



Diagnostic Value of 3-Dimensional Ultrasound in the Prenatal Diagnosis of Intestinal Malrotation due to Ladd's Bands

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Abstract

Objective: The present study aimed to evaluate the role of Three-Dimensional (3D) ultrasound in the prenatal diagnosis of Intestinal Rotational Abnormalities (IRA).

Methods: We present four cases in which intestinal malrotation was suspected antenatally with one case in which Ladd's bands were strongly suspected and confirmed by a fetopathological examination. Stored volumes were prospectively and subsequently analyzed offline.

Results: With 3D ultrasound, we were able to evoke the diagnosis of intestinal malrotation due to Ladd's bands by a 3D anatomical reconstruction that was confirmed by a fetopathological examination. Anatomical image reconstruction enabled us to see the characteristic "corkscrew" appearance, clearly showed the abnormal position of the duodenojejunal junction at the right side and gave us an anatomical 3D image that correlated excellently with fetopathological examination.

Conclusion: 3D ultrasound offers a high-resolution volume rendering image that provides excellent delineation of the gastrointestinal tract and add significantly to detection and understanding of the aberrant anatomy of intestinal malrotation. Here, we propose a novel "multiple bubble sign" may have a potential diagnostic utility in the diagnosis of malrotation caused by Ladd's bands. Further Studies should proceed to further clarify our findings and shed new light on the role of 3D ultrasound in the antenatal diagnosis of IRA.

Keywords: Malrotation; Midgut; Volvulus; Neonate; 3DUS; Ladd's bands; Corkscrew sign; Duodenal obstruction; Whirlpool sign; Heterotaxy syndrome

Introduction

Intestinal Rotational Abnormalities (IRA) represents one of the most common congenital anomalies of the gastrointestinal tract encountered by surgeons. The reported incidence of IRA is variously appreciated and varies according to the different studies, depending largely on the criteria of definition: 1 in 200, 1 in 500 live births [1,2] symptomatic 1 in 6000 live births [3], incidental finding on approximately 2 out of 1000 upper gastrointestinal contrast studies [4].

Although intestinal malrotation has been considered to occur predominantly in infants and rarely in adults [5], a recent study on about 200 cases found that 31% were infants, 21% were aged 1 to 18 years, and the remaining 48% were either symptomatic or asymptomatic adults [6]. Some patients become symptomatic only in adulthood, whereas some may even live their entire lives being asymptomatic [7]. Intestinal malrotation can be an incidental finding in barium studies, angiographies, and computer tomography scans, presenting mild symptoms, but it can also lead to intestinal obstruction or acute ischemia due to a midgut torsion requiring immediate surgical intervention [8,9].

For this reason, all surgeons need to have a clear understanding of the embryology, diagnosis, and treatment of IRA. In order to better understand IRA, we present a brief overview of the embryology of the intestine, which is extensively reviewed in detail elsewhere [10].

Mall et al. [11] was the first to describe the complex embryogenesis and fixation of intestines at Johns Hopkins. Intestinal development is traditionally described as a process of elongation, rotation,

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Received Date: 10 Feb 2020

Accepted Date: 27 Feb 2020

Published Date: 02 Mar 2020

Citation:

El Guindi W, Carles G, Herlicoviez M, Lambert V, Benoist G, Dreyfus M. Diagnostic Value of 3-Dimensional Ultrasound in the Prenatal Diagnosis of Intestinal Malrotation due to Ladd's Bands. *Clin Surg*. 2020; 5: 2747.

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Table 1: Cases Investigated.

	Case 1	Case 2	Case 3	Case 4
Heart position	Normal	Mesocardia	Normal	Dextrocardia
Stomach	Left	Left	right	Left
IVC	Normal	Interruption	Interruption	Interruption
Interruption of IVC with azygos continuation	No	Yes	Yes	Yes
Liver	Normal	Median	Median	Median
Cardiac malformations	No	AVC-Single ventricle	Aortic arch hypoplasia	AVC
		Right umbilical artery	Pulmonary artery stenosis	Interruption of the 4th aortic arch
				LPSVC
Digestive anomalies		Midline liver	Midline liver	Midline liver
		Polysplenia.	Asplenia	Polysplenia.
		Intestinal malrotation	Intestinal malrotation	Intestinal malrotation
			Small bowel on the right side, colon on the left side.	Appendix and GB on the right side, rectosigmoid on left side
Caryotype	46XX	46 XX	46XY	46XY
Devenir	IUFD	IUFD	Pregnancy termination	Pregnancy termination
Diagnosis	IRA+Ladd Bands+volvulus.	Heterotaxy syndrome. RAI+ Ladd Bands + Obstruction without volvulus	Heterotaxy syndrome. LAI Nonrotation. No obstruction	Heterotaxy syndrome. RAI. Malrotation. No obstruction.

