The etiology of pneumoperitoneum in the 21st century

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BACKGROUND: We sought to determine the origin of free intraperitoneal air in this era of diminishing prevalence of peptic ulcer disease and imaging studies. In addition, we attempted to stratify the origin of free air by the size of the air collection.

METHODS: We queried our hospital database for "pneumoperitoneum" from 2005 to 2007 and for proven gastrointestinal perforation from 2000 to 2007. *Massive* amount of free air was defined as any air pocket greater than 10.0 cm.

RESULTS: Among patients with free air, the predominant causes were perforated viscus (41%) and postoperative (<8 days) residual air (37%). For patients with visceral perforation, only 45% had free air on imaging studies, and for these patients, the predominant cause was peptic ulcer (16%), diverticulitis (16%), trauma (14%), malignancy (14%), bowel ischemia (10%), appendicitis (6%), and endoscopy (4%). The likelihood that free air was identified on an imaging study by lesion was 72% for perforated peptic ulcer, 57% for perforated diverticulitis, but only 8% for perforated appendicitis. The origin of massive free air was equally likely to be gastroduodenal, small bowel, or colonic perforation.

CONCLUSION: The cause of free air when surgical pathology is the source has substantially changed from previous reports. (*J Trauma Acute Care Surg*. 2012;73: 542–548. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level IV.

KEY WORDS: Free intraperitoneal air; pneumoperitoneum; viscus perforation; peptic ulcer perforation; perforated diverticulitis.

Up to 40% of hospital admissions for emergency surgery are caused by acute abdominal pain, a significant percentage of which result from perforation of an abdominal hollow viscus.[1,2] Despite advances in imaging, surgical care, and antimicrobial drugs, the mortality of secondary peritonitis after gastrointestinal perforation remains 20% to 36%.[3–5] Rapid diagnosis and surgical intervention are critical in the treatment of these patients, which frequently depends on the appropriate interpretation of abdominal imaging studies.[6]

Some data exist regarding the specificity and sensitivity of imaging modalities for the detection of pneumoperitoneum.[7–16] Plain abdominal radiographs have been reported to have an overall sensitivity of 30% to 59% for the detection of intraperitoneal free air, although the sensitivity approaches 100% for large-volume pneumoperitoneum.[7–14] The finding of pneumoperitoneum on an abdominal imaging study suggests gastrointestinal perforation but leads to nontherapeutic operations (in which no perforation is identified) in 5% to 15% of cases.[12,13,17–19] The abdominal x-ray is not particularly accurate at predicting the location of gastrointestinal perforation in the setting of pneumoperitoneum. Free air is present on plain abdominal radiographs in 45% to 56% of gastroduodenal perforations, 27% of colon perforations, and 7% to 14% of small bowel perforations, but in 10% to 14%, no perforation is identified.[12,13]

The accuracy of identifying free air by new imaging modalities, such as abdominal computed tomographic (CT) scan has led to improved detection rates, with sensitivities ranging from 96% to 100%.[7–9,11,15] Abdominal CT imaging can now be used to identify the specific location of viscus perforation with 80% to 90% accuracy.[20–24] Studies based on CT scan have reported the site of perforation in pneumoperitoneum as gastroduodenal 43% to 54%, colon 30% to 32%, small bowel 10% to 11%, appendix 7% to 12%, and rectum 3% to 7% of time.[20,21] We sought to determine the origin of free intraperitoneal air in the era of declining incidence of peptic ulcer disease and improved imaging.

PATIENTS AND METHODS

The University of Texas Health Science Center at San Antonio Institutional Review Board approved this retrospective study. Records were queried for adult patients admitted to University Hospital in San Antonio, Texas, from December 2000 to June 2007 from two different databases. A DRG International Classification of Diseases—9th Rev. (ICD-9) code database was queried for hollow viscus perforation, and a radiology database was queried for studies with the phrase *pneumoperitoneum*, *free air*, or *pneumatosis* in the radiology written report. Of the 188 patients from ICD-9 query, 83 were

