Published in final edited form as:

Pediatr Radiol. 2008 October ; 38(10): 1074–1083. doi:10.1007/s00247-008-0944-4.

Clinical and Computed Tomography Features of Benign Pneumatosis Intestinalis in Pediatric Hematopoietic Stem Cell Transplant and Oncology Patients

M. Beth McCarville, MD^{1,2}, Sarah B Whittle, BS¹, Geoffrey S Goodin, MD^{1,2}, Chin-Shang Li, PhD³, Matthew P Smeltzer, MS³, Gregory A Hale, MD^{4,5}, and Robert A Kaufman, MD^{1,2,5}

¹Department of Radiological Sciences, St Jude Children's Research Hospital, 332 North Lauderdale Street, Memphis, TN 38105

²Department of Radiology, The University of Tennessee, College of Medicine, Memphis, TN

³Department of Biostatistics, St Jude Children's Research Hospital, 332 North Lauderdale Street, Memphis, TN 38105

⁴Department of Oncology, St Jude Children's Research Hospital, 332 North Lauderdale Street, Memphis, TN 38105

⁵Department of Pediatrics, The University of Tennessee, College of Medicine, Memphis, TN

Abstract

Background—Pneumatosis intestinalis in children is associated with a wide variety of underlying conditions and often has a benign course. The computed tomography features of this condition have not been systematically investigated.

Objective—Defining benign pneumatosis intestinalis as cases that resolved with medical management alone, we sought to: 1) determine whether the incidence of benign pneumatosis intestinalis had increased at our pediatric cancer hospital, 2) characterize computed tomography features of benign pneumatosis intestinalis, and 3) determine the relation between imaging features and clinical course of benign pneumatosis intestinalis in this cohort.

Materials and Methods—Radiology reports from November 1994 to December 2006 were searched for “pneumatosis intestinalis,” “free intraperitoneal air,” and “portal venous air or gas.” Corresponding imaging was reviewed by two radiologists who confirmed pneumatosis intestinalis, recorded presence of extraluminal free air, degree of intramural gaseous distension, number of involved bowel segments, and time to pneumatosis resolution.

Results—Twelve boys and 4 girls had pneumatosis intestinalis; 11 were hematopoietic stem cell transplant recipients. Annual incidences of benign pneumatosis have not changed at our institution. Increases in intramural distension marginally correlated with increases in bowel segments involved ($P=0.08$). Three patients had free air and longer times to resolution of pneumatosis ($P=0.03$).

Conclusions—Male children may be at increased risk for benign pneumatosis intestinalis. The incidence of benign pneumatosis at our institution is proportional to number of hematopoietic stem cell transplants. Degree of intramural distension may correlate with number of bowel segments involved. Patients with free air have a longer time to resolution of benign pneumatosis.

Introduction

During childhood, pneumatosis intestinalis, or air in the bowel wall, is most commonly seen in premature infants as a sign of bowel ischemia. After the first year of life, pneumatosis intestinalis is less common, has a more benign presentation and clinical course, and often is referred to as “benign pneumatosis intestinalis” (BPI)[1,2]. Benign pneumatosis intestinalis in children is associated with a large variety of underlying illnesses, including immunosuppression (often in association with steroid use), mucosal disruption from trauma or bowel obstruction, obstructive pulmonary disease, and congenital heart disease [1, 3-8]. In these patients the clinical course of pneumatosis intestinalis ranges from a self-limited process, requiring little or no treatment, to a life-threatening condition, requiring surgical intervention.

