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ORIGINAL ARTICLE

Quantification of pleural effusion from single area measurements on CT

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Abstract The objective of this study was to determine if area measurements of pleural fluid on computed tomography (CT) reflect the actual pleural fluid volume (PEvol) as measured at autopsy, to establish a formula to estimate the volume of pleural effusion (PEest), and to test the accuracy and observer reliability of PEest.132 human cadavers, with pleural effusion were divided into phase 1 (n=32) and phase 2 (n=100). In phase 1, PEvol was compared to area measurements on axial (axA), sagittal (sagA), and coronal (corA) CT images. Linear regression analysis was used to create a formula to calculate PEest. In phase 2, intra-class correlation (ICC) was used to assess inter-reader reliability and determine the agreement between PEest and PEvol. PEvol correlated to a higher degree to axA (r_s mean=0.738; p<0.001) than to sagA (r_s mean=0.679, p<0.001) and corA (r_s mean=0.709; p<0.001). PEest can be established with the following formula: axA×0.1=PEest. Mean difference between PEest and PEvol was less than 40 mL (ICC=0.837–0.874; p<0.001). Inter-reader reliability was higher between two experienced readers (ICC=0.984–0.987; p<0.001) than between an inexperienced reader and both experienced readers (ICC=0.660–0.698; p<0.001). Pleural effusions may be quantified in a rapid, reliable, and reasonably accurate fashion using single area measurements on CT.

Keywords Emergency radiology · Chest CT · Pleural effusion · Volumetry · Postmortem CT

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Introduction

Pleural effusions are a frequent finding on computed tomography (CT) of the chest in patients with a variety of underlying medical emergencies, ranging from pulmonary infection to cardiovascular emergencies and chest trauma [1–3]. Emergency radiologists are regularly asked to quantify the volume of such pleural fluid collections on CT. The size of an effusion can significantly impact patient management, especially in critically ill patients [4, 5]. Simple rules of thumb to estimate pleural fluid volume on thoracic sonography and chest radiographs have been proposed in the literature [6–9]. For CT, segmentation is regarded as gold standard

method to quantify fluid collections, both in the chest and the abdomen [6, 10]. However, in the personal experience of the authors, segmentation techniques are not regularly used in emergency radiology. Segmentation is a relatively time-consuming process, and the majority of picture archiving and communication system (PACS) workstations in clinical use do not offer segmentation capability. If available at all, the required software programs are usually installed on one or a few dedicated workstations in a radiology department. Therefore, segmentation is often regarded as an untenable interruption of an emergency radiologist's workflow and concentration. In order to gain acceptance, methods to quantify pleural effusions on CT should be simple enough to be remembered, easy to perform, applicable on standard PACS workstations, and sufficiently accurate to support clinicians in their decisions regarding emergency patient management.

The aim of this study was to (1) determine if area measurements of pleural effusions on CT reflect actual pleural fluid volume (PEvol) as measured at autopsy, (2) establish a formula to estimate pleural fluid volume (PEest) from CT measurements, and (3) test the accuracy and observer reliability in estimating pleural fluid volume using the new formula.

Subjects and methods

Subjects

The responsible local justice department and the ethics committee of the university both approved this study. The CT images of all cases referred to our institution for whole-body postmortem CT and forensic autopsy between 10 August 2010 and 29 July 2011 were retrospectively reviewed on our PACS. Unilateral or bilateral pleural effusion was identified in 165 of all 474 postmortem CTs. Thirty-three of these 165 cases were excluded from the final study population. Exclusion criteria were as follows: age< 18 year (n=4), signs of decomposition [11] (n=18), unilateral or bilateral pneumothorax (n=8), and presence of thoracostomy tube(s) (n=3). The final study population consisted of 132 adult human cadavers (80 male, 52 female); mean age at death was 59 years (range 19–95 years, median 62). The final study population was divided into two groups. The first group (n=32) was used in phase 1 of the study to establish the correlation of different area measurements on CT with PEvol and generate a formula to calculate pleural fluid volume based on area measurements. The second group (n=100) was used in phase 2 to test the accuracy and inter-observer reliability of the newly generated formula. To avoid selection bias during the division of the study population, every fourth case of the final study population was labeled as group 1 for use in phase 1 on a chronologically organized, anonymized list; all other cases were labeled as group 2 for use in phase 2.

