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Transient and persistent small-bowel intussusception in children: a decision tree analysis model based on ultrasound and clinical findings

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Abstract

Purpose To develop a systematic and efficient decision tree analysis (DTA) model to improve the diagnostic accuracy of transient small-bowel intussusception (TSBI) and persistent small-bowel intussusception (PSBI) in children.

Methods From February 2019 to June 2022, ultrasound (US) features and clinical findings of pediatric patients with small-bowel intussusception (SBI)—including SBI diameter, outer bowel wall thickness, thickness of the head and body of the intussusceptum, length of the intussusceptum, and presence of pathological lead points (PLPs)—were recorded and analyzed. A classification and regression tree algorithm was then used to develop a DTA model, which was trained and validated by randomly categorizing the patients into training (60%, 200/331) and validation (40%, 131/331) datasets to assess diagnostic performance.

Results A total of 331 patients with SBI (270 with TSBI and 61 with PSBI) were included; the maximum age was 9 years. The initial diagnostic predictor in the DTA model was the detection of a PLP via US, followed by intussusceptum length ($P < 0.001$). The sensitivity, specificity, and accuracy of the DTA model were 98.2%, 100%, and 98.6%, respectively.

Conclusion The DTA model developed in this study facilitated the differential diagnosis of TSBI and PSBI in pediatric patients with SBI, with a clinical concordance rate of 98.6%.

Keywords Ultrasound, Children, Small-bowel intussusception, Transient, Model

Introduction

Intussusception, one of the most common pediatric abdominal emergencies, occurs when a segment of the intestine invaginates into an adjacent segment [1–3]. It can be classified by location (small-bowel, ileocolic, ileo-ileocolic, and colocolic intussusception) [4, 5] and by pathology as either transient small-bowel intussusception (TSBI) or persistent small-bowel intussusception (PSBI). TSBI refers to intussusception that resolves spontaneously, whereas PSBI does not resolve without intervention [6–8]. TSBI is more common than PSBI [9–14]. Intervening in cases of TSBI is unnecessary and may lead to increased surgical trauma in children [15]. Conversely, timely intervention is essential for patients with PSBI, as delayed treatment can result in serious complications such as intestinal necrosis, perforation, or even death [16, 17]. Therefore, differentiating TSBI from PSBI is critical for determining appropriate treatment strategies in patients with small-bowel intussusception (SBI).

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The clinical presentation of SBI varies; thus, differentiating TSBI from PSBI based on symptoms is difficult. Abdominal pain, nausea, vomiting, lethargy, "currant jelly" stools, and even asymptomatic presentation can be observed in both TSBI and PSBI patients [18]. Physical examination, blood tests, and imaging techniques (ultrasound [US], X-ray, computed tomography [CT], magnetic resonance imaging [MRI], and barium enema) can aid in identifying TSBI and PSBI [19]. X-ray is more sensitive than US for diagnosing pneumoperitoneum or high-grade bowel obstruction in patients suspected of having SBI [17]. Although CT, MRI, and barium enema provide more detailed information, their use is generally discouraged in children due to adverse effects such as the need for sedation and exposure to radiation [19]. As US is a simple, repeatable, radiation-free, and cost-effective technique, it is particularly suitable for examining and diagnosing SBI in children. It can assist in differentiating TSBI from PSBI as well as in detecting pathological lead points (PLPs) [20]. Therefore, US is the preferred modality for diagnosing SBI in pediatric patients [21, 22]. The US features of SBI are well established (e.g., "concentric circles" and "pseudokidney" signs), and correlations between PLPs, length, thickness, and other findings as independent predictors of surgical intervention have been documented in previous studies [11, 21]. However, a systematic, simple, and efficient decision tree analysis (DTA) model for identifying TSBI and PSBI in children is lacking, especially for novice sonographers. A DTA model is a machine learning approach that recursively splits data into subsets based on feature values to maximize purity (e.g., minimizing entropy or Gini impurity), forming a tree-like structure of decisions and outcomes. Its strength lies in simplicity, interpretability, and its ability to mimic human decision-making by prioritizing the most discriminative features at each node to classify or predict outcomes. In this study, we aimed to develop a DTA model to improve the diagnostic accuracy of TSBI and PSBI.

