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Diagnosis of diaphragm injuries using modern 256-slice CT scanners: too early to abandon operative exploration

Rindi Uhlich,[1] Jeffrey David Kerby,[2] Patrick Bosarge,[2] Parker Hu[2]

[1]Department of Surgery, University of Alabama at Birmingham, Birmingham, Alabama, USA
[2]Division of Acute Care Surgery, Department of Surgery, University of Alabama at Birmingham, Birmingham, Alabama, USA

Correspondence to
Dr Parker Hu, Division of Acute Care Surgery, Department of Surgery, University of Alabama at Birmingham, Birmingham, AL 35294-0012, USA; phu@uabmc.edu

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ABSTRACT

Background Missed injury of the diaphragm may result in hernia formation, enteric strangulation, and death. Compounding the problem, diaphragmatic injuries are rare and difficult to diagnose with standard imaging. As such, for patients with high suspicion of injury, operative exploration remains the gold standard for diagnosis. As no current data currently exist, we sought to perform a pragmatic evaluation of the diagnostic ability of 256-slice multidetector CT scanners for diagnosing diaphragmatic injuries after trauma.

Methods A retrospective review of trauma patients from 2011 to 2018 was performed at an American College of Surgeons-verified level 1 trauma center to identify the diagnostic accuracy of CT scan for acute diaphragm injury. All patients undergoing abdominal operation were eligible for inclusion. Two separate levels of CT scan technology, 64-slice and 256-slice, were used during this time period. The prospective imaging reports were reviewed for the diagnosis of diaphragm injury and the results confirmed with the operative record. Injuries were graded using operative description per the American Association for the Surgery of Trauma guidelines.

Results One thousand and sixty-eight patients underwent operation after preoperative CT scan. Acute diaphragm injury was identified intraoperatively in 14.7%. Most with diaphragmatic injury underwent 64-slice CT (134 of 157, 85.4%). Comparing patients receiving 64-slice or 256-slice CT scan, there was no difference in the side of injury (left side 57.5% vs. 69.6%, p=0.43) or median injury grade (3 (3, 3) vs. 3 (2, 3), p=0.65). Overall sensitivity, specificity, and diagnostic accuracy of the 256-slice CT were similar to the 64-slice CT (56.5% vs. 45.5%, 93.7% vs. 98.1%, and 89.0% vs. 90.2%).

Discussion The new 256-slice multidetector CT scanner fails to sufficiently improve diagnostic accuracy over the previous technology. Patients with suspicion of diaphragm injury should undergo operative intervention.

Level of evidence I, diagnostic test or criteria.

INTRODUCTION

Traumatic diaphragmatic injury (TDI) is rarely encountered, but potentially devastating if not accurately diagnosed and repaired. Missed TDIs are often detected during subsequent hospital admission, when patients present with symptoms related to visceral herniation and strangulation, with reported rates of mortality of greater than 10%.[1] Lack of reliable diagnostic imaging has led most experts to recommend operative visualization when TDI is suspected.[2–5] However, operative exploration, although highly sensitive in detecting injury, may be negative in up to 60% to 80% of cases.[6–8] The ability to reliably exclude TDI through a non-invasive approach would decrease unnecessary operations and reduce associated morbidity and cost.

Plain film and CT are the most commonly used radiologic studies after injury. However, the diagnostic sensitivity of CT to detect TDI has historically been poor, with reported ranges of 14% to 61%.[9–12] Most literature on the subject is relatively dated when compared with current technology and consists primarily of studies evaluating the diagnostic capability of 4-slice to 32-slice scanners.[11 13–18] The few studies available investigating CT scanners with multiple detectors capable of obtaining 64-slice images per revolution have demonstrated some improvement in diagnostic sensitivity but are still unable to reliably exclude TDI.[19–21]

To date, no studies have evaluated the use of the newly developed 256-slice CT in the management of diaphragmatic trauma. This new technology represents an upgrade over the previous 64-slice CT, scans a significantly larger body surface area per revolution, and allows for faster area imaging, improved spatial resolution, and superior image quality. Such improvements may potentially provide a non-invasive method to reliably detect TDI. Similar application of the 256-slice CT scanner to other dynamic anatomic structures, such as coronary CT angiography, has resulted in improved image quality and diagnostic accuracy.[22 23] We sought to compare the sensitivity of the 256-slice CT with the older 64-slice CT among trauma patients with proven TDI, with the hypothesis that the new technology would demonstrate improved diagnostic sensitivity.

