the diagnostic potential of ultrasonographic features such as the triangular cord sign (TC) and Doppler flow patterns in detecting BA [4], [5], [6]. However, their diagnostic accuracy has often been inconsistent due to factors such as operator dependency, lack of standardized imaging protocols, and variability in parameter thresholds. Despite these limitations, ultrasonography remains the preferred initial imaging modality for BA, owing to its non-invasiveness, real-time imaging capability, and broad accessibility in clinical settings. Recent advancements in ultrasonographic technology including high-resolution B-mode and color Doppler imaging have significantly improved the ability to visualize specific sonographic markers of BA. Among these, the triangular cord sign (TC), hepatic artery to portal vein (HAD/PV) ratio, and hepatic subcapsular flow (HSF) have emerged as key diagnostic indicators. These features provide structural and hemodynamic insight into hepatobiliary abnormalities.

This study, conducted by pediatric radiologists at Dr. Soetomo General Academic Hospital, aims to evaluate the diagnostic utility of these ultrasonographic parameters using standardized imaging protocols and digital systems. By addressing the limitations of earlier studies, this research contributes to the refinement of non-invasive diagnostic strategies for early detection of BA in neonates.

BA is a chronic fibroinflammatory disorder that blocks both intrahepatic and extrahepatic bile ducts, representing about 25–30% of neonatal cholestasis cases [7], [8], [9]. The worldwide occurrence of biliary atresia is estimated at 1 per 3,000–20,000 live births, but reports

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indicate that it is more common in East Asia [9], [10]. Despite this, comprehensive epidemiological data on BA in Indonesia are still lacking. Clinically, early-stage BA is often misclassified as benign neonatal jaundice, leading to delays in appropriate diagnosis and intervention [11], [12], [13]. Moreover, there is a notable absence of local studies evaluating the diagnostic accuracy of specific ultrasonographic (USG) parameters such as the triangular cord sign, hepatic artery to portal vein (HAD/PV) ratio, and hepatic subcapsular flow (HSF) when applied using standardized imaging protocols and modern ultrasound equipment. This research gap necessitates a focused investigation to validate the diagnostic performance of these features within the Indonesian clinical context and to support earlier and more accurate detection strategies for BA [14], [15], [16], [17].

BA was initially described in 1817 as an “incurable condition of the biliary system”; however, with scientific progress, different therapeutic approaches started to be applied by the 1950s [18]. During this period, Kasai Portoenterostomy (KP), a surgical procedure developed in Japan, emerged as a promising treatment option. To date, KP remains the definitive management for BA [19], [20]. Despite the significant outcome of KP, the prognosis of KP still depends on the age at the time of surgery. The five-year survival rate for patients with biliary atresia who underwent Kasai Portoenterostomy before the age of 30 days is greater than 65% [21]. However, the survival rate decreases when the treatment is performed at an older age, with a survival rate of less than 50% at an age greater than 91 days and a survival rate of 29.2% at an age greater than 121 days. It is crucial to diagnose the condition at the earliest possible stage, as the timing of surgery can significantly impact the prognosis [15], [16], [22], [23].

Given the inherent limitations of many diagnostic techniques for biliary atresia, ultrasonography remains the most widely used initial modality due to its non-invasive nature, cost-effectiveness, and accessibility in neonatal care. However, previous studies have often lacked standardized imaging protocols, objective evaluation criteria, and advanced imaging technology, which has contributed to variable diagnostic accuracy. Compared to earlier research, this study offers a more rigorous diagnostic approach by employing high-resolution ultrasound equipment (GE LOGIQ Series E9 XDClear 2.0), a standardized imaging protocol, and blinded image analysis by certified pediatric radiologists using the HOROS DICOM viewer. These methodological strengths aim to minimize observer bias and improve diagnostic consistency. The objective of this study is to investigate the diagnostic utility of ultrasonographic markers triangular cord sign, HAD/PV ratio, and hepatic subcapsular flow for distinguishing biliary atresia from other neonatal cholestasis disorders, with validation against histopathology in an Indonesian clinical population.

