Original Article

Fluoroscopic criteria for on-site evaluation of failed intussusception reduction during air enema technique

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Background: There is no reliable fluoroscopic criteria for failed intussusception reduction during air enema technique.

Methods: This retrospective case-control study included 373 episodes of ileocolic intussusceptions who had undergone air enema under fluoroscopy. All procedures were initially classified by conventional fluoroscopic criteria: presumptive successful procedures (PSP) *vs.* presumptive failed procedures (PFP). PFP were divided into true failure, false failure, and undetermined groups. The configuration and size of the residual mass were evaluated on fluoroscopic images. Statistical analyses included Mann-Whitney U-test, Fisher's exact test, receiver operating characteristic (ROC) analysis, logistic regression analyses, and Kruskal-Wallis rank sum test with a post hoc Tukey test.

Results: PSP was 264 episodes (71%) and PFP was 109 episodes (29%). The true failure was 40 (37%) and false failure was 48 (44%). The true failure group commonly showed a larger size and round configuration for the residual mass than false failure (P<0.001). Multivariable analysis revealed configuration (P=0.004) and transverse diameter (P=0.007) as significant parameters that differentiated true and false failure. The optimal cut-off value of the transverse diameter of the residual mass was 2.3 cm. The sensitivity and specificity of conventional fluoroscopic criteria for failed reduction was 100% and 85%, respectively. The combination of new fluoroscopic findings and conventional criteria increased the specificity to 100%.

Conclusions: Fluoroscopic finding of round-shape and larger size residual mass combined with conventional criteria may be useful for differentiating false failure from truly failed enema reduction in children with intussusception.

Keywords: Intussusception; air enema; failed reduction; fluoroscopy

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Introduction

Intussusception is the most common abdominal emergency in early childhood, occurring primarily within the first 2 years of life (1). The primary treatment of choice for ileocolic intussusception is image-guided reduction with the use of an enema technique, but cases with failed enema reduction need surgery (2,3). Of the various enema techniques, air enema under fluoroscopy guidance is the most popular method and has a high overall success rate of 80–86% (4,5). The air enema is a cleaner and faster technique that delivers less radiation than hydrostatic enema under fluoroscopy guidance (6).

The hallmark of a successful air enema reduction is the disappearance of the intussusception mass and visualization of air reflux into the small bowel. By contrast, the conventional criteria for a failed enema reduction is characterized by a remaining intussusception mass and no air reflux (7). However, an edematous ileocecal (IC) valve may appear as a filling defect on post-reduction fluoroscopic images (3,7), and it can be incorrectly interpreted as unreduced intussusception (*Figure 1*). In addition, an edematous IC valve may prevent air reflux into the small bowel, even following successful enema reduction (8). Ultrasonography (US) with Doppler may aid to differentiate edematous IC valve from residual intussusception. However, no reliable fluoroscopic parameters during air enema have yet been identified that would enable differentiating falsely unsuccessful reduction with edematous IC valve from unreduced intussusception mass.

The purpose of this study was to determine the fluoroscopic criteria that would enable on-site diagnosis of truly failed air enema reduction in children with ileocolic intussusceptions. We present the following article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-21-1239/rc).

Methods

Study population

This retrospective case-control study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Samsung Medical Center (2019-02-116) and individual consent for this retrospective analysis was waived.

A retrospective search of the data entries from January 2003 and May 2018 in the electronic database from the Department of Radiology at the Samsung Medical Center yielded 386 episodes of intussusception that met the following criteria: (I) patients younger than 18 years of age and (II) patients who had undergone fluoroscopic air enema technique for ileocolic intussusception reduction. Of these 386 episodes, 13 were excluded because of (I) repeat intussusception episodes occurring within 24 h during observation after air enema (n=7), (II) a remaining intussusception mass beyond the hepatic flexure at post-reduction fluoroscopic images (n=3), (III) episodes for which the radiologic reports mentioned no intussusception found during air enema (i.e., presumed misdiagnosis or spontaneous reduction of intussusception prior to air enema) (n=2), and (IV) an episode of colo-colic intussusception (n=1). We choose this inclusion time to include as many patients as possible. Episodes of ileocolic intussusception in the same child occurring more than 24 h after air enema for the first episode were considered as separate episode and were included in the study as independent subjects.

