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Utility of Computed Tomography for Evaluation of Normal Small Bowel Rotation in Children Less than 2 Years of Age

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Abstract

Background: Traditionally, the fluoroscopic upper gastrointestinal (UGI) exam with either barium or water-soluble contrast has been used to assess potential small bowel malrotation in children. Computed tomography (CT) has not generally been used to assess malrotation in children. **Objective:** We investigated whether CT could potentially be used to evaluate the position and course of the normal duodenum in infants and very young children. **Materials & Methods:** A retrospective review was performed of children ages 0 - 2 who underwent a CT of the abdomen and pelvis. Patients with known altered anatomy were excluded. Demographic data of patients, including age, gender, ethnicity, and body mass index (BMI), were collected from the electronic health record. CTs were reviewed by board-certified and subspecialty-trained pediatric radiologists to assess if the normal course and position of the duodenum could be determined on CT. Confidence in visualization was recorded on a modified Likert scale (1 = not confident, 2 = somewhat confident, 3 = moderately confident, 4 = very confident). Inter-reader reliability was also assessed. A linear mixed regression model was used to predict confidence in visualizing the course of the duodenum. **Results:** A total of 202 CT scans in 155 unique patients were included. The duodenal course could be seen in 86% (95% CI: 80% - 90%) of cases. The mean ± SD confidence score in visualizing the course of the duodenum was 3.2 ± 1.1 (median 4/4, representing 53% of cases). IV contrast improved confidence by 0.47 points (SE 0.16). A collapsed duodenum was the most common limiting factor identified (30% of cases), reducing confidence by 1.54 (0.14; all $p < 0.01$). Inter-rater agreement for confidence in identifying the course of the duodenum, measured on a 1 - 4 Likert scale, was 0.52 (95% CI: 0.33 - 0.72), using a two-way random effects, single unit type intra-class correlation coefficient ($p < 0.01$). **Conclusion:** The course of the normal duodenum can be seen in a high percentage of CT exams in very young children with a moderately high confidence level. The most important factor for increasing confidence in identifying the duodenal course was the use of IV contrast; the most limiting factor was underdistension of the duodenum.

Keywords

Pediatric, CT, Malrotation

1. Introduction

Intestinal malrotation is a congenital condition of abnormal positioning and fixation of the bowel within the peritoneal cavity due to aberrant rotation of the bowel during embryonic development. It occurs in approximately 1 in 500 births [1] [2]. The history and embryology of the condition have been well described previously [3] [4]. The majority of symptomatic cases of malrotation, up to 75%, are detected in newborns, with up to 90% within the first year of life [1] [2] [5] [6]. Because of abnormal fixation and mesenteric bands that may coexist, malrotation predisposes patients to volvulus of the small bowel or "midgut."

Abdominal radiographs are commonly employed as first-line imaging in children with abdominal pain, vomiting, or distension. While they may be suggestive of an obstruction, conventional radiographs are not sensitive to malrotation or mid-gut volvulus and may lead to a delay in diagnosis if clinicians rely only on the normal or non-specific findings [7]. Radiographs may even be normal in the setting of malrotation [4] [8].

Ultrasound (US) has been explored as a possible imaging modality for the diagnosis of malrotation and midgut volvulus, but has not been uniformly adopted. It is based on the visualization of the position of the third portion of the duodenum, superior mesenteric artery (SMA), and superior mesenteric vein (SMV) [9]. US for malrotation and midgut volvulus has a reported sensitivity of 92% - 100% [10]-[13], but also has been reported to have a fairly high false-positive rate (21%) and a variable false-negative rate (2% - 33%) [9] [14]. While the US does not involve ionizing radiation, it can be operator dependent, and a normal position of the SMA and SMV does not necessarily exclude malrotation [9] [15] [16]. Bowel gas may obscure proper visualization. Furthermore, providing specific training and sufficient experience to each sonographer to become proficient in performing these exams is not always feasible. Despite these potential challenges, pediatric radiologists have begun to incorporate US for malrotation into their practice, which has been enhanced with the backing of an expert panel review [17].