II. MATERIALS AND METHOD

A. Respondents or Objects

This study involved neonatal patients with a diagnosis of cholestasis who were hospitalized at Dr. Soetomo General Academic Hospital from January 2019 to December 2023. A total of 82 patients were included, consisting of both biliary atresia and non-biliary atresia cases with a 1:1 ratio. The subjects were neonates aged ≤90 days at the time of initial examination. Data on gender, age, body weight, and clinical history were retrieved from electronic medical records. All included patients had undergone abdominal ultrasonography and liver biopsy for histopathological confirmation. The inclusion criteria required the availability of complete ultrasound image data and histopathological results.

B. Data Acquisition

Ultrasound imaging was performed using a GE LOGIQ Series E9 XDClear 2.0 high-resolution ultrasound machine equipped with B-mode and Doppler capabilities. The parameters assessed in this study were the triangular cord sign (TC), hepatic artery to portal vein ratio (HAD/PV), and hepatic subcapsular flow (HSF). Raw image data in DICOM (Digital Imaging and Communication in Medicine) format were retrieved from the hospital’s Radiology Information System (RIS).

C. Data Processing

The DICOM image files were re-evaluated by the research team under the supervision of two independent pediatric radiology consultants using the HOROS DICOM viewer software. To maintain objectivity, the reviewers were kept unaware of the patients’ identities and their histopathological findings. Each parameter was assessed according to a standardized scoring sheet developed for this study. Discrepancies between reviewers were resolved by consensus.

D. Data Collection

In addition to imaging data, patient demographic information including age, gender, clinical symptoms, and histopathological diagnosis was extracted from electronic medical records. All information was anonymized to protect patient privacy and entered into a standardized data collection form for later evaluation.

E. Data Analysis

Statistical analyses were carried out using SPSS version 23. Descriptive statistics, such as mean and standard deviation, were employed to summarize demographic data and imaging findings. Cohen’s kappa test was applied to assess inter-observer agreement, which showed a high level of reliability ($\kappa = 0.8–0.9$; $p < 0.05$). Inferential statistics were employed to evaluate associations between ultrasonographic features and histopathology-confirmed biliary atresia. A 95% confidence interval (CI) was utilized, and results with a p-value below 0.05 were considered statistically significant.

III. RESULTS

A. Study Sample Demography

The study population comprised 82 patients, of whom 49

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were male and 33 were female. Forty-one patients were diagnosed with biliary atresia based on histopathology or clinical consensus.

Table 1. Distribution of Age

Age range (days)	Diagnose		Total
	Biliary Atresia	Non-Biliary Atresia	
≤30	0 (0%)	2 (4.9%)	2 (2,4%)
31-60	8 (19.5%)	10 (24.4%)	18 (22.0%)
61-90	11 (26.9%)	12 (29.2%)	23 (28.0%)
91-120	6 (14.6%)	5 (12.2%)	11 (13.4%)
≥121	16 (39.0%)	12 (29.3%)	28 (34.2%)
Total	**41 (100%)**	**41 (100 %)**	**82 (100%)**

Table 1 showed the sample comprised 82 individuals, 49 males (59.8%) and 33 females (38.4%). Biliary atresia diagnosis was more prevalent in males than in females, with 23 males (56.1%) and 18 females (43.9%) affected.

The group with histopathological results that did not support biliary atresia consisted of other diagnoses, including neonatal hepatitis (18 patients), TORCH infection with severe malnutrition (9 patients), CMV neonatal hepatitis (7 patients), hypothyroidism with severe malnutrition (1 patient), ABO incompatibility (1 patient), chronic cholecystitis (1 patient), and other intra/extrahepatic cholestasis (4 patients). The age range ≤30 days was the smallest group, consisting of two patients (2.4%), while above a third of the samples (28 patients, 34.2%) constituted the age group of ≥121 days.

