The role of multidetector computed tomography in predicting the site of gastroduodenal perforation

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Abstract. – OBJECTIVE: This study aims to evaluate the value of multidetector computed tomography (MDCT) in detecting the location of gastroduodenal perforation.

PATIENTS AND METHODS: This cross-sectional descriptive study was conducted with 47 patients who underwent contrast-enhancing MDCT and were diagnosed with gastroduodenal perforation during surgery between July 2021 and June 2022. Radiologic findings included pneumoperitoneum (distribution and quantity) and analyzed the image findings for localizing the site of gastroduodenal perforation.

RESULTS: Pneumoperitoneum was the most common finding [95.74% (45 out of 47 patients)]. Regarding air distribution, the sensitivity (Se) and negative predictive value (NPV) of abdominal free air and supramesocolic free air were the highest (100% for both). The accuracy (Acc) of supramesocolic free air was the highest (93.6%), followed by abdominal free air (89.4%). Subphrenic free air also had a high Acc value (89.4%), with Se, specificity (Sp), and positive predictive value (PPV) being 90%, 85,7%, and 97.3%, respectively. The Sp PPV of falciform ligament/ligamentum teres sign, and periportal free air were also high (100% for both). In contrast, retroperitoneal free air was valuable in determining retroperitoneal duodenal perforation with an Sp, Se of 100%, and Acc of 89.4%. The thickness of abdominal free air was ≥5.5 mm, suggesting gastroduodenal perforation with a Se, Sp, PPV, NPV, and Acc of 82.5%, 100%, 100%, 50%, and 85.1%, respectively.

CONCLUSIONS: Subphrenic free air, periportal free air, falciform ligament sign, and the air above transverse mesocolon were correlated to gastric and duodenal bulb perforation. Retroperitoneal air indicates the perforation at the retroperitoneal duodenum. The thickness of abdominal free air ≥5.5 mm indicates gastric and duodenal bulb perforation.

Key Words:
Gastroduodenal perforation, Multidetector computed tomography, Site of perforation.

Introduction

The vast majority of gastroduodenal perforation was found in the gastrointestinal perforation (38.1%) with a high risk of complication and mortality; therefore, prompt diagnosis and treatment are essential[1]. In a review of the literature[2] about evaluating gastrointestinal tract perforation using MDCT, more than half of the studies related to gastroduodenal perforation. The typical location was the anterior wall of the first duodenal segment, followed by the antrum and lesser curvature of the stomach. The parallels of physiologic and anatomic features between gastric and duodenal bulb segments were based on the similarity of MDCT findings. Furthermore, the clinical signs and management methods are indistinguishable between these two locations[3]. On the other hand, due to the retroperitoneal duodenal segments (D2 to D4), the perforations at these segments cause retroperitoneal free air (right anterior perirenal space predominantly)[4]. In general, the anatomical site of retroperitoneal duodenal segments makes them less likely to experience trauma; however, due to their locali-

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zation being near the spine, the D2 and D3 segments are much more vulnerable to injury than the other parts[5].

In recent articles[6-9] that determine the value of MDCT in predicting the perforation site based on abdominal free air and other findings (around the site of gastroduodenal perforation), the correlation between the perforated location and peritoneum is outlined by the distribution and amount of free air from any given position. MDCT with thin slices, high resolution in short examination time and evaluation on different windows (abdominal window, lung window) have outstanding value compared to other methods such as ultrasound, x-ray, and MRI in determining these signs. Previous research has only focused on evaluating the perforation in separating segments such as the colon, stomach, and duodenum[7,10,11]. Thus, the discrimination between gastroduodenal perforation – especially in the duodenal bulb segment – and the other segment perforation has not been fully assessed. In this study, we evaluate the value of radiological findings of MDCT in detecting the location of gastroduodenal perforation.

Patients and Methods

Study Population

Forty-seven patients (37 males and 11 females, mean age: 54.13±20.42, 7-94 years old) who underwent contrast-enhancing MDCT at Viet Duc University Hospital between July 2021 and June 2022 were included in this prospective cross-sectional study. The definitive diagnosis of gastroduodenal perforation was confirmed during surgery. Ethical clearance was granted by the institutional Ethics Committee (Ref: 1888/QĐ-DHYHN), and patients' informed consent was waived.