Currently, the most established and common practice to assess for potential small bowel malrotation and midgut volvulus is to perform a fluoroscopic upper gastrointestinal (UGI) exam with either barium or water-soluble contrast [18]. The UGI series has been advocated as the test of choice for this diagnosis since its introduction in the 1960s [8] [19]-[21]. UGI has been the time-tested gold standard for the diagnosis of malrotation, with a sensitivity reported up to 96% [22]. The sensitivity of UGI in the diagnosis of midgut volvulus has been reported from 88% to 96% [22] [23], with false negative rates of 3%-15% and false positive rates of 7% [24] to 15% [24]-[26].

Traditionally, CT has not been used for the diagnosis of malrotation or midgut volvulus. This may be due to the traditional preference for UGI and concern for higher doses of ionizing radiation with CT. As with the US, some have used the position of the SMA and SMV on CT to diagnose malrotation with midgut volvulus, but with less than optimal results [27]. However, with recent advancements in CT technology, including rapid acquisition, lower doses, photon-counting CT, and deep learning reconstruction or artificial intelligence [28] [29], CT could potentially be used to investigate bowel rotation in infants and very young children. This may be especially useful in practices that do not have specialized pediatric radiologists readily available or where specific US training is not practical.

The purpose of this study was to determine the feasibility of CT for confidently identifying the course of the duodenum (the traditional marker of normal bowel rotation) in young children with normal small bowel rotation.

2. Materials and Methods

2.1. Inclusion Criteria and Scan Technique

An IRB-exempted retrospective review was performed from 2013 to 2017 at a quaternary medical center of children ages 0 - 2 who underwent a CT of the abdomen or abdomen and pelvis. CTs were performed for a variety of indications (none for malrotation/midgut volvulus). The timing of the IV or enteric contrast administered was based on the clinical indication of the scan. All CT exams were performed on modern 128-slice scanners (Definition Flash or Definition Edge, Siemens, Germany) with a pitch of 1.4, CAREDose4D on, CAREkV off with kV/mAs adjusted based on patient weight (<8 kg - 80 kVp, 8 - 30 kg - 100 kVp, >30 kg - 120 kVp), with reconstruciton kernel I30, iterative reconstruction strength setting of 3, and image slice thickness between 0.6 mm and 3 mm. Patients with known altered anatomy of their proximal small bowel (abdominal tumor mass effect, heterotaxy, prior abdominal surgery) were excluded. Demographic data of patients, including age, gender, ethnicity, and body mass index (BMI), were collected from the electronic health record (EPIC Systems, Verona, Wisconsin).

2.2. Image Review

CTs were reviewed by board-certified and subspecialty-trained pediatric radiologists (initials and years of experience: 3 years, 7 years, 9 years, 24 years, 25 years, 8 years) to assess if the course and position of the normal duodenum could be determined on CT. Each radiologist independently reviewed an equal portion (approximately 34 scans per reader) of the total number of exams. A sample of the study exams of twenty randomly selected CTs was reviewed by all six pediatric radiologists to estimate inter-rater reliability. Inter-rater reliability for confidence in identifying the course of the duodenum, measured on a 1 - 4 Likert scale, was recorded and calculated. Radiologists were free to review the scan in standard planes (axial, coronal, sagittal) or make reformations on the PACS system as needed (Visage Imaging, San Diego, California). Standard slice thickness available for review was 3 mm and 1 mm. Confidence in visualization was recorded on a modified Likert scale (1 = not confident, 2 = somewhat confident, 3 = moderately confident, 4 = very confident). Inter-reader reliability was also assessed. If available, CT results of the duodenal course were compared to a UGI to confirm consistency. Visualization of the superior mesenteric artery (SMA) and superior mesenteric vein (SMV) was also documented. The vertebral level at which the duodenum crossed the midline was also recorded. Estimated dose levels of computed tomography dose index-volume (CTDIvol) and dose length product (DLP) were recorded for each scan.