METHODS

The University of Alabama at Birmingham Medical Center (UABMC) trauma registry was queried for all adult trauma patients requiring exploratory laparotomy or laparoscopy, from January 2011 to February 2018. The UABMC is an American College of Surgeons-verified level 1 trauma center and tertiary referral center for the region. All trauma patients undergo expeditious evaluation as per Advanced Trauma Life Support guidelines on presentation. In January 2017, the CT equipment in the emergency department was upgraded to the iCT Philips 256 machine (Koninklijke Philips NV, Amsterdam), a 256-slice CT scanner, replacing the Philips Brilliance Power 64-channel CT scanner, a 64-slice machine.

Demographics, injury characteristics, and outcomes were extracted from the electronic medical record. Operative reports were reviewed to confirm the presence or absence of a TDI. Injuries were graded using the American Association for the Surgery of Trauma injury scale for diaphragmatic trauma, based on the description provided in the attending surgeon's operative report. If length of injury was not documented, attempts to grade the injury were performed according to the following guidelines: For a single gunshot wound described, the injury was considered grade 2. Multiple gunshot wounds were considered grade 3. Other injuries without description of length were ungraded. Patients without preoperative imaging at the UABMC, pregnant, or ≤18 years of age were excluded from the study.

Preoperative diagnosis of TDI was based on the official interpretation of the CT images, by the attending radiologist, at the time of injury. Positive diagnosis was assigned to reports with either identified injury or with an interpretation of "possible" or "suggestive" or "unable to exclude" injury to the diaphragm. Examinations were identified as negative for diaphragm injury if described as no injury to the diaphragm or if there was no mention of the diaphragm in the report.

Patients were categorized into two cohorts, those evaluated preoperatively with the 256-slice CT scanner and those evaluated with the 64-slice CT scanner. Data were expressed as number (proportion) or as median (IQR). Univariate comparisons were performed using the Pearson's χ^2 and Mann-Whitney U tests for categorical and continuous variables, respectively. An a priori p value ≤0.05 was set to identify statistical significance. All analyses were performed using IBM SPSS Statistics for Windows V.24.0.

Table 1 Comparison of demographics and injury patterns of patients with diaphragm injury undergoing preoperative CT imaging

	256-slice CT (n=23)	64-slice CT (n=134)	P values
Demographics			
Age (years)	35.0 (28.8–40)	36.5 (27.0–50.3)	0.64
Gender (%)			
Male	20 (87.0)	106 (79.1)	0.34
Female	3 (13.0)	28 (20.9)	
Race (%)			
Caucasian	8 (34.7)	66 (49.3)	0.50
African–American	15 (65.2)	67 (50.0)	
Hispanic	0	1 (0.7)	
Clinical			
Mechanism of injury (%)			
Blunt	6 (26.1)	47 (35.1)	0.57
Penetrating	17 (73.9)	87 (64.9)	
Injury Severity Score	23.0 (16.5–41.0)	24.0 (14.0–34.0)	0.59
Associated injury (%)			
Hemothorax	17 (73.9)	86 (64.2)	0.53
Traumatic brain injury	2 (8.7)	8 (6.0)	0.67
Liver injury	12 (52.2)	74 (55.2)	0.64
Renal injury	4 (17.4)	8 (6.0)	0.069
Grade of renal injury	0 (0, 0)	0 (0, 0)	
Gastric injury	4 (17.4)	20 (14.9)	0.83
Small bowel injury	1 (4.3)	14 (10.4)	0.33
Colon injury	4 (17.4)	20 (14.9)	0.83
Pancreatic injury	2 (8.7)	6 (4.5)	0.43
Splenic injury	9 (39.1)	42 (31.3)	0.55

Data presented as median (IQR) unless otherwise noted.
Estimates from Pearson's χ^2 and Mann-Whitney U for categorical and continuous variables, respectively.

