A New, Simple Method for Estimating Pleural Effusion Size on CT Scans

Matthew P. Moy, MD; Jeffrey M. Levsky, MD, PhD; Netanel S. Berko, MD; Alla Godelman, MD; Vineet R. Jain, MD; and Linda B. Haramati, MD, FCCP

Background: There is no standardized system to grade pleural effusion size on CT scans. A validated, systematic grading system would improve communication of findings and may help determine the need for imaging guidance for thoracentesis.

Methods: CT scans of 34 patients demonstrating a wide range of pleural effusion sizes were measured with a volume segmentation tool and reviewed for qualitative and simple quantitative features related to size. A classification rule was developed using the features that best predicted size and distinguished among small, moderate, and large effusions. Inter-reader agreement for effusion size was assessed on the CT scans for three groups of physicians (radiology residents, pulmonologists, and cardiothoracic radiologists) before and after implementation of the classification rule.

Results: The CT imaging features found to best classify effusions as small, moderate, or large were anteroposterior (AP) quartile and maximum AP depth measured at the midclavicular line. According to the decision rule, first AP-quartile effusions are small, second AP-quartile effusions are moderate, and third or fourth AP-quartile effusions are large. In borderline cases, AP depth is measured with 3-cm and 10-cm thresholds for the upper limit of small and moderate, respectively. Use of the rule improved interobserver agreement from $\kappa = 0.56$ to 0.79 for all physicians, 0.59 to 0.73 for radiology residents, 0.54 to 0.76 for pulmonologists, and 0.74 to 0.85 for cardiothoracic radiologists.

Conclusions: A simple, two-step decision rule for sizing pleural effusions on CT scans improves interobserver agreement from moderate to substantial levels. *CHEST* 2013; 143(4):1054–1059

Abbreviations: AP = anteroposterior

Pleural effusion is the pathologic accumulation of fluid in the pleural space. The physiologic amount of pleural fluid is approximately 5 mL. This volume may increase as a consequence of numerous pathologic conditions that disrupt the equilibrium of fluid flowing in and out of the pleural space, including congestive heart failure, pneumonia, pleuropulmonary malignancy, connective tissue diseases, and trauma.^{1,2}

Pleural effusion is common, with an incidence in the United States of approximately 1.5 million people per year.³ Pleural effusion may be detected on physical examination and imaged by radiography,⁴ ultrasonography⁵ or CT scanning.⁶

Several systems of classification of effusion size on plain radiographs are in use.⁷ For example, volume can be predicted by visibility on the lateral view (50 mL), visibility on the posteroanterior view (200 mL), or by loss of the diaphragm contour on the posteroanterior view (500 mL).⁸ In specific circumstances, etiology and outcome can be predicted radiographically.^{9,10}

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Affiliations: From the Departments of Radiology (Drs Moy, Levsky, Berko, Godelman, Jain, and Haramati) and Medicine (Dr Haramati), Albert Einstein College of Medicine & Montefiore Medical Center, Bronx, NY.

Dr Moy is currently at the Department of Radiology, Massachusetts General Hospital (Boston, MA).

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Correspondence to: Jeffrey M. Levsky, MD, PhD, Department of Radiology, Albert Einstein College of Medicine, Montefiore Medical Center, Gold Zone, Ground Floor, 111 E 210th St, Bronx, NY 10467-2490; jlevsky@montefiore.org

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Radiography and ultrasound are the most frequently used and most appropriate modalities to evaluate pleural effusions and guide thoracentesis. CT scans are performed for a wide variety of indications, including assessment of pleural disease. CT scanning demonstrates small pleural effusions with excellent sensitivity, assesses the underlying lung parenchyma, and is superior to radiography in differentiating pleural and parenchymal disease.¹¹ The British Thoracic Society 2010 guidelines recommend CT imaging for patients with pleural effusion to diagnose empyema, distinguish lung abscess from empyema, and differentiate between benign and malignant pleural thickening.¹²