2.3. Statistical Analysis

A linear mixed regression model was used to predict confidence in visualizing the course of the duodenum, accounting for inter-rater differences as a random effect. Fixed covariates included dummy codes for IV contrast, oral contrast, duodenal collapse, and its interaction with oral contrast, presence of surgically altered anatomy, and reviewer assessment of motion, dose, and artifact limitations. Random slope for the reviewer was used to account for reviewer variation in confidence scores.

3. Results

3.1. Visualization of the Duodenum and Superior Mesenteric Vessels

A total of 202 CT scans in 155 unique patients were included in the review, with patient demographic data displayed in **Table 1**. The duodenal course could be seen in 86% (95% CI: 80% - 90%) of cases. The SMA and SMV were also seen in 86% (95% CI: 80% - 90%) of cases, overlapping but not exclusively those with a visible course of the duodenum. The mean ± SD confidence score in visualizing the course of the duodenum was 3.2 ± 1.1 (median 4/4, representing 53% of cases). As mentioned above, a linear mixed regression model was used to predict confidence in visualizing the course of the duodenum, accounting for inter-rater differences as a random effect. Within this model, IV contrast improved confidence by 0.47 points (SE 0.16). **Figure 1** illustrates the influence of IV contrast and a distended vs. collapsed duodenum.

3.2. Factors Affecting Confidence

Reviewers describing a scan as motion-limited, artifact-limited, or having altered anatomy reduced confidence by 1.45 (0.23), 1.32 (0.31), and 1.03 (0.42), respectively; a collapsed duodenum was the most common limiting factor identified (30% of cases), reducing confidence by 1.54 (0.14; all $p < 0.01$). **Figure 2** demonstrates

Table 1. Summary of demographic data of included patients.

Age	<1: 57% (88)	>1 and <2: 43% (67)	
Gender	Male: 55% (86)	Female: 45% (69)	
BMI	Mean: 15.88	Median: 16.05	Range: 3 - 22
Ethnicity	White: 77% (120)	Black/Asian/Hispanic: 9% (14)	Other/Unknown:14% (21)

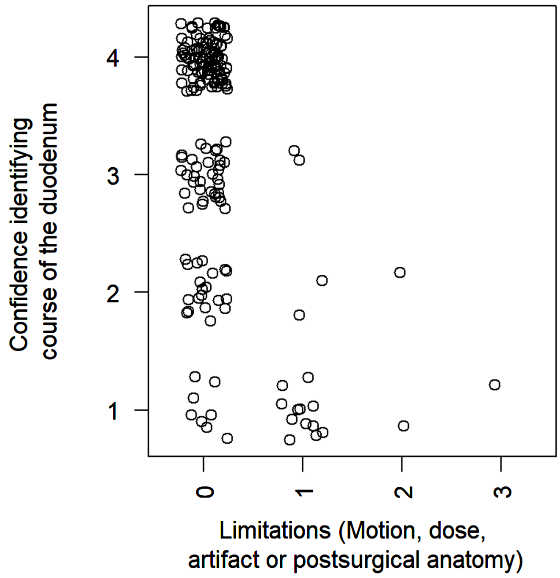

Figure 1. IV contrast (p = 0.003) and distended duodenum (p < 0.001) predicted confident identification of the course of the duodenum (Confidence score mean ± [A: bootstrapped 95% CI, B: SD, C: median, IQR]).