We noted an increase in the number of children with pneumatosis intestinalis at our large pediatric cancer hospital; many of the patients were hematopoietic stem cell transplant (HSCT) recipients. In 2001, Kurbegov and colleagues reported that in a general pediatric hospital, 43% (3/8) of children with a poor outcome from pneumatosis intestinalis (requiring surgical intervention or death) were transplant recipients with graft- versus-host disease (GVHD) colitis [9]. These investigators also found that portal venous gas and low serum bicarbonate levels correlated to a poor outcome in children. A more recent review by Ho and colleagues included a discussion of the computed tomographic (CT) features of this condition in adults, however, the correlation between CT features and the clinical course of pneumatosis intestinalis was not systematically investigated by these investigators or others. The purpose of our study was thus: 1) to determine whether the incidence of BPI at our institution had, in fact, increased over the past decade in HSCT or non-HSCT cancer patients and, if so, to determine the underlying cause; 2) to characterize the CT imaging and clinical features of BPI in children being treated for cancer or undergoing HSCT; and 3) to determine the relation among various imaging features, and the relation between these imaging features and the clinical features of BPI in this select pediatric population. In this study, we define BPI as those cases of pneumatosis intestinalis that resolved with medical management alone and did not have clinical or imaging evidence of bowel ischemia, such as: portal venous gas, signs or symptoms of peritonitis, need for surgical intervention, or death from complications of this condition.

Materials and Methods

Patient Selection and Image Analysis

We searched our diagnostic imaging database for reports filed from November 1994 through December 2006 that contained the words “pneumatosis intestinalis,” “free intraperitoneal air,” “portal venous air” or “portal venous gas.” After our IRB waived informed consent, and in compliance with the Health Information Portability and Accountability Act of 1996, the plain abdominal radiographs and CT scout and axial images corresponding to these reports were jointly reviewed by two pediatric radiologists (with 12 years and 29 years of experience), who, by consensus, confirmed the presence of pneumatosis intestinalis and recorded the date of documented diagnosis of pneumatosis and associated imaging findings, including the presence of free intraperitoneal, retroperitoneal, mediastinal or pleural air and portal venous gas. The pattern of pneumatosis was recorded as cystic (small, round air collections within the bowel wall), linear (linear air collection in the bowel wall), or both. Because there is no standard method of grading pneumatosis intestinalis on radiography, we assessed the degree of bowel involvement by dividing the colon into four segments (ascending, transverse, descending and sigmoid/rectum), and the number of involved colonic segments and small bowel involvement (yes or no) was recorded. Because pneumatosis intestinalis is sometimes related to bowel ischemia we also recorded the colonic distribution

of pneumatosis based on vascular supply: superior mesenteric artery (SMA) territory only (cecum through splenic flexure), inferior mesenteric artery (IMA) territory only (descending colon, sigmoid and rectum), or both SMA and IMA territory [11]. Because there are no published studies defining bowel distension in children, the reviewers used their professional judgment to jointly determine whether bowel distension was present on abdominal plain radiographs or CT scout images.

All CT imaging was reviewed at a Picture Archive and Communication System workstation and images were reviewed in both the abdominal and lung window settings. In this retrospective review the longest time interval between date of pneumatosis diagnosis and CT imaging was 3 weeks. Therefore, from axial CT images of cases imaged within 3 weeks of the pneumatosis intestinalis diagnosis, the reviewers determined the degree of intramural (bowel wall) gaseous distension by calculating the ratio of the sum of both bowel walls to the total serosal-to-serosal bowel diameter in the area of greatest bowel distension (Fig. 1). For patients having bowel distension, the distension was considered predominantly intraluminal when this ratio was < 50% (Fig. 1A) and predominantly intramural when 50% (Fig. 1B). Because we suspected that many cases were diagnosed incidentally on imaging performed for a variety of clinical reasons, the indication for the imaging examination and the imaging modality on which the diagnosis of pneumatosis intestinalis was made also were recorded. Images obtained within 3 months before and after the recorded diagnosis or suspicion of pneumatosis intestinalis were reviewed to: 1) determine whether the diagnosis had been missed before the documented diagnosis, and 2) to estimate the time to resolution of pneumatosis intestinalis on follow-up imaging. The time to pneumatosis intestinalis resolution was defined as the number of days between initiation of pneumatosis intestinalis treatment and resolution of pneumatosis on follow-up abdominal imaging.