Currently, the size of the effusion is described qualitatively on CT scans rather than quantitatively, since there is no standardized system to grade pleural effusion size. The terms small, moderate, and large are most often used, yet there is no consensus on the limits of these sizes. One study characterized effusions occupying less than one-third, one-third to two-thirds, and greater than two-thirds of the hemithorax as small, moderate, and large, respectively.¹³ More commonly, each clinician uses a unique set of subjective criteria. Consequently, there is significant variation in descriptions of pleural effusion size on CT scans. Accurate and consistent description of the size of a pleural effusion is important in the communication of findings and the perceived severity of disease. In addition, pleural effusion size affects the relative ease of thoracentesis. Chemical and cytologic pleural fluid evaluation is a primary factor in several clinical algorithms and has well-documented diagnostic utility.^{14,15} Effusions that measure <1 cm on a lateral decubitus chest radiograph (corresponding to a volume ≤ 300 mL) have traditionally been relatively contraindicated for thoracentesis without imaging guidance.^{16,17} In these cases, imaging guidance is often used for safe sampling because accurate diagnoses can be made using small samples.¹⁸

Several studies document the ability of CT scanning to exactly quantify the volume of pleural effusions,¹⁹⁻²¹ although the methods required to do so require manual input and can be laborious. The present study was undertaken to develop and validate a simple, standardized system for quantifying pleural effusions on CT scans based on qualitative and simple quantitative features. The goal is to improve communication of findings and serve as a potential guide in determining the need for imaging guidance for thoracentesis.

MATERIALS AND METHODS

Subjects

The study was retrospective, Health Insurance Portability and Accountability Act-compliant, and approved by the Montefiore

Medical Center institutional review board (approval #10-10-322E). Informed consent was not required. A search of the radiology information system database of reports identified sequential adults who underwent chest CT scanning from January 1, 2010, through November 30, 2010, that demonstrated unilateral or bilateral pleural effusions. Cases were then placed in order according to reported effusion size. Original images were reviewed by a single investigator (N. S. B.) to evaluate for exclusion criteria and to sort cases by approximate size. Exclusion criteria were: CT-scan findings of loculation, central bronchial obstruction, pneumothorax, or a drainage catheter. The same investigator selected a total of 34 cases that spanned the spectrum of effusion sizes and also represented an approximately equal number of bilateral and unilateral effusions. In patients with bilateral effusions, the larger one was studied.

The size of each pleural effusions was measured on 3- to 5-mm-thick slices using a morphometric segmentation tool in TeraRecon Aquarius iNtuition software version 4.4 (TeraRecon Inc). The CT scan dataset was loaded onto the workstation. One investigator (M. P. M.) used the tool to manually outline the pleural effusion and the ipsilateral hemithorax on each CT scan slice. The workstation calculated the volume based on the tracings and the thickness of each CT scan slice using Simpson's rule. To correct for different patient sizes and body shapes, pleural effusion volume was normalized to the hemithorax volume and expressed as a percentage ("effusion percent").

The population comprised 19 women and 15 men with a mean age of 64 years (range: 22-88). Fifty-three percent (18 of 34) of effusions were bilateral, 29% (10 of 34) were right sided, and 18% (six of 34) were left sided. Effusion percents ranged from 5.85% to 89.05%, with a mean of 37.42%.

Development of a Classification Rule

Two fellowship-trained cardiothoracic radiologists (J. M. L., L. B. H.) analyzed all CT scans ($n = 34$) in consensus for qualitative and quantitative features that correlate with effusion size based on literature² and their clinical experience. The relationship between these features and effusion percent was used to develop a simple rule to categorize pleural effusions as small, moderate, or large. The performance of the qualitative and quantitative variables served as a guide to separate the effusions into three groups. Cutoffs were chosen at <20%, 20% to 40%, and >40% of the hemithorax for small, moderate, and large effusions, respectively.

The qualitative characteristics were: (1) degree of passive atelectasis: none, subsegmental, segmental, multisegmental, lobar, multilobar (lobar was included when multiple segments in different lobes were atelectatic and it summed to a lobar equivalent); (2) greatest anteroposterior (AP) quartile, measured as the anterior-most quartile in which the effusion was seen (Fig 1) on the axial image superior to the ipsilateral hemidiaphragm where the effusion had greatest thickness (Fig 2); (3) greatest craniocaudal height using anatomic landmarks (ipsilateral inferior pulmonary vein, transverse right pulmonary artery, carina, aortic arch, lung apex); (4) fluid in the major fissure; (5) mediastinal shift; and (6) predominantly subpulmonic location. The quantitative characteristics were: (1) number of completely atelectatic lung segments, (2) craniocaudal length in cm, and (3) maximum AP depth of the effusion in cm on the axial image superior to the hemidiaphragm, including atelectatic lung completely surrounded by effusion (Fig 3); this was measured in the midclavicular line and in the largest AP dimension.