AVC: Atrioventricular Canal; IVC: Inferior Vena Cava; SVC: Superior Vena Cava; IUFD: Intrauterine Fetal Death; VO: Umbilical Vein; LAI: Left Atrial Isomerism; RAI: Right Atrial Isomerism; IRA: Intestinal Rotational Abnormalities; GB: Gall Bladder

and fixation. Early in the second month of gestation, the gut elongates too fast in the abdominal cavity of the embryo, with a consequent herniation of the developing intestines in a U-shaped loop into the extra-embryonic celom of the proximal part of the umbilical cord as a temporary and Physiological Umbilical Hernia (PUH) [12].

PUH occurs at about the sixth week of life, returning to the abdominal cavity at about 10 weeks of embryonic development. The gut loops within the umbilical cord, experiencing a rotation of 90° counter clockwise around the axis of the superior mesenteric artery, so that the future duodenum and proximal small intestine lie in the right abdomen and the future large intestine lies in the left abdomen [10].

During the 10th week, the intestines return to the abdomen (reduction of midgut hernia) and rotate an additional 180° counter clockwise to produce the definitive configuration of the small and large intestines. As the intestines return to the abdomen during the 10th week, it is accompanied by a pronounced >10-fold decrease in the growth rate of both small and large intestines (rotations: 90° in the umbilical cord + 180° within the abdominal cavity =270°) [13,14]. After a complete rotation, the small bowel is fixed by a broad mesentery that runs obliquely across the long axis of the abdomen from the duodenojejunal junction (from the ligament of Treitz) in the left upper quadrant to the ileocecal valve in the right lower abdomen [15]. This broad fixation stabilizes the small bowel, preventing it from volvulizing around the superior mesenteric artery [16].

However, if the bowel does not rotate and fix itself in the abdomen properly, the scene is set for later obstruction or volvulus. When this normal rotation and fixation do not occur, the cecum typically remains in the mid abdomen or left upper quadrant. Attempted cecal fixation results in band formation across the first and second portion of the duodenum (Ladd's bands) [17].

In 1932, an American surgeon, William E. Ladd (1880-1967), was the first to describe these “mesenteric attachments” as a cause

of congenital duodenal obstruction. He attributed them to failure in the normal rotation. Ladd's procedure, named after William E. Ladd, is the standard surgical technique for the removal of these peritoneal bands [18].

These bands typically extend from the abnormally positioned cecum to the peritoneum and liver, crossing the duodenum in their course. However, it can extend to further parts of the intestine. Ladd's bands compress the duodenum and can potentially cause a variable degree of compression until complete obstruction of the duodenum, however, most commonly, the bands are present with no or mild resultant obstruction, as in our cases (Case 1: no obstruction, Case 2: obstruction) [1].

The bands may also distort the course of an incompletely obstructed or non-obstructed duodenum in a Z-shaped configuration outlining the lack of normal rotation and fixation of the duodenum (Figures 2f and 5c) [19,20]. This Z-shaped duodenum may appear as a characteristic corkscrew-like appearance of the volvulus, but it does not indicate the volvulus itself. It must be stressed, however, that in most children with malrotation, obstruction is caused by the volvulus with the band having a lesser impact or no role at all (Case 1) [21].

Ladd's bands can pass over the duodenum, causing extrinsic incomplete congenital duodenal obstruction, and is diagnosed antenatally to a varying degree on ultrasonographic by the presence of a characteristic d of double-bubble appearance and polyhydramnios [22,23].

With malrotation and malfixation, the normally broad mesenteric attachment at the base of the small bowel mesentery is typically narrow, and the entire mid gut is attached by only a narrow band of tissue around the SMA, predisposing it to twist and create a distinctive “whirlpool” appearance, as observed by Fisher in a midgut volvulus [1,24,25].