Imaging Protocol

A 16-detector row CT scanner (Optima 2019, GE Healthcare, Milwaukee, United States) and a 64-detector row CT scanner (Optima CT660 LightSpeed VCT, GE Healthcare, Chicago, United States) were used in this study. Images were acquired craniocaudally from the diaphragmatic dome to the pubic symphysis with a 5 mm image slice thickness at 120 kVp and 350 mAs. The images were then reconstructed in a 0.625 mm slice thickness on axial, coronal, and sagittal planes with abdominal and lung windows. A multiphasic CT scan was performed, including non-contrast, arterial (25-35 s delaying), and portal venous phases (60-70 s delaying).

Image Analysis

All the data were stored on a PACS system (Infinitt Pacs, Infinitt Healthcare, Seoul, South Korea). The CT images were independently analyzed by two radiologists with more than five years of abdominal experience. A consensus-based discussion resolved any disagreements.

The sites of perforation were classified into gastric and duodenal bulb segments (N1) and retroperitoneal duodenal segments (N2). The radiologic findings were evaluated on pre- and postcontrast MDCT, including abdominal free air (distribution and amount) and other findings to localize the site of gastroduodenal perforation. Abdominal free air was considered as retroperitoneal free air [free air in perirenal space (Figure 1) and around psoas muscles], and periportal free air (free air in periportal space), subphrenic free air, falciform ligament/ligamentum teres sign (free air outlined falciform ligament/ligamentum teres) (Figure 2), mesenteric free air (free air in the small bowel mesentery and sigmoid mesentery), supramesocolic free air, inframesocolic free air, pelvic free air. The free air thickness was measured by the largest diameter of free air (on the axial plane). The findings which helped to predict perforated location included a focal wall defect (a low-density linear which runs through all bowel layers, with no post-contrast enhancement), segmental bowel wall thickening (gastric antrum wall ≥7 mm, gastric body and small bowel wall ≥3 mm, and colonic wall ≥5 mm)[12], extraluminal air bubbles (free air bubbles surround abnormal bowel loops), fatty stranding, and localized fluid collection (Figures 1-2).

Statistical Analysis

The data were analyzed by the SPSS 20.0 software package (IBM Corp., Armonk, NY, USA). The MDCT findings were investigated by calculating frequency, percentage, Chi-square and Fisher's exact test, which aimed to identify whether there was a statistical difference between two quantitative values where a p-value<0.05 was considered statistically significant. The value of MSCT findings in predicting the location of perforation was determined by assessing the sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and