From medical records, we recorded the patient's sex, age at diagnosis of pneumatosis intestinalis, primary diagnosis, history and date of HSCT and GVHD (where applicable), steroids, chemotherapy and radiation therapy within 30 days before pneumatosis developed and stool culture results within 30 days before and after pneumatosis developed. Because abnormally low serum bicarbonate concentration has been reported to be prognostic of a poor outcome from pneumatosis intestinalis [9] we recorded the serum bicarbonate concentration within 6 days of pneumatosis intestinalis diagnosis. We recorded symptoms that could be related to pneumatosis intestinalis, including abdominal pain, diarrhea, nausea, vomiting, constipation, as well as the management and outcome of pneumatosis. Patients were considered to have *benign* pneumatosis intestinalis (BPI) if it resolved with medical management alone and they did not have clinical or imaging evidence of bowel ischemia, such as: portal venous gas, signs or symptoms of peritonitis, need for surgical intervention, or death from complications of pneumatosis intestinalis. Because pneumatosis intestinalis was suspected to be more common among HSCT recipients than other patients, we determined the incidence per year in HSCT patients and non-HSCT patients separately. The number of HSCT patients treated at our institution per year was obtained from the Transplant and Gene Therapy Program database. The number of non-HSCT patients treated per year was obtained from our institutional electronic medical record.

Statistical Methods

Summary statistics were calculated for each continuous variable. We tested for a difference in group medians using the Wilcoxon-Mann-Whitney test (2 categories) or the Jonckheere-Terpstra test (>2 ordered categories). These median tests are based on rank and do not assume that the data are normally distributed. Associations between pairs of continuous variables were explored using Spearman's rank-order correlation coefficient. We tested for associations for singly-ordered Row $\times$ Column tables using the Exact Chi-Square test.

We modeled time to resolution using the Kaplan-Meier method for the whole cohort of patients and for patients grouped by degree of intramural gaseous distension (bowel wall A + bowel wall B/total bowel diameter < 50% or ≥ 50%), sex and associated imaging findings. Because only one patient had pneumatosis intestinalis distributed in the IMA only territory, the distribution of pneumatosis based on vascular supply was considered a dichotomous variable: SMA only vs. other (IMA only and both SMA and IMA). The exact log-rank test was used to investigate the differences in the distributions of each subgroup. The effects of continuous covariates on time to resolution were tested using Cox Proportional Hazards models.

The sample sizes for this analysis are small, and statistical tests may lack adequate power; all results should be interpreted with caution, and all P values should be interpreted as exploratory. Alpha was set at 0.05, and all tests were two tailed. Analyses were performed using SAS Version 9.1.

Results

Patient Characteristics

Pneumatosis intestinalis was confirmed by abdominal image and medical record review for 12 boys and 4 girls, with a mean age of 9 years 11 months (range, 1 year 2 months to 22 years 9 months). All 16 patients had *benign* pneumatosis intestinalis (BPI); none had portal venous gas, signs of peritonitis, required surgical intervention or died of complications of pneumatosis. Patient characteristics are summarized in Table 1. Of the 16 cases, 13 were diagnosed after 2003; 9 of the 13 occurred in HSCT recipients (Fig. 2A). In 2001, there was a marked increase in number of clinical trials involving HSCT at our institution. As a result, the average number of HSCT patients per year increased from 97 before 2001 to 162 after January, 2001. The number of non-HSCT patients did not substantially vary from year to year during the study period. The incidence of BPI did not differ significantly from one year to the next in either the HSCT patients ($P=0.54$) or in the non-HSCT patients ($P=0.06$; Fig. 2B).

Imaging Indications and Findings

The indications for imaging, imaging modalities with which pneumatosis intestinalis was initially diagnosed, imaging findings and time to resolution of BPI are summarized in Table 2. Two cases were initially overlooked on abdominal CT that had been performed 18 days and 1 day, respectively, before pneumatosis intestinalis was documented by chest CT in the first case and review of the original abdominal CT in the second. In both cases, pneumatosis was not readily apparent on the axial images viewed in the abdominal window setting but was apparent when images were reviewed in the lung window setting and on the scout images used for CT planning (Figs. 3A, 3B).