Validation of the Classification Rule

Nine physicians (three radiology residents in their third postgraduate year, three board-certified experienced pulmonologists,

FIGURE 1. Line drawing of the assessment of the anteroposterior (AP) quartile.

and three board-certified cardiothoracic radiologists) who were not involved in case selection, effusion measurement, or the initial analyses each subjectively graded the pleural effusions in random order as small, moderate, or large. After a delay of at least 1 week, each physician underwent a teaching session to learn the proposed classification rule and then individually graded the pleural effusions in a different random order.

Statistical Analysis

Bivariate regressions were performed for each of the qualitative and quantitative variables using effusion percent as the dependent variable. Multivariate regression included each variable that demonstrated a statistically significant correlation in order to select features that best predicted effusion percent. This was used to make a practical model of CT imaging features to discriminate among small, moderate, and large effusions. A P value $< .05$ was considered significant.

Fleiss κ analysis was used to compare inter-reader agreement before and after implementation of the rule. Agreement of all

FIGURE 3. CT images of the thorax. A, The measurement of AP depth does not include atelectatic lung that is anterior to the effusion. Note that the measurement is not perpendicular to the plane of the figure because the patient is slightly rotated. B, The measurement does include atelectatic lung that is completely surrounded by pleural fluid. See Figure 1 legend for expansion of abbreviation.

nine physicians and for each subgroup of readers was studied. Agreement was assessed on the following scale: < 0.00 : poor; $0.00-0.20$: slight; $0.20-0.40$: fair; $0.40-0.60$: moderate; $0.60-0.80$: substantial; and $0.80-1.00$: near perfect.²²

RESULTS

Bivariate Regressions

Greatest AP quartile and large subpulmonic component showed very strong relationships to the effusion percent ($P < .0001$) and had little overlap among classes. Craniocaudal height ($P = .0007$), fluid in the major fissure, degree of atelectasis, and mediastinal shift ($P < .0001$ for each) were significantly related to effusion percent; however, there was overlap among classes. The relationship between mean effusion size and each qualitative variable is found in Table 1. Table 2 summarizes the relationship between effusion percent and each imaging characteristic. All of the quantitative variables showed a significant relationship with percent-effusion size ($P < .0001$).

Multivariate Analysis

On multivariate regression, the CT imaging features that remained in the model and were predictive of effusion percent were AP quartile ($P = .0476$), qualitative assessment of passive atelectasis ($P = .0052$), and maximum AP depth measured in the midclavicular line ($P = .0423$). This model had an R^2 value of 0.8695.

Classification Rule

Two variables, AP quartile and maximum AP depth, were used to group effusions on the three-point scale explained in the "Materials and Methods" section. (Table 3). This rule was developed based on the variables' performance in consistently sorting the effusions into separate groups. An easy, two-step classification rule was developed based on AP quartile and depth measurements. First, AP quartile is estimated. For borderline cases near the quartile bounds (ie, close to 25% or 50%), maximum AP depth is measured as a

FIGURE 2. CT images of the thorax. A, A left effusion measuring 17% of the hemithorax and reaching the first AP quartile (0%-25%). B, A left effusion measuring 38% of the hemithorax and reaching the second AP quartile (25%-50%). C, A right effusion measuring 40% of the hemithorax and reaching the third AP quartile (50%-75%). D, A right effusion measuring 82% of the hemithorax and reaching the fourth AP quartile (75%-100%). See Figure 1 legend for expansion of abbreviation.

Table 1—Qualitative Characteristics and Effusion Percent

Qualitative Characteristic	Mean Effusion		
	PE, No.	Percent	SD, %
First AP quartile	11	14.14	7.47
Second AP quartile	10	31.34	12.10
Third AP quartile	4	46.47	7.19
Fourth AP quartile	9	68.60	15.69
Large subpulmonic component	11	65.28	16.13
No large subpulmonic component	23	24.09	13.80
Involving major fissure	14	56.23	19.78
Not involving major fissure	20	24.25	17.63
Below inferior pulmonary vein	1	10.74	N/A
Above inferior pulmonary vein	1	8.46	N/A
Above right pulmonary artery	0	N/A	N/A
Above carina	1	5.85	N/A
Above aortic arch	10	17.34	8.06
Reaches lung apex	21	51.13	20.37
Mediastinal shift	12	62.81	17.51
No mediastinal shift	22	23.57	13.94
No atelectasis	3	9.85	5.94
Subsegmental atelectasis	11	20.20	14.10
Segmental atelectasis	3	32.01	1.16
Multisegmental atelectasis	6	42.03	17.42
Lobar atelectasis	6	49.41	13.13
Multilobar atelectasis	5	75.16	17.51