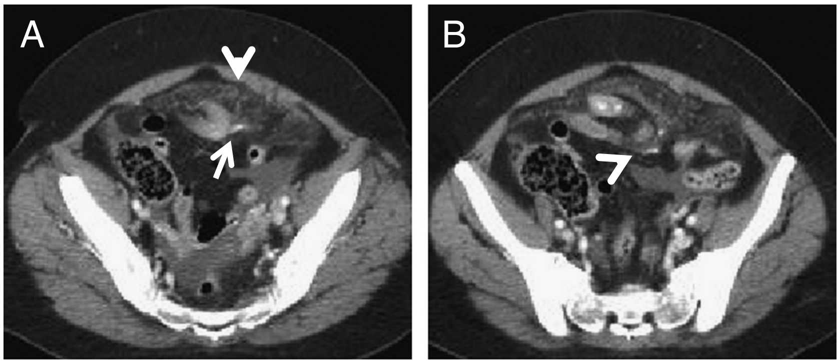

Figure 1. Spontaneous small bowel perforation in a 39-year-old man with the diagnosis of small bowel lymphoma on chemotherapy. Axial CT images of the abdomen at different levels after oral and intravenous contrast administration show contrast leak from a segment of small bowel (*arrow*) with associated mesenteric and omental fat stranding (*arrowhead*). Note also free contrast in the peritoneal cavity (*arrow* in *B*).

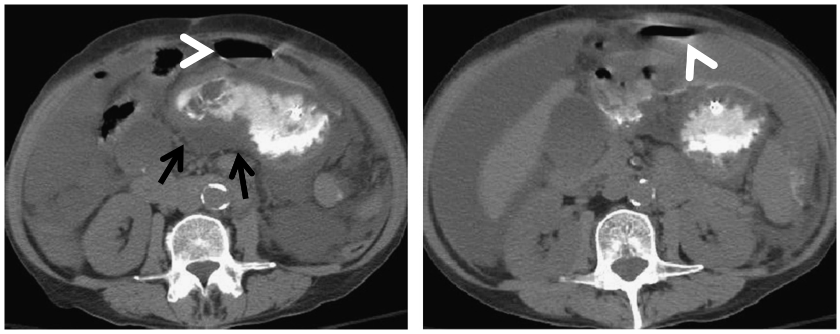

Figure 2. Gastric perforation in a 39-year-old woman secondary to gastric ulcer. Axial CT images of the abdomen after oral contrast administration show diffuse wall thickening of the antropyloric region of the stomach (*arrows*) with perigastric free intraperitoneal air (*arrowheads*) suggestive of gastric perforation.

excluded because of the following: if age is less than 18 years (n = 49), if their record lacked both discharge summary and operative report (n = 9), if patient had both pneumoperitoneum and perforation (n = 14), or if their perforation was not a hollow viscus perforation (n = 11). From a total of 1,227, 1,111 patients on the radiographic query were excluded, owing to the following: if age is less than 18 years (n = 76); if the staff radiologist's report did not explicitly state the presence of pneumoperitoneum (n = 1,014) or described equivocal findings of pneumoperitoneum, free air, or pneumatosis (n = 8); or if the patient was accounted for in the ICD-9 query (n = 13). Hollow viscus perforations were confirmed by operative report, discharge summary, or explicit diagnosis by a staff radiologist on CT scan.

Overall, 221 patients were included (105 and 116 from ICD-9 and pneumoperitoneum query, respectively). On further chart review, 114 patients were found to have visceral perforation intraoperatively. Patients with available preoperative images (n = 98) were reviewed by two radiologists (an attending radiologist and a radiology resident in the final year of his training). Findings evaluated on the imaging studies were direct visualization of the site of a defect of contrast extravasations from the bowel wall (Fig. 1), focal bowel wall thickening (Fig. 2), air surrounding the focal segment of the bowel (Fig. 3), and focal fat stranding and fluid collections surrounding the bowel wall (Fig. 4).

Presence of pneumoperitoneum was categorized into three groups by preoperative imaging. *Minimal* free air was defined as any number of small pockets of air, with the largest being 2.0 cm or less in diameter. *Large* free air was defined as any pocket of air greater than 2.0 cm. As a subset of large air group, massive amount of free air was defined as any patient with an air pocket greater than 10.0 cm.