At least one segment of colon was involved in all 16 patients, and the terminal ileum was involved in 3. Twelve patients had pneumatosis in the distribution of the SMA only, one in the distribution of the IMA only and three in the distribution of both the SMA and IMA. Four patients had extraluminal free air associated with BPI, one with subcutaneous emphysema in the neck secondary to pneumomediastinum (Figs. 1B, 3C, 3D). No patient had portal venous gas. Of 14 patients with bowel distension, 11 were evaluated by CT; 8 had distension that was predominantly intraluminal and 3 predominantly intramural (Figs. 1B, 4).

Patients whose bowel distension was predominantly intramural tended to have more bowel segments involved than those whose distension was predominantly intraluminal ($P=0.08$). The degree of intramural or intraluminal distension was not associated with the presence of

extraluminal free air ($P=0.77$). Patients with extraluminal free air had a median bowel wall:total bowel diameter ratio of 0.18 (minimum=0.08, maximum=0.81) which was not significantly different from those without extraluminal air (median=0.27, minimum=0.13, maximum=0.81; $P=0.63$). The time to resolution was significantly longer in patients with extraluminal free air compared to those without ($P=0.03$) (Fig. 5). Time to resolution was not affected by bowel distension categorized as predominantly intramural vs. intraluminal ($P=0.95$), number of bowel segments involved ($P=0.51$) or categorization of pneumatosis distribution by vascular supply ($P=0.68$).

Associated Clinical Findings, Management, and Outcomes

Of the 11 HSCT patients, 10 had GVHD (8 chronic, 2 acute at the time of BPI); all 10 had gut involvement, 7 also had skin involvement, and 4 had liver involvement. When pneumatosis was detected, 13 of the 16 patients were mildly symptomatic (Table 1). The remaining 3 were asymptomatic. At the time of BPI diagnosis, thirteen patients had normal serum bicarbonate concentration; two had low serum bicarbonate concentration and one a high concentration. All 16 patients were either already hospitalized when BPI was detected or admitted for treatment. All were placed on bowel rest and given some combination of intravenous antibacterial, antifungal, or antiviral therapy; 14 were given intravenous nutritional support. All cases resolved with medical management and no patient had more than one episode of pneumatosis intestinalis.

Of 13 cases followed to complete resolution, the mean time to resolution was 14.8 days (median, 13 days; range, 5 to 29 days). The two patients with low serum bicarbonate concentrations resolved in 13 days and 17 days; the one with a high serum bicarbonate resolved in 23 days. Time to resolution did not differ significantly between boys and girls ($P=1.0$).

Discussion

At least three plausible causes for BPI have been proposed. These include a mechanical cause [12], a pulmonary cause [13], and immunosuppression [14, 15]. The original mechanical theory implied that air under pressure from pyloric obstruction entered the gastric wall through a break in the gastric mucosa and then spread to other segments of bowel either along lymphatic channels or the mesentery [12]. The pulmonary theory suggests that alveolar rupture results in dissection of air along pulmonary interstitium to the mediastinum and then retroperitoneally along vessels to the abdominal viscera [16]. The theory of immunosuppression was proposed in 1973 by Borns and Johnston who reported 15 pediatric cases of pneumatosis intestinalis detected over 4 years; 10 of the 15 patients had received steroids. The authors postulated that lymphoid depletion, either because of steroids or stress, caused the Peyer patches to shrink, and the subsequent loss of structural integrity allowed intraluminal air to dissect the non-inflamed bowel wall [15]. In our study, all 16 children were immunosuppressed, either because of recent cancer therapy or stem cell transplantation, 15 had recently received steroids, 10 of 11 HSCT patients had gut GVHD, and 8 had gastrointestinal infections. Because steroids cause Peyer patches to shrink, and gut GVHD and gastrointestinal infections cause mucositis, our findings support the theories that a loss of bowel wall integrity and mucosal disruption predispose patients to develop BPI [12, 17].

