



# Diagnostic value of the acute angle between the prestenotic and poststenotic duodenum in neonatal annular pancreas

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## Abstract

**Objectives** To analyze the ability of upper gastrointestinal (GI) saline-contrast ultrasound (US) to detect neonatal annular pancreas.

**Methods** Sixty-two neonates, who presented duodenal obstruction and were examined by upper GI saline-contrast US before treatment, were retrospectively analyzed and categorized into four groups according to their final diagnosis: group A, annular pancreas ( $n = 28$ ); group B, duodenal atresia ( $n = 2$ ); group C, descending duodenal septum ( $n = 25$ ); and group D, normal ( $n = 7$ ). The ultrasonic characteristics were analyzed that especially focused on whether the angle between the prestenotic and poststenotic descending duodenum (at or below a derived cutoff) could identify neonatal annular pancreas.

**Results** To detect annular pancreas using the concave contour of the distal prestenotic duodenum, the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were determined at 71.4%, 100%, 100%, and 80.9%, respectively. When using the hyperechogenic band around the constricted duodenum, the sensitivity, specificity, PPV, and NPV were determined at 82.1%, 94.1%, 92%, and 86.5%, respectively. For using the 40.7° acute angle cutoff between prestenotic and poststenotic descending duodenum, the values of sensitivity, specificity, PPV, and NPV were determined at 100%, 97.1%, 96.6%, and 100%, respectively, of which the area under the receiver operating characteristic curve was 0.979.

**Conclusions** Upper GI saline-contrast US has a lower possibility for misdiagnosis of neonatal annular pancreas when considering the acute angle between the prestenotic and poststenotic descending duodenum.

## Key Points

- This study includes the largest series of neonates with annular pancreas of which the characteristics were analyzed using the upper GI saline-contrast US.
- Neonatal annular pancreas may be diagnosed by the characteristics—concave contour of the distal prestenotic duodenum; acute angle cutoff of 40.7° between the prestenotic and poststenotic duodenum; the “S” shape formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum.
- The acute angle with the highest diagnostic value can be used to quantitatively diagnose neonatal annular pancreas and avoid potential misdiagnosis caused by sonographers’ subjectivity.

**Keywords** Ultrasound · Neonate · Duodenum · Pancreas

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## Abbreviations

AUC	Area under the ROC curve
GI	Gastrointestinal
NPV	Negative predictive value
PPV	Positive predictive value
ROC	Receiver operating characteristic
US	Ultrasound

## Introduction

An annular pancreas surrounds completely or partially the descending duodenum [1]. The explanation of the embryological

development postulated by Hays et al [2] and Lecco [3] is that one portion of the ventral pancreas adheres abnormally to the ventral wall of the descending duodenum, while the other portion attached to the choledochus migrates to the right, dorsally, and then to the left of the descending duodenum, making the encirclement complete. Subsequent enlargement of the descending duodenum surrounded by pancreatic tissue is improbable and is followed by the development of the segment into duodenum stenosis or atresia. Overall, the prevalence of annular pancreas is approximately 1 in every 2000 persons [4, 5], and about half of these show duodenal obstruction in the neonatal period [6].

Neonates with annular pancreas are affected by typical symptoms of duodenal obstruction, including vomiting, abdominal distention, and feeding intolerance [7]. Additionally, neonatal annular pancreas is frequently associated with Down syndrome, intestinal atresia, intestinal septum, malrotation, imperforate anus, Meckel's diverticulum, and so on [8, 9]. In general, neonates with annular pancreas and associated abnormalities require urgent surgery after birth [7]. For this reason, an early and accurate diagnosis of annular pancreas is crucial for predicting associated abnormalities, determining the surgical procedure, and decreasing postoperative morbidity and mortality [10, 11].

There are two main diagnosis tools that can be used to investigate duodenal-related abnormalities in neonates or fetuses. The first tool includes the upper gastrointestinal (GI) barium-contrast study, which is the first examination used to diagnose neonatal duodenal obstruction by the “double-bubble” sign caused by a dilating stomach and proximal duodenum [11]. However, while the upper GI barium-contrast study can determine the extent of duodenal obstruction, it is difficult to determine the pathological patterns of the obstruction using this approach [12, 13]. The second tool includes the prenatal ultrasound (US), which is the main method used to diagnose fetal annular pancreas by the “double-bubble” sign and hyperechogenic band, which is equivalent to pancreatic tissue surrounding the descending duodenum [12, 14, 15]. However, only 56% of neonatal annular pancreas cases show the “double-bubble” sign on prenatal US images [7], and the prenatal US imaging is limited by gestational age, movements, position, and low image contrast. Thus, it is extremely difficult to diagnose annular pancreas by identifying the hyperechogenic band using prenatal USs [16, 17].