The fluoroscopic images during air enema were evaluated using a consensus approach by two pediatric radiologists (with 17 and 10 years of pediatric imaging interpretation experience, respectively) who were blinded to the clinical information. All air enemas were classified by their conventional fluoroscopic criteria into presumptive successful procedures (PSP) and presumptive failed procedures (PFP). The PSP were determined by air reflux into the small bowel and/or resolution of an intussusception mass, whereas PFP were identified as no air reflux into the small bowel and a residual intussusception mass (7). According to the outcome, the PFP group was further allocated into true failure group (truly failed enema reduction), false failure group (falsely failed enema reduction), and undetermined group based on the clinical follow-up, post-reduction US, or the surgical records.

After air enema, the patients were observed for at least 24 h, and were then discharged when symptoms and signs

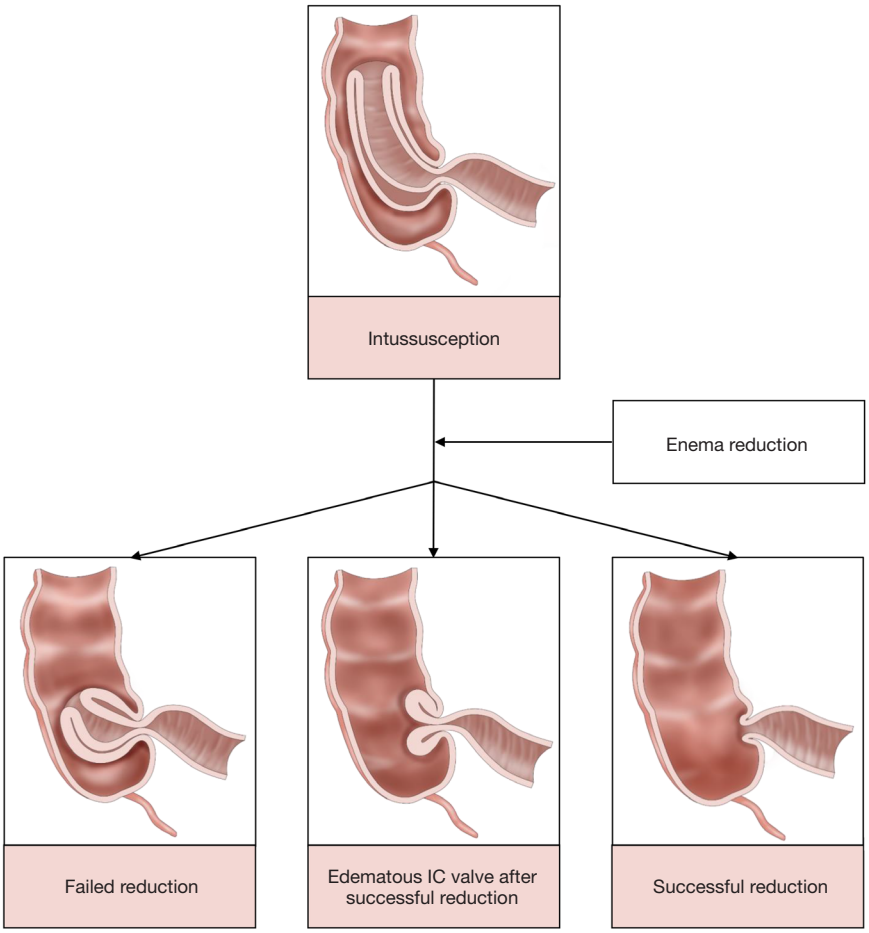

Figure 1 Schematic drawing of results of enema technique for ileocolic intussusception. IC, ileocecal.

had resolved. Patients whose reduction failed were referred to the pediatric surgical team. The true failure group was determined by intraoperative evidence of ileocolic intussusception at surgery (justified surgery), while the false failure group was identified as cases that showed both reduced intussusception at post-reduction US and improved condition during observation. The undetermined group was defined by episodes that showed no intraoperative evidence of ileocolic intussusception (unnecessary surgery) or those in which the condition improved during observation but did not undergo post-reduction US. This undetermined group may constitute actually successful enema reduction or spontaneous reduction subsequent to the enema attempt.

Clinical data collection

The medical records of eligible episodes were reviewed to collect demographic data, laboratory data, and clinical outcomes after air enema or surgery. The following presenting symptoms were documented: colicky pain, bloody stool, vomiting/emesis, and irritability. The presence of pathologic lead points and intraoperative findings were also documented.