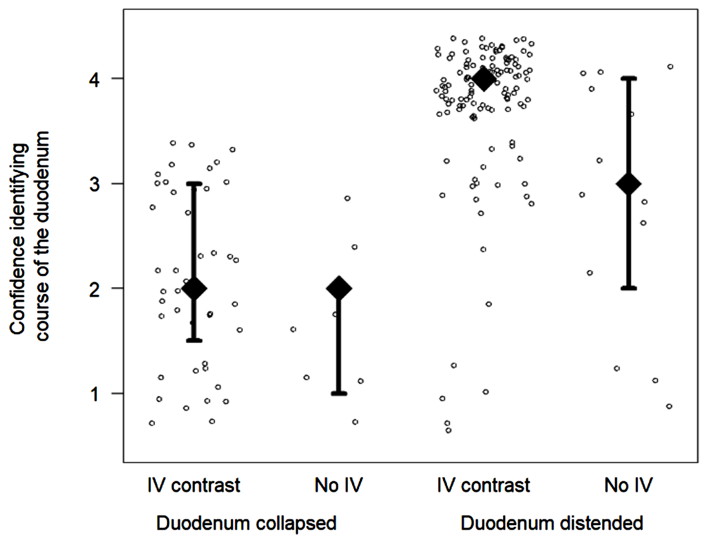

Figure 2. The course of the duodenum was identified with high confidence in the majority of cases. Confidence decreased with an increasing number of limitations. Model p < 0.001 for the effect of motion, dose, and artifact-limited exams. p = 0.01 for postsurgical anatomy.

decreasing confidence in identifying the course of the duodenum with an additive negative impact of cumulative limitations. The presence of enteric contrast did not improve confidence and did not interact with or prevent duodenal collapse from reducing confidence.

3.3. Inter-Rater Agreement

Twenty randomly selected cases were reviewed by all six pediatric radiologists. Inter-rater agreement for confidence in identifying the course of the duodenum, measured on a 1 - 4 Likert scale, was 0.52 (95% CI: 0.33 - 0.72), using a two-way random effects, single unit type intra-class correlation coefficient ($p < 0.01$).

3.4. Demographic Data & Radiation Dose

BMI, CTDI, and DLP did not predict confidence in identifying the course of the duodenum. The mean CTDIvol was 2.13 mGy, and the mean DLP was 60.34 mGy*cm for CTs of the abdomen or abdomen and pelvis. Although the number of CTs identified as dose-limited was small ($n = 7$), this subjective designation by reviewers was associated with significantly lower confidence in identifying the course of the duodenum (−0.98 regression coefficient, $p < 0.001$). Studies identified as dose-limited were indeed predicted by lower CTDIvol (−1.07 log odds, $p = 0.047$) and trended lower in DLP (−0.028, $p = 0.066$). However, the CTDIvol and DLP did not predict lower confidence in identifying the course of the duodenum in the sample at large, possibly due to the small number of cases identified as dose-limited.

3.5. CT vs UGI

Forty-nine of the included patients also had a UGI for comparison. The UGI exams had previously been performed for a variety of reasons (examples: distension, vomiting, and to rule out malrotation). There were no discrepancies in bowel rotation between CTs and UGIs. In such cases, all had a UGI performed previously, prior to the CT being performed. Three patients had a history of malrotation, and these cases were not included in the statistical analysis. The duodenum crossed the midline at a range of levels from T12 to L4, with L3 being the most frequent (**Figure 3**).

4. Discussion

4.1. High Percentage of Duodenal Course Visualization

This study demonstrates that the course of the normal duodenum can be visualized in a high percentage of CT exams in very young children with a moderately high confidence level, even when the indications, protocols, and exam indications are not uniform. The use of IV contrast increased confidence in identifying the duodenal course and was the most important factor under the control of the radiologist. This may be due to differentiation between soft tissue structures in the upper midline of the abdomen, such as the transverse duodenum, pancreas, stomach, and other small bowel loops with contrast present.