Because of the shortcomings of the two above-mentioned diagnosis tools, various studies have placed emphasis on postnatal US (especially upper GI saline-contrast US) to diagnose neonatal annular pancreas. These studies conclude that the neonates with duodenal obstruction have a dilated stomach and proximal duodenum on the US images, while neonates with annular pancreas have a hyperechogenic band around the stenotic duodenum [8, 11, 18]. However, the hyperechogenic band occurred only in limited cases [8, 11, 18, 19]. This is because there is only a classic hyperechogenic band surrounding the stenotic descending duodenum in some neonates that have a thick circumferential annular pancreas [19]. In contrast, the

classic band is not clear in neonates that have a thin circumferential annular pancreas or an incomplete annular pancreas [19]. In addition, to the best of our knowledge, the previous studies included fewer than five cases. Therefore, the value of postnatal US for detecting neonatal annular pancreas is still equivocal as larger studies are required. Our study's aim is to analyze the ability of upper GI saline-contrast US to detect neonatal annular pancreas, and particularly thin circumferential and incomplete annular pancreas, which is crucial to determine the required surgical procedure and improve the patient's prognosis.

## Materials and methods

Between March 2016 and May 2018, a total of 62 neonates, who presented duodenal obstruction and were examined by upper GI saline-contrast US before treatment in our institution, were retrospectively analyzed and categorized into four groups (A to D) based on their final diagnosis. Here, group A included 28 neonates (15 boys and 13 girls, with a mean age at birth of  $37.43 \pm 1.34$  weeks, and a mean birth weight of  $2523.57 \pm 422.32$  g) with a confirmed annular pancreas via operation, of which 23 were diagnosed before the operation with annular pancreas and of which five were originally misdiagnosed with duodenal atresia; group B included two neonates (one boy and one girl, with a mean age at birth of  $36.50 \pm 0.71$  weeks and a mean birth weight of  $2495.00 \pm 205.06$  g) confirmed with duodenal atresia but originally misdiagnosed with annular pancreas before the operation; group C included 25 neonates (14 boys and 11 girls, with a mean age at birth of  $37.76 \pm 1.26$  weeks and a mean birth weight of  $2638.00 \pm 326.10$  g) diagnosed and confirmed with a descending duodenum septum; and group D included seven neonates (two boys and five girls, with a mean age at birth of  $38.71 \pm 1.11$  weeks, and a mean birth weight of  $3020.00 \pm 285.02$  g) with normal ultrasonic and clinical results.

The institutional ethics committee's approval was obtained prior to this study. The possible adverse effects were fully explained to all the parents, who signed informed consent forms for the inclusion of their children in the study. The following inclusion criteria had to be fulfilled: (1) patients presenting with duodenal obstruction with a final diagnosis of annular pancreas, duodenal atresia, duodenal septum, or normal exam; (2) all imaging performed in our institution; and (3) all surgical interventions performed in our institution. The exclusion criteria were as follows: (1) patients with other severe associated abnormalities; (2) patients lost to follow-up; and (3) patients with other upper GI abnormalities.

The ultrasonic examinations were performed using an Acuson 2000 (Siemens Healthineers) with a linear 9-MHz transducer or an SSA-790A (Canon Medical Systems Corporation) with a linear 7.5-MHz transducer. The procedure of the upper GI saline-contrast US was as follows:

- The gastric tube (6 Fr, Tianping) was placed into the neonate's stomach and used to first remove as much gas as possible from the stomach and proximal duodenum before the examination.
- Soothers were administrated when necessary.
- Before the fluid intake, neonates in the supine position were examined by ultrasonic scans of the entire abdomen, including the stomach, pylorus, duodenum, pancreas head, jejunioileum, and colorectum.
- For the cases having a complete duodenal obstruction, less than 60 ml of sterile water was used to dilate the neonate's stomach [20], and in view of the possibility of gastroesophageal reflux and possible aspiration in a vomiting neonate, 15 ml of saline in a 20-ml injector was used to dilate the stomach—with a right-side-down position to enhance the flow of fluid from the stomach into the duodenum.
- After the fluid intake, the neonates in the supine or right-side-down position were examined with ultrasonic scans of the entire abdomen.
- After the examination, the gastric tube was used to remove as much saline as possible from the stomach and proximal duodenum.

Clinical findings were recorded, and the characteristics of upper GI saline-contrast US, especially the angle between the two right lateral walls of the prestenotic and poststenotic descending duodenum, were analyzed by two sonographers who had 6 or 9 years of experience in diagnosing GI anomalies and were blinded to the clinical findings.