Materials and methods

Patients

Pediatric patients with SBI (younger than 18 years) were prospectively analyzed from February 2019 to June 2022. Patients with incomplete data—due to missing measurements or unclear images caused by excessive crying—were excluded. Patients with severe underlying conditions or other acute abdominal diseases were also excluded. The inclusion and exclusion criteria are presented in Fig. 1.

The included children underwent US examination after being suspected of having SBI by the emergency physician. Their demographic information (age and sex), clinical presentations (including abdominal pain, nausea, vomiting, and "currant jelly" stools), US-measured data (SBI diameter, outer bowel wall thickness, thickness of the head and body of the intussusceptum [the folded and distal portions of the inserted small bowel], and length of the intussusceptum), and the presence or absence of a PLP on US were recorded. Data on diagnosis, treatment, and follow-up were also collected.

Identifying information was removed during the study to maintain anonymity, and the research results did not involve any commercial interests. All screening and documentation procedures were performed after obtaining informed consent from the children's parents. The maximum age of the children included in this study was 9 years. This study

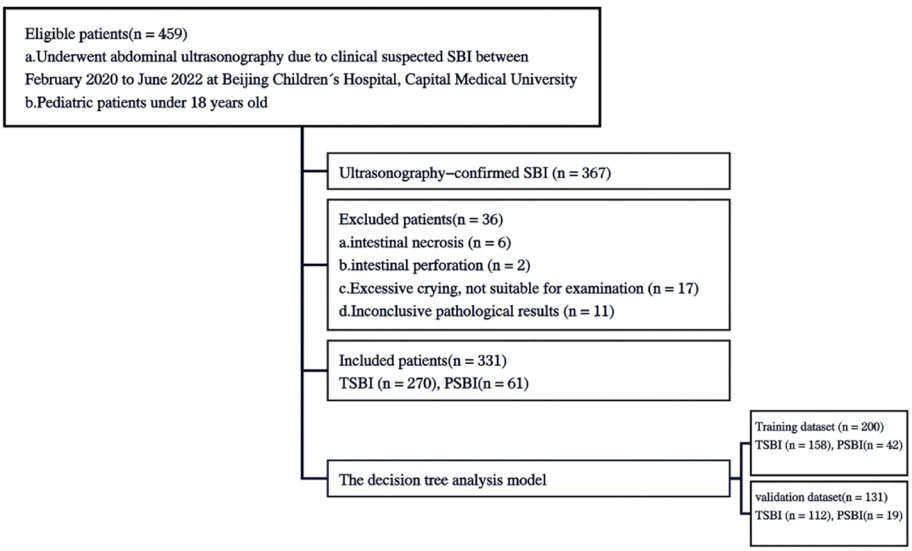

Fig. 1 Flowchart of the established and validated DTA model that met the inclusion and exclusion criteria

was approved by the Ethics Committee of Beijing Children's Hospital, affiliated with Capital Medical University (No.: IEC-C- 006-A04-V.06).

US instruments and image collection

US instruments

Philips IU22 (with L12 - 5 probe, frequency 5–12 MHz) and Hitachi Totem (with L7 - 3 probe, frequency 3–7 MHz) US systems were used as appropriate, depending on the child's size and body habitus.

Image collection

US was performed with the child lying calmly on the examination bed. If the child was crying and could not be examined properly, 10% chloral hydrate (0.5–1.0 mL/kg, administered orally for sedation) was given by clinicians after obtaining parental consent. Only nine children cried excessively, and their parents requested sedation prior to the examination.

When "concentric circles" and "pseudokidney" signs were detected, the SBI diameter was measured on the largest transverse section of the concentric circle, whereas the outer bowel wall thickness, thickness of the head and body of the intussusceptum, and length of the intussusceptum were measured on the longitudinal section. The presence or absence of a PLP—secondary factors within the SBI such as a swollen intestinal wall or a cystic or solid mass—was assessed via US, particularly at the head of the inserted bowel. The PLP was most easily identified at the center of the concentric circles or the head on the longitudinal image. Blood flow in the intestinal wall was evaluated using Doppler US. Patients were re-examined with US 45 min after the initial scan to determine whether the SBI had resolved spontaneously [2]. If spontaneous resolution was observed, the case was classified as TSBI. If the SBI was only partially resolved and there were no signs of ischemia, US was repeated at 45-min intervals until complete resolution occurred. If the SBI showed no loosening, it was classified as PSBI. All measurement data were collected and recorded by the study group sonographers using a standardized imaging protocol.