Malrotation is not a single distinct entity but, rather, a continuum of abnormalities reflecting a failure of normal rotation and fixation

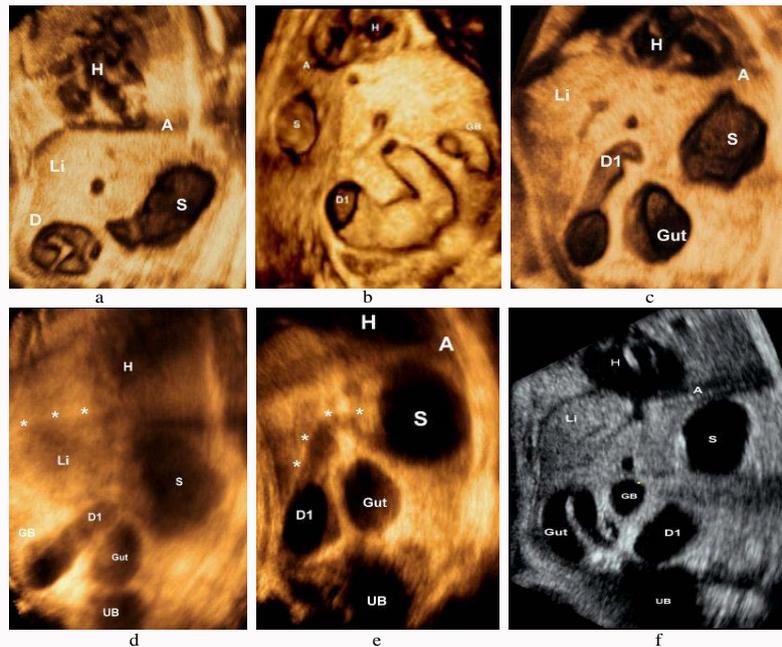


Figure 1: a) Grey scale frontal view, showing the characteristic “double-bubble” appearance of the stomach and duodenum, note that the apex of the heart is toward the stomach i.e. left side.
 b) Double-bubble” appearance, the left part is a sagittal view showing the heart and stomach and the right side is a frontal view with the duodenum being reconstructed.
 c) Grey scale 3D construction showing “multiple -bubble” appearance, dilated stomach, D1 and distal gut. (The same case a,b).
 d,e) Mode x ray (intrauterine) showing “multiple -bubble” appearance.
 f) 3 D ultrasound in multiplanar mode showing that the duodenojejunal junction is located in abnormal position, at the right side.
 In d, e and f: Note the abnormal position of the duodenojejunal junction to the right side, a sign of gut malrotation.
 H: Heart; A: Apex of the heart; S: Stomach; GB: Gall Bladder; UB: Urinary Bladder; D1: First part of duodenum; Li: Liver. Asterisks in D: Diaphragm; in E: Connection between stomach and duodenum.
 NB: Duodenojejunal junction normally cross to the left of the left pedicle of the vertebral body and is located inferior to the duodenal bulb.

at any stage in midgut development [26]. It is associated with a wide spectrum of congenital abnormalities, ranging from apparent omphalocele in newborns to asymptomatic non rotation of the large and small bowel in adults [27,28]. From a general standpoint, they may be grouped in to two broad categories: Non-rotation and incomplete rotation [29,30].

The term non-rotation is misleading because the initial 90° of rotation has occurred, resulting in the entire small bowel localizing to the right abdomen and the colon localizing to the left abdomen, as a result of the absence of a ligament of Treitz (Case 3, Figure 3c) [31,32].

“Incomplete rotation” represents a failure, which occurs during the final 180° counterclockwise rotation of the small bowel and/or the final 180° counterclockwise rotation of the colon. Often, this is confusingly termed “malrotation.” Other names include “mixed rotation” and “partial rotation” [33]. In this paper, we focus on the association between Heterotaxy syndrome and IRA. Heterotaxy syndrome (also known as a trial isomerism or situs ambiguous) refers to a wide spectrum of abnormalities in which the usual left and right distribution of the thoracic and abdominal organs does not entirely correspond neither to the normal arrangement “situs solitus” nor to the mirror image “situs inversus” [27]. In 3 out of 4 cases diagnosed with this syndrome intestinal malrotation was confirmed (Table 1).

Material and Methods

The present study aimed to evaluate the role of Three-Dimensional (3D) ultrasound in the diagnosis of antenatal IRA. Examinations

were performed *via* Voluson 730 Pro (General Electric, Milwaukee, WI, USA) with a volumetric abdominal transducer (4-8 MHz). Stored volumes were prospectively and subsequently analyzed offline.