RESULTS

Evaluation of Patients With Visceral Perforation

Among patients with visceral perforation (n = 114), the most common cause was appendicitis (34%, n = 39) (Table 1). Other causes were diverticulitis (12%, n = 14), peptic ulcer (10%, n = 11), bowel ischemia (9%, n = 10), trauma (9%, n = 10), malignancy (8%, n = 9), endoscopy-related (2%, n = 3), and biliary perforation was seen in 2% (n = 3).

Only 51 or 45% of these patients had free air on imaging studies (Table 1). Among these patients with free air after visceral perforation, peptic ulcer (16%) and diverticulitis (16%) were the leading cause of perforation in presence of free intraperitoneal air, followed by trauma (14%), malignancy (14%), bowel ischemia (10%), appendicitis (6%), and endoscopy (4%).

The likelihood of free air being identified on imaging studies according to the surgical condition was 78% for malignancy; 72% for peptic ulcer, 70% for trauma; 67% for endoscopy, 57% for diverticulitis; 50% for bowel ischemia, but only 8% for perforated appendicitis.

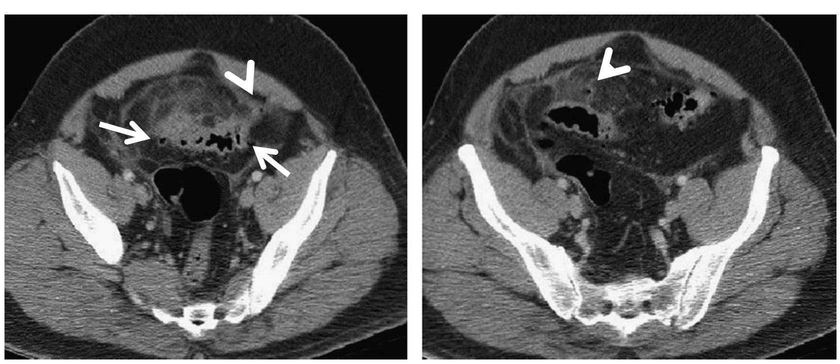

Figure 3. Perforated sigmoid diverticulitis in a 55-year-old man. Axial contrast CT images of the pelvis show diverticulitis of the sigmoid colon (*arrows*) with small air pockets surrounding the colon (*arrowheads*) suggestive of perforation.

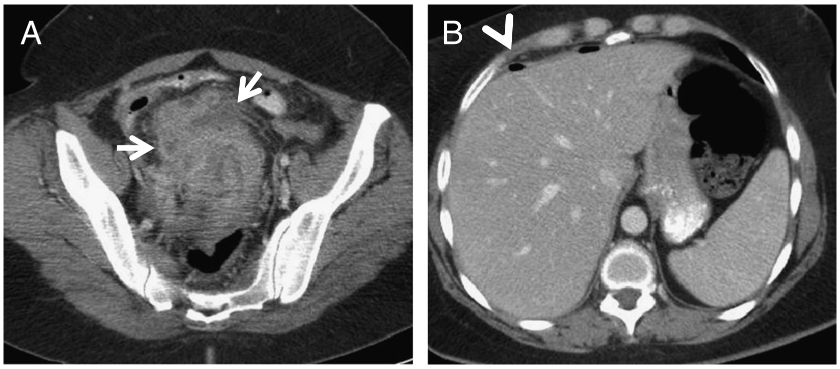

Figure 4. Colonic perforation in a 76-year-old man with the diagnosis of sigmoid colon cancer. Axial contrast-enhanced CT images of the abdomen at different levels show heterogeneously enhancing mass arising from the sigmoid colon with extensive pericolonic fat stranding (*arrows*) and associated free intraperitoneal air (*arrowhead*) suggestive of perforation.

Evaluation of All Patients With Pneumoperitoneum

One hundred forty-two patients were found to have free air, and among them, perforated viscus (42%, n = 59) was the predominant cause, followed by postoperative (<8 days) residual air (37%, n = 53). Postendoscopy (5%, n = 7) and barotrauma (2%, n = 3) were less common causes, with approximately 14% of episodes related to miscellaneous causes.