Treatment and follow-up results

Patients with TSBI required no treatment, whereas those with PSBI required further management with medication (antispasmodic therapy) or surgical intervention. During this process, children were to be promptly evaluated by a physician if any warning signs appeared, such as decreased or absent intestinal wall blood flow signals.

Statistical analysis

Measurement data are expressed as M (P25, P75), and differences between the TSBI and PSBI groups were evaluated using the Mann–Whitney U test. All eligible samples were summarized and randomized using the Excel random function, and patients were assigned to training and validation sets in a 6:4 ratio, which were used for model development and validation, respectively. Based on US findings, demographic information, and postoperative diagnoses of patients in the training set, a classification and regression tree (CART) algorithm was applied to generate a diagnostic decision tree. The performance of the CART model was then evaluated using the validation set.

Complex parameters were used for the CART model, and cross-validation was employed to verify the results. The analysis indicated that when the complexity parameter (cp) was set to 0.0015, the DTA model met stability requirements while maintaining efficient performance, and the level of branching demonstrated acceptable generalizability. The final DTA model was derived by pruning the initial model based on the selected cp value. In the training set, the DTA model achieved a perfect fit, with an area under the receiver operating characteristic curve (AUROC) of 1.00 (95% CI: 0.982–1.000). The AUROC for the validation dataset was 0.98 (95% CI: 0.949–0.999), indicating that the model performed consistently on new data and demonstrated strong generalizability.

Table 1 Clinical information of the 331 patients patients

	Number	Proportion (%)
Age (years)		
< 2	151	45.6
2–5	159	48.0
5–9	21	6.3
Sex		
Male	176	53.2
Female	155	46.8
Clinical manifestations		
Abdominal pain	169	51.1
Crying	142	42.9
Vomiting	218	65.9
Bloody stool	68	20.5
Palpable mass	172	52.0

Table 2 Pathological lead points in patients with SBI

	Number	Proportion (%)
Meckel's diverticulum	9	19.6
Intestinal polyps	14	30.4
Duplication of intestine	2	0.1
Malignant lymphoma	5	10.9
Peutz–Jeghers syndrome	6	13.0
Purpura abdominalis	5	10.9
Ectopic pancreas	2	0.1
Postoperative adhesions	3	6.5

Table 3 Comparison of ultrasound parameters between TSBI and PSBI

Parameter	TSBI ($n=270$)	PSBI ($n=61$)	Z value	*P* value*
Lesion diameter (cm)	2.0 (1.7, 2.4)	3.2 (3.0, 3.4)	− 10.041	< 0.001
Lesion length (cm)	2.6 (2.1, 3.075)	4.3 (3.5, 4.65)	− 10.008	< 0.001
Outer bowel wall thickness (mm)	2.2 (2.0, 2.4)	1.8 (1.6, 2.05)	− 7.236	< 0.001
SBI head thickness (mm)	2.6 (2.5, 2.7)	3.5 (3.1, 3.8)	− 10.665	< 0.001
SBI body thickness (mm)	2.4 (2.3, 2.5)	2.6 (2.4, 2.85)	− 4.096	< 0.001

*: Kruskal–Wallis Test

R software version 4.0 was used for statistical analysis, with the *rpart* package as the extension. Default values were applied for the relevant parameters of the decision tree. After the initial decision tree model was established, tenfold cross-validation was used to prune the tree and obtain the final model ($P < 0.05$).

Results

Clinical information and therapeutic outcomes

In this study, the patients' ages ranged from 2 months to 9 years, with a mean age of 4.58 ± 4.42 years. Among the 331 pediatric patients with SBI enrolled between February 2019 and June 2022, 61 were diagnosed with PSBI and 270 with TSBI. The demographic information and clinical presentations of these patients are summarized in Table 1.