Sonography images and videos were then sent *via* the internet or Visio conference to a prenatal diagnosis reference center (Caen Teaching Hospital, France), and the initial diagnosis was confirmed or revised. A multidisciplinary team including a pediatric gastroenterologist, a neonatologist, and a pediatric surgeon provided comprehensive prenatal counseling to each expectant mother. We present four cases in which intestinal malrotation was suspected antenatally, either directly or indirectly, with one case in which Ladd's bands had been strongly suspected and confirmed by a fetopathological examination. To our knowledge, this is one of few studies to evaluate the role of 3D ultrasound in the diagnosis of antenatal IRA. Moreover, 3D reconstruction clearly showed the characteristic “corkscrew” appearance of the duodenum and distal jejunum, showing that the duodenojejunal junction is located in an abnormal position at the right side (normally, it crosses to the left and is located inferior to the duodenal bulb). In this study, we propose a new ultrasonographic sign, the “multiple bubble sign,” that may be useful in the diagnosis of malrotation caused by Ladd's bands (Case 1).

Results

Intestinal obstruction was easily diagnosed in two cases by a characteristic “double-bubble” appearance (Figure 1a). The first case represented an anatomic challenge for the interpretation of the images.

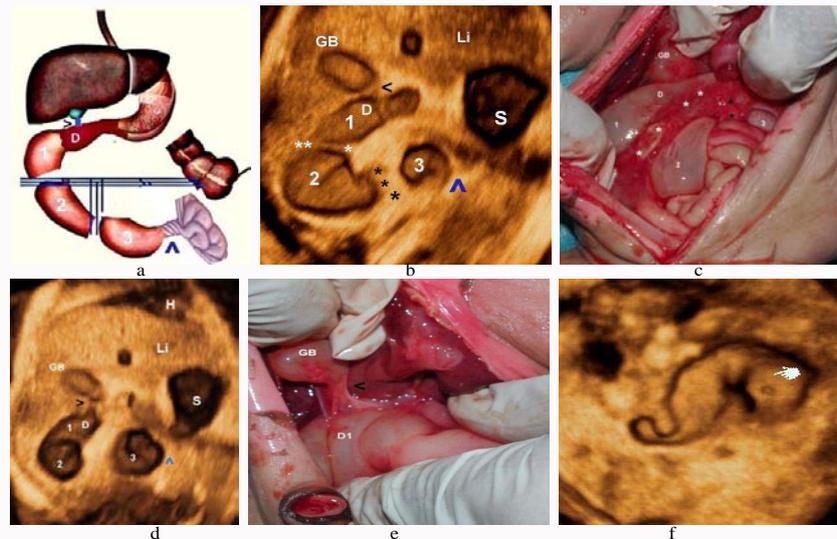


Figure 2: a) Drawing showing the course of Ladd Bands and its false impression of duodenal obstruction at sites that exactly corresponds to the sites of these bands in autopsy examination giving a multiple bubble appearance 1, 2 and 3.
 b,c) Linear extrinsic impression on the different portions of the duodenum giving the appearance of multiple bubble appearance due to false impression of obstruction (asterisks), upward arrowhead denotes the real site of obstruction (echo-anatomic correlation).
 d) 3D reconstruction of the duodenum not showing the first impression of obstruction between 1 and 2 but that impression exists between 2 and 3, this impression in artefactual, black arrowhead denotes hepatoduodenal ligament (echo-anatomic correlation).
 f) Reconstruction of the duodenum revealing a characteristic “corkscrew” appearance without discontinuation seen in b and d.
 Note the correlation between prenatal ultrasound and autopsy findings.
 H: Heart; A: Apex of the heart; S: Stomach; GB: Gall Bladder; UB: Urinary Bladder; D1: First part of duodenum; Li: Liver

