IOP Publishing Biomed. Phys. Eng. Express 8 (2022) 055028 https://doi.org/10.1088/2057-1976/ac8554

Biomedical Physics & Engineering Express

PAPER

Comparative estimation of pleural effusion volume based on lateral decubitus position of chest x-ray and CT scan imaging

RECEIVED
21 March 2022

REVISED
3 July 2022

ACCEPTED FOR PUBLICATION
28 July 2022

PUBLISHED
26 August 2022

Bambang Satoto[1], Wahyu S Budi[2,*], Ali Khumaeni[2,*], Yuyun Yueniwati[3,*] and Noorhamdani Noorhamdani[4,*]

[1] Radiology Consultant of Dr Kariadi General Hospital/Medical Faculty of, Diponegoro University Semarang, Indonesia
[2] Department of Physics Faculty of Sciences and Mathematics, Diponegoro University Semarang, Indonesia
[3] Medical Faculty of, Brawijaya University Malang, Indonesia
[4] Department of clinical Microbiology, Brawijaya University Malang, Indonesia
* Authors to whom any correspondence should be addressed.

E-mail: bambang99satoto@gmail.com, wahyu.sb@fisika.fsm.undip.ac.id, khumaeni@fisika.fsm.undip.ac.id, yuyun@ub.ac.id dr.noorhamdani@gmail.com

Keywords: estimation modeling, pleural effusion volume (PEV), chest x-ray, CT scan

Abstract

Previous study using thoracic phantom for estimating fluid volume has been obtained which represents the case of pleural effusion based on the size of the x-ray radiograph. The models are obtained in the form of three equations, the pleural effusion volume as a function of height, length times the height, and area of the radiograph image. The three models of estimation have high linearity with ratio value more than 0.988, higher than the modelling measurement using ultrasonography modality. The modelling is expected to give a contribution on developing method for helping clinicians estimate the pleural effusion volume as a basic for performing fluid aspiration and to monitor the therapy. However, because modelling is developed using phantoms, then to be applied clinically, further research is needed for its application to patients. The height function model yields correlation value of 0.966 and paired T-test value of 0.892. The height times length function model yields correlation value of 0.982 and paired T-test value of 0.611. The area function model yields correlation value of 0.997 and paired T-test value of 0.647. From the three equations, measurement of estimated pleural effusion volume using area function on chest x-ray lateral decubitus position is the most appropriate equation. Corresponding to the results of the measurement of gold standard using a CT scan. Height measurement is the measurement that is the fastest and easiest in the application. Limitation of the study is it only can be done in right lateral decubitus position of the patient, and also cannot be applied to patients with condition such as post lung surgery, massive subpulmonic/supradiaphragmatic pleural effusion, empyema, an atypical pleural effusion such as septated, encapsulated, loculated pleural effusion and anatomical deformity, scoliosis, or abnormalities of thoracic cavity.

Introduction

Modelling the estimated of pleural effusion volume using imaging modalities such as ultrasonography (USG) or computerized tomography (CT) scan is generally a mathematical model of a relationship between volume and dimensions of the image [1, 2]. In a previous study using a unique thoracic phantom [3], a model for estimating fluid volume in phantom has been obtained which represents the case of pleural effusion based on the size of the x-ray radiograph. A phantom was made with acrylic by measuring mid clavicular line, mid axillary line, medial line of the body, and depth of thoracic cavity for the model. The phantom was filled with water with volumes ranging from 20 ml to 800 ml, at each increase of 20 ml. The model obtained in the form of three equations that connect in a row, the pleural effusion volume as a height function of radiograph image, volume as a function of length times the height of the image and volume as an area function of the image. Those three models of estimation have high linearity with ratio value more than 0.988 [4], higher than the modelling measurement using ultrasonography modality [5]. Another advantage of the model developed is the easy and fast of estimating the pleural effusion volume, as well as the image of the radiograph needed that can be obtained at health facilities with x-ray equipment for chest radiographs.

The modelling is expected to give a contribution on developing method for helping clinicians estimate the pleural effusion volume as a basic for performing fluid aspiration and to monitor the success of therapy. However, because modelling is developed using phantoms, it cannot perfectly represent the real thoracic cavity that may have many variation compared to the phantom. Then to be applied clinically, further research is needed for its application to patients.