In this study, the statistical analysis was performed using the MedCalc program, version 18.2 (MedCalc Software). The receiver operating characteristic (ROC) curve was used to determine whether the angle between the prestenotic and

poststenotic descending duodenum could identify neonatal annular pancreas. The area under the curve (AUC) was calculated as well and the optimal threshold determined.

## Results

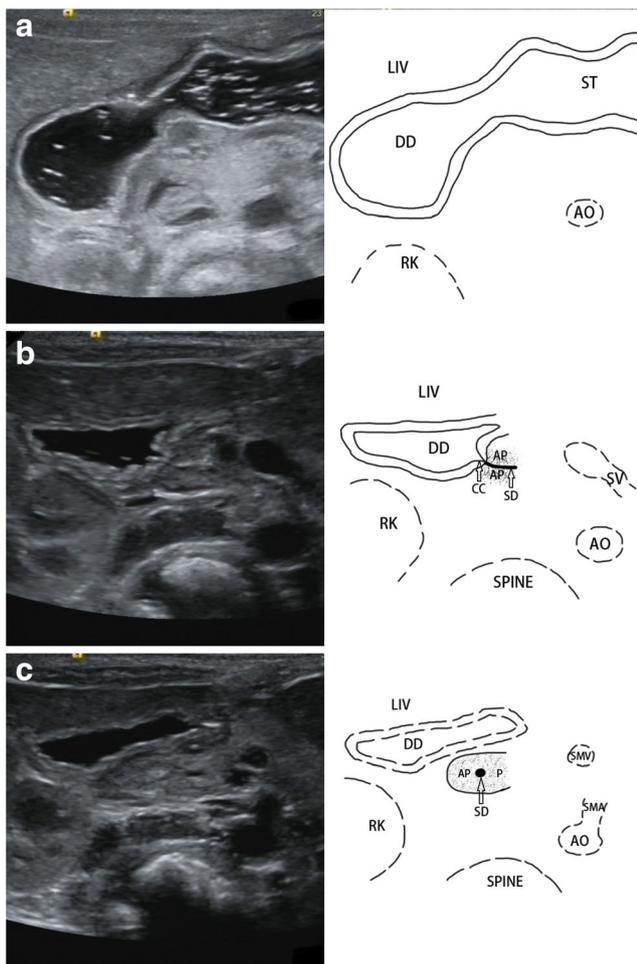
The diagnostic value of the ultrasonic characteristics in neonatal annular pancreas is shown in Table 1. In group A (neonates confirmed with annular pancreas), before saline intake, the ultrasonic images showed little fluid and some air in the stomach and proximal duodenum, no fluid or air in the distal duodenum and jejunioileum, but some meconium in the colorectum. After saline intake, the images of the upper abdomen displayed a dilated and hypertrophic stomach and proximal duodenum (Fig. 1a). The concave contour of the distal prestenotic duodenum was found in 20 neonates diagnosed with annular pancreas before the operation (Fig. 1b). For these neonates, at the level of the pancreas head, the descending duodenum was remarkably constricted (Fig. 1b). Furthermore, for the 23 neonates diagnosed with annular pancreas, a hyperechogenic band was found that partially (12 of the 23) or completely (11 of the 23) surrounded the constricted duodenum (Fig. 1c). And for the five neonates misdiagnosed with duodenal atresia, a classical hyperechogenic band was not evident. An acute angle between the prestenotic and poststenotic descending duodenum was found for all 28 neonates (mean angle,  $21.25 \pm 9.78^\circ$ ; range,  $5.0\text{--}40.7^\circ$ , Fig. 2a). The special "S" shape was formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum (Fig. 2a).

During the examinations, little fluid in the poststenotic descending duodenum was found in 26 neonates of group A, while the dilation of the poststenotic descending duodenum

**Table 1** Diagnostic value of the ultrasonic characteristics in neonatal annular pancreas

Ultrasonic features	Surgical findings					
	Positive ( <i>n</i> = 28)	Negative ( <i>n</i> = 34)	Sensitivity ( <i>n</i> )	Specificity ( <i>n</i> )	PPV ( <i>n</i> )	NPV ( <i>n</i> )
Gastroduodenal dilation						
Positive ( <i>n</i> = 55)	28	27	100% (28/28)	20.6% (7/34)	50.9% (28/55)	100% (7/7)
Negative ( <i>n</i> = 7)	0	7				
Concave contour						
Positive ( <i>n</i> = 20)	20	0	71.4% (20/28)	100% (34/34)	100% (20/20)	80.9% (34/42)
Negative ( <i>n</i> = 42)	8	34				
Hyperechogenic band						
Positive ( <i>n</i> = 25)	23	2	82.1% (23/28)	94.1% (32/34)	92% (23/25)	86.5% (32/37)
Negative ( <i>n</i> = 37)	5	32				
"S" shape						
Positive ( <i>n</i> = 30)	28	2	100% (28/28)	94.1% (32/34)	93.3% (28/30)	100% (32/32)
Negative ( <i>n</i> = 32)	0	32				