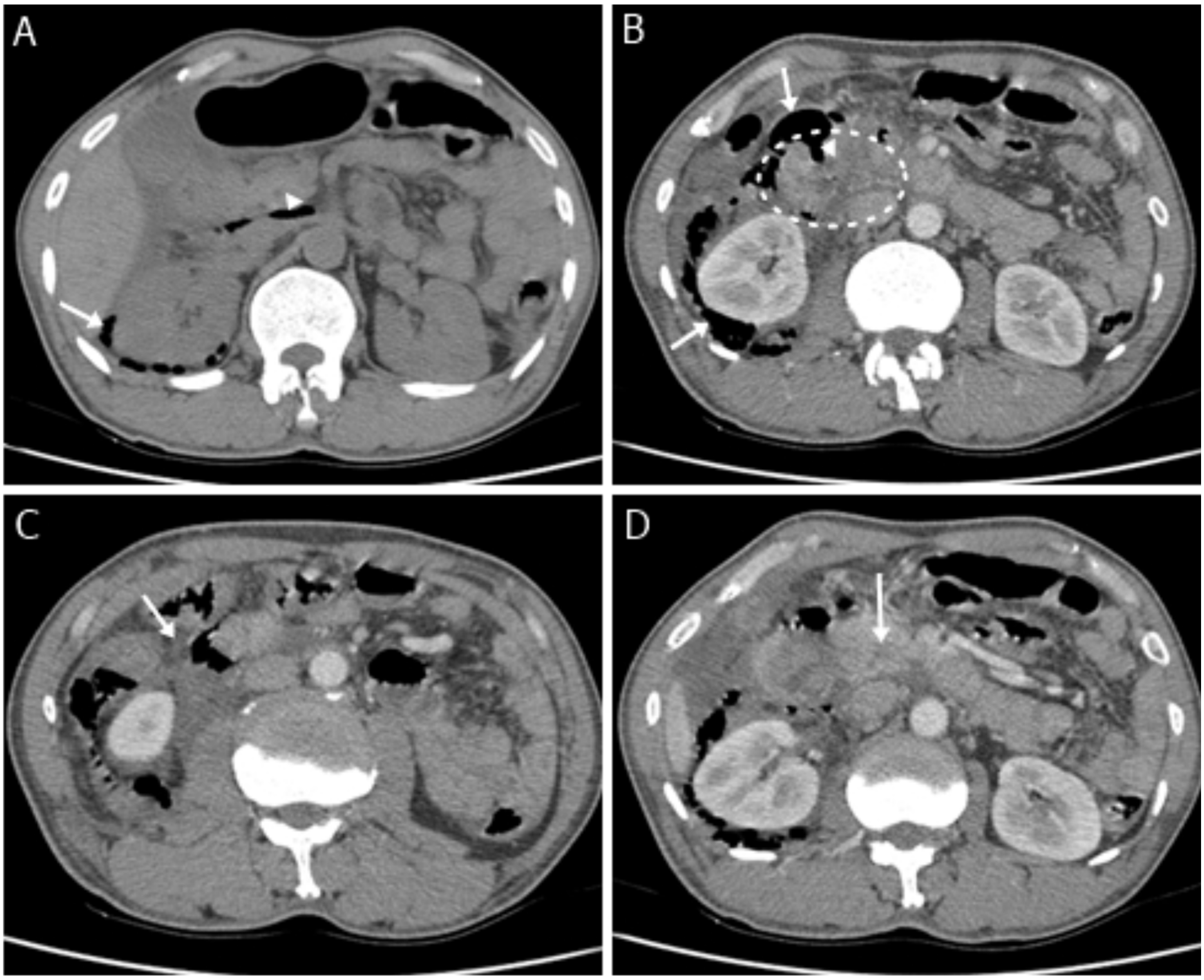

Figure 1. Abdominal CT scan with contrast agent of a 38-year-old male with duodenal injury at the D3 segment due to abdominal injury. **A,** Axial non-contrast CT image showed retroperitoneal air (*arrow*) and air into the right perirenal space (*arrow*). **B,** Axial portal venous phase CT image showed wall-thickening of the D3 segment (*dashed circle*) and discontinuity at the anterior wall of the D3 segment (*arrow*) and adjacent air (*arrow*). **C,** Axial portal venous phase CT image showed fatty stranding next to the duodenal wall discontinuity (*arrow*). **D,** Axial portal venous phase CT.

accuracy (Acc) of MDCT findings, which were compared with results from surgical reports. The thickness of free air (non-standard variables according to Shapiro-Wilk test) was analyzed using a Mann-Whitney U test, with a p-value<0.05 indicating statistical significance. Drawing the ROC curve to identify the most effective cut-off value and determining Sp, Se, PPV, NPV, and Acc at this cut-off value.

Results

The general features of the N1 group and the N2 group are illustrated in Table I. There were 40 patients in N1 and 7 patients in N2. The most common cause in the N1 group was gastroduodenal ulceration, which affected 32 patients (80%), and the most common cause in the N2 group was trauma, which affected 5 patients (71.4%). The mean age of the study subjects was 54.13±20.4, in which group N1 was 55.95±20.67, higher than group N2 which was 43.71±16.53. The difference between the two groups was not statistically significant with p=0.88 (>0.05). Male patients outnumbered female patients (male:female=3.3:1). In the N1 group, there were 29 (72.5%) male patients, and 7 (100%) patients in the N2 group were males.