US examinations

All US examinations [both pre- (n=302) and post-reduction US (n=65)] were performed independently by one of the four pediatric radiologists (who had 9, 5, 3, and 2 years of experience in pediatric US, respectively, at the time each first assessed the study subjects) or by radiology residents under supervision. The US systems (Sequoia, Siemens Healthineers, Erlangen, Germany or LOGIQ E9, GE Healthcare, Waukesha, WI, USA) had curved array transducers (6, 4, and 1–5 MHz) and linear-array transducers (5–10, 9, and 6–15 MHz).

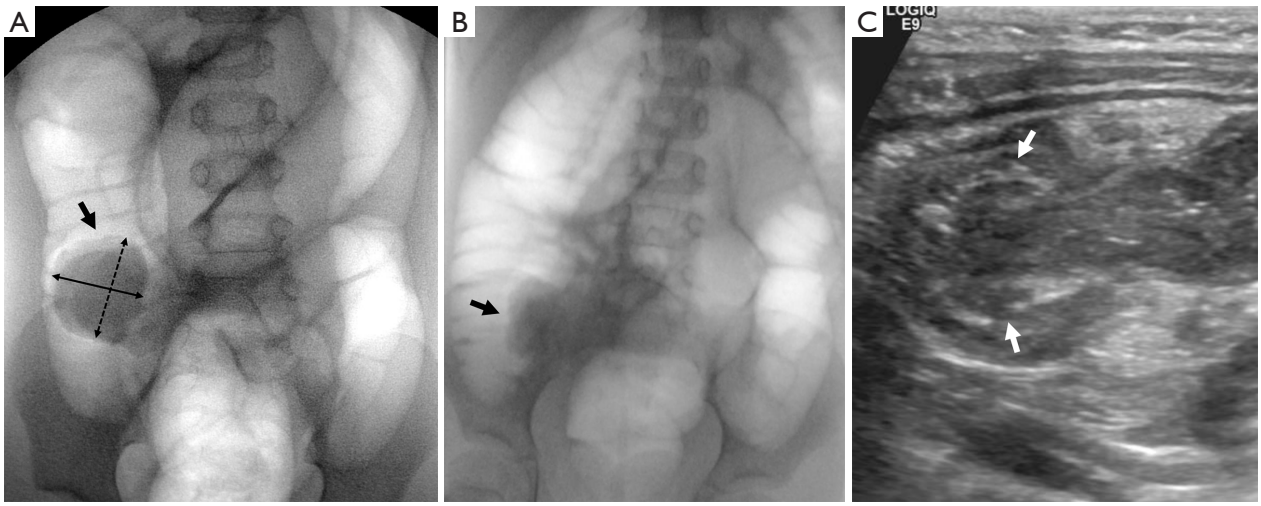

Figure 2 Typical configuration and size of the residual mass in the true and false failure groups. (A) A 3-year-old boy in the true failure group. Post-reduction fluoroscopic image shows a large residual mass (36 mm in transverse diameter, arrow) with round configuration. Solid line = transverse diameter, dashed line = vertical diameter. (B,C) A 3-year-old girl in the false failure group. Post-reduction fluoroscopic image (B) shows a small residual mass (17 mm in transverse diameter, arrow) with indented configuration. Post-reduction US image (C) shows successful intussusception reduction and an edematous IC valve (arrows). IC, ileocecal.

The two pediatric radiologists, who had 17 and 10 years of pediatric imaging interpretation experience, reviewed in consensus all the US images. The parameters assessed by pre-reduction US included the antero-posterior diameter of the intussusception mass on the transverse images, the presence of entrapped fluid between both folded limbs of the intussusceptum, the presence of free peritoneal fluid, and decreased blood flow in the bowel wall by color Doppler imaging. Post-reduction US evaluated the reduction status of ileocolic intussusception after air enema.