PPV positive predictive value, NPV negative predictive value



**Fig. 1** The ultrasonic images of a 3-day-old neonate with annular pancreas after 15 ml of saline intake by a gastric tube. Panel **a** shows an axial scan of the upper abdomen showing the dilated stomach and proximal duodenum with the wall thickening (highlighted by two solid lines in the schematic drawing). Panel **b** shows an oblique scan of the upper abdomen showing the dilated proximal duodenum, concave contour of the distal prestenotic duodenum, stenotic descending duodenum, and the tissue of the annular pancreas anterior and posterior to the stenotic descending duodenum (highlighted by a solid line or a shaded area). Panel **c** shows an axial scan of the stenotic descending duodenum showing a hyperechogenic band equivalent to the encircling tissue of annular pancreas (highlighted by a shaded area). LIV, liver; ST, stomach; DD, dilated proximal duodenum; RK, right kidney; AO, abdominal aorta; CC, concave contour; SD, stenotic descending duodenum; AP, annular pancreas; SV, splenic vein; SPINE, spine; P, pancreas; SMV, superior mesenteric vein; SMA, superior mesenteric artery

was revealed in two neonates of group A, whose ultrasonic images displayed a septum in the lumen of the distal duodenum (Fig. 3a). The transverse images of the upper abdomen showed in one neonate the rotation of the superior mesenteric vein winding around the superior mesenteric artery (Fig. 3b); no other GI malformations were seen on the images.

During surgery, the 23 neonates diagnosed with annular pancreas were found with pancreatic tissue surrounding the constricted duodenum partially (3 of the 23) or completely (20 of the 23), and most of the circumferential annular pancreases

were extremely thin. For the five neonates originally misdiagnosed with duodenal atresia, the pancreatic tissue was surrounding the descending duodenum partially. In addition, associated GI anomalies were found during operation, including malrotation in one case, duodenal septum in two cases, and Meckel's diverticulum in three cases. All of the 28 neonates underwent diamond-shaped duodenoplasty, of which six underwent subsequent procedures, such as Ladd's procedure, septum resection, or Meckel's diverticulum resection. The neonates had no reoperation or complications during a follow-up period of 2–20 months after treatment.

In group B (neonates with duodenal atresia, but originally misdiagnosed with annular pancreas), after saline intake, the images of the upper abdomen showed gastroduodenal dilation, a hyperechogenic band partially surrounding the constricted descending duodenum, an acute angle ( $14.7^\circ$  and  $43.3^\circ$ ) between the prestenotic and poststenotic descending duodenum (Fig. 2b), and the special “S” shape (Fig. 2b). During surgery, the two neonates were found to have duodenal atresia with significant adhesion to the surrounding tissue, followed by diamond-shaped duodenoplasty.