Imaging protocol

Imaging was performed on a dual-source CT scanner (Flash Definition, Siemens, Forchheim, Germany). Tube voltage was 120 kVp. All scans were performed using the automatic dose modulation software (CARE Dose 4D, Siemens, Forchheim, Germany). Collimation was 256 mm×0.6 mm. All image reconstructions were performed with a slice thickness of 1.0 mm in increments of 0.5 mm using the soft tissue kernel.

Measurement of pleural effusion at autopsy

In all cases, the volume of pleural effusion was measured during autopsy in milliliters, using a medical scoop and a measuring container.

Measurements of pleural effusion on CT

All CT datasets were reviewed using multiplanar reconstructions (MPR) on a PACS workstation (IDS7, Sectra, Linköping, Sweden). The region of interest (ROI) area tool was used to manually measure the maximal sagittal (sagA) and coronal circumferential areas (corA) of pleural effusions (in mm^2) on sagittal and coronal reconstructions as well as the axial circumferential area (axA) of pleural effusions (in mm^2) on the supradiaphragmatic slice (i.e., on the axial slice cranial to the dome of the diaphragm; Fig. 1). All measurements were performed separately for the right and left sides of the chest (Fig. 2).

Inter-reader reliability of CT measurements

CT measurements in phase 2 of the study were performed by three readers with varying degrees of experience (reader 1: radiologist with 6 years of experience; reader 2: radiographer with 16 years of experience; reader 3: medical intern with little experience in radiology) to assess inter-reader reliability.

Statistical analysis

All statistical calculations were performed using a statistical software (SPSS 17.0, IBM, Chicago, IL, USA). Normality of the distribution was assessed using the Shapiro–Wilk test in both phases of the study. We used Spearman's rho correlation coefficients (r_s) and linear regression analysis to assess the correlation between PEvol and axA, sagA, and corA, respectively, in phase 1. In phase 2, Spearman's rho correlation coefficient was used to determine the significance of the

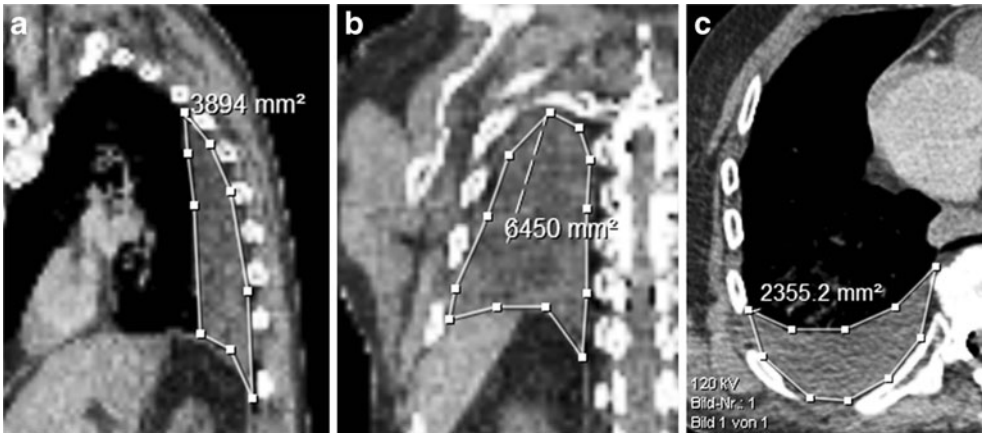

Fig. 1 Middle-aged male with right-sided pleural effusion. The region of interest (ROI) area tool was used to manually measure the maximal sagittal and coronal circumferential areas (corA) of pleural effusions on sagittal (**a**) and coronal (**b**) reconstructions as well as the axial circumferential area of pleural effusions on the last axial slice cranial to the dome of the diaphragm (**c**)

difference between PEvol and PEest. Intra-class correlation (ICC) test was also used in phase 2 to assess intra-reader reliability and the agreement between PEvol and PEest. An ICC of 1.0 indicates absolute agreement. A p value<0.05 indicates statistical significance.

Results

Phase 1 (group 1)

Table 1 contains the mean, range, standard deviation, and median values of PEvol, PEest, axA, sagA, and corA measurements of group 1. PEvol was not normally distributed. Correlation between PEvol and axA (left side r_s=0.739, p<0.001; right side r_s=0.737, p<0.001), sagA (left side r_s=0.650, p<0.001; right side r_s=0.708, p<0.001), and corA (left side r_s=0.646, p<0.001; right side r_s=0.771, p<0.001) was good. Mean correlation coefficients were higher for axA (r_s mean=0.738; p<0.001) than for sagA (r_s mean=0.679, p<0.001) and corA (r_s mean=0.709; p<0.001).