Fluoroscopic air enema technique

The reduction technique used in our institution (tertiary referral center, Samsung Medical Center, Seoul, Republic of Korea) was air enema under fluoroscopy guidance. Our protocol fulfilled the elements put forth by the American College of Radiology-Society for Pediatric Radiology practice guidelines for pediatric fluoroscopic contrast enema examinations (9). The procedures were performed using digital fluoroscopic systems (GE Advantx RF, GE healthcare, Milwaukee, WI, USA or Sonialvision ZS100I, Shimadzu, Kyoto, Japan). A soft non-balloon catheter was inserted in the lower rectum, fixed to the buttocks with tape, and connected to the air insufflator device (Tycos Classic Hand Aneroids, Welch Allyn, NC, USA; Gamma G5, Heine, Herrsching, Germany). The air was insufflated at a pressure of 80–120 mmHg and monitored with a manometer. No premedication, such as sedation or antibiotics, was administered. All procedures (n=373) were performed by the one of the four mentioned pediatric radiologists or by radiology residents under supervision.

The first air enema consisted of three separate 3 min attempts. If the first air enema failed, delayed repeated enemas were attempted up to 2 times within a few hours. All attempts, including both first and delayed repeated enema attempts, were considered as one episode.

The parameters assessed by fluoroscopy included the configuration and size of the residual intussusception mass on the last images taken at the end of delayed repeated enema attempts. The two pediatric radiologists assessed the configuration of the residual mass together in consensus. The shape of the residual mass was classified into round or indented configurations. The round configuration was defined when the outer surface of the residual mass had a round appearance as observed from the IC valve, whereas the indented configuration was defined when the outer surface of the residual mass had a central indentation (*Figure 2*). Two observers measured the sizes of the residual mass and then averaged them. The measured size of the residual mass around the IC valve included both transverse and vertical diameters (*Figure 2*).

Statistical analysis

Statistical analysis was performed with software (R 3.5.1; http://www.R-project.org/) and a two-tailed P value <0.05 was considered statistically significant. Continuous data were presented as medians and interquartile ranges (IQR) and were analyzed with the Wilcoxon rank sum test. Differences in categorical variables were tested with the Chi-square test and Fisher's exact test, and expressed as counts and percentages. Univariable logistic regression analysis was performed to assess the ability of fluoroscopic findings to differentiate the true and false failure groups. Multivariable logistic regression analysis was performed using a stepwise selection method to evaluate the independent values for differentiation of the true and false failure groups. Receiver operating characteristic (ROC) curve analyses were carried out to choose the optimal cut-off value for the size of the residual intussusception mass for distinguishing the true and false failure groups. The best diagnostic performance was calculated by combining the conventional criteria and the newly found significant fluoroscopic parameters. Differences between the median sizes of the residual mass and the three different groups of false failure, true failure, and PSP were compared using Kruskal-Wallis rank sum test with a post hoc Tukey test.

Results

Study population

A total of 331 patients with 373 episodes of intussusception met the inclusion criteria. Our study population consisted of 331 patients with a mean age of 1.7 years (range, 0.2–13.2 years) and included 210 boys (mean age: 2.4 years; range, 0.2–13.2 years) and 121 girls (mean age: 2.1 years; range, 0.2–8 years). The diagnosis of intussusception was made by US (n=302), CT (n=15), or air enema (n=56), and the diagnoses were confirmed based on therapeutic air enema, surgery, or both.

Of the 373 episodes, 109 (29%, 104 patients) were PFP and 264 (71%, 242 patients) were PSP (*Figure 3*). Based on the final outcome, 312 (84%) episodes were truly successful enema reductions, 40 (11%) were truly failed enema reductions, and 21 (6%) were undetermined. The demographic and clinical data, US findings, and fluoroscopic findings for both the true and false failure groups are listed in *Table 1*.

Of the 104 patients with PFP, 9 patients (9%) developed recurrent intussusceptions, with 1 to 2 episodes (10 recurrences in total) at intervals of 1 day to 2.6 years. Among the 242 patients with PSP, intussusceptions recurred in 23 children (10%), who had 1 to 4 recurrent episodes of intussusception (a total of 32 recurrences) at intervals of 2 days to 3 years.

Presumptive failed enema reduction by conventional criteria

Of the 109 cases with PFP, 45 episodes (41%) underwent surgery, whereas 64 episodes (59%) showed clinical improvement during follow-up, without surgery (*Figure 3*). Of 64 episodes of clinical improvement during follow-up, 48 episodes showed successful reduction on post-reduction US (false failure group), and 16 episodes did not undergo post-reduction US (undetermined group). Of 45 episodes referred for surgery, 5 (11%) had no intraoperative evidence of intussusception (unnecessary surgery, undetermined group), whereas 40 (89%) underwent surgical procedures for treatment of intussusception (justified surgery, true failure group) (*Figure 3*). Unnecessary surgery was done after an average of 6 h (range, 3.3–9.2 h) following the air enema. No significant statistical difference was noted between the false (17%, 8/48) and true failure (25%, 10/40) groups, according to the conductors (pediatric radiologists *vs.* radiology residents) of air enema (P=0.428).