Review of Preoperative Imaging by Radiologists

Of the 114 patients with known viscus perforation, 98 had preoperative imaging available for review by radiologists (Table 2). Among these patients, only 51% (n = 50) had free air on imaging studies. In the presence of free air, the origin as determined by imaging was colonic in 34%, appendicitis in 18%, small bowel in 14%, and gastroduodenal in 10%, and no radiologic diagnosis was made in 24%.

Of the 50 patients with free air, 30 were categorized as large free air (any pocket of air >2.0 cm), 7 of which had a massive amount of free air (any pocket of air >10.0 cm), and 20 patients were therefore ascertained to have minimal free air (any number of small pockets of air, with the largest being ≤2.0 cm in diameter).

Colonic perforation was the cause in 30% of cases in the presence of large free air on imaging, followed by small bowel perforation in 20%, and gastroduodenal perforation in 17%. No radiologic diagnosis could be made in 33% (these patients typically underwent surgery after obtaining only plain radiographs). Among patients with massive amounts of free air (n = 7), the location of perforation was found to be evenly distributed among gastroduodenal, small bowel, and colon (n = 2 each); and in one case, the site of perforation could not be localized.

If minimal free air was noted on imaging, the most common site of perforation was the appendix (45%), followed by the colon (40%). Regarding cause of perforation, diverticulitis (25%) was the second most common cause associated with the finding of minimal free air on imaging after appendicitis (45%).

Five patients (17%) in large–free air group had only plain radiographs preoperatively (CT scan was not done). Location of perforation could not be predicted on review of preoperative imaging by radiologists for these patients with a large amount of intra-abdominal free air; but the site of perforation was accurately predicted in 80% (n = 20) of patients who had a CT scan performed. In contrast, minimal free air was seen only by CT scan. In the case of minimal free air, the site of perforation could not be localized in two cases, and in one case, it was predicted as small bowel when the perforation was in large bowel. Thus, the site of perforation was accurately identified in 85% (n = 17) of patients in this minimal free air group during review of preoperative imaging by our radiologists.

DISCUSSION

The Original Descriptions of Abdominal Free Air

The first mention of pneumoperitoneum in the literature was by Kelling[25] in 1902. Popper[26] in 1915 suggested the radiographic visualization of a subphrenic collection of gas with the patient in upright position as an aid to diagnosis of perforated peptic ulcer. Subsequently, Lenk[27] described the finding of pneumoperitoneum on x-ray after bullet wounds of the abdomen in soldiers. Dandy[28] (1919) noted a subphrenic air collection on the chest plate of a patient with perforated ulcer of the transverse colon. Vaughn and Brams[29] in 1925 published the

TABLE 1. Site of Perforation and Its Association With Free Intraperitoneal Air

Cause	Total, n	Percentage of All Perforations	Free Air, n	Percentage With Free Air
Appendicitis	39	34	3	8
Diverticulitis	14	12	8	57
Peptic ulcer	11	10	8	72
Bowel ischemia	10	9	5	50
Trauma	10	9	7	70
Malignancy	9	8	7	78
Postsurgical	4	4	4	100
Endoscopic injury	3	2	2	67
Biliary source	3	2	0	0
Other	11	10	7	64
Total	114	100	51	

TABLE 2. Site of Perforation as Diagnosed by Radiologists on Review of Preoperative Imaging

Overall	Percentage	Minimal* (n = 20)	Percentage	Large† (n = 30)	Percentage	Massive‡ (n = 7)	Percentage
Colon	34	Appendix	45	Colon	30	Gastroduodenal	29
Appendix	18	Colon	40	Small bowel	20	Small bowel	29
Small bowel	14	Small bowel	5	Gastroduodenal	17	Colon	29
Gastroduodenal	10	No diagnosis	10	No diagnosis	33	No diagnosis	13
No diagnosis	24						

*Minimal free air, any number of small pockets of air being 2.0 cm or less.
†Large free air, any pocket of air greater than 2.0 cm.
‡Massive free air, any patient with an air pocket greater than 10.0 cm.

first series of cases in which they reported subphrenic accumulation of gas in 86% of 29 proven cases of acute perforation of peptic ulcers; similar finding was reported by Vaughn and Singer[30] in 1929 in a series of 63 cases of perforated peptic ulcer.