Using simple linear regression analysis, a formula was drawn from the relationship between PEvol and axA in group 1 to calculate the volume of pleural effusion (PEcal) on CT for the left and right sides of the chest individually:

$$\text{PEcal left side (mL)} = \left(\text{axA mm}^2 \times 0.108\right) + 20.972\text{mL}; R^2 = 0.74,$$

$$\text{PEcal right side (mL)} = \left(\text{axA mm}^2 \times 0.107\right) + 2.33\text{mL}; R^2 = 0.79.$$

From these two formulas, a simplified equation was developed to allow for an estimation of the volume of pleural effusion on CT with one single formula for the left and the right side of the chest:

$$\text{PEest (mL)} = \text{axA } \left(\text{mm}^2\right) \times 0.1.$$

Phase 2 (group 2)

Table 2 contains the mean, range, standard deviation, and median values of PEvol, PEest, and axA measurements from group 2. PEvol was not normally distributed. Intra-reader reliability was higher between readers 1 and 2 (left side ICC=0.984; p<0.001; right side ICC=0.987, p<0.001) than between reader 3 and both reader 1 (left side ICC=0.698; p<0.001; right side ICC=0.676; p<0.001) and reader 2 (left side ICC=0.666; p<0.001; right side ICC=0.660; p<0.001). Correlation between PEvol and mean axA was excellent (left side r_s=0.859, p<0.001; right side r_s=0.890, p<0.001).

The ICC revealed a high agreement between PEest and PEvol (ICC=0.874, p<0.001 on the left side and ICC=0.837, p<0.001 on the right side). The mean difference between PEest and PEvol was only 37 mL on the left (95 % confidence interval (CI) 13–60 mL; p=0.002) and 18 mL on the right (95 % CI −4–40 mL; p=0.107).

Discussion

This study demonstrates that area measurements of pleural fluid on CT reflect the actual pleural fluid volume, as

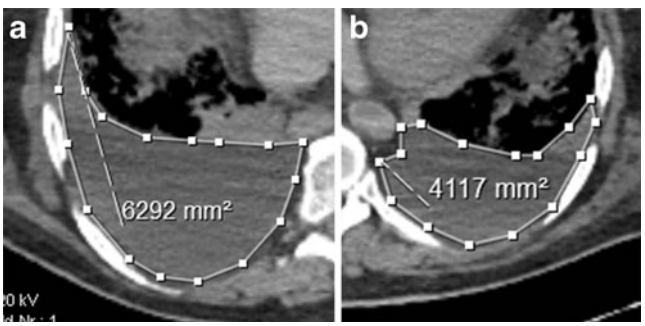

Fig. 2 Middle-aged man with bilateral pleural effusion. Measurement on the right (**a**) and left (**b**) sides of the chest was performed separately and on different levels of the chest, depending on the height of the dome of the diaphragm

Table 1 Phase 1 (group 1): mean, range, standard deviation, and median values

Category	Size	Unit	Mean	Range		SD	Median
	n			Min	Max		
PEvol left side	32	mL	340	90	1,400	310	215
PEvol right side	32	mL	306	100	1,500	300	210
axA left side	32	mm^2	2,568	12	8,631	2,030	2,421
sagA left side	32	mm^2	4,659	770	12,945	3,277	4,441
corA left side	32	mm^2	7,692	2,312	19,527	4,200	7,004
axA right side	32	mm^2	2,477	176	9,051	1,930	2,062
sagA right side	32	mm^2	4,208	268	14,819	3,249	3,197
corA right side	32	mm^2	7,912	1,417	17,845	4,025	7,496

PEvol pleural effusion volume at autopsy, *axA* circumferential area of pleural effusion on axial CT images, *sagA* circumferential area of pleural effusion on sagittal CT images, *corA* circumferential area of pleural effusion on coronal CT images

measured at autopsy, and that the volume of pleural effusion on CT may be calculated in a reliable and reasonably accurate fashion with a simple formula. Phase 1 of the study revealed that axA correlates to a higher degree to PEvol than to sagA and corA. Based on this observation, measurements in phase 2 were limited to axA. In addition, measurements on the axial images are also most compatible with clinical routine; performing MPR is slightly more time-consuming than measuring on original axial images and therefore represents an interruption of the workflow and concentration of the emergency radiologist.