As shown in Table II, abdominal free air was the most frequent finding in gastroduodenal perforation patients [95.74% (45 out of 47

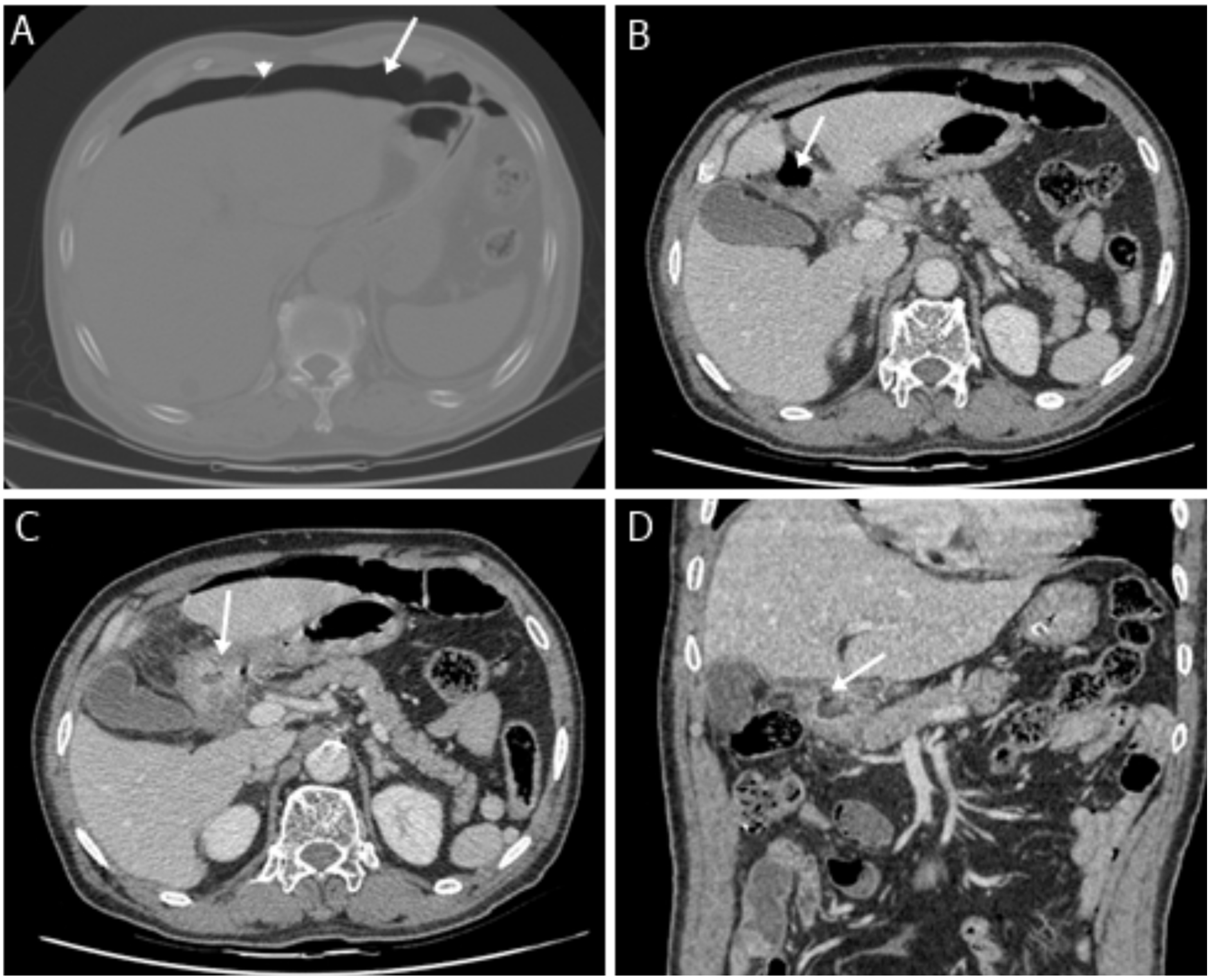

Figure 2. Abdominal CT scan with contrast agent of a 76-year-old male with gastroduodenal perforation due to peptic ulcer disease. **A,** Axial image with wide window setting showed peritoneal air at the prehepatic space (*arrow*) and the falciform ligament/ligamentum teres sign (arrow). **B,** Axial portal venous phase image showed free air near the duodenal bulb. **C,** Axial portal venous phase image showed wall-thickening of the duodenal bulb (arrow) and small air bulb adjacent. **D,** Coronal portal venous phase image showed discontinuity of the duodenal bulb wall (*arrow*).