B. Ultrasound Finding

The abdominal ultrasound examination performed at our center was conducted to identify the triangular cord sign (TC Sign) (Fig 1), a fibrotic ductal remnant appears as a triangular or tubular structure, characterized by thickened echogenic tissue along the anterior aspect of the portal vein wall, located distal to the right portal vein. This examination was conducted from a longitudinal projection, and the right hepatic artery, which was located anterior or in close proximity to the branching of the portal vein, was excluded from the imaging. The TC sign was considered positive if the thickness was 2 mm or 4 mm, including the hepatic artery caliber. However, this measurement was highly dependent on the position and skill of the operator [16], [24].

An additional diagnostic marker of biliary atresia is an elevated hepatic artery-to-portal vein diameter ratio. In this study, the diameters of the hepatic artery and portal vein were measured at the proximal site of the right portal vein bifurcation (into anterior and posterior branches) by positioning the electronic cursor from inner wall to inner wall. A suspicion of biliary atresia arises when the hepatic artery diameter is greater than 1.5 mm or when the artery-to-vein ratio exceeds 0.45. [16], [25], [26].

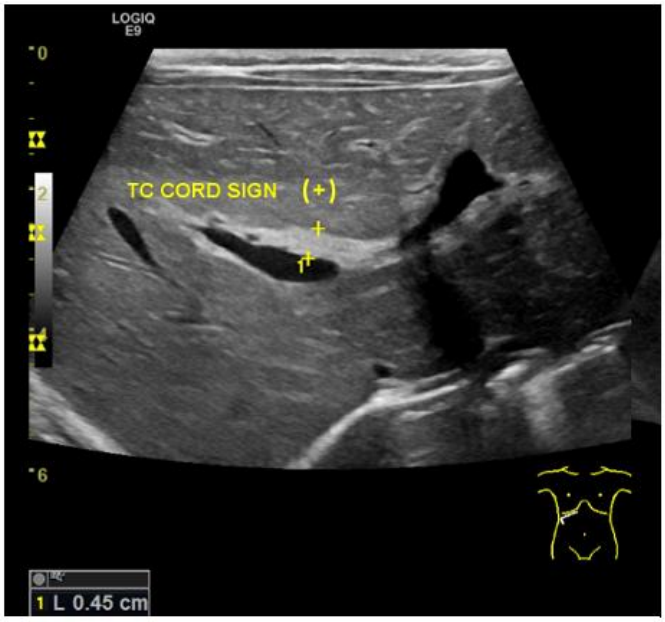

Fig 1. True Positive Triangular Cord Sign In Biliary Atresia

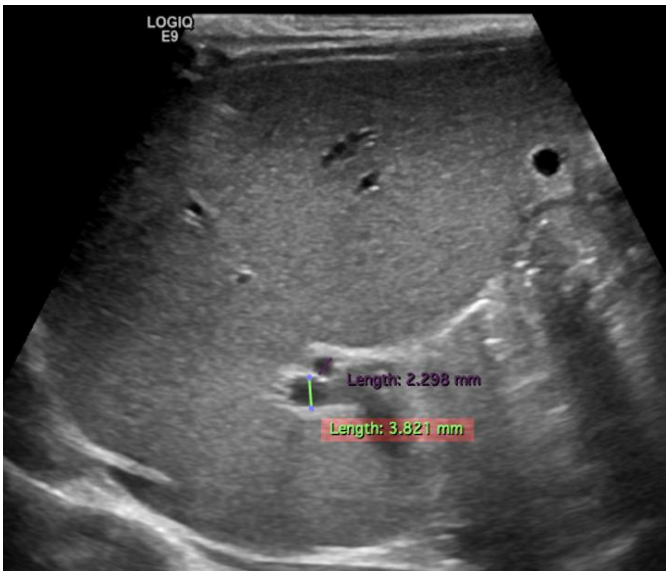

Fig 2. . True Positive Increase Ratio HAD/PV (0,6) in Biliary Atresia

Fig 2. Ultrasound image showing the measurement of the hepatic artery and portal vein diameters at the proximal bifurcation of the right portal vein. The green line (2.298 mm) indicates the inner-to-inner wall diameter of the hepatic artery, while the red line (3.821 mm) indicates the portal vein diameter. These measurements were taken using the GE LOGIQ E9 ultrasound system with high-resolution B-mode imaging. A HAD/PV ratio greater than 0.45 or a hepatic artery diameter exceeding 1.5 mm may suggest the presence of biliary atresia