In this study, an estimation of the pleural effusion volume (PEV) was based on the size of thoracic imaging of patients with lateral decubitus position [5, 6], using three estimation models, namely ; PEV = 126.9 × h, PEV = 6.584 × (h × l) and PEV = 6.574 × A, h: height of pleural effusion on image, l: length of pleural effusion on image and A: area of pleural effusion on image [4]. The estimation of pleural effusion volume for each patients was measured by three models, then compared or correlated with measurements using CT scans. As a comparison, measurements using CT scan were chosen because it was accurate and detailed in evaluating the thoracic wall, pulmonary parenchyma, and mediastinum, and was able to distinguish between fluid and tissue clearly and produced image in the form of two-dimensional images, three-dimensional images, and various organ composition images as well as gold standard measuring the pleural effusion volume [1, 2].

Methods

Chest x-ray with right lateral decubitus position and thoracic CT scan were done for a number of patients. Right lateral decubitus position is chosen to avoid interference from the heart that occurs when tilted to the left. The height, length and area of pleural effusion were measured from photostimulabel plate computed radiography (CR) of chest x-ray imaging. Then, estimation of pleural effusion volume was developed based on three models [4]. On CT scans imaging, the estimation of pleural effusion volume was done using a standard program on CT modalities.

The Siemens somatom emotion CT scans 64 slices was used in this study, using 0.6–5 mm thickness slices. The protocol of CT scans was used in this study, using kV 120 and mAs 66, pitch 1.4. The picture criteria should be included chest image from the apex to the posterior costiphrenic region, thoracic wall image, as well as the adjascent muscles, the major mediastinal vessels, pleuromediastinal margin, endotracheal and endobronchial margins, the intrathoracic oesophagus, endotracheal and endobronchial margins. The procedure that has been performed are the patients lay on lateral decubitus position on the examination table (head first or feet first), create a topogram with slices from lung's apex to the costae phrenicus sinus, create slices each with 5 mm thickness, form 5 mm thickness slices then should be reconstructed into 1.5 mm thickness slices, from 1.5 mm thickness slices could be reconstructed into 3D picture so we can make axial, coronal, and sagittal cuts, at the time of scanning with the commad 'inhale, hold your breath' until the examination is complete, and when printing was made with the condition of lung and mediastinal window.

Contrast media was needed to differentiated pleural effusion and lung parenchyma or consolidation. Osiris software was used to analized the height, length, and area measurement.

This study used an Observational design with a Cross Sectional approach. The results of the measurement of pleural effusion volume estimation with the model in patients performed based on thoracic x ray images of decubitus position (figures 1–3) were correlated (compared) with the results of measurements of pleural effusion volume from CT scan. Furthermore, each estimation of PEV value from three models based on lateral decubitus position of chest x-ray were statistically tested using T- test against the results from CT scan.

Results

Of the 25 patients with pleural effusion, 5 patients did not fit the inclusion and exclusion criteria, only data from 20 patients with pleural effusion were used for analysis. Most of the study subjects were women (66.7%). The average age of the subjects was (49.9 ± 11.3) years, with the youngest was 20 years old and the oldest was 69 years old. The average age of male subjects was older than female subjects.

This research has been approved by ethical committee, as shown in ethical clearance from Health Research Ethics Committe, Faculty of Medicine, Diponegoro University No. 884/EC/KEPK/FK-UNDIP/IX/2016.

Results of PEV Estimation Based on Height on Lateral Decubitus Chest x-ray Images in figure 4, a graph shows the correlation between the estimated pleural effusion volumes in patients as a height function image of pleural effusion with 95% confident interval (CI), it appears that there is only one point outside the region with a value close to the border of the highest deviation value. Assessment of PEV calculation on CT scans compared with formula of PEV = 126.9 × height (height based on chest x-ray with lateral decubitus position) has a very significant correlation value, namely: 0.966, sig 0,000. There was a significant correlation between the volume of pleural effusion calculated in CT scans and the volume calculated with the PEV = 126.9 × h (height, based on chest x-ray with lateral decubitus position).