Radiographic Signs of Free Intra-abdominal Air

A number of signs for the identification of intra-abdominal free air on plain abdominal x-ray have been reported (summary is presented in Table 3, Figs. 1–4). In 1970, Miller and Nelson[14] showed that a radiograph in left lateral position followed by upright chest, upright abdomen, and supine film of the abdomen facilitated demonstration of as little as 1 mL of intraperitoneal gas. Unfortunately, particular signs of free air on plain radiographs are typically identified in the setting of massive pneumoperitoneum. They have an overall sensitivity of just 30% to 59% for the detection of intraperitoneal free air (although the sensitivity approaches 100% for large-volume pneumoperitoneum).

In contrast, the sensitivity of abdominal CT scan for the detection of pneumoperitoneum is considerably higher than abdominal plain film, ranging from 96% to 100% even for small volumes of free air.[40–44] Stapakis and Thickman[9] compared the sensitivity of CT scan with upright chest radiography for the detection of free intraperitoneal air in trauma patients who had introduction of intraperitoneal air from diagnostic peritoneal lavage. An abdominal CT scan was obtained within 24 hours of the lavage, and then an upright chest radiography was performed within the next 4 hours. Intraperitoneal free air was seen only in 38% of the patients on plain radiography in comparison with 100% on abdominal CT scan. Plain radiography was unable to delineate minimal pneumoperitoneum (less than three 1-mm pockets of air); in the moderate pneumoperitoneum group (greater than three 1-mm pockets, but <13-mm diameter collection of air), it was 33% sensitive, but in the large pneumoperitoneum group (>13-mm collections of air), it was 100% sensitive.

A number of CT signs are indicative of significant bowel injury. These signs include bowel wall defects, extraluminal gas, intramural air, intraperitoneal contrast material, and extraluminal intestinal content. Focal bowel wall thickening, mesenteric hematoma, and fat stranding are less specific signs and may be indicative of nonsignificant bowel, mesenteric injury, or other injuries.[45,46] It should be noted that the location of free air on traditional abdominal CT scan has not previously correlated well with the location of the perforation,[16,47,48] but multidetector CT scan seems to have improved accuracy.[49,50]

Other imaging modalities including ultrasound and magnetic resonance imaging (MRI) have been evaluated for the identification of pneumoperitoneum. Ultrasound is a rapid, noninvasive, and inexpensive imaging modality with a reported sensitivity of 93% and specificity of 64%.[42] Other investigators have reported a very high accuracy (sensitivity of 100%, and specificity of 99%) using the "enhanced peritoneal stripe sign" for diagnosing pneumoperitoneum by ultrasound for patients presenting with acute abdomen.[41] However, ultrasound fails to identify the site of perforation and is highly user dependent.[6,40,41] MRI is not a good choice for evaluation of acute abdominal pain owing to the difficulties in image interpretation, time required to complete the test, high cost, contraindications (patients with pacemaker and claustrophobia), and incompatibility with standard life-support equipments. Finally, MRI does not seem to offer any advantage over CT scan in accuracy of detecting pneumoperitoneum.[51]

The most recent reports in the surgical literature regarding the cause of free abdominal air seem to emanate from the 1980s. In that era, plain radiographs typically revealed free intraperitoneal air originating from perforation of peptic ulcers (59–69%) or colonic diverticulitis (37–46%).[12,13] When compared with earlier reports, our study suggests an increase in the detection of pneumoperitoneum with small bowel perforation (69% in comparison with 30–41%), for colon (73% in comparison with 37–46%) and for gastroduodenal perforation (73%