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In Fig 3. Color Doppler ultrasound image showing prominent hepatic subcapsular flow, evidenced by increased arborization and proliferation of hepatic arterial branches near the liver capsule (marked in red). This finding is indicative of compensatory arterial remodeling typically seen in biliary atresia, particularly in advanced fibrotic changes. Subcapsular flow is considered a supportive diagnostic feature of BA, though its visibility may vary depending on ultrasound settings and operator experience. The final finding was the appearance of hepatic subcapsular flow, indicating the abnormal enlargement and proliferation of the hepatic artery branches. These parameters are useful for predicting biliary atresia and provide valuable insight when bridging fibrosis leads to the secondary feature of cirrhosis; however, discrepancies in hepatic subcapsular flow detection may be attributed to the difference in the ultrasound machine and parameter settings. In the absence of a detailed description of the quantification of this sign in the prior literature, it is frequently employed as a supplementary indicator in the examination of patients with biliary atresia [27], [28], [29].

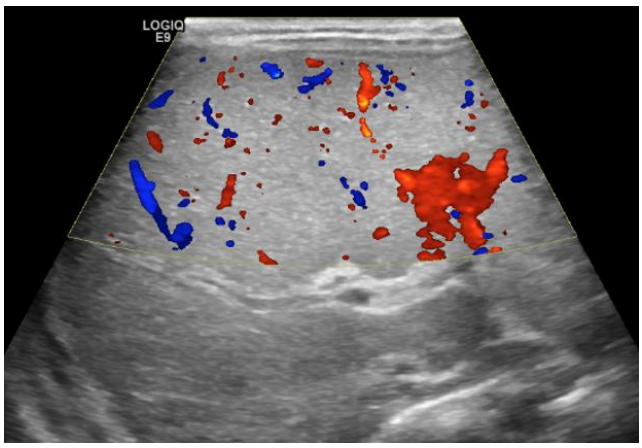

Fig 3. Detection of Hepatic Subcapsular Flow in Patients with Biliary Atresia

Ultrasonographic imaging protocols were able to visualize TC signs as echogenic bands anterior to the portal vein (Figure 3). The Doppler mode effectively identified hepatic subcapsular arterial flow patterns in suspected BA cases. The results also indicated operator dependency in image acquisition and the need for standardized imaging techniques.

C. Ultrasound Finding

The data analysis was conducted by testing the correlation between the ultrasonographic findings and biliary atresia, as outlined in Table 2. Ultrasonographic findings showed that the triangular cord sign had a statistically significant association with BA (p = 0.024; OR = 3.158), as did hepatic subcapsular flow (p = 0.003; OR = 5.635). The HAD/PV ratio was elevated in several cases but did not reach statistical significance (p = 0.087).

Table 2. Correlation Between Ultrasonographic Findings And Biliary Atresia

Variable	Significance	Sensitivity	Specificity	PPV	NPV	Accuracy	OR
TC Sign	0,024	73,17%	53,65%	61,22%	66,66%	63,41%	3,158
HSF	0,003	43,90%	87,80%	78,26%	61,01%	65,85%	5,635
HAD /PV Ratio	0,087	-	-	-	-	-	-

TC Sign = Triangular Cord Sign; HSF = Hepatic subcapsular flow; HAD/PV Ratio = Hepatic Artery Diameter/Portal Vein Ratio.