RESULTS

A total of 1068 patients underwent abdominal operation with preoperative CT scan during the study period. Most were evaluated with the 64-slice CT (887 of 1068). One hundred and fifty-seven overall suffered injury of the diaphragm. Of these patients, 85.4% (134 of 157) underwent evaluation with the 64-slice CT and the rest were evaluated with the 256-slice CT.

Patients were demographically similar, with no differences in median age, gender, or race. There were no differences in injury patterns among patients imaged with either scanner. Penetrating injury was more common among both groups. Median Injury Severity Scores were almost identical between the two cohorts. Further, there were no differences in rates of associated injuries, including rates of other thoracic or abdominal trauma (table 1).

Overall, most patients had injuries isolated to the left hemidiaphragm (59.2%). Fewer patients suffered isolated right-sided injury (39.4%), and a small minority demonstrated bilateral injury (1.3%). There were no differences in laterality of injury comparing patients imaged with the 64-slice versus the 256-slice CT (table 2). In total, 77 (49.7%) patients suffered grade 3 injury, which was the most common. A large majority of patients suffered at least grade 2 injury (96.3%). However, there were no differences among the two cohorts in terms of median injury grade or length of injury.

Of patients with intraoperatively confirmed TDI, only 77 (47.1%) were accurately diagnosed with preoperative CT imaging. Among patients with diaphragm injury, the 256-slice CT correctly identified 56.5% of injuries, whereas the 64-slice CT was able to diagnose 45.5% of injuries (p=0.36). Overall, there was no difference between the 64-slice CT and the 256-slice CT in rates of correct or missed diagnoses for diaphragm injury, regardless of mechanism or side of injury (table 3). There were significant increases in rates of false-positive diagnoses with the 256-slice CT compared with the 64-slice CT. As a result, the sensitivity and negative predictive value were improved whereas the specificity and positive predictive value declined after conversion to the 256-slice CT (table 4). Diagnostic accuracy remained similar between the two CT scanners, regardless of subpopulation.

DISCUSSION

We identified that the new 256-slice CT scan fails to significantly improve diagnostic sensitivity and negative predictive value over the 64-slice CT scan and fails to obviate the need for operative visualization in the diagnosis of TDI. Furthermore, we identified a significant increase in rates of false-positive diagnoses with the 256-slice CT scan, with associated declines in specificity and positive predictive value. Diagnostic accuracy remains similar between the two CT scanners. Overall, it does not appear the new technology has sufficiently improved to rule out the possibility of suspected diaphragm injury.

We hypothesized that development and deployment of CT scanners capable of 256-slice imaging would improve diagnostic yield, specifically for TDI, given the improved image acquisition and quality when similarly applied to other areas requiring

Table 2 Comparison of patients with diaphragm injury undergoing preoperative CT imaging

	256-slice CT (n=23)	64-slice CT (n=134)	P values
Injury			
Diaphragm injury laterality (%)			
Left	16 (69.6)	77 (57.5)	0.43
Right	7 (30.4)	55 (41.0)	
Bilateral	0	2 (1.5)	
Diaphragm injury grade	3 (3, 3)	3 (2, 3)	0.65
1	0	5 (3.7)	0.32
2	0	25 (18.7)	0.02
3	19 (82.6)	58 (43.3)	0.002
4	2 (8.7)	27 (20.1)	0.13
5	0	0	–
Length of injury (cm)	5.5 (2.0–8.8)	4.0 (2.0–10.0)	0.87
Visceral herniation with initial diagnosis (%)	6 (26.1)	23 (17.2)	0.36
Visceral herniation with delay in diagnosis (%)	0	2 (1.5)	0.55
Diagnosis with preoperative CT (%)	13 (56.5)	61 (45.5)	0.36
Diagnosis with X-ray (%)	0	9 (6.7)	0.19
Delay in diagnosis (%)	2 (8.7)	4 (3.0)	0.21
Operative			
Repair in index hospitalization (%)	23 (100)	124 (92.5)	0.17
Laparoscopy (%)	1 (4.3)	1 (0.7)	0.17
Thoracoscopy (%)	1 (4.3)	1 (0.7)	0.17
Laparotomy (%)	23 (100)	129 (96.3)	0.92
Thoracotomy (%)	1 (4.3)	11 (8.2)	0.49
Suture repair (%)	23 (100)	123 (91.8)	0.49
Mesh repair (%)	0	3 (2.2)	0.46