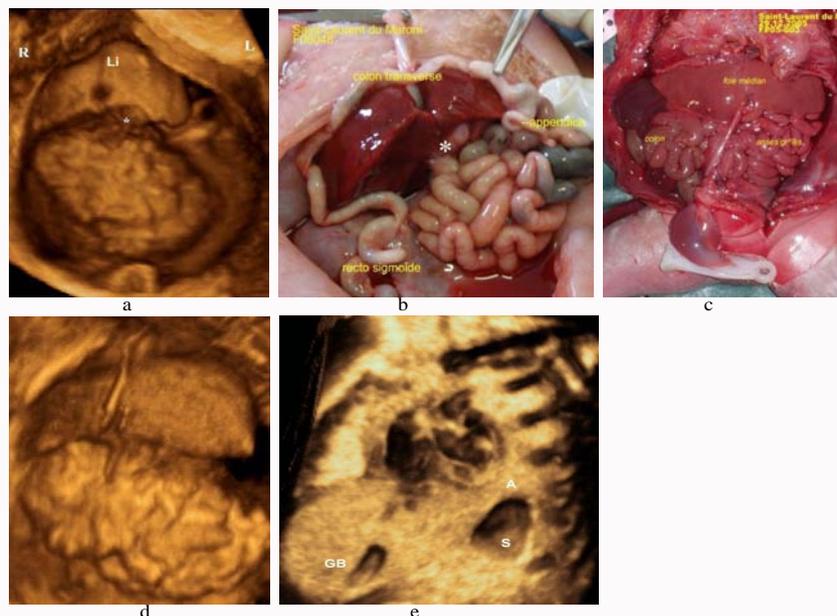


Figure 3: a,b) Liver in the median position (echo-anatomic correlation), appendix and gall bladder (‘) are on the left side, rectosigmoid is on the right side.
 c) Non-rotation: The entire small bowel localizing to the right abdomen and colon localizing to the left abdomen.
 d) Liver in the median position (echo-anatomic correlation with c),
 e) Case control, 3D volume of normal situs solitus (28 weeks’ Gestation). The heart and stomach are on the left; the gallbladder is on the right, liver is predominantly on the right side.

At first, we were easily able to have characteristic “double-bubble” appearance, representing a fluid-filled stomach and proximal duodenum with a presumptive diagnosis of duodenal obstruction. Then, a more detailed evaluation enabled us to see “multiple bubble appearance”, (Figure 1c-1f) where the duodenum seems to be interrupted at three sites; two of the sites show that the interruption was not a fixed anatomic obstruction as the duodenum distal to these

segments was dilated.

Moreover, we were able to reconstruct the duodenum with a characteristic corkscrew appearance, without interruption of its continuity, especially at the sites that seemed initially interrupted (Figure 2f and Figure 2c). When the obstruction is due to a fixed anatomical blockage, a dilated distal duodenum should not be seen.

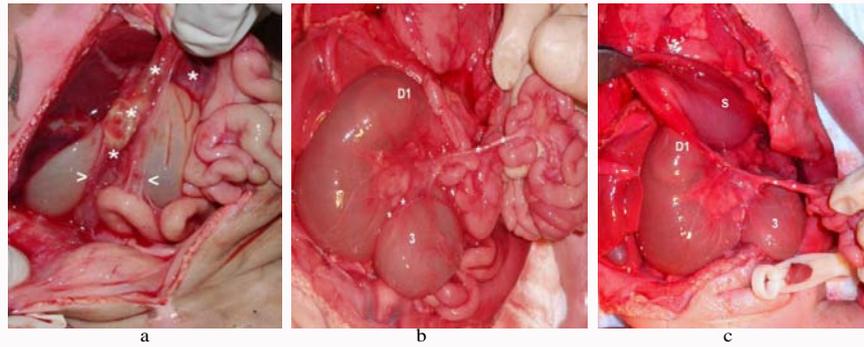


Figure 4: Ladd Bands.

a) Case 1: Note the adhesions to the small intestines < >. The band is not causing obstruction at this site.
 b,c) Case 2: Extend from the abnormally positioned cecum to duodenum.
 D1: First part of duodenum; S: Stomach; * Ladd's bands (cause of obstruction)

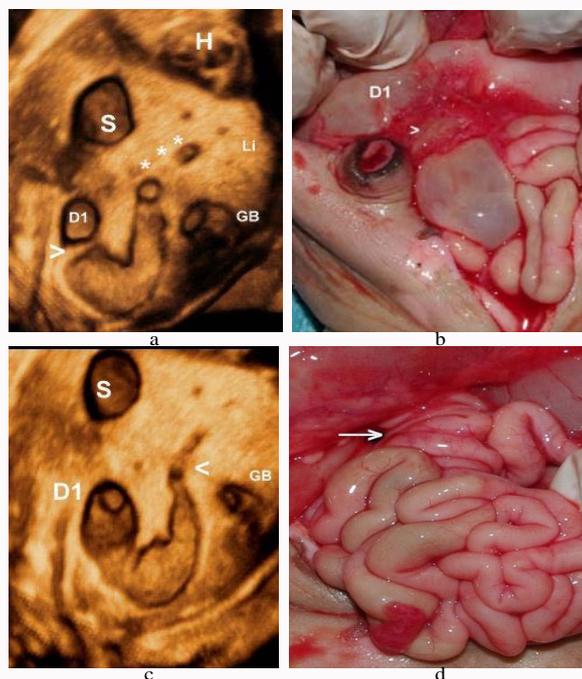


Figure 5: A Ladd bands.