IV. DISCUSSION

Ultrasound-based diagnostics have proven to be essential in the early detection of biliary atresia. The integration of high-frequency transducers and Doppler imaging has significantly improved the visualization of sonographic markers such as the triangular cord sign and hepatic subcapsular flow. Table 1 demonstrates that he ratio of hepatic artery diameter to portal vein diameter did not yield a statistically significant correlation in this study. This may be attributed to the study sample, which was predominantly comprised of subjects within the age range of >121 days, which could indirectly result in prolonged hepatic inflammation, an event that might obscure the results of this study. The elevated ratio of hepatic artery diameter to portal vein diameter may be attributed to the hepatic artery enlargement, which serves as a compensatory mechanism for the increased blood supply to the biliary tree. Furthermore, the presence of vascular malformations and decreased portal flow, which are secondary signs of cirrhosis of the liver, may also contribute to these findings. As has been noted in other studies, the diameter of the hepatic artery to portal vein ratio is difficult to standardize. The range of specificity is considerable (0.46–0.79), and measuring the hepatic artery diameter can be challenging for operators, particularly in patients who are less than 30 days old [24], [25], [30].

Another notable feature identified in this study was the triangular cord sign, consistent with findings from previous research. Prior studies have reported a strong association between the triangular cord sign and biliary atresia. It is currently considered one of the most reliable

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non-invasive diagnostic indicators. Nevertheless, in early or mild cases, this sign may not be detected initially but tends to become more evident as the disease advances. [16], [24], [31], [32].

The results indicated that the triangular cord sign had the highest sensitivity, with an accuracy of 63.41% against biliary atresia. However, this sign is highly dependent on operator technique and experience, resulting in discrepancies in imaging and calculation. Consequently, reported sensitivity varies considerably, from 23% to 100%. Ultrasound assessment may become challenging in cases of periportal inflammation or cirrhosis, as the cord sign is often absent [24], [26], [33].

Hepatic subcapsular flow is also an imaging finding that may be used to establish the diagnosis of biliary atresia in accordance with the recommendations by the North American Society for Gastroenterology, Hepatology and Nutrition (NASPGHAN) and the European Society for Gastroenterology, Hepatology and Nutrition (ESPGHAN) [24], [34], [35]. Although the exact mechanism remains unclear, this phenomenon is believed to represent a compensatory adaptation that enhances biliary blood flow and is often seen in cirrhosis. According to Lee et al., hepatic subcapsular flow demonstrated 100% sensitivity, 86% specificity, 85% positive predictive value, and 100% negative predictive value. The present study produced comparable findings, with a specificity of 87.80%. El-Guindi et al. further reported that incorporating hepatic subcapsular flow with biopsy-confirmed ductular proliferation significantly improved diagnostic accuracy, achieving a sensitivity of 96.3% and specificity of 100% [28], [29], [34], [36].

Our findings validate the use of the triangular cord sign as a sensitive marker and demonstrate the high specificity of hepatic subcapsular flow. These parameters are particularly valuable when examined using advanced imaging protocols. Although the HAD/PV ratio showed promise, variability in vessel measurement and patient age likely influenced its significance. This highlights the importance of imaging standardization and training in the application of radiological technology.

The use of DICOM-based analysis software such as HOROS allowed for consistent image review and facilitated inter-observer reliability. The findings support the integration of imaging informatics in radiological diagnostics, particularly in pediatric hepatobiliary diseases

The findings of this study diverge from those of previous studies due to the discrepancies in the number of samples and the age of the participants. The present study had a larger sample size, while the previous study included a relatively older cohort, with an age range of 121 days or more comprising the majority of the group. Additionally, seven patients were diagnosed with non-biliary atresia with CMV hepatitis, which may have reduced the sensitivity of hepatic subcapsular flow; in accordance with the other research, in patients with CMV hepatitis, a hepatic subcapsular flow pattern can be observed, as illustrated in Figure 4 [29], [36].