US findings

The US detection rate of PLP was 93.5% (43/46), representing 70.5% (43/61) of PSBI cases and 13% (43/331) of all cases in this study. Among patients without a PLP, 5.4% (15/61) of those with PSBI had an intussusception length ≥ 3.8 cm ($P < 0.001$).

Pathology results

In this study, 75.4% (46/61) of PSBI cases were found to be associated with a PLP, with eight types of pathologies identified as causes (Table 2). PLPs in three patients—due to Meckel's diverticulum (MD), ectopic pancreas, and postoperative adhesions—were not detected via US. In 11.6% (5/43) of patients whose PLP was detected via US, the US findings were inconsistent with the pathological results. One case each of MD, heterotopic pancreas, and intestinal duplication was misdiagnosed on US as intestinal duplication, a small intestinal polyp, and a mesenteric cyst, respectively. Additionally, two cases of abdominal purpura were misdiagnosed as inflammatory edema. All patients in this study had favorable prognoses.

Establishment of the DTA model

The US-measured data (SBI diameter, outer bowel wall thickness, thickness of the head and body of the intussusceptum, and length of the intussusceptum) differed significantly between the TSBI and PSBI groups ($P < 0.001$). The presence or absence of a PLP was also statistically significant ($P < 0.001$) (Table 3).

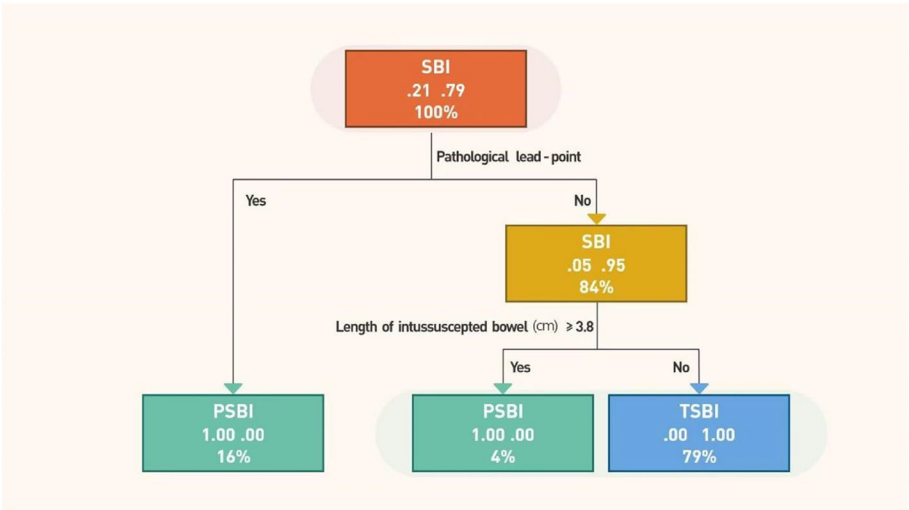

Fig. 2 Results of the DTA model generated using the statistical software

The patient cohort was categorized into a training set of 200 patients (158 with TSBI and 42 with PSBI) and a validation set of 131 patients (112 with TSBI and 19 with PSBI) in a 6:4 ratio. In the training set, PLPs detected via US accounted for 73.8% (31/42) of PSBI cases, whereas PLPs not detected via US but identified during surgical exploration accounted for 4.8% (3/42), including cases of MD and ectopic pancreas (two cases). Approximately 21.4% (9/42) of patients with PSBI without a PLP had an intussusception length ≥3.8 cm. Among patients with TSBI, no PLPs were detected, and all had an intussusception length <3.8 cm ($P < 0.001$). Based on the training set data, a systematic and efficient DTA model was established by post-pruning the CART (Fig. 2).