a) The arrow head denotes a false impression of obstruction , duodenal dilatation after this site indicates that the site of real obstruction is distal to this site.
 b) Fetopathological photo showing Ladd band giving the false impression of obstructuin in a, note the correlation with a.
 c) Shows abnormal course of duodenum, which fails to cross midline and has spiral (corkscrew) appearance, consistent with malrotation with volvulus, note that the duodenum is being reconstructed without interruption proving that the impression of obstruction in photo a is not genuine.
 d) Arrow heads denote the site of obstruction (volvulus) (Case 1).

Distal to the third point of obstruction, no dilated small bowel was seen; therefore, we hypothesized that this site represents a genuine bowel obstruction (Figure 5b-5d), transition between the dilated proximal and non-dilated distal bowel, (fixed obstruction due to volvulus), which was confirmed by fetopathological examination (Figure 5b-5d). Apparent breaks of intestinal continuity were produced by extrinsic band-like defects at levels that exactly correspond to the sites of these bands (echo-fetopathology correlation- Figure 2b-2d and Figure 5a-5c). This apparent discontinuity of the duodenum at the first two sites was artifactual due to the refraction of the sound beam at the interface between the amniotic fluid and Ladd’s bands.

We have been able to reconstruct the 3D anatomy of the upper gastrointestinal tract with a characteristic corkscrew appearance at the distal duodenum, demonstrating an abnormal position of the

duodenojejunal junction at the right side (normally, it crosses to the left and is located inferior to the duodenal bulb) (Figure 1f and 5c).

The other 3 cases were diagnosed with heterotaxy syndrome. In the second case, heterotaxy syndrome was associated with duodenal stenosis/atresia based on demonstration of the “double bubble” sign on ultrasound, polyhydramnios, and findings that accompany right atrial isomerism. Follow-up scans were not performed because of fetal death in utero. On a fetopathological examination, Ladd’s bands were not found to be the cause of obstruction (Case 2, Figures 4b-4c).

In other cases, the two fetuses were diagnosed to have heterotaxy syndrome (atrial isomerism-isomerism of the atrial appendages). There was no intestinal dilatation, but intestinal malrotation was

inferred from the fact that heterotaxy is frequently associated with intestinal malrotation at an incidence of 60% to 83% [34]. A midline liver and a left-sided gallbladder were seen on ultrasonographic examination in case 4 (Figures 3a,3b), and a midline liver was seen in case 3 (Figure 3c,3d). These ultrasonographic findings were confirmed by autopsy examination. Clinical data of the patients and ultrasonographic findings are summarized in Table 1.

Discussion

Prenatal screening to identify fetal abnormal bowel positioning is not a priority during a routine prenatal ultrasound because of their rare occurrence. As with these anomalies, there is a high association with a congenital diaphragmatic hernia, omphalocele, and heterotaxy syndromes, and to a lesser extent, duodenal or intestinal atresia or web, biliary atresia, Meckel diverticulum, and heart disease. Early diagnosis of intestinal malrotation is of paramount importance to prevent potentially life-threatening complications such as midgut volvulus [28]. In 2016, Lesieur E et al. [35] published the first reported case of prenatally diagnosed complete non-rotation of fetal bowel with the combined use of ultrasound and magnetic resonance imaging [35].

Ultrasonography can be used to determine the position of mesenteric vessels and, thus, may be helpful in the diagnosis of malrotation. Normally, the superior mesenteric vein lies to the right of the superior mesenteric artery. Malrotation could be diagnosed by sonography if the superior mesenteric vein lies either anteriorly or to the left of the superior mesenteric artery. Unfortunately, this is inconsistent and does not lead to a definitive diagnosis [36]. To date, the role of ultrasound in the diagnosis of these conditions remains a challenge when prior knowledge of the condition is absent because it is highly operator dependent. Its reproducibility remains to be explored [37]. The use of fetal MR imaging for gastrointestinal indications is variable, depending on local expertise in ultrasound and MRI [38].