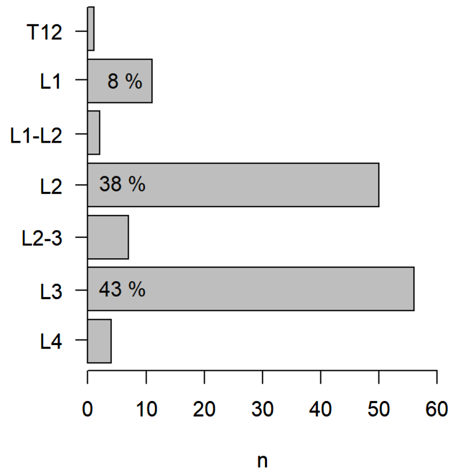

Figure 3. Distribution of the position of the duodenum crossing the midline in 130 children, assessed by CT.

4.2. Factors Limiting Visualization

The most limiting factor was under-distension of the duodenum. This is to be expected, as a decompressed transverse duodenum often cannot be easily recognized with confidence as it passes the midline and is adjacent to other soft tissue structures, particularly in this age group, when there is often so little intra-abdominal fat present. Distension of the duodenum with air or fluid made the duodenal course more conspicuous (Figure 4 and Figure 5). Unfortunately, the use of enteric contrast did not reliably distend or outline the course of the duodenum, likely because the timing of contrast was not optimized for distention and assessment of the duodenum in this retrospective study. Future work might assess the utility of CT performed promptly after enteric contrast is given.

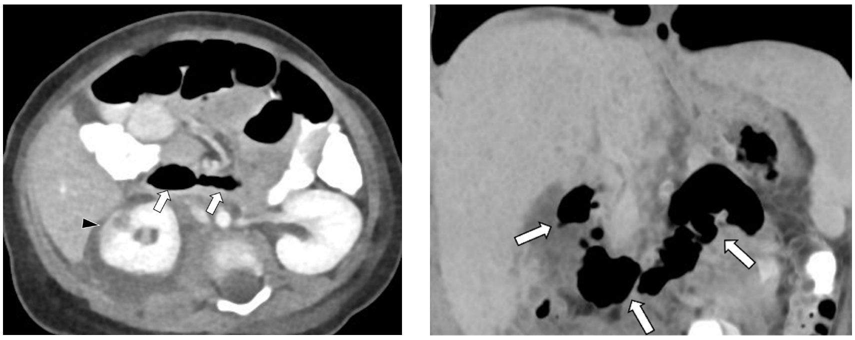

Figure 4. An infant presented to the emergency room with abdominal pain, fever, and a toxic appearance. CT with IV contrast was performed to evaluate the source of symptoms. Axial contrast-enhanced image with enteric contrast (left) and coronal minimum intensity projection (MinIP) image (right) show an air-distended duodenum (arrows). Note that the peripheral hypoenhancement in the right kidney is compatible with pyelonephritis (black arrowhead).

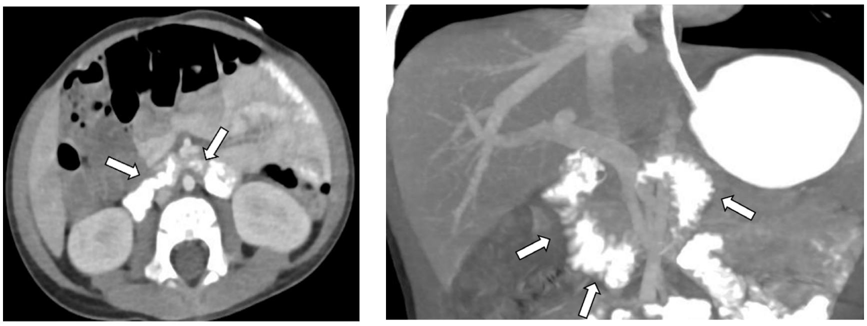

Figure 5. A toddler with abdominal pain underwent a contrast-enhanced CT with enteric contrast given via nasogastric tube. Left: Axial image shows enteric contrast within the duodenum as it crosses the midline (arrows). Right: Coronal maximum intensity projection (MIP) image shows the course of the duodenum (arrows).