Data presented as median (IQR) unless otherwise noted.
Estimates from Pearson's χ^2 and Mann-Whitney U for categorical and continuous variables, respectively.

Table 3 Comparison of the accuracy of CT in the identification of diaphragmatic injury among trauma patients prior to abdominal exploration

	256-slice CT (n=181)	64-slice CT (n=887)	P values
Overall			
True positive	13 (7.2)	61 (6.9)	0.88
True negative	148 (81.8)	739 (83.3)	0.61
False positive	10 (5.5)	14 (1.6)	0.001
False negative	10 (5.5)	73 (8.2)	0.22
Blunt			
True positive	5 (4.8)	28 (4.7)	0.98
True negative	90 (86.5)	537 (90.9)	0.17
False positive	7 (6.7)	8 (1.4)	0.001
False negative	2 (1.9)	18 (3.0)	0.53
Penetrating			
True positive	8 (10.4)	33 (11.1)	0.85
True negative	58 (75.3)	202 (68.2)	0.23
False positive	3 (3.9)	6 (2.0)	0.34
False negative	8 (10.4)	55 (18.6)	0.09
Left-sided			
True positive	9 (5.3)	35 (4.3)	0.54
True negative	148 (86.6)	739 (90.2)	0.41
False positive	7 (4.1)	5 (0.6)	0.03
False negative	7 (4.1)	40 (4.9)	0.69
Right-sided			
True positive	4 (2.5)	25 (3.1)	0.67
True negative	148 (93.7)	739 (91.8)	0.96
False positive	3 (1.9)	9 (1.1)	0.02
False negative	3 (1.9)	32 (4.0)	0.19

Data presented as number and proportion of patients with preoperative CT imaging.
Estimates from Pearson's χ^2 analysis.

high definition of dynamic structures, such as in coronary CT angiography. However, similar to previous studies in which the diagnostic sensitivity ranges from 17% to 67%, the sensitivity rates for injury detection were still unacceptably low in our study.[11 21 24 25] Possibly, the lack of improvement despite improved imaging stems from the inherent difficulty in radiographic diagnosis of what are often small lacerations. This may explain why our study showed that the 256-slice CT scanner was better able to identify blunt than penetrating injuries. Numerous signs have been described to help identify TDI on CT, including the collar, dependent viscera, and discontinuous diaphragm signs (table 5).[26] However, our study suggests that the technology is not yet sufficiently sensitive to appreciate focal diaphragm disruptions.

Interestingly, there was an increase in the proportion of patients with false-positive diagnoses on installation of the 256-slice CT scanner. The resolution with the new images may be improved to allow visualization of questionable thickening of the diaphragm that was previously unappreciable, and which may be mistaken for potential injury. However, this decrease in positive predictive value should not preclude operative exploration to confirm the presence of injury given the potential and the gravity of missed diagnoses.

The majority of TDIs in the USA are the result of penetrating trauma, which was consistent with our study results (66.2% penetrating).[27] Most gunshot and stab wounds result in small lacerations of the diaphragm that are difficult to identify radiographically, as evidenced by previously cited diagnostic sensitivities of 8% to 63%.[6 15 24 25] We found that detection of these injuries with the new 256-slice CT scanner remains similarly low in our study, with sensitivity rates of only 50.0%. Identification of contiguous injuries or use of tractography has previously been used to improve the rates of diagnosis in penetrating trauma.[13 16 19] Potentially, reformatted images demonstrating the injury tract with the new 256-slice CT may further improve diagnostic accuracy. However, we did not identify significant improvement in diagnostic accuracy among all patients who underwent preoperative CT after trauma.