In phase 2, we found excellent intra-reader reliability between the two experienced readers. The ICC between the inexperienced reader and both experienced readers was lower but still good. This difference between experienced and inexperienced readers suggests that inexperienced readers have more difficulties identifying the border between pleural effusion and areas of abnormal lung tissue of similar density (atelectatic or consolidated lung) commonly seen in the lung bases. This problem could be minimized through the use of appropriate grayscale windows. Shifting the window towards the soft tissue rather than the lung tissue may improve the differentiation between fluid collections and the atelectatic lung tissue.

Our results concur with the findings of previous studies regarding the degree of correlation between pleural effusion and estimated pleural effusion on CT [4, 5]. This observation is important: our approach is comparable to the approach of ultrasonography and chest radiography where practicality is also often more important than accuracy [6–9].

Despite the fact that our approach is based on a simplified equation, we found a very high correlation between the actual volume and the estimated volume of pleural effusion. In phase 2, the mean difference between PEest and PEvol was less than 40 mL (p=0.002) on the left and 20 mL (p=0.107) on the right side of the chest. It is conceivable that the different anatomy of the left and right lungs caused this slight difference in the agreement between the left and right sides of the chest. Although the difference between PEest and PEvol proved to be statistically significant on the left side, it is clinically insignificant; the therapeutic management of a patient is unlikely to change because of 40 mL of pleural effusion. It is important to note that pleural effusions can also be detected with high accuracy on low-dose chest

Table 2 Phase 2 (group 2): mean, range, standard deviation, and median values

Category	Size	Unit	Mean	Range		SD	Median
	n			Min	Max		
PEvol left side	100	mL	224	0	1,500	226	150
PEvol right side	100	mL	234	0	1,300	243	150
PEest left side	100	mL	187	2	773	179	131
PEest right side	100	mL	216	1	1,081	201	139
R1 axA left side	100	mm^2	1,662	0	8,044	1,633	1,151
R2 axA left side	100	mm^2	1,606	0	7,052	1,618	1,141
R3 axA left side	100	mm^2	2,343	0	12,297	2,554	1,445
R1 axA right side	100	mm^2	1,954	0	9,995	2,001	1,269
R2 axA right side	100	mm^2	1,894	0	10,212	1,993	1,250
R3 axA right side	100	mm^2	2,639	0	12,215	2,753	1,457

PEvol pleural effusion volume at autopsy, *PEest* estimated volume of pleural effusion, *axA* circumferential area of pleural effusion on axial CT images, *R* reader

CT [12]. This means that low-dose CT may represent a suitable method to follow up on patients after therapeutic drainage of pleural effusions.

Several limitations of this study deserve comment. First, our measurements were performed in human cadavers. Postmortem distribution of pleural effusions may not exactly reflect the distribution of pleural effusions in living patients. However, comparing CT measurements with autopsy findings permitted us to compare radiologic findings with the actual volume of the pleural effusion in every case. This is a clear advantage over clinical studies where the volume of pleural effusion has either to be quantified during thoracentesis [7, 8], which may not represent the total fluid volume—especially in large pleural effusions, or using segmentation techniques [5], which represents a calculated volume. Nevertheless, measurements could be affected by respiration. However, both the observation that the typical crescent-like shape of non-loculated pleural effusions is also present in postmortem CT and the agreement between previous clinical studies and our results suggest that this effect may not significantly affect volume estimation [4, 5]. Second, there were no cases with loculated pleural effusions in our population. In almost all cases referred to our institution for postmortem investigation, pleural fluid collections were the result of acute injury or disease such as chest trauma or cardiovascular emergencies [2, 3]. In these cases, pleural fluid collections are rarely loculated. Therefore, further studies are needed with a different population to test the validity of this method to estimate loculated pleural effusion.

In conclusion, single circumferential area measurements of pleural effusions on CT, as measured on the axial slice cranial to the dome of the diaphragm, correlate to PEvol. PEest agreed closely with PEvol, with a clinically insignificant mean difference between the estimated and the actual pleural fluid volumes. PEest can be calculated with a simple equation: axA (mm^2)×0.1=PEest (mL). This method allows for the quantification of pleural effusion volume on CT in a reliable, accurate, and straightforward fashion applicable in emergency radiology.

Conflict of interest The authors declare that they have no conflict of interest.

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