An unexpected finding in our study was that the majority (75%; 12/16) of patients were boys, suggesting a possible male predilection, especially in the setting of HSCT. Although the reason for this finding is unclear, it is in agreement with the study by Kurbegov et. al. who found that, in a general pediatric setting, 78% (25/32) of children with pneumatosis intestinalis were male [9]. The same investigators found that a poor outcome (the need for

surgical intervention or death) from pneumatosis intestinalis was more prevalent among children with gut GVHD and decompensated cardiac disease than other patients and some patients had recurrent episodes of pneumatosis. Furthermore, they found that a low serum bicarbonate concentration and the presence of portal venous gas correlated with a poor outcome. In our study, all patients, including those with gut GVHD (n=10) and low serum bicarbonate concentration (n=2), had only benign pneumatosis intestinalis that completely resolved with medical management alone and no patient had more than one episode. The reason for these differences in outcome is unknown but could be related to differences in patient management. Our institutional practice is to aggressively treat patients with pneumatosis intestinalis with hospitalization, bowel rest, intravenous nutritional support as needed and antimicrobial therapy. In contrast, some patients included in the review by Kurbegov were treated with bowel rest alone (n=5), antibiotics alone (n=3) or with no therapy (n=1). Our findings suggest that a more aggressive medical approach may be warranted, especially in children with gut GVHD, however, this needs to be confirmed in future studies.

A finding of BPI that has not been previously investigated is the potential correlation between bowel wall gaseous distension, detected by CT imaging, and other imaging features and clinical outcome. By measuring the ratio of the sum of bowel wall thicknesses to total bowel diameter, we found varying degrees of intramural gaseous distension on cross-sectional imaging. In some cases (3/11), bowel distension noted on plain radiography was caused primarily by inflation of the bowel wall rather than the lumen. We also found that greater degrees of intramural gaseous distension tended to be associated with an increase in number of bowel segments involved by pneumatosis. We speculate that both the degree of intramural distension and the number of involved bowel segments reflect the severity of BPI such that increases in both would be seen in more severe cases. However, the only imaging variable that predicted a longer time to resolution of BPI was the presence of extraluminal free air. Perhaps as intramural air collects, it reaches a crucial pressure at which point it decompresses into the surrounding intraperitoneal, retroperitoneal, and thoracic cavities, thereby reducing the degree of intramural distension and possibly the number of bowel segments involved. Thus, the presence of extraluminal free air may represent an endpoint of BPI and such patients would be expected to have a prolonged time to resolution.

Our study was prompted by a perceived increase in the number of patients detected with pneumatosis intestinalis during treatment at our large children's cancer hospital. In their review, Ho et. al. suggest that an apparent increase in the diagnosis of pneumatosis intestinalis in adults may be due to an increased use of CT (which is more sensitive than plain radiography for its detection) or to an increase in the incidence of pneumatosis intestinalis related to the introduction of new surgical procedures or medications [10]. As anticipated, the majority of our pneumatosis patients were HSCT recipients. Although there were multiple changes to our HSCT regimen during the study period, we found no significant increase in the annual incidences of BPI over the past decade. Therefore, we conclude that the increase in BPI cases was caused by an increase in the number of HSCTs being performed at our institution and not by an increase in use of cross-sectional imaging or a change in the HSCT regimen.

In our study most cases were discovered incidentally on imaging examinations performed for reasons unrelated to bowel pathology or symptoms. Two cases were overlooked on abdominal CT because axial images were evaluated in the abdominal window setting, and the scout images, which clearly revealed pneumatosis intestinalis, were ignored. Consistent with other reports, four of our patients had alarming associated imaging findings, including pneumomediastinum leading to subcutaneous emphysema in the neck, and free intraperitoneal and retroperitoneal air, yet relatively mild abdominal symptoms. Patients

with BPI and extra-luminal free-air may present with abdominal bloating, cramping, or pain but do not require surgical intervention [9,10,18]. On close review of medical records, 13 of our 16 patients had documented mild symptoms that could be related to pneumatosis intestinalis, suggesting that this condition may be overlooked clinically in most patients.