AP = anteroposterior; N/A = not applicable; PE = pleural effusion.

second step. Pleural effusion characteristics when classified by the rule are summarized in Table 4. Qualitative assessment of passive atelectasis did not accurately distinguish between moderate and large effusions; therefore, it was not used in formulation of the classification rule.

Interobserver Agreement

Prior to education with the classification rule, the interobserver agreement among the nine readers was “moderate” ($\kappa = 0.56$). The radiology residents and pulmonologists both showed “moderate” agreement ($\kappa = 0.59$ and 0.54 , respectively), while cardiothoracic radiologists showed “substantial” agreement ($\kappa = 0.74$).

Table 2—Bivariate Regression of Effusion Percent and Imaging Characteristics

Characteristics	R ²	P Value
Qualitative		
Large subpulmonic component	0.6509	< .0001
Craniocaudal length	0.3254	.0007
AP quartile	0.7912	< .0001
Involving major fissure	0.4434	< .0001
Mediastinal shift	0.6228	< .0001
Degree of atelectasis	0.6798	< .0001
Quantitative		
Atelectatic segments	0.7111	< .0001
Craniocaudal length	0.4120	< .0001
AP depth (midclavicular line)	0.8018	< .0001
AP depth (maximum)	0.7968	< .0001

See Table 1 legend for expansion of abbreviation.

Table 3—Criteria for Three-Point Prediction Rule

Effusion Size	Criterion	
	AP Quartile	AP Depth
Small	0%-25%	< 3.0 cm
Moderate	25%-50%	3.0-10.0 cm
Large	50%-75% or 75%-100%	> 10.0 cm

See Table 1 legend for expansion of abbreviation.

Agreement among the nine readers improved to “substantial” ($\kappa = 0.79$) after education with the classification rule ($P < .0001$). Agreement improved within each of the three subgroups, with radiology residents and pulmonologists showing “substantial” agreement ($\kappa = 0.73$ and 0.76 , respectively). Agreement among cardiothoracic radiologists also improved to “near perfect” ($\kappa = 0.85$).

DISCUSSION

Chest radiography and ultrasonography remain the primary tools for imaging pleural effusions and guiding thoracentesis.^{1-6,23} Several systems for grading pleural effusions on radiographs have been validated and used in clinical algorithms.⁸⁻¹⁰ CT imaging plays a secondary, but important, role in assessment of some patients with pleural effusions.¹² In addition, pleural effusions are frequently demonstrated on CT scans performed for a variety of indications. We developed and validated a simple rule for quantitating pleural effusion size on CT scans with a three-point scale (small, moderate, and large) based the AP quartile and maximum AP depth. The rule improved interobserver agreement among all readers. In fact, the level of agreement between radiology residents and pulmonologists who were trained with the newly developed rule improved to the level of cardiothoracic radiologists who had not used the rule. This observation suggests that the classification rule can improve the interpretive consistency of physicians with more limited training in cross-sectional diagnostic imaging to the level of subspecialty fellowship-trained cardiothoracic radiologists. To our knowledge, this is the first such system that has been designed for CT imaging data and validated by a variety of physicians.

Assessment of the significance of a pleural effusion is facilitated by expressing its volume as a percent of

Table 4—Means and SDs of Effusion Sizes According to the Classification Rule by Consensus of All Nine Physician Readers

Effusion Size	Mean Effusion Percent (SD)	Mean Effusion Volume, mL (SD)
Small	12.61 (5.16)	195 (95)
Moderate	34.10 (10.52)	662 (330)
Large	63.20 (16.98)	1,832 (1085)

the hemithorax, thus correcting for body size and habitus. Small effusions in this study, measuring $\leq 20\%$ of the hemithorax, corresponded to ≤ 328 mL (data not presented). This may be helpful in planning thoracentesis when needed clinically. Small effusions often merit ultrasonography or CT scanning for guidance. Moderate effusions, measuring 20% to 40% of the hemithorax, corresponded to a mean of 690 mL (data not presented). These effusions are generally large enough that thoracentesis can be confidently performed.¹⁷ It is expected that imaging guidance may still be useful for sampling some effusions of this size. Large effusions, measuring $> 40\%$ of the hemithorax, corresponded to a mean of 1,806 mL (data not presented). Imaging guidance will likely add less value to sampling large effusions.