Fetal MRI does not suffer from inherent limitations compared with ultrasound, confirming its role in the diagnostic algorithm for evaluation of fetal gastrointestinal abnormalities. Previous studies have shown that the inclusion of T1-weighted MRI sequences can add relevant new information to ultrasound findings, especially the position of the proximal jejunum using T2-weighting [39]. Early suspicion of intestinal volvulus allows the clinician to refer the patient to a tertiary center to confirm the diagnosis and perform an appropriate follow-up in order to identify the proper time of delivery [40].

Fetal primary bowel volvulus is extremely rare but represents a serious life-threatening condition. Prenatal diagnosis enables appropriate surgical management immediately after birth [41].

In a recent study, among 13 cases, Bartholmot et al. [42] found that the most common signs for the diagnosis of antenatal intestinal volvulus were the whirlpool sign (77%) and a fluid-filled level in dilated intestinal loops (38.5%) [42].

The pathognomonic finding of midgut volvulus in the upper gastrointestinal tract examination is a spiral or “corkscrew appearance” of the twisted distal duodenum and jejunum that is located in the middle of the abdomen. [43].

Conventionally, Ladd's procedure is performed with an open technique to treat the intestinal malrotation and has been the

gold standard [44]. Current early evidence supports laparoscopic correction of malrotation. Laparoscopy is a feasible, effective, and safe procedure that offers the advantages of a laparoscopic approach [45]. Parents screening and early detection of IRA in patients diagnosed with heterotaxy syndrome provide parents, patients, and medical team with valuable insight into potential risks of patient's condition and would enable timely and accurate diagnosis and allow for prompt intervention. The benefit of decreasing the future risk of volvulus in an asymptomatic individual must be balanced with the potential operative and anesthetic risk of performing a Ladd procedure on a stable comorbid condition like severe cardiac anomalies [27]. We do believe that screening asymptomatic patients for IRA is warranted in this population, prophylactic vs. symptomatic Ladd procedures on asymptomatic heterotaxy syndrome patients remain an area of controversy. A randomized controlled trial is needed to determine the gold standard approach [46]. With 3D ultrasound, we were able to evoke the diagnosis of intestinal malrotation due to Ladd's bands by a 3D anatomical reconstruction that was confirmed by a fetopathological examination. Anatomical image reconstruction enabled us to see the characteristic “corkscrew” appearance, and showed the abnormal position of the duodenojejunal junction at the right side (normally, it crosses to the left and is located inferior to the duodenal bulb) and gave us an anatomical 3D image that correlated excellently with fetopathological examination. The apparent discontinuity of the duodenum at different locations seen on ultrasound was artifactual due to refraction of the sound beam at the interface between the amniotic fluid and Ladd's bands, thus, creating the false impression that duodenal breaks exist at different sites, consequently creating a multiple bubble appearance, as seen on ultrasound.

Breaks in the continuity of the duodenum artifactually created by Ladd's bands resulted in multiple bubble appearance that could be of a potential diagnostic utility in antenatal diagnosis of congenital intestinal malrotation caused by Ladd's bands. It was Sigmund Freud who famously said that anatomy is destiny, and according to the great man, malrotation and its dreaded complication of midgut volvulus is like a ticking bomb lying within that is destined to go off at any moment or will never go off.

It is our responsibility to sniff out that time bomb before it goes off; in consequence, understanding the embryology, anatomy diagnostic criteria, and appropriate therapy for this putative emergency is imperative for all surgeons.

Conclusion

In conclusion, 3D ultrasound offers a high-resolution volume rendering image that provides excellent delineation of the gastrointestinal tract and add significantly to detection and understanding of the aberrant anatomy of intestinal malrotation. To the best of our knowledge, this is the first study evoking the antenatal diagnosis of Ladd's bands.

Breaks in the continuity of the duodenum artifactually created by Ladd's bands resulted in multiple bubble appearance, a novel sign that may have a potential diagnostic utility in the antenatal diagnosis of congenital intestinal malrotation caused by Ladd's bands.

Further Studies should proceed to further clarify our findings and shed new light on the role of 3D ultrasound in the antenatal diagnosis of IRA.

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