Post-reduction US was performed in 60% (65/109) of the episodes with PFP and correctly identified the reduction status [successful (n=48) *vs.* failed reduction (n=15)] in 97% (63/65). In remaining two episodes, a small residual mass was interpreted as unreduced short segmental ileocolic intussusception on post-reduction US, although the edematous IC valve was subsequently found at surgery.

The multivariable logistic regression model revealed the configuration and transverse diameter of the residual mass as significant parameters for differentiating the true and false failure groups (P=0.004 and P=0.007, respectively) (*Table 2*). The optimal cut-off value for the transverse diameter of the residual mass was 2.3 cm, with an area under the ROC curve (AUC) of 0.98, sensitivity of 90%, specificity of 96%, and accuracy of 93% (*Figure 4*).

The diagnostic performance of the conventional criteria of air enema for intussusception showed a sensitivity of 100% (40/40), specificity of 85% (264/312), positive predictive value of 45% (40/88), negative predictive value of 100% (264/264), and accuracy of 86% (304/352). Recognition of a mass configuration and measurement of its size, in combination with the conventional criteria,

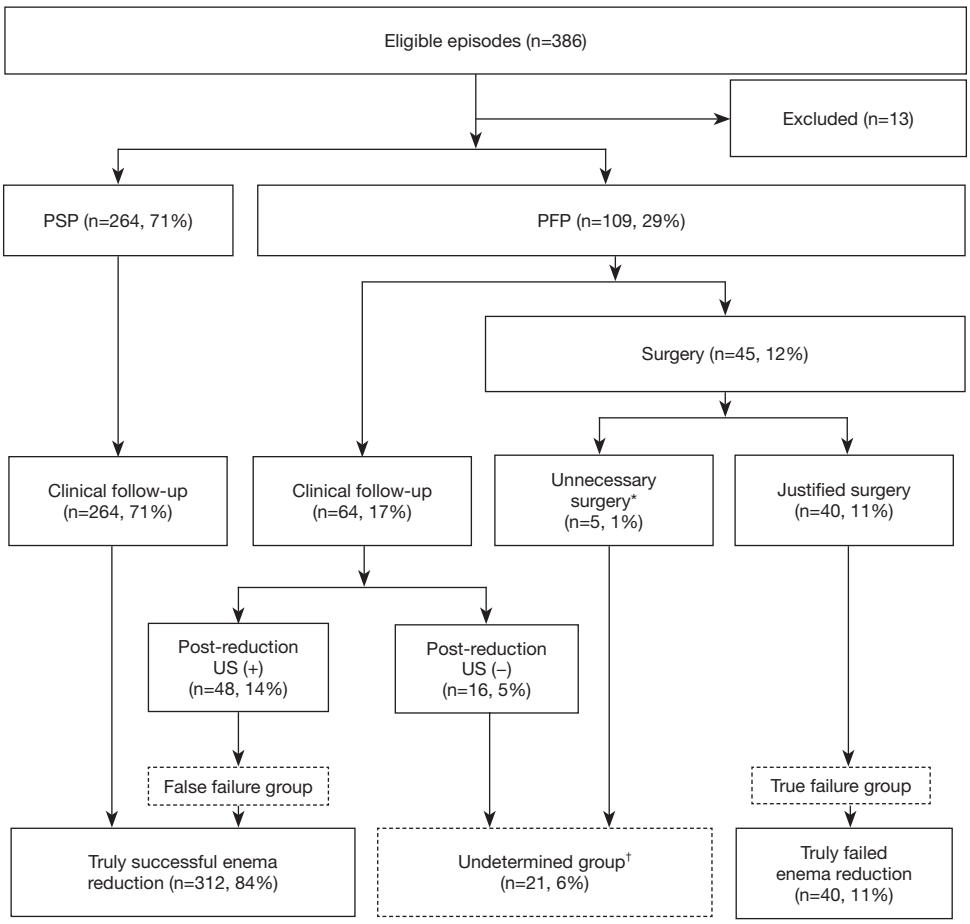

Figure 3 Outcome of fluoroscopic air enema. *, unnecessary surgery: no intraoperative evidence of ileocolic intussusception; †, undetermined group may represent practically successful enema reduction or spontaneously reduced intussusception subsequent to enema attempt; US (+), US was performed and demonstrated the successful reduction; US (–), US was not performed. PSP, presumptive successful procedures by conventional fluoroscopic criteria; PFP, presumptive failed procedures by conventional fluoroscopic criteria; US, ultrasonography.