Table I. The general features of the study population.

Causes	N1 (n = 40)	N2 (n = 7)
Ulceration	32 (68.1%)	0 (0.0%)
Trauma	1 (2.1%)	5 (10.6%)
Diverticulum	4 (8.5%)	0 (0.0%)
Tumor	3 (6.4%)	0 (0.0%)
Foreign body	0 (0.0%)	2 (4.3%)
Total	40 (85.1%)	7 (14.9%)
Age (54.13 ± 20.42)	55.95 ± 20.67	43.71 ± 16.53
$p = 0.88$ (*)		
Sex		
Male (n = 36)	29 (72.5%)	7 (100%)
Female (n = 11)	11 (27.5%)	0

*The *p*-value calculated using Fisher's exact test was statistically significant ($p<0.05$).

patients)]. In the N1 group, abdominal free air and supramesocolic free air were present in all 40 patients (100%), subphrenic free air in 36 patients (90%), falciform ligament/ligamentum teres sign in 25 patients (67.5%), and periportal free air in 17 patients (42.5%). These were all higher than in the N2 group ($p<0.05$). In the N2 group, retroperitoneal free air was found in 2 patients (28.6%) and was higher than in the N1 group (0 patients) ($p<0.05$). The thickness of free air in the N1 group was 11.38±7.37 mm and was higher than in the N2 group ($p<0.01$). There was no significant differentiation between the two groups for inframesocolic free air, mesenteric free air, pelvic free air, segmental

Table II. The MDCT findings of gastroduodenal perforation.

MDCT findings	N1 (n = 40) n (%)	N2 (n = 7) n (%)	*p*-value
Abdominal free air	40 (100)	5 (71.4)	0.019*
Subphrenic free air	36 (90)	1 (14.3)	< 0.001*
Falciform ligament/ligamentum teres sign	25 (67.5)	0 (0.0)	0.001*
Periportal free air	17 (42.5)	0 (0.0)	0.039*
Supramesocolic free air	40 (100)	3 (42.9)	< 0.001*
Inframesocolic free air	29 (72.5)	3 (42.9)	0.188
Mesenteric free air	13 (32.5)	1 (14.3)	0.657
Pelvic free air	5 (12.5)	0 (0.0)	1.000
Retroperitoneal free air	0 (0.0)	2 (28.6)	0.019*
Segmental bowel wall thickening	34 (90.0)	5 (71.4)	0.585
Focal wall defect	34 (85.0)	5 (71.4)	1.000
Extraluminal air bubbles	28 (70.0)	5 (71.4)	0.214
Localized fluid collection	22 (55.0)	5 (85.7)	1.000
Fat stranding	37 (92.5)	7 (100)	0.215
Free air thickness	11.38 ± 7.37	1.29 ± 2.22	0.001**

*The *p*-value calculated using Fisher's exact test was statistically significant ($p < 0.05$). **The *p*-value calculated using the Mann-Whitney U test was statistically significant ($p < 0.05$).

Table III. The value of MDCT findings in gastroduodenal perforation.

Location	MDCT findings	Se	Sp	PPV	NPV	Acc
N1 group	Abdominal free air	100	28.6	88.9	100	89.4
	Subphrenic free air	90.0	85.7	97.3	60.0	89.4
	Falciform ligament/ligamentum teres sign	67.5	100	100	35.0	72.3
	Periportal free air	42.5	100	100	23.3	51.1
	Supramesocolic free air	100	57.1	93.0	100	93.6
	The thickness of free air (with cut-off point 5.5 mm)	82.5	100	100	50	85.1
N2 group	Retroperitoneal free air	28.6	100	100	88.9	89.4

bowel wall thickening, focal wall defect, extraluminal air bubbles, localized fluid collection, and fatty stranding finding.