Our study has several limitations. Because of its retrospective nature, follow-up imaging was not obtained at specific time points or in a uniform manner. Some cases of BPI may have resolved between imaging examinations and, therefore, we may have over-estimated the average time to resolution. Also, because BPI is often associated with only mild or non-specific symptoms, imaging may not have been obtained in some cases, which would underestimate the incidence. Finally, due to the small sample size our statistical tests may lack adequate power; non-significant P values do not necessarily indicate the absence of possible differences and the significant P value should be interpreted with caution.

In conclusion, we found that the number of cases of BPI is proportional to the number of HSCTs performed at our institution. In children, the condition may occur more commonly in boys and may be associated with alarming imaging findings. Aggressive medical management including bowel rest and antimicrobial therapy may result in a better clinical outcome and fewer recurrent episodes of pneumatosis intestinalis than is achieved with less aggressive management, but this needs to be confirmed in further studies. We postulate that, patients who have substantial intramural air and numerous bowel segments involved may be at an increased risk of developing extraluminal free air. Patients with extraluminal free air have a longer time to resolution of BPI than those without.

Acknowledgments

Supported in part by The Pediatric Oncology Education Program Grant 5R25 CA23944 from the National Cancer Institute and The American, Lebanese and Syrian Associated Charities.

References

1. Fenton LZ, Buonomo C. Benign pneumatosis in children. *Pediatr Radiol*. 2000; 30(11):786–793. [PubMed: 11100497]
2. Knechtle SJ, Davidoff AM, Rice RP. Pneumatosis intestinalis. Surgical management and clinical outcome. *Ann Surg*. 1990; 212(2):160–165.
3. West KW, Rescorla FJ, Grosfeld JL, Vane DW. Pneumatosis intestinalis in children beyond the neonatal period. *J Pediatr Surg*. 1989; 24(8):818–822. [PubMed: 2671335]
4. Keats TE, Smith TH. Benign pneumatosis intestinalis in childhood leukemia. *Am J Roentgenol Radium Ther Nucl Med*. 1974; 122(1):150–152.
5. Sivit CJ, Josephs SH, Taylor GA, et al. Pneumatosis intestinalis in children with AIDS. *Am J Roentgenol*. 1990; 155(1):133–134. [PubMed: 2112836]
6. Yeager AM, Kanof ME, Kramer SS, et al. Pneumatosis intestinalis in children after allogeneic bone marrow transplantation. *Pediatr Radiol*. 1987; 17(1):18–22. [PubMed: 3547276]
7. Hernanz-Schulman M, Kirkpatrick J Jr. Shwachman H, Herman T, Schulman G, Vawter GF. Pneumatosis intestinalis in cystic fibrosis. *Radiology*. 1986; 160(2):497–499. [PubMed: 3726132]
8. Burton EM, Mercado-Deane MG, Patel K. Pneumatosis intestinalis in a child with AIDS and pseudomembranous colitis. *Pediatr Radiol*. 1994; 24(8):609–610. [PubMed: 7724293]
9. Kurbergov AC, Sondheimer JM. Pneumatosis intestinalis in non-neonatal pediatric patients. *Pediatrics*. 2001; 108:402–406. [PubMed: 11483806]
10. Ho LM, Paulson EK, Thompson WM. Pneumatosis intestinalis in the adult: benign to life-threatening causes. *Am J Roentgenol*. 2007; 188:1604–1613. [PubMed: 17515383]
11. Byrd BF, Sawyers JL, Bomar RL, Klatte EC. Reversible vascular occlusion of the colon: recognition and management. *Ann Surg*. 1968; 167(6):901–907. [PubMed: 5652374]
12. Stiennon OA. Pneumatosis intestinalis in the newborn. *Am J Dis Child*. 1951:651–663.