improved the diagnostic performance with a specificity of 100% (312/312), and positive predictive value of 100% (36/36), and the diagnostic accuracy was also increased to 99% (348/352) (*Table 3*).

Presumptive successful enema reductions by conventional criteria

All 264 episodes of PSP demonstrated truly successful enema reduction (*Figure 3*). Among them, 118 episodes (45%) showed an edematous IC valve with an air reflux into the small bowel (*Figure 5*). The median transverse diameter of the edematous IC valve in PSP group was 1.3 (IQR, 1.2–1.6) cm. The median size of the edematous IC valve differed significantly in the three groups of false failure, true failure, and PSP (P<0.001). The median size of the edematous IC valve in the PSP group was significantly smaller than that of the residual mass in the true failure group (1.3 *vs.* 3.1 cm, P<0.001); however, no statistically significant difference was found between the edematous IC valve in the PSP group and the residual mass of false failure group (1.3 *vs.* 1.4 cm, P=0.901). In addition, most (95%, 112/118) of edematous IC valve demonstrated an indented configuration, which was analogous to residual mass of the false failure group (94%, 45/48) (P=0.719).

Discussion

We assessed novel fluoroscopic findings for on-site determination of failed intussusception reduction during

Table 1 Demographic and clinical data, US findings, and fluoroscopic findings for the true and false failure groups

Variables	False failure group (n=48)	True failure group (n=40)	P
Demographic and clinical data (n=88)			
Age (years)[a]	2.3 (1.6–3.4)	2.1 (0.7–3.6)	0.343
Male	33/48 (69%)	21/40 (53%)	0.119
Colicky pain	38/48 (79%)	25/40 (63%)	0.084
Bloody stool	9/48 (19%)	16/40 (40%)	0.028*
Vomiting/emesis	12/48 (25%)	12/40 (30%)	0.600
Irritability	9/48 (19%)	7/40 (18%)	0.880
Symptom duration (days)[a]	0.5 (0.3–1)	0.9 (0.5–1)	0.003*
Presence of pathologic lead points	0/48 (0%)	6/40 (15%)	0.007*
Leukocytosis	19/48 (40%)	21/40 (53%)	0.184
Elevated C-reactive protein	22/48 (46%)	18/40 (45%)	0.976
US findings (n=82)			
Diameter of intussusception (cm)[a]	2.9 (2.6–3.3)	3 (2.6–3.6)	0.367
Presence of entrapped fluid	1/47 (2%)	7/35 (20%)	0.018*
Presence of peritoneal fluid	5/47 (11%)	13/35 (37%)	0.004*
Decreased blood flow of bowel wall	0/47 (0%)	4/35 (11%)	0.030*
Fluoroscopic findings (n=88)			
Round-shape residual mass	3/48 (6%)	39/40 (98%)	<0.001*
Transverse diameter of a residual mass (cm)[a]	1.4 (1.1–1.7)	3.1 (2.6–3.4)	<0.001*
Vertical diameter of a residual mass (cm)[a]	2.2 (1.9–2.7)	3.6 (3.1–4.6)	<0.001*

Unless otherwise indicated, data are numbers of patients with percentages in parentheses. [a], data are median (IQR); *, P<0.05, the difference is statistically significant. US, ultrasonography; IQR, interquartile ranges.

Table 2 Significant fluoroscopic findings that can differentiate the true failure from the false failure groups

Variables	Odds ratio	P
Univariable logistic regression analysis		
Round-shape residual mass	585 (358.4–5,854.9)	<0.001*
Transverse diameter of a residual mass	238.7 (14.2–4,009.9)	<0.001*
Vertical diameter of a residual mass	16.9 (5.1–356.2)	<0.001*
Multivariable logistic regression analysis		
Round-shape residual mass	128.2 (4.5–3,623.9)	0.004*
Transverse diameter of a residual mass	82.1 (3.3–2,025.3)	0.007*

Numbers in parentheses are 95% confidence intervals. *, P<0.05, the difference is statistically significant.