Results of PEV Estimation Based on Height Times the Length on the Lateral Decubitus Chest x-ray Images. Figure 5 shows the graph of the correlation

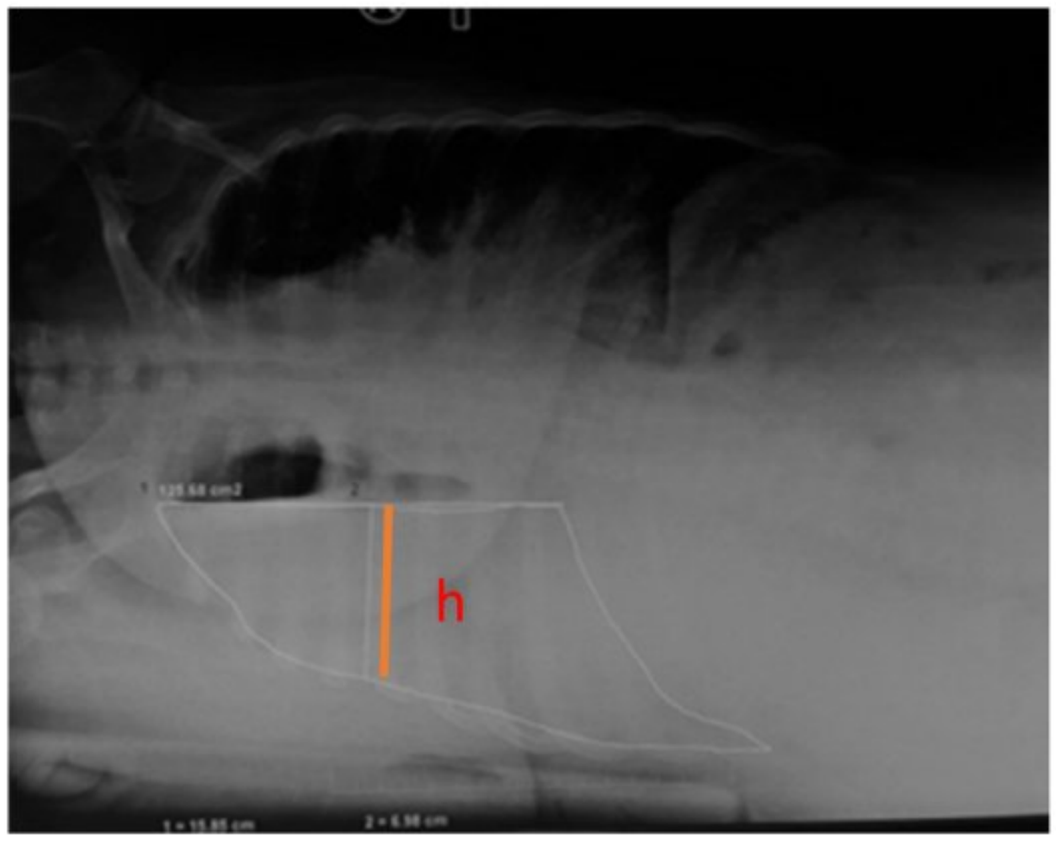

Figure 1. Height measurement of image of pleural effusion (h) of lateral decubitus position of chest x-ray.