Validation of the DTA model

The PLP detected via US was considered the initial diagnostic indicator in the DTA model, followed by the intussusception length. The model was then validated using the validation dataset. In the validation set, PLPs detected via US accounted for 63.2% (12/19) of PSBI cases, whereas PLPs not detected via US but identified during surgical exploration accounted for 5.3% (1/19). Approximately 36.8% (7/19) of patients with PSBI without a PLP had an intussusception length ≥3.8 cm. The DTA model established with the training set showed 100% sensitivity, specificity, and accuracy. In the validation dataset, the model demonstrated a sensitivity of 98.2% (95% confidence interval), specificity of 100%, and accuracy of 98.6%.

Discussion

For the differential diagnosis of TSBI and PSBI in children, this study found that the presence of a PLP detected via US and an intussusception length of ≥3.8 cm were the most important predictors in the DTA model. The model demonstrated sensitivity, specificity, and accuracy values of 98.2%, 100%, and 98.6%, respectively.

In this DTA model, the presence of a PLP detected via US was considered the initial predictor. PLPs were identified in 43 patients (93.5%) using US. Among them, 38 patients were accurately diagnosed with conditions such as intestinal polyps, MD, intestinal duplication, malignant lymphoma, Peutz–Jeghers syndrome, abdominal purpura, ectopic pancreas, and postoperative adhesions. The detection of PLPs provides critical information for diagnosing PSBI [6, 23] (Figs. 3, 4, 5) and guiding clinical management [22]. In this study, the diagnostic accuracy of PLP detection via US was 88.4%.

Intestinal polyps accounted for the highest proportion of PLPs (30.4%), followed by MD (19.6%). Among patients with intestinal polyps, the positive detection rates on US for circular nodules in longitudinal images, polyp pedicles, and radial blood flow signals were 100% (14/14), 78.6% (11/14), and 78.6% (11/14), respectively. Additionally, 14.3% (2/14) of the intestinal polyps were juvenile polyps, characterized by multiple small sacs within the nodules on US.

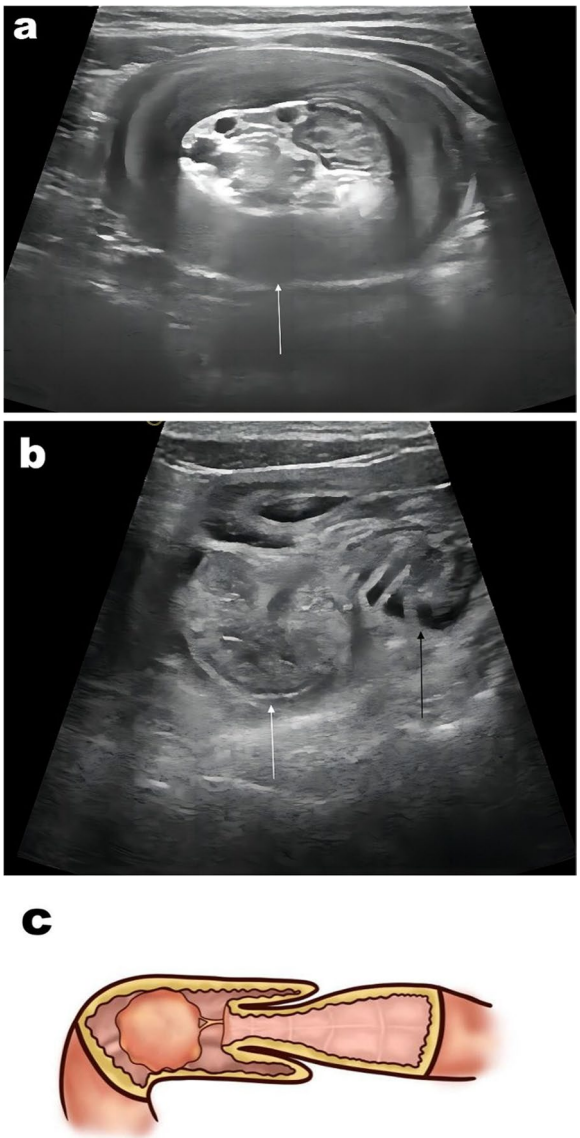

Fig. 3 An 11-year-old girl with intermittent abdominal pain for 1 month. **a** Transverse sonogram showing an intestinal polyp at the center of the concentric circles (arrow). **b** Longitudinal sonogram showing the intestinal polyp located at the head of the SBI (arrow). **c** Schematic diagram