Although multiple reports are available of improved diagnostic sensitivity, with rates between 76% and 100%, the majority of these studies consist of retrospective imaging review and must be interpreted with caution given associated diagnostic review bias.[13 14 16 17 19 20] This is illustrated by one such study, in which analysis of prospective reports followed by retrospective image review found that 75% of injuries missed prospectively were identified during the retrospective review.[24] The tendency for improved diagnostic sensitivity with CT in these studies must

Table 4 Comparison of diagnostic ability of 64-slice and 256-slice CT scanners

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Diagnostic accuracy (%)
64-slice					
Overall	45.5	98.1	81.3	91.0	90.2
Blunt	60.9	98.5	77.8	96.8	95.6
Penetrating	37.5	97.1	84.6	78.6	79.4
Left-sided injury	46.7	99.3	87.5	94.9	94.5
Right-sided injury	43.9	98.8	73.5	95.8	94.9
256-slice					
Overall	56.5	93.7	56.5	93.7	89.0
Blunt	71.4	92.8	41.7	97.8	91.3
Penetrating	50.0	95.1	72.7	87.9	85.7
Left-sided injury	56.3	95.5	56.3	95.5	91.8
Right-sided injury	57.1	98.0	57.1	98.0	96.2

therefore be weighed with the potential that increased suspicion for injury may increase detection rate.

Left hemidiaphragm injuries are typically viewed as more significant given the higher potential for visceral herniation and strangulation. Importantly, left-sided injuries were identified more frequently (56.3%) using the 256-slice CT scanner than those with the 64-slice CT scanner (46.7%), although not significantly. These injuries, although potentially more dangerous to the patient, are fortunately easier to detect given that right-sided injuries may be obscured by the liver. The new CT was less likely to detect right-sided injury than with the 64-slice CT. However, this was also non-significant.

The current study is clearly limited, as the analysis was conducted with retrospective data from a single center. Limited numbers of patients were evaluated using the 256-slice CT. Potentially, a multi-institutional study may confirm the results of our study. Additionally, reliance on attending radiology's interpretation to determine diagnostic accuracy does not take into account the potential for TDIs that may have been identified by the trauma team physicians, who were able to interpret the original images at the point of care. These results and their influence are not available here. Use of the radiologist's interpretations though prevents diagnostic review bias that is commonly seen in other similar studies requiring retrospective review of images.

Table 5 Described signs on CT to identify diaphragm injury

Sign	Description
Collar	Constriction of the viscera within the diaphragmatic defect (ie, collar too tight).
Dependent viscera	Viscera seen dependent on thoracic wall after herniating through the defect.
Contiguous injury	Injury tract visible on both sides of the diaphragm.
Diaphragm thickening	Thickening due to diaphragm retraction.
Curled diaphragm	Irregular diaphragm thickening.
Hump	Hump shape of the liver herniated through right-sided injury (similar to collar sign on the left).
Band	Linear area of hypoattenuation through herniated liver.
Discontinuous diaphragm	Focal defect in the diaphragm.
Dangling diaphragm	Free edge of the diaphragm curls inward toward the center of the body.
Visceral herniation	Herniation of organs into the thoracic cavity.

Instead, our study offers a pragmatic view of the real-time information that would be available to trauma surgeons at the time of injury.

Despite its limitations, our study represents the first to examine the use of the 256-slice CT in the diagnosis of diaphragm injury. Additionally, unlike most studies in which a small subpopulation is examined, our study offers the results of all patients with abdominal operation and preoperative CT to provide the true measure of diagnostic accuracy for the detection of diaphragm trauma in the general trauma patient. Given that the 256-slice CT failed to identify over 40% of injuries, we think that intraoperative evaluation of the diaphragm must remain the gold standard for diagnosis in the setting of suspected injury. Currently, CT technology carries an unacceptably high false-negative rate and has not demonstrated the ability to diagnose injury with sufficient sensitivity to warrant the risk of missed injury and potential complication.

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