Fig 4. Color Doppler ultrasound image showing hepatic subcapsular flow in a neonate. Although such flow patterns are typically associated with biliary atresia, this particular case was later confirmed as cytomegalovirus (CMV) hepatitis, indicating a false-positive result. This

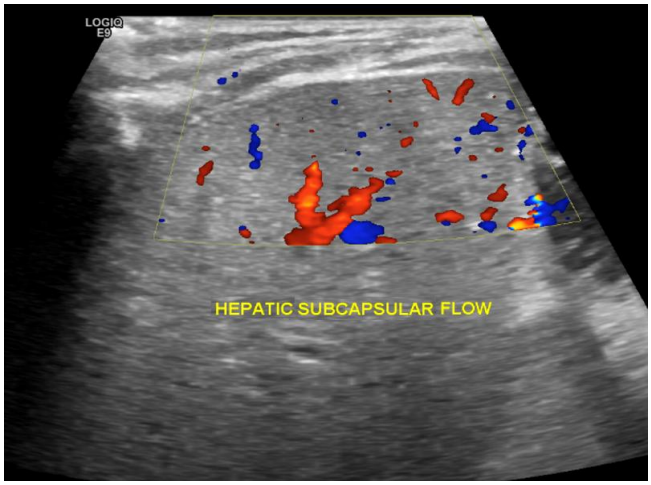

Fig 4. False Positive Hepatic Subcapsular Flow In a Patient With CMV Hepatitis

highlights the need for cautious interpretation of hepatic subcapsular flow and the importance of combining imaging findings with clinical and laboratory data.

This study adopted a retrospective approach, with data obtained from the DICOM database, leading to the limited ability to confirm findings in cases where there were significant discrepancies between examination results. A number of patients were suspected of having biliary atresia, but no liver biopsy was performed. Consequently, the final diagnosis was reached through clinical consensus based on the patient's medical history, which was recorded in the electronic medical record.

This study has several limitations. Firstly, the relatively small sample size and uneven distribution of cases across different neonatal age groups limited our ability to analyze age-related diagnostic variability. Future studies should incorporate age stratification to examine whether ultrasonographic parameters vary significantly by age. Additionally, employing a mixed-methods approach with an agreed imaging protocol and a multidisciplinary diagnostic team may help capture more representative patient data and improve data homogeneity.

These findings emphasize the importance of enhancing early screening protocols for neonates suspected of cholestasis. Prompt recognition of essential ultrasonographic indicators, including the triangular cord sign and hepatic subcapsular flow, can play a crucial role in minimizing surgical delays and enhancing long-term outcomes in biliary atresia, especially within resource-constrained and developing regions.

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V. CONCLUSION

This research aimed to determine the diagnostic accuracy of selected ultrasonographic features, including the triangular cord sign, hepatic artery-to-portal vein (HAD/PV) ratio, and hepatic subcapsular flow (HSF), in the early identification of biliary atresia through the use of standardized imaging techniques and objective analysis. Among 82 neonates with cholestasis, the triangular cord sign and HSF demonstrated statistically significant associations with biliary atresia ($p = 0.024$; OR = 3.158 and $p = 0.003$; OR = 5.635, respectively), whereas the HAD/PV ratio was not significant ($p = 0.087$). The mean HAD/PV ratio in the BA group was 0.65 ± 0.11 compared to 0.72 ± 0.09 in non-BA subjects. The integration of high-resolution ultrasound equipment with blinded interpretation improved diagnostic reliability and minimized observer bias.

Future work should explore the incorporation of automated image analysis and artificial intelligence (AI)-based diagnostic tools to enhance objectivity and reproducibility. Larger multicenter studies are also recommended to validate these findings and support the development of national diagnostic protocols for biliary atresia

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