13. Keyting WS, McCarver RR, Kovarik JL, Daywitt AL. Pneumatosis intestinalis: a new concept. *Radiology*. 1961; (76):733–741. [PubMed: 13752845]
14. Kleinman PK, Brill PW, Winchester P. Pneumatosis intestinalis. Its occurrence in the immunologically compromised child. *Am J Dis Child*. 1980; 134(12):1149–1151. [PubMed: 6934694]
15. Borns PF, Johnston TA. Indolent pneumatosis of the bowel wall associated with immune suppressive therapy. *Ann Radiol*. 1973; 16(3-4):163–166.
16. Pear BL. Pneumatosis intestinalis: a review. *Radiology*. 1998; 207(1):13–19. [PubMed: 9530294]
17. Maile CW, Frick MP, Crass JR, Snover DC, Weisdorf SA, Kersey JH. The plain abdominal radiograph in acute gastrointestinal graft-vs.-host disease. *Am J Roentgenol*. 1985; 145(2):289–292. [PubMed: 3895857]
18. Feczko PJ. Clinical significance of pneumatosis of the bowel wall. *RadioGraphics*. 1992; (12): 1069–1078. [PubMed: 1439012]

Fig. 1.

We determined the ratio of bowel wall A + bowel wall B:serosal-to-serosal bowel diameter on computed tomography (CT) images of the colon in children with benign pneumatosis intestinalis (BPI). **(A)** 15-year-old boy, hematopoietic stem cell transplant (HSCT) recipient for acute myeloid leukemia, with a small amount of intramural air (A and B) relative to total bowel diameter (C). The ratio =0.28. **(B)** 8-year-old boy, with history of HIV/AIDS and leiomyosarcoma who was being treated for Hodgkin lymphoma at the time of this CT image showing large amount of intramural air (A and B) relative to total bowel diameter (C). The ratio=0.81.

Fig. 2.

A) Number of BPI cases in patients who had undergone hematopoietic stem cell transplant (HSCT; gray bars) and non-HSCT patients (black bars) in each year of the study. The number of cases increased after 2003. **(B)** The incidence of BPI in HSCT (gray bars) and non-HSCT patients (black bars) in each year of the study. Changes over time were not statistically significant.

Fig. 3.

This 12-year-old boy, HSCT recipient for acute lymphoblastic leukemia, underwent abdominal and pelvic CT for evaluation of iliac vein thrombus. **(A)** BPI (arrows) was missed because images were viewed using the abdominal window setting. **(B)** BPI (arrows) was evident (but overlooked) on this scout image. **(C)** 3 weeks later this chest CT was obtained for suspected pneumonia. The untreated BPI (white arrow) had progressed with subsequent

development of free intraperitoneal (straight black arrows) and retroperitoneal air (curved black arrows), (**D**) pneumomediastinum (black arrows) and pneumothorax (white arrows).

Fig. 4. This 9-year-old girl, HSCT recipient for SCA, underwent abdominal CT imaging to assess for possible ascites and splenic sequestration. **(A)** Bowel distension (arrows) seen on the scout image was predominantly due to **(B)** intramural gaseous distension of the colon (straight arrows). Note, only a small amount of intraluminal air is present without intraluminal distension (curved arrow).

Fig. 5. This Kaplan-Meier curve shows that patients with extraluminal free air had a longer time to resolution of BPI than those without.

TABLE 1

Clinical Characteristics of 16 Children with Benign Pneumatosis Intestinalis (BPI)

Pt #	Sex	Age at BPI diagnosis	[¥] Primary diagnosis	Received [§] HSCT	[£] Treatments within 30 days before BPI	Serum bicarbonate concentration within 6 days of BPI	[¡] Gastro-intestinal infection 30 days before or after BPI	[¶] Signs and symptoms
1	M	1y 2m	AML	Y	S	normal	B	Emesis
2	M	2y 10m	AML	Y	S, C, TBI	normal	no	Diarrhea, abdominal pain
3	F	8y 9m	AML	Y	S	normal	F, B	Diarrhea
4	M	15y 11m	AML	Y	S	low	V,F	Diarrhea, abdominal pain
5	F	12y 5m	ALL	Y	S	low	V, F, B	Nausea, diarrhea, abdominal pain
6	M	12y 6m	ALL	Y	S	normal	no	Diarrhea
7	F	9y 11m	SCA	Y	S	normal	no	none
8	M	13y 7m	SCA	Y	S	normal	B	none
9	M	9y 0m	NB	Y	TBI	normal	no	Emesis, diarrhea, abdominal pain
10	F	18y 0m	RMS	Y	S, C, XRT	high	no	Diarrhea, abdominal pain
11	M	22y 9m	CML	Y	S	normal	F,B	N/V, abdominal pain and tenderness
12	M	3y 1m	ALL	N	S, C	normal	no	Diarrhea, abdominal distension
13	M	3y 10m	ALL	N	S, C	normal	V	Diarrhea
14	M	6y 10m	ALL	N	S, C	normal	B	Diarrhea, abdominal pain
15	M	8y 5m	HIV/LS/HD	N	S, C	normal	F	none
16	M	9y 7m	MB	N	S	normal	no	Abdominal pain and distension, constipation