TABLE 3. Signs for Identification of Pneumoperitoneum on Plain Radiography

Sign on Radiograph	Description
Right upper quadrant sign[10]	Air collection around the liver
Rigler's sign[31]	Air on both sides of the intestinal wall
Falciform-ligament sign[10]	Air outlining the falciform ligament
Football sign[32]	Air outlining the peritoneal cavity
Inverted V sign[33]	Air outlining the umbilical ligaments
Telltale sign[34]	Air between two bowel loops and parietal peritoneum
Visible gallbladder sign[35]	Air surrounding the gallbladder
Diaphragm muscle slip sign[36]	Air silhouetting the subdiaphragmatic muscular slips
Hyperlucent liver sign[37]	Air anterior to ventral hepatic surface
Cupola sign[38]	Air in the median subphrenic space
Urachus sign[39]	Air delineating urachus

TABLE 4. Comparison of Site of Perforation Reported by Different Studies

Author	Year	Site of Perforation				Imaging Modality
		Gastroduodenal, %	Colon, %	Appendix, %	Small Bowel, %	
Roh et al.[13]	1983	45	34	N/A	21	Radiography
Winek et al.[12]	1988	45	41	N/A	14	Radiography
Maniatis et al.[23]	2000	22	47	8	20	CT scan only
Current study	2011	13	26	34	11	CT scan/radiography

no change in image modality.

TABLE 5. Comparison of the Likelihood of Free Air Identified on Imaging Studies, Related to Location of Perforation

Author	Year	Free Air With Bowel Perforation				Imaging Modality
		Gastroduodenal, %	Colon, %	Appendix, %	Small Bowel, %	
Roh et al.[13]	1983	59	46	N/A	41	Radiography
Winek et al.[12]	1988	69	37	N/A	30	Radiography
Maniatis et al.[23]	2000	100	67	50	53	CT scan only
Hainaux et al.[20]	2006	100	100	100	67	CT scan only
Imuta et al.[21]	2007	99	97	44	100	CT scan only
Current study	2011	73	73	8	69	Radiography/CT scan

in comparison to 59–69%).[12,13] Our findings are consistent with the data from the radiology literature[20,21,23] based on CT scan imaging (Tables 4 and 5). We found a decrease in the incidence of gastroduodenal perforation as a cause of pneumoperitoneum in our study (10%), in comparison with 45% reported Roh et al.[13] and Winek et al.[12] in the 1980s. A reduced incidence of gastroduodenal perforation might be expected with a decline in the incidence of complicated peptic ulcer disease, which we observe today as surgeons.[23] Appendiceal perforation has replaced gastroduodenal perforation as the most common cause of viscus perforation in our series. This is most likely related to our enhanced capability to diagnose even minuscule amounts of air during routine CT imaging of patients with perforated appendicitis. Diverticulitis was the second leading cause of bowel perforation after appendicitis in our series and caused 12% of viscus perforation. Our radiologists found colonic perforation to be the leading cause when a large amount of free intraperitoneal air (>2 cm) was present. Appendiceal perforation was found to be most frequently associated with small amount of pneumoperitoneum (≤2.0 cm). Among patients with known viscus perforation and pneumoperitoneum, accurate diagnosis was made 82% of the time on review of preoperative CT scan by radiologists, which is consistent with the accuracy of CT scan for predicting the location of bowel perforation as reported by others (80–90%).[20–24]

Our investigation is limited by its relatively small population, retrospective nature, and our focus on a select group of patients who had site of bowel perforation confirmed during surgery. The study did not provide assessment of the impact of imaging findings on the patient management or outcomes. Finally, there were a few patients with free air related to trauma included, which may have affected the percentages slightly.

In conclusion, the cause of free air from visceral perforation has substantially changed from previous reports. The relative incidence of gastroduodenal perforation as a cause of pneumoperitoneum seems to be dramatically reduced when compared with that of the 1980s. This seems to be primarily related to improved imaging modalities and may be influenced by the declining incidence of complicated peptic ulcer disease.

AUTHORSHIP

A.K., M.T.M., and S.M.C. designed this study. A.K., M.T.M., S.M.C., and M.A.S. conducted the literature search. A.K., M.T.M., M.A.S., and V.S.K. collected data, which A.K., M.T.M., S.m.C., D.B.L., and V.S.K. analyzed and interpreted. A.K., M.T.M., S.M.C., and M.A.S. participated in writing the article. A.K., S.M.C., and V.S.K. prepared the figures.

DISCLOSURE

The authors declare no conflicts of interest.

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