4.3. Radiation Dose Considerations

The mean CTDIvol for the CTs in this study was 2.13 mGy, which is similar to but slightly higher than that of a standard UGI series as reported by Rao *et al*. of 1.88 mGy [30], and higher than estimates in phantoms [31]. Certainly, radiation exposure is a variable that must be considered when selecting the most appropriate exam, and the ALARA principle should be followed. However, the exams in this study were not tailored for the specific indication of evaluating small bowel rotation but were done for a variety of indications. If CT were to be utilized to evaluate bowel rotation, specific protocols could be developed to reduce dose and optimize visualization of the duodenum. Additionally, the scan range could be limited from the dome of the diaphragm to L4-L5, as this would most likely include the transverse duodenum, as most cross the midline at L3. In this investigation, studies subjectively identified by radiologists as dose-limited were less likely to be given confident delineation of the course of the duodenum; dose-limited studies did trend lower for CTDIvol and DLP, although these quantitative parameters did not directly predict confidence scores with statistical significance.

4.4. Future Directions

Additional studies are needed to continue evaluating the utility of CT in assessing bowel rotation in young children. The diagnosis of malrotation, and especially midgut volvulus, is of vital importance and needs to be made with a test that provides both rapid results and a high degree of accuracy. If an optimized protocol were developed to help distend the duodenum, visualization and the confidence level of visualization would likely increase. A possible protocol could include a scan range as suggested above, use of IV contrast with standard weight-based dosing (~2.2 ml/kg), and an attempt to distend the duodenum by having the patient drink fluid or administering fluid via a nasogastric tube within 15 minutes of the CT scan. Nevertheless, with ever-improving spatial and contrast resolution in CT imaging, more advanced protocols could potentially obviate the need for intravenous contrast material.

4.5. Study Limitations

This study has many limitations. First, it is retrospective. The included exams that were not performed for the indication that was evaluated in this study, and not all were performed on the same CT scanner or with the same timing of IV or enteric contrast. Not all patients had a UGI exam for comparison. Additionally, there was a very limited number of cases with known malrotation in our cohort to determine the accuracy of detecting malrotation with CT; this requires further study. Including positive cases of malrotation and midgut volvulus would have been more ideal and would have mimicked a more realistic clinical scenario. However, only three cases of malrotation were found in our data query that had a CT exam, and unfortunately, those CT exams were performed after a UGI and surgery had already been completed, thus limiting the study to determine if malrotation could have been confidently identified. There were also no cases of midgut volvulus included, which limited our determination of CT's accuracy in detecting this critical diagnosis. Although CT confidently identified the duodenal course in a high percentage of cases, inter-radiologist agreement was moderate, suggesting that CT may not be sufficient for all cases. Additionally, the fasting status of the patient, sedation during the exam, and timing of enteric contrast were not recorded, given the heterogeneity of exam indications and retrospective nature of the study. Knowledge of these factors could potentially also influence confidence in the visualization of the course of the duodenum.

While there are limitations, the data show that the course of the duodenum could be seen in a high percentage of cases, even with diverse indications and heterogeneity in scanners and protocols, and by multiple radiologists with varying levels of experience. These promising data could serve as a step toward further research and development for the diagnosis of malrotation (and potentially acute midgut volvulus) with CT. Specialized protocols, along with the addition of newer technologies including dual energy CT, photon counting CT, and dose reduction methods such as the use of a tin filter and deep learning, increase the potential for use of CT for this diagnosis. CT could also lend itself to more rapid diagnosis and less waiting for on-call pediatric radiologists and/or sonographers to arrive to perform UGI or US. Just as US for malrotation was perceived with concerns and doubt in its infancy, it has now been shown to be effective with proper training. CT may have this same potential but with increased rapidity and less operator dependence.

5. Conclusion

The course of the duodenum can be seen in a high percentage of CT exams in very young children with a moderately high confidence level. The most important factor for increasing confidence in identifying the duodenal course was the use of IV contrast; the most limiting factor was under distension of the duodenum.

Ethical Compliance

This study was performed in compliance with ethical standards and was deemed exempt by our IRB: 19-009688.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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