[¥] Primary Diagnoses: AML=acute myelogenous leukemia, CML=chronic myelogenous leukemia, SCA=sickle cell anemia, ALL=acute lymphoblastic leukemia, NB=neuroblastoma, RMS=rhabdomyosarcoma, MB=medulloblastoma, HIV=human immunodeficiency syndrome, LS=leiomyosarcoma, HD=Hodgkin disease

[§] HSCT=hematopoietic stem cell transplantation; Y=yes; N=no

[£] Treatments: S=steroids, C=chemotherapy, TBI=total body irradiation (myeloablative), XRT=targeted therapeutic irradiation

[¡] Gastrointestinal Infections: F=fungal, B=bacterial, V=viral

[¶] Signs and Symptoms: N/V=nausea and vomiting

TABLE 2

Imaging Features of 16 Children with BPI and Time to BPI Resolution

Pt #	Indication for Imaging	*Imaging Modality BPI Diagnosis	•Bowel distension present	^a Pneumatosis Pattern	Ratio of Bowel Wall/ Bowel Diameter	Number of Bowel Segments Involved	[‡] Extraluminal Free Air	Time to BPI Resolution (days)
1	Crackles in lungs	CXR	N	Linear	N/A	2	N	5
2	Abdominal distension	AXR	Y	Both	N/A	3	Y (PP)	20*
3	Diarrhea	AXR	Y	Both	N/A	1	N	23
4	Abdominal pain	Abd CT	Y	Both	0.28	2	N	18
5	Chest pain	CXR	Y	Both	0.27	4	N	13
6	Follow-up pneumonia	Chest CT	Y	Both	0.18	3	Y (PM, PT, PP, RP, SQ)	29
7	Possible ascites and splenic sequestration	Abd CT	Y	Cystic	0.44	1	N	13
8	Possible lymphoproliferative disease	Abd/Pelvis CT	Y	Both	0.81	5	Y(PM, PP, RP)	N/A
9	Tumor response evaluation	Abd/Pelvis CT	Y	Both	0.2	3	N	9
10	Tumor response evaluation	Abd/Pelvis CT	Y	Both	0.08	2	Y (PP)	23
11	Check gastric tube position	AXR	N	Both	N/A	1	N	6*
12	Diarrhea	AXR	Y	Linear	N/A	2	N	7
13	Fever, cough	CXR	Y	Both	0.68	3	N	6
14	Abdominal pain	AXR	Y	Both	0.13	3	N	6
15	Check central line position	CXR	Y	Both	0.81	4	N	15
16	€Unknown	Abd CT	Y	Both	0.15	1	N	25

* Imaging Modalities: CXR=chest x-ray; AXR=abdomen x-ray

° Bowel Distension Present: Y=yes; N=no

^a Pneumatosis Pattern: Linear=linear collection of air in bowel wall; Cystic=cystic collection of air in bowel wall; Both=both cystic and linear collections of air in bowel wall

[‡] Extraluminal Free Air: Y=yes; N=no; PP=pneumoperitoneum; PM=pneumomediastinum; PT=pneumothorax; RP=retroperitoneal air; SQ=subcutaneous emphysema in neck

€ Unknown because imaging was performed at an outside institution

* BPI nearly resolved at this time point, no subsequent follow-up imaging

N/A=no follow-up imaging available to assess variable