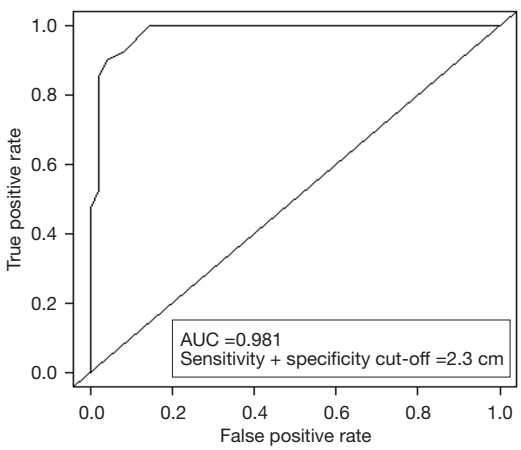

Figure 4 ROC curve for optimal cut-off value for the transverse diameter of the residual mass (by Youden's index). AUC, area under the receiver operating characteristic curve; ROC, receiver operating characteristic.

Table 3 Diagnostic performance of conventional criteria, in combination with newly found fluoroscopic findings in intussusception to differentiate true failure and false failure groups

Parameter	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Accuracy
Conventional criteria alone	100% (40/40)	85% (264/312)	45% (40/88)	100% (264/264)	86% (304/352)
Conventional criteria + configuration	98% (39/40)	99% (309/312)	93% (39/42)	100% (309/310)	99% (348/352)
Conventional criteria + transverse diameter	90% (36/40)	99% (310/312)	95% (36/38)	99% (310/314)	98% (346/352)
Conventional criteria + configuration + transverse diameter	90% (36/40)	100% (312/312)	100% (36/36)	99% (312/316)	99% (348/352)

Fluoroscopic criteria for failed intussusception reduction. Conventional criteria, remaining intussusception mass and no air reflux into the small bowel. Configuration, round-shape residual mass (*vs.* indented-shape). Transverse diameter, ≥2.3 cm.

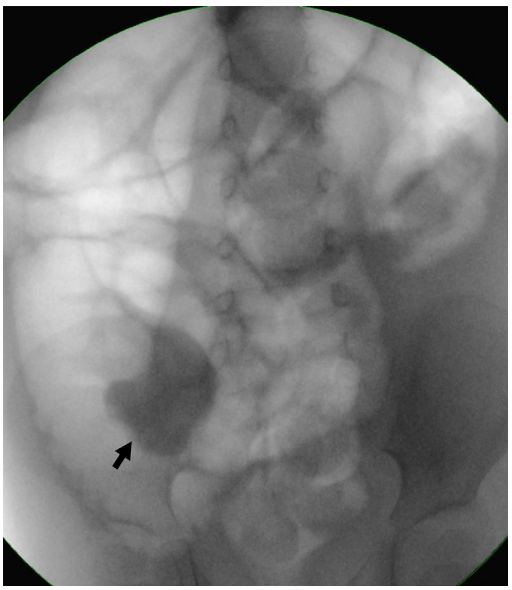

Figure 5 A 2-year-old boy in the PSP group. Post-reduction fluoroscopic image shows an edematous IC valve (17 mm in transverse diameter and indented configuration, arrow) and air reflux into the small bowel. PSP, presumptive successful procedures; IC, ileocecal.

fluoroscopic air enema technique. The present study demonstrates that the size and configuration of the residual intussusception mass had independent values for differentiating false failure from truly failed enema reduction. A larger mass with round configuration was characteristic of the true failure group, while a smaller mass with indented configuration was characteristic of the false failure group. A cutoff value of 2.3 cm or greater for the transverse diameter of the residual mass distinguished the true failure group from the false failure group with an AUC of 0.98, sensitivity of 90%, specificity of 96%, and accuracy of 93%.

The characteristic post-reduction fluoroscopic images in the false failure group demonstrated a small-size residual mass with indented configuration. This could represent an edematous IC valve and could be the cause of the lack of air contrast reflux into the small bowel, even if an intussusception had been successfully reduced. The indented configuration may characterize the edematous upper and lower lips of the IC valve, with central beaking indicating the orifice of the terminal ileum. Our study supports this notion, because the residual mass in the false failed group was very similar in shape and size to that of the edematous IC valve in the PSP group.