As shown in Table III, in the N1 group, the Se and NPV values were highest in abdominal free air and the supramesocolic free air findings (100% for both). The Acc value was also highest in supramesocolic free air (93.6%), followed by abdominal free air (89.4%). The subphrenic free air also registered a high Acc value of 89.4%, with Se 90.0%, Sp 85.7%, and PPV 97.3%. The highest Sp and PPV values were found in falciform ligament/ligamentum teres sign and periportal free air findings (100% for both). The retroperitoneal free air was valuable in diagnosing retroperitoneal duodenal perforation with Sp 100%, Se 100%, and Acc 89.4%.

The free air thickness's area under the curve (AUC) was 0.907 at the 5.5 mm cut-off point (Figure 3). It was statistically significant in discri-

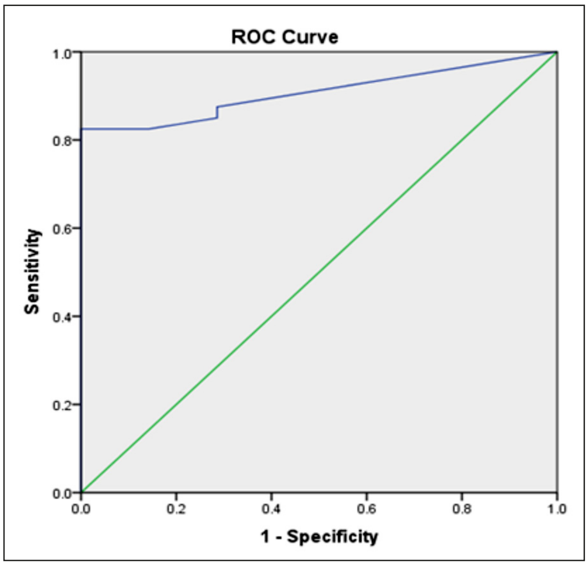

Figure 3. Receiver operator characteristic (ROC) curve for free air thickness between gastroduodenal and retroperitoneal duodenal perforation.

minating between the gastric and duodenal bulb perforation and retroperitoneal duodenal perforation with a Se value of 82.5%, Sp of 100%, PPV of 100%, NPV of 50%, and an Acc of 85.1%.

Discussion

Gastroduodenal perforations are common emergencies and can be life-threatening[13]. These conditions result from various etiologies (Table I), of which peptic ulcer diseases are the most frequent causes. Gastroduodenal perforations are observed in approximately 5 to 10%[4,11] of peptic ulcer patients. The perforation risks are associated[4,11] with older age, *Helicobacter pylori*, non-steroid anti-inflammatory drugs, corticoid use, stress, and alcoholism. Isolated duodenal injuries are occasional, accounting for 3 to 5% of abdominal injury cases; however, this was a common injury site observed in the patients in the study groups at the central hospital specializing in trauma, where this was the second leading cause, accounting for 10.6% of gastroduodenal perforation patients[14,15].

In this study, free air was present in 91.3% of gastroduodenal perforation patients. Similar to the study by Lee et al[16], the frequency of this sign was 97%, and in the study by Toprak et al[1], the rate was 94.7%. This was the specific sign that had to be found in the CT scan of the patient with a suspicious hollow viscera perforation and gastroduodenal perforation, in particular.

Multislice CT with a wide window setting for the air window helps find tiny air bulbs and minimizes missing lesions[5]. The appearance and distribution of extraluminal free air are proper in CT findings for diagnosing of the perforated sites, of which subphrenic air sign, falciform ligament/ligamentum teres sign, periportal air sign, and supramesocolic free air sign are associated with gastroduodenal perforation. Research by Cho et al[17] assessed 30 gastrointestinal perforation patients and 29 gastroduodenal ulcer patients. The suggestive findings from gastrointestinal perforation included periportal free air with a Se value of 93%, falciform ligament/ligamentum teres sign with an Sp value of 57 to 91%, and a PPV value of 71 to 89%, which were lower than the results of our study. This difference can be explained by the mobility of the small intestine in Cho et al[17] research (which was excluded in our research), leading to a change in gas distribution. There was no difference between mesenteric free air in upper gastrointestinal and lower gastrointestinal perforation. This result was similar to Topark et al's study[1], in which the Se, Sp, ACC of subphrenic free air were 56.4%, 84.9-85.2%, and 72-73.1%, respectively, and the Se of periportal free air was 69.2%.