Several alternative methods for grading effusion size on CT scans could be considered. A different set of cutoffs could be used, for example, by simply dividing the hemithorax into thirds.¹³ We chose to use approximate cutoffs of 20% to separate between small and moderate sizes and 40% to separate between moderate and large sizes based on volume cutoffs that may be helpful for planning thoracentesis. Other alternatives might involve greater or fewer than three gradations. A three-point scale was chosen for ease of implementation of a two-step decision rule using the AP quartile and maximum AP depth.

Of note, all of the quantitative and qualitative features culled from the literature and clinical practice that were believed to relate to effusion size were significantly correlated with effusion percent on bivariate analysis. This validates the standard clinical practice. Of the studied variables, only estimated AP quartile, the qualitative degree of passive atelectasis, and the measured maximum AP depth remained significant at multivariate analysis. The AP quartile and the measurement of the AP depth are closely related CT imaging features; however, both were independent, statistically significant predictors of size in the multivariate regression analysis. Since the two features are measured on the same axial slice, it is easy to use these criteria together, as indicated in cases with borderline AP quartile.

This study had several limitations. First, our sample size was relatively small ($n = 34$). This limitation is mitigated by the fact that we found strong, statistically significant relationships between each of the imaging features and pleural effusion size. Even so, our observations may be less applicable to patients with unusual body sizes or shapes. Second, cases of pleural effusion used for developing and testing the rule were not selected randomly; they were prescreened and selected to span a continuum of effusion sizes. Since small effusions are much more common than moderate and large effusions, many more cases would have had to be included accord-

ing to a random selection process in order to construct a rule for all sizes. This selection bias does not compromise external validity because the goal of the classification rule is to categorize effusions of any size, not just those most commonly found in the population. A third limitation was that we chose demarcations for small ($< 20\%$), moderate (20%-40%), and large ($> 40\%$) sizes only after initiation of the study and review of the ability of the studied variables to separate effusions into groups. This limitation arose because there is no clear consensus among clinicians and there are no published CT imaging criteria for pleural effusion sizes. Therefore, we developed our criteria empirically as part of the study. Fourth, we included patients with bilateral pleural effusions, which likely affected several of the features investigated, such as the presence of mediastinal shift. We believe inclusion of bilateral effusions was essential to preserve the generalizability of the classification rule. We excluded loculated effusions and cases with central bronchial compromise because these findings interfere with several of the CT imaging features analyzed. Application of the described rule to cases with loculation or bronchial obstruction should be done with caution. Finally, we did not validate CT-scan effusion measurements with drained fluid volumes or with plain radiograph-based grading systems. Measurements based on segmentation and Simpson's rule are well validated in many areas of biometrics, including pleural effusions.¹⁹⁻²¹

CONCLUSIONS

In summary, we developed and validated a simple, two-step rule for quantifying pleural effusions on CT scans using a three-point scale. Effusion size is assigned by estimation of the AP quartile. First AP-quartile effusions are small, second AP-quartile effusions are moderate, and third or fourth AP-quartile effusions are large. In borderline cases, AP depth is measured with 3-cm and 10-cm thresholds for the upper limits of small and moderate, respectively. This system significantly improves interobserver variation, is useful in improving consistency and accuracy of reporting, and may have a role in determining the need for image guidance in patients requiring thoracentesis.

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Author contributions: Drs Moy, Levsky, and Haramati had full access to all of the data in the study and take responsibility for the integrity of the work as a whole.

Dr Moy: contributed to data collection and analysis; writing, revision, and approval of the manuscript; and served as principal author.

Dr Levsky: contributed to data collection and analysis, and writing, revision, and approval of the manuscript.

Dr Berko: contributed to data collection and writing, revision, and approval of the manuscript.

Dr Godelman: contributed to data collection and critical review, revision, and approval of the manuscript.

Dr Jain: contributed to data collection and critical review, revision, and approval of the manuscript.

Dr Haramati: contributed to data collection and analysis, and writing, revision and approval of the manuscript.

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