Approximately 88.9% (8/9) of MDs were detected via US, and 77.8% (7/9) of these cases were consistent with the pathological findings. The positive detection rates on US for abnormally shaped intestines, swelling of the diverticular wall, and secondary perforation of

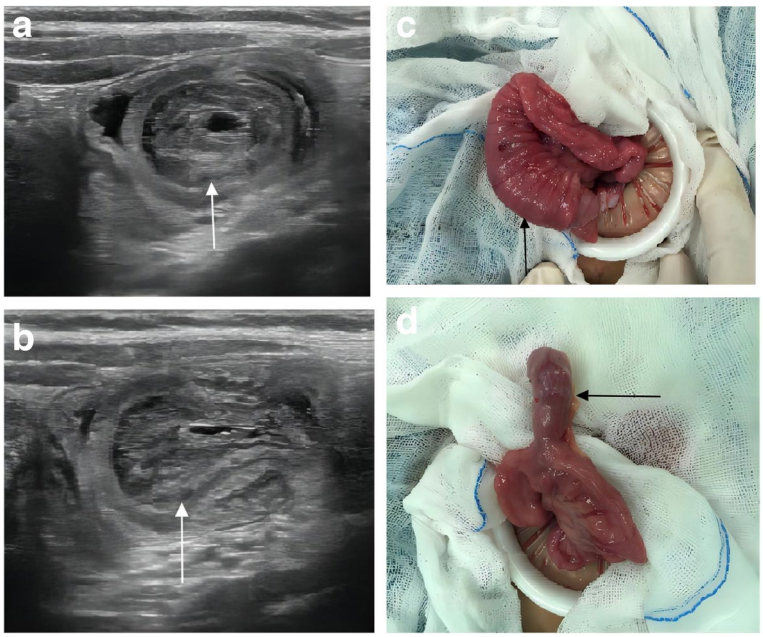

Fig. 4 A 12-year-old boy with a 2-month history of intermittent hematochezia. **a, b** Transverse and longitudinal sonograms showing a Meckel's diverticulum at the head of the SBI (white arrows). c Intraoperative image of the SBI (black arrow). **d** Surgical image showing the exposed Meckel's diverticulum after manual reduction of the SBI (black arrow)

the diverticulum with adhesion were 77.8% (7/9), 71.4% (6/9), and 11.1% (1/9), respectively. The detection rate of MD via US was higher in children than in adults, likely due to the thinner abdominal wall in pediatric patients. In this study, the diagnostic accuracy of MD detection via US reached 77.8%.

Due to the small size of the lesions and the limitations of US—particularly its susceptibility to interference from intestinal gas—eight patients with PLP were not diagnosed. This highlights the importance of increasing awareness of PLP screening in every patient with SBI. Additionally, using high-resolution, high-frequency probes can help sonographers detect PLPs more quickly and accurately [24, 25].

An intussusception length of ≥ 3.8 cm was the second predictor in this DTA model. This finding is consistent with those of previous studies [4, 5, 26], although some numerical differences were observed. Munden [16] reported that an intussusception length of ≥ 3.5 cm was a sensitive and specific predictor for the need for surgical intervention (sensitivity: 93%; specificity: 100%), whereas Wang [5] suggested that an intussusception length of ≤ 3.0 cm does not require surgical treatment.

In previous studies, confirmation of the ileocecal location has been used to distinguish SBI from other types of intussusception. Additionally, single factors—such as SBI diameter, intussusceptum length, or the presence of PLPs—have often been used as key indicators to differentiate between TSBI and PSBI [4, 5, 26]. We believe that more detailed and comprehensive measurements can yield more accurate statistical results. Single-factor analysis revealed that the head-of-intussusceptum thickness had the highest diagnostic efficiency (AUC = 0.984 [95% CI: 0.955–0.996]), followed by intussusception length (AUC = 0.959 [95% CI: 0.922–0.982]). Analysis of 200 training cases and 131 validation cases identified 3.8 cm as the cutoff value for intussusception length. However, due to the limitations of relying on single factors, we developed a DTA model incorporating multiple variables. This comprehensive approach, using the two most specific predictors, increased the sensitivity to 98.2%, making the model more efficient and practical than single-factor methods.