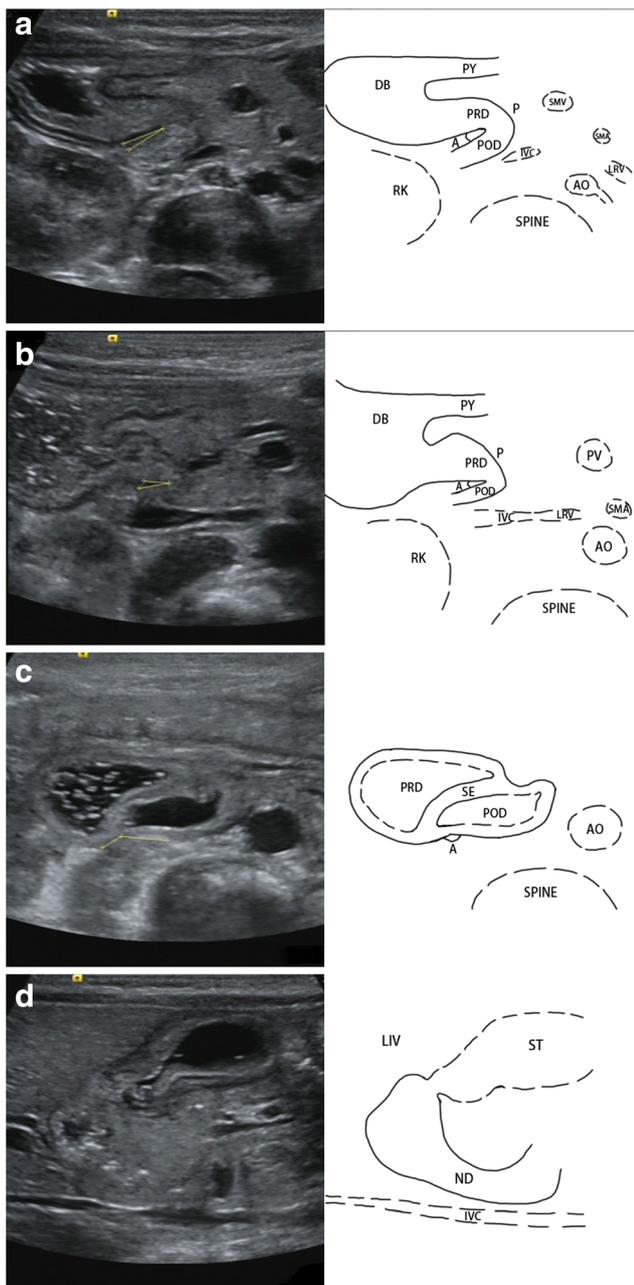
In group C (neonates diagnosed and confirmed with a descending duodenum septum), the images of the upper abdomen displayed gastroduodenal dilation, a flat contour of the distal prestenotic duodenum, a septum in the lumen of stenotic descending duodenum (Fig. 2c), absence of a hyperechogenic band surrounding the stenotic duodenum, and an obtuse angle between the prestenotic and poststenotic descending duodenum (mean angle,  $159.51 \pm 10.35^\circ$ ; range,  $140.1$ – $177.5^\circ$ , Fig. 2c). During surgery, duodenotomy was longitudinally performed at locations where a septum was observed, then excised circumferentially, and finally transversely closed.

In group D (neonates with normal ultrasonic and clinical results), the images displayed the saline flowing normally from the stomach into the distal duodenum, with the descending duodenum elongated and straight (Fig. 2d). Finally, these seven cases were diagnosed without any GI abnormalities and released from the hospital in good condition.

A ROC analysis of the angle between the prestenotic and poststenotic duodenum was performed to discriminate between neonates with and without annular pancreas. These results showed an AUC of 0.979 and an optimal threshold value of  $40.7^\circ$  for the angle (Fig. 4).

## Discussion

The obtained images during this study of all the cases of duodenal obstruction showed a dilated and hypertrophic stomach and proximal duodenum. A possible explanation is that the persistent dilation of the stomach and proximal duodenum might have resulted in the degeneration of smooth muscle and enteric neurons, which are similar in characteristics in regard



**Fig. 2** The ultrasonic characteristics of a descending duodenum in neonates with or without annular pancreas. In panel **a**, ultrasonic images of a 3-day-old neonate with annular pancreas are shown. Here, an oblique scan of the upper abdomen is illustrated showing an acute angle between the two right lateral walls of the prestenotic and poststenotic descending duodenum, the “S” shape formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum (highlighted by an arc or a solid line). Then in panel **b**, the ultrasonic images of a 2-day-old neonate with descending duodenal atresia are shown. Here, an oblique scan of the upper abdomen is illustrated showing an acute angle between the two right lateral walls of the prestenotic and poststenotic descending duodenum, the “S” shape formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum (highlighted by an arc or a solid line). In panel **c**, the ultrasonic images of a 3-day-old neonate with descending duodenal septum are shown. Here, an oblique scan of the upper abdomen is illustrated showing an obtuse angle between the prestenotic and poststenotic descending duodenum and a septum in the lumen (highlighted by an arc or two solid lines). Finally, in panel **d**, the ultrasonic images of a 6-day-old neonate with a normal exam are shown. Here, an oblique scan of the upper abdomen is illustrated showing the elongated and straight descending duodenum (highlighted by two solid lines). PY, pylorus; DB, duodenal bulb; PRD, prestenotic descending duodenum; POD, poststenotic descending duodenum; A, angle; P, pancreas; IVC, inferior vena cava; SMV, superior mesenteric vein; SMA, superior mesenteric artery; LRV, left renal vein; LRA, left renal artery; RK, right kidney; AO, abdominal aorta; SPINE, spine; PV, portal vein; SE, septum; ND, normal duodenum