In addition, in the study by Choi et al[10], the Sp and PPV of the falciform ligament/ligamentum teres sign were 76.7% and 80.6%, respectively, and were helpful in upper gastrointestinal perforation diagnosis. These gastroduodenal perforation findings were similar to those in Furukawa et al's research[18]. The presence of retroperitoneal free air is valuable in duodenal perforation at D2 to D4 segments because the anatomical site of these duodenal segments is in the retroperitoneal cavity[19]. The frequencies of the wall-thickening sign, discontinuous wall sign, free air bulb nearby bowel loop, and fatty stranding sign were high at 90%, 85%, 70%, and 92.5%, respectively. These results were similar to those in the study by Lee et al[16], as the rate of the fatty stranding sign was 89%, the second most common occurrence after the abdominal free air sign, followed by the rate of discontinuous wall sign (84%) and wall-thickening sign (72%).

The results in our study were similar to the study by Drakopoulos et al[20] in terms of the amount of abdominal free air; the significant volume of free air at the upper abdominal cavity (>185 ml) was indicative of upper gastrointestinal perforation. In our research, the remaining duodenal perforation cases, the amount of free air was much lower than perforation at the other site (1.29±2.22 mm), showing a significant difference ($p<0.05$). This result was different to the result of Drakopoulos et al's study[20]; however, in this previous study[20], the author did not subdivide the population study. Drakopoulo et al[20] only divided it into upper gastrointestinal and lower gastrointestinal, leading to no assessment of the value of each sign at a particular sub-group of perforated sites. The amount of abdominal free air was valuable in the differential diagnosis of gastric, duodenal bulb perforation, and duodenal perforation at the retroperitoneal cavity. In gastric and duodenal bulb perforation cases, the volume of abdominal free air was larger, with a mean thickness of free air of 11.38±7.37 mm. At the cut-off level of 5.5 mm, the Se, Sp, PPV, NPV, and ACC were 82.5%, 100%, 100%, 50%, and 85.1%, respectively.

In our study, we measured the free air thickness to simplify the calculation of abdominal free air volume. Although there are more accurate methods than this, it provides a quick assessment and reduces the error with an uncomplicated analysis of CT images. Another limitation of our study was that the sample size needed to be bigger to gain high reliability. Therefore, the increase in sample size and the standardization of free air measurements might boost the reliability of diagnostic signs.

Conclusions

The distribution of abdominal free air significantly indicates the perforated sites, of which subphrenic free air, periportal free air, falciform ligament sign and air above transverse mesocolon were correlated to gastric and duodenal bulb perforation. Retroperitoneal air indicates the perforation at the retroperitoneal duodenum. The thickness of abdominal free air (equal to or greater than 5.5 mm) indicates gastric and duodenal bulb perforation.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Ethics Approval

The institutional Ethics Committee of Hanoi Medical University approved our prospective research (Ref: 1888/QĐ-DHYHN).

Informed Consent

Informed consent was waived for the study by the Ethics Committee of Hanoi Medical University (Ref: 1888/QĐ-DHYHN), and the analysis used anonymous clinical data.

Availability of Data and Material

The datasets generated and/or analyzed during the current study are not publicly available due to privacy concerns but are available from the corresponding author on reasonable request.

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Authors' Contribution

D.-H. Nguyen and M.-D. Nguyen prepared, drafted, and revised the manuscript critically, for important intellectual content. D.-M. Nguyen, D.-H. Nguyen, and M.-D. Nguyen contributed substantially to the acquisition, analysis, and interpretation of data. Each author gave final approval to the version of the manuscript submitted for publication and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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