Although both clinical information and US findings were considered in establishing the DTA model, none of the clinical variables were identified as significant predictors. This may be because clinical information is often incomplete, as children cannot accurately express their symptoms [27]. Furthermore, the presence of asymptomatic cases significantly reduces the sensitivity and specificity of SBI diagnosis. Therefore, clinical information was not suitable as a diagnostic predictor in this model [28–30].

We successfully established and validated our DTA model. However, this study had several limitations. First, the study population was limited, and both the

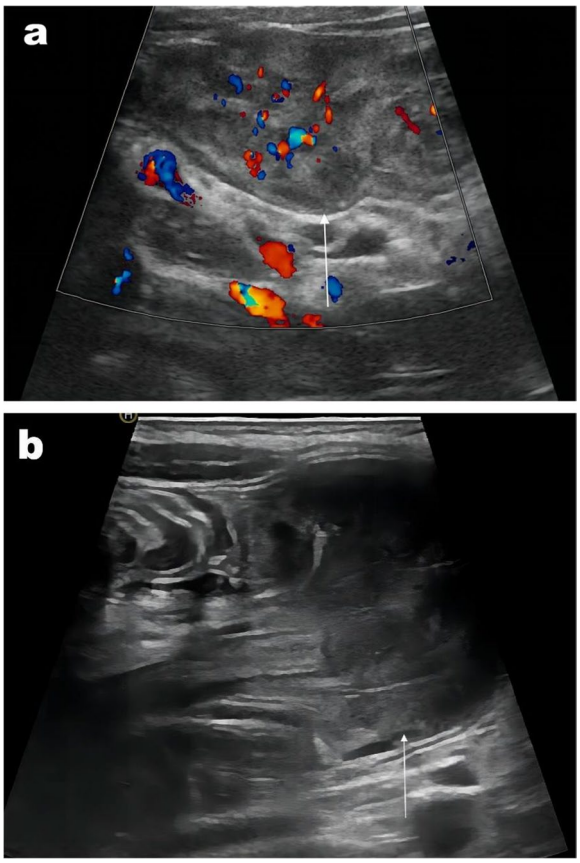

Fig. 5 A 6-year-old girl with intermittent abdominal pain for several months. **a, b** Longitudinal sonograms showing increased blood flow signals in the malignant lymphoma (arrow in a) and the malignant lymphoma located at the head of the SBI (arrow in b)

development and validation of the decision tree for SBI were based on data from a single tertiary hospital. A multicenter collaborative study should be conducted in the future. Second, the size of the training set was relatively small; therefore, we selected a nonlinear algorithm suitable for small sample sizes. With a larger sample, other algorithms may be explored to develop a more robust diagnostic model. Third, all measurements were performed manually, introducing a certain degree of subjectivity.

In conclusion, an effective DTA model was established to differentiate between TSBI and PSBI. Moreover, the identification of PLPs can aid clinicians in managing these patients. The application of the DTA model in the diagnosis of SBI may reduce the surgical rate in patients with TSBI and facilitate accurate and early diagnosis and treatment in patients with PSBI.

Abbreviations

CART	Classification and regression tree
CT	Computed tomography
DTA	Decision tree analysis
MD	Meckel's diverticulum
MRI	Magnetic resonance imaging
PSBI	Persistent small-bowel intussusception
PLP	Pathological lead point
SBI	Small-bowel intussusception
TSBI	Transient small-bowel intussusception
US	Ultrasound

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Author contributions
Shao Wang and Yu Wang were responsible for the experimental design, data collection, and statistical calculations. Shao Wang also produced figures and tables and wrote the manuscript, which was revised by Liqun Jia and Xiaoman Wang.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the principles of the Declaration of Helsinki. All screening and documentation procedures were performed with informed consent from the children's parents (the maximum age of children included in this study was 9 years). The study was approved by the Ethics Committee of Beijing Children's Hospital, affiliated with Capital Medical University (Approval No.: IEC-C- 006-A04-V.06).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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