In our study, post-reduction US was helpful for confirming the reduction status of the intussusception in 97% of the cases. A post-reduction US following either air or hydrostatic enema reduction is also of value (I) for evaluating interval spontaneous reduction in patients with partially reduced intussusception; (II) for determining the presence of pathologic lead points; and (III) for evaluating patients with persistent or recurrent abdominal pain after air enema. The edematous IC valve can be distinguished from residual or recurrent intussusception, as it lacks multiple concentric rings and invaginated mesentery and, is smaller than the target sign produced by intussusception (2,10,11). Our study does not undermine the role of post-reduction US. Instead, our data confirmed the importance of post-reduction US to differentiate edematous IC valve from residual intussusception.

Pierro *et al.* (8) reported that 19% (11/59) of the patients showed no contrast reflux into the terminal ileum, although hydrostatic reduction was eventually successful; these findings are comparable to the percentage found in our

study (14%, 48/333). They also ascribed its etiology to an edematous IC valve, and none of their cases required additional treatment or developed recurrent intussusception.

Several investigations (12-14) have demonstrated no intraoperative evidence of intussusception in 7–12% of patients who underwent operative exploration after failed enema reduction. For example, Kanglie *et al.* (12) re-evaluated fluoroscopic images in 13 patients (12%) who had negative intraoperative findings and found that 7 children showed no contrast reflux into the terminal ileum when filled up to the cecal valve, which could be considered as indicating an edematous IC valve. Overall, three of the remaining six patients were considered to have errors in the interpretation of their fluoroscopic images (visible contrast reflux into the terminal ileum), while the other three patients were thought to have developed a spontaneous reduction of the intussusception by the time of surgery.

Hedlund *et al.* (7) and Murakami *et al.* (15) described another pitfall of air enema for intussusception reduction, as they reported four patients, including three infants and one adolescent, who showed an extensive air reflux into the small bowel under low pneumatic pressure but without complete reduction of the ileocolic intussusception. The etiology may be an insufficient intraluminal pressure, which could not be sustained because the patent central lumen of the intussusceptum allowed air reflux through the IC valve. In contrast to these two studies, all cases in the present study that showed air reflux into the small bowel achieved successful enema reduction.

Specific US findings, such as a lack of blood flow by color Doppler imaging or the presence of entrapped fluid, free peritoneal fluid, and pathologic lead points, were reported as predictive of a low rate of reducibility in patients with ileocolic intussusception (16-19). Similarly, our study also found these US findings more frequently in the true failure group than in the false failure group.

Our study was limited by a single-center retrospective study with inherent selection bias. Another limitation was that the size of the residual mass might depend on patient's age, body volume, and position. The interpretation of the configuration of residual mass may also be observer-dependent. The last limitation was the possibility that a spontaneous reduction of the intussusception may have occurred in the period between the air enema and subsequent surgery or during observation after the air enema. To minimize this limitation, we classified the episodes that had potential for a spontaneous reduction of the intussusception as an undetermined group and excluded them from the analysis. Spontaneous reduction has been reported to occur in 13–17% of the radiologically irreducible ileocolic intussusceptions by the time the child has reached the operating room (20,21). Therefore, when persistent filling defects showing small size and indented configuration are observed during fluoroscopic air enema but patients are clinically stable, a reasonable policy would be to observe and perform post-reduction US, rather than directly refer the patient to the surgical team.

In conclusion, the conventional fluoroscopic criteria for failed enema reduction cannot alone enable a reliable diagnosis of truly failed enema reduction, although the conventional criteria for successful enema reduction can guarantee truly successful intussusception reduction. The discriminative power of the conventional fluoroscopic criteria can be considerably improved when combined with the configuration and size of the residual mass after air enema. Validation of our findings in a larger population may be warranted to define a reliable means for accurately diagnosing the reduction status after air enema for ileocolic intussusception. If future studies establish the refined fluoroscopic criteria, radiation dose and procedure time of the enema technique can be reduced in practice.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-21-1239/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-21-1239/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Samsung Medical Center (2019-02-116) and individual consent for this retrospective analysis was waived.

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