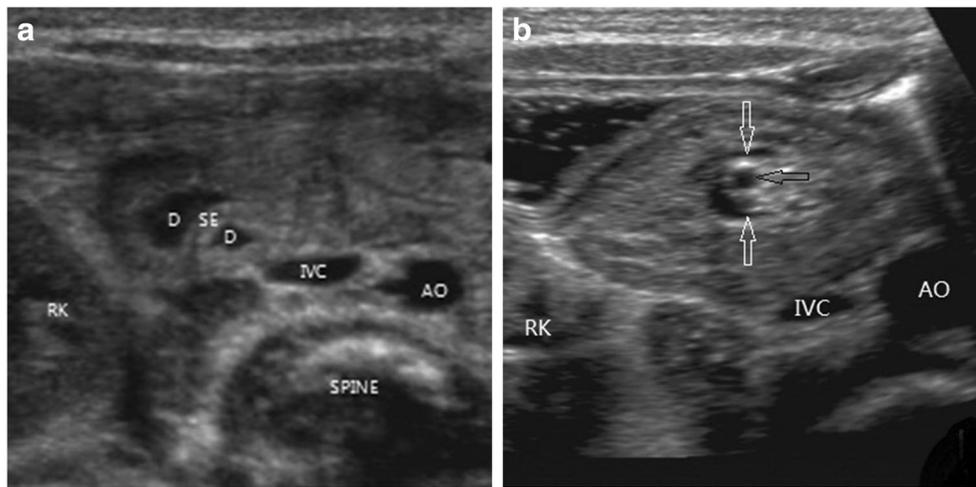
prestenotic duodenum presented a concave contour, similar to the shape of a funnel.

Our results also showed that the circumferential or incomplete hyperechogenic band could be used to diagnose most cases of annular pancreas, which is a similar finding found in a study by Peschka et al [22]. However, in our study, the number of circumferential annular pancreases diagnosed by US was lower than the number confirmed by subsequent surgery. This may be because the circumferential pancreatic tissue was too thin to be completely identified by US. More importantly, five cases of incomplete annular pancreas were not accurately diagnosed by US, but they were misdiagnosed as duodenal atresia instead. Our findings indicated that it was difficult to identify the hyperechogenic band in neonates with thin circumferential or incomplete annular pancreas by US, which is comparable to the finding of a study by Vijayaraghavan [19]. Furthermore, we concluded that duodenal atresia might be misdiagnosed as annular pancreas by an incomplete hyperechogenic band around the atresic duodenum, and the possible reason for this misdiagnosis was severe adhesion around the atresic duodenum. Our conclusion was different from the study by Dankovcik et al [14], where it was found that all the annular pancreases could be diagnosed using the hyperechogenic band, which was difficult to misinterpret other structures with. The reason for the difference may be that not only rare cases of annular pancreas but also prenatal routine USs were considered in their study.

The acute angle cutoff of  $40.7^\circ$  between the prestenotic and poststenotic duodenum and the “S” shape formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum—with the acute angle as the most

to those found in megaduodenum [11, 21]. Similarly, Chen QJ et al [11] demonstrated that duodenal obstruction was diagnosed from the evident dilation and hypertrophy of the stomach and proximal duodenum.

In this study, we concluded that the concave contour of the distal prestenotic duodenum could be used to diagnose circumferential annular pancreas. However, the obtained results did not show the concave contours on the images of incomplete annular pancreas. The reason may be that—in view of circumferential pancreatic tissue surrounding the descending duodenum—with saline intake, the lumen of the distal

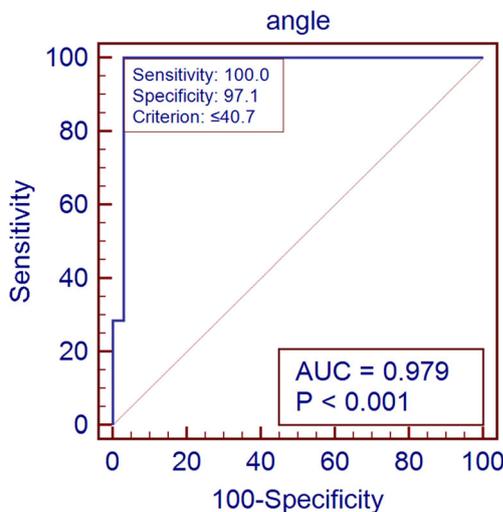


**Fig. 3** The gastrointestinal abnormalities associated with annular pancreas. In panel **a**, the ultrasonographic images of a 3-day-old neonate with descending duodenal septum are shown. Here, the oblique scan of the upper abdomen shows a septum in the lumen. In panel **b**, the ultrasonographic images of a 1-day-old neonate with malrotation are shown.