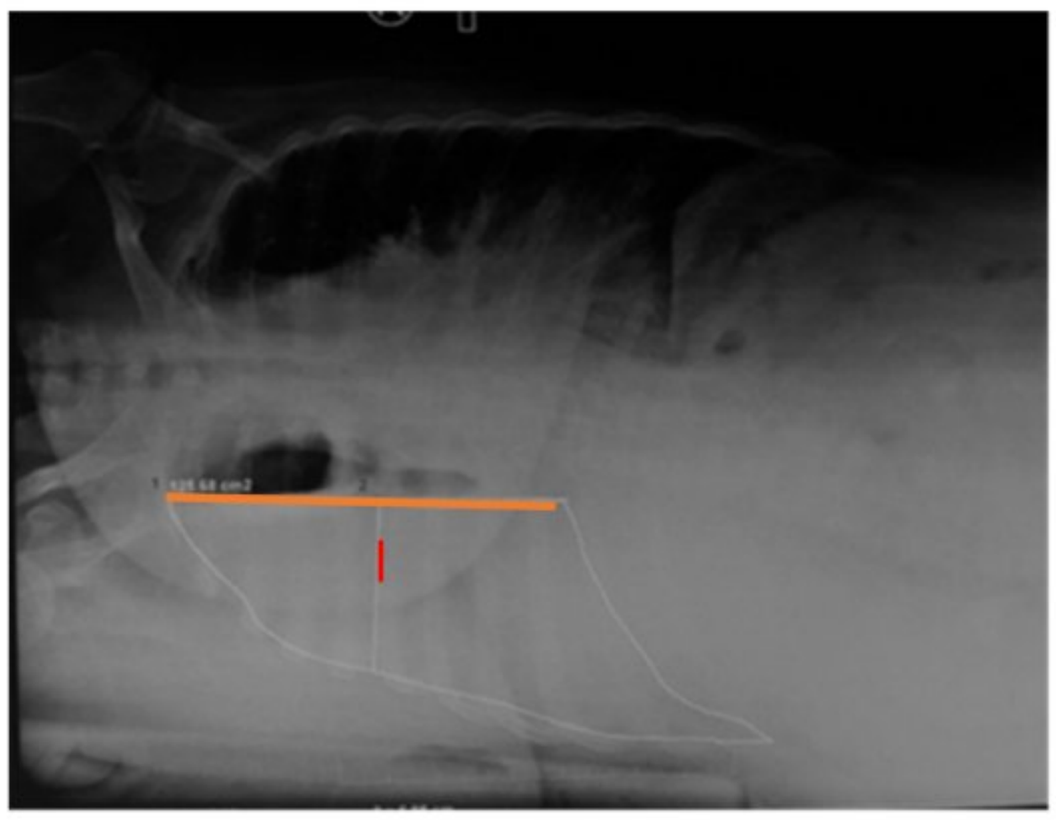

Figure 2. Length measurement of image of pleural effusion (l) of lateral decubitus position of chest x-ray.

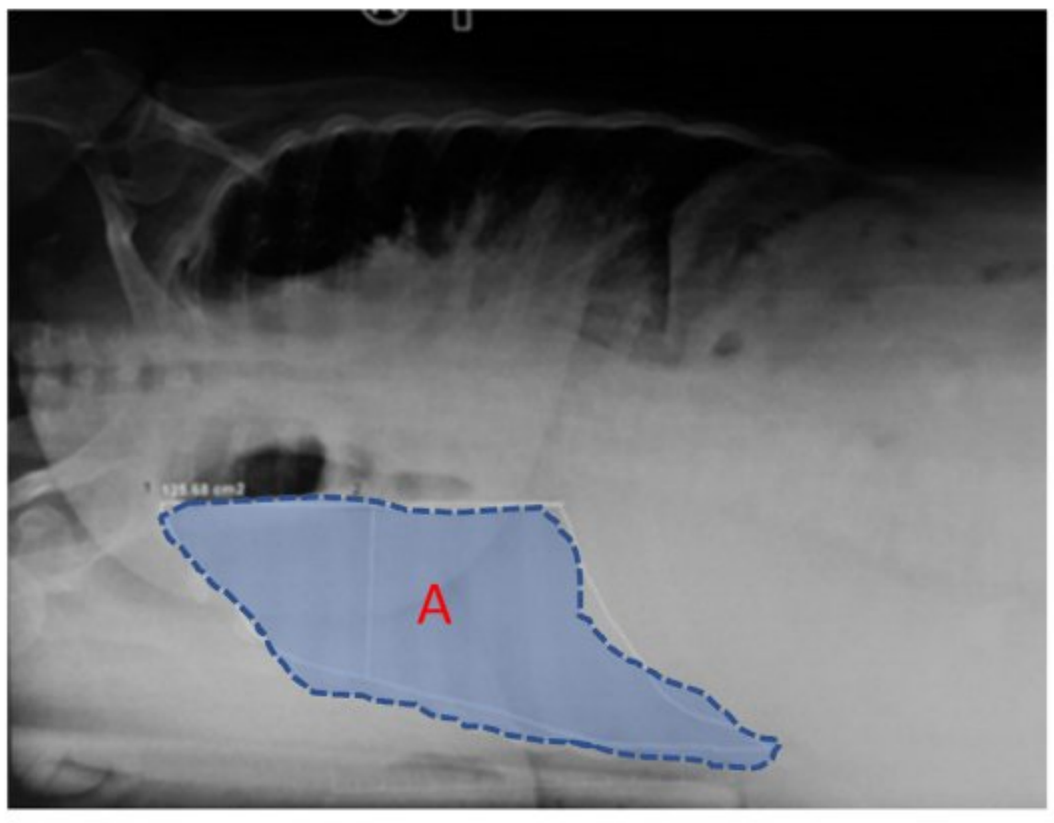

Figure 3. Area measurement of image of pleural effusion (A) of lateral decubitus position of chest x-ray.