Here, the axial scan of the superior mesentery artery shows the rotation of the superior mesenteric vein (white arrow) winding around the superior mesenteric artery (black arrow). D, duodenum; SE, septum; IVC, inferior vena cava; AO, abdominal aorta; RK, right kidney; SPINE, spine

valuable characteristic—could be used to diagnose annular pancreas. The reasoning for this can be explained by two explanations. The first explanation is that during the embryological development of annular pancreas, the ventral pancreas encircling partially or completely the descending duodenum migrates from the right of the duodenum to the left following the choledochus prior to the eighth week of gestation [2, 3]. Then, the portion of descending duodenum encircled by the pancreatic tissue may gradually shift to the left following the left shift of the ventral pancreas, which might then be followed

by an angle formation between the proximal and distal descending duodenum. Then, the second explanation is that during the first 8–12 weeks of gestation, the enlargement of the surrounded descending duodenum is improbable, while the enlargement of the prestenotic and poststenotic duodenum caused by vacuolization and recanalization of the duodenum keeps getting more significant [8], especially in the prestenotic duodenum. As a result, the angle between the prestenotic and poststenotic duodenum keeps getting smaller, and the special “S” shape is formed.



**Fig. 4** The receiver operating characteristic (ROC) curve of the angle between the prestenotic and poststenotic duodenum for the diagnosis of annular pancreas. The ROC curve showed the area under the curve (AUC) at 0.979 (95% confidence interval, 0.906 to 0.999) and the optimal threshold at 40.7°. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were 100% (95% CI, 87.7 to 100.0%), 97.1% (95% CI, 84.7 to 99.9%), 96.6% (95% CI, 80.2 to 99.5%), and 100%, respectively

The acute angle between the prestenotic and poststenotic duodenum and the “S” shape were also found in the two cases of descending duodenal atresia in this study (group B). Although the embryological development of the acute angle and “S” shape in neonates with descending duodenal atresia was still not clear, the operation method of the descending duodenal atresia was consistent with that of annular pancreas [23].

The three cases of Meckel’s diverticulum associated with annular pancreas were not diagnosed by the preoperative US; instead, they were found via surgery. This was comparable to the results from Pepper et al [24], who concluded that it was relatively difficult to reveal Meckel’s diverticulum without any complications by US. Additionally, in most cases, no complications such as diverticulitis and intussusception occurred in patients with Meckel’s diverticulum.

To our knowledge, our study included the largest series of neonates (28 in total) with annular pancreas where the characteristics were analyzed using upper GI saline-contrast US. What is more, we specifically selected the cases of descending duodenal atresia, descending duodenal septum, and normal exam versus annular pancreas, because the causes of descending duodenal obstruction included mainly duodenal atresia, duodenal septum, annular pancreas, preduodenal

portal vein, and malrotation [25], where the latter two may have more typical anatomical abnormality [11, 26]. Additionally, it is sometimes difficult to find the hyperechogenic band, so we emphasized for the first time that neonatal annular pancreas could be diagnosed by specific characteristics, including the concave contour of the distal prestenotic duodenum, the acute angle cutoff of  $40.7^\circ$  between the prestenotic and poststenotic duodenum, and the “S” shape. From these, particularly, the acute angle has the highest diagnostic value, and it may be used to quantitatively diagnose neonatal annular pancreas and avoid potential misdiagnosis caused by sonographers’ subjectivity. Finally, we also tried to find associated GI abnormalities from the images of the entire GI tract.

During upper GI saline-contrast US, the measurement of the angle between the prestenotic and poststenotic duodenum might be mildly affected by the severity of prestenotic duodenal dilation. Furthermore, the ultrasonographic criteria for neonatal annular pancreas were not sufficient for diagnosis with the limited cases, and thus, it is still necessary to assess the diagnostic value of the acute angle in a large number of cases.

## Conclusions

Upper GI saline-contrast US can be used to diagnose neonatal annular pancreas by the characteristics of a dilated stomach and proximal duodenum, concave contour of the distal prestenotic duodenum, circumferential or incomplete hyperechogenic band, acute angle between the prestenotic and poststenotic descending duodenum, and the “S” shape formed by the pylorus, the duodenal bulb, and the prestenotic and poststenotic descending duodenum. Particularly, the acute angle cutoff of  $40.7^\circ$  with the highest diagnostic value could quantitatively analyze the characteristic of neonatal annular pancreas, particularly in cases with a thin circumferential or incomplete annular pancreas.

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## Compliance with ethical standards

**Guarantor** The scientific guarantor of this publication is Dr. Hongying Wang.

**Conflict of interest** The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

**Statistics and biometry** No complex statistical methods were necessary for this paper.

**Informed consent** Written informed consent was obtained from all subjects (patients) in this study.

**Ethical approval** Institutional Review Board approval was obtained.

## Methodology

- retrospective
- diagnostic or prognostic study
- performed at one institution

## References

1. Papachristou GI, Topazian MD, Gleeson FC, Levy MJ (2007) EUS features of annular pancreas (with video). *Gastrointest Endosc* 65:340–344
2. Hays DM, EM Jr, Hill JT (1961) Annular pancreas as a cause of acute neonatal duodenal obstruction. *Ann Surg* 153:103–112
3. Lecco TM (1910) Zur Morphologie des Pankreas annulare. *Sitzungsb Akad Wissensch* 119:391–406
4. Mortelé KJ, Rocha TC, Streeter JL, Taylor AJ (2006) Multimodality imaging of pancreatic and biliary congenital anomalies. *Radiographics* 26:715–731
5. Jimenez JC, Emil S, Podnos Y, Nguyen N (2004) Annular pancreas in children: a recent decade’s experience. *J Pediatr Surg* 39:1654–1657
6. Back SJ, Maya CL, Khwaja A (2017) Ultrasound of congenital and inherited disorders of the pediatric hepatobiliary system, pancreas and spleen. *Pediatr Radiol* 47:1069–1078
7. Zyromski NJ, Sandoval JA, Pitt HA et al (2008) Annular pancreas: dramatic differences between children and adults. *J Am Coll Surg* 206:1019–1025
8. Norton KI, Tenreiro R, Rabinowitz JG (1992) Sonographic demonstration of annular pancreas and a distal duodenal diaphragm in a newborn. *Pediatr Radiol* 22:66–67
9. Mittal S, Jindal G, Mittal A, Singal R, Singal S (2016) Partial annular pancreas. *Proc (Bayl Univ Med Cent)* 29:402–403
10. Kilbride H, Castor C, Andrews W (2010) Congenital duodenal obstruction: timing of diagnosis during the newborn period. *J Perinatol* 30:197–200
11. Chen QJ, Gao ZG, Tou JF et al (2014) Congenital duodenal obstruction in neonates: a decade’s experience from one center. *World J Pediatr* 10:238–244
12. Kim JY, You JY, Chang KH et al (2016) Association between prenatal sonographic findings of duodenal obstruction and adverse outcomes. *J Ultrasound Med* 35:1931–1938
13. Milone L, Okhunov Z, Gumbs AA (2012) Laparoscopic diagnosis of annular pancreas in a patient with mucinous cystadenoma of the body of the pancreas. *J Gastrointest Cancer* 43:367–369
14. Dankovcik R, Jirasek JE, Kucera E, Feyereisl J, Radonak J, Dudas M (2008) Prenatal diagnosis of annular pancreas: reliability of the double bubble sign with periduodenal hyperechogenic band. *Fetal Diagn Ther* 24:483–490
15. Martin-Hirscl A, Cantrell CJ, Hulka F (2004) Antenatal diagnosis of a choledochal cyst and annular pancreas. *J Ultrasound Med* 23:315–318
16. Hill LM, Peterson C, Rivello D, Hixson J, Belfar HL (2010) Sonographic detection of the fetal pancreas. *J Clin Ultrasound* 17: 475–479
17. Desdicioglu K, Malas MA, Evcil EH (2010) Foetal development of the pancreas. *Folia Morphol (Warsz)* 69:216–224

18. Hernanz-Schulman M (1999) Imaging of neonatal gastrointestinal obstruction. *Radiol Clin North Am* 37:1163–1186
19. Vijayaraghavan SB (2002) Sonography of pancreatic ductal anatomic characteristics in annular pancreas. *J Ultrasound Med* 21: 1315–1318
20. Cohen HL, Haller JO, Mestel AL, Coren C, Schechter S, Eaton DH (1987) Neonatal duodenum: fluid-aided US examination. *Radiology* 164:805–809
21. Zhang XW, Abudoureyimu A, Zhang TC et al (2012) Tapering duodenoplasty and gastrojejunostomy in the management of idiopathic megaduodenum in children. *J Pediatr Surg* 47: 1038–1042
22. Peschka J, Deeg KH (2016) Duodenal obstruction caused by an annular pancreas - sonographic diagnosis in a 4-month-old dystrophic infant. *Ultraschall Med* 38:318–319
23. Chiarenza SF, Bucci V, Conighi ML et al (2017) Duodenal atresia: open versus MIS repair-analysis of our experience over the last 12 years. *Biomed Res Int* <https://doi.org/10.1155/2017/4585360>
24. Pepper VK, Stanfill AB, Pearl RH (2012) Diagnosis and management of pediatric appendicitis, intussusception, and Meckel diverticulum. *Surg Clin N Am* 92:505–526
25. Mboyo A, Khadir SK, Guillaume MP et al (2013) An exceptional cause of duodenal obstruction detected antenatally: a compressive preduodenal portal vein. *J Pediatr Surg Case Rep* 1:420–424
26. Thirumoorthi AS, Cowles RA (2016) Preduodenal portal vein. *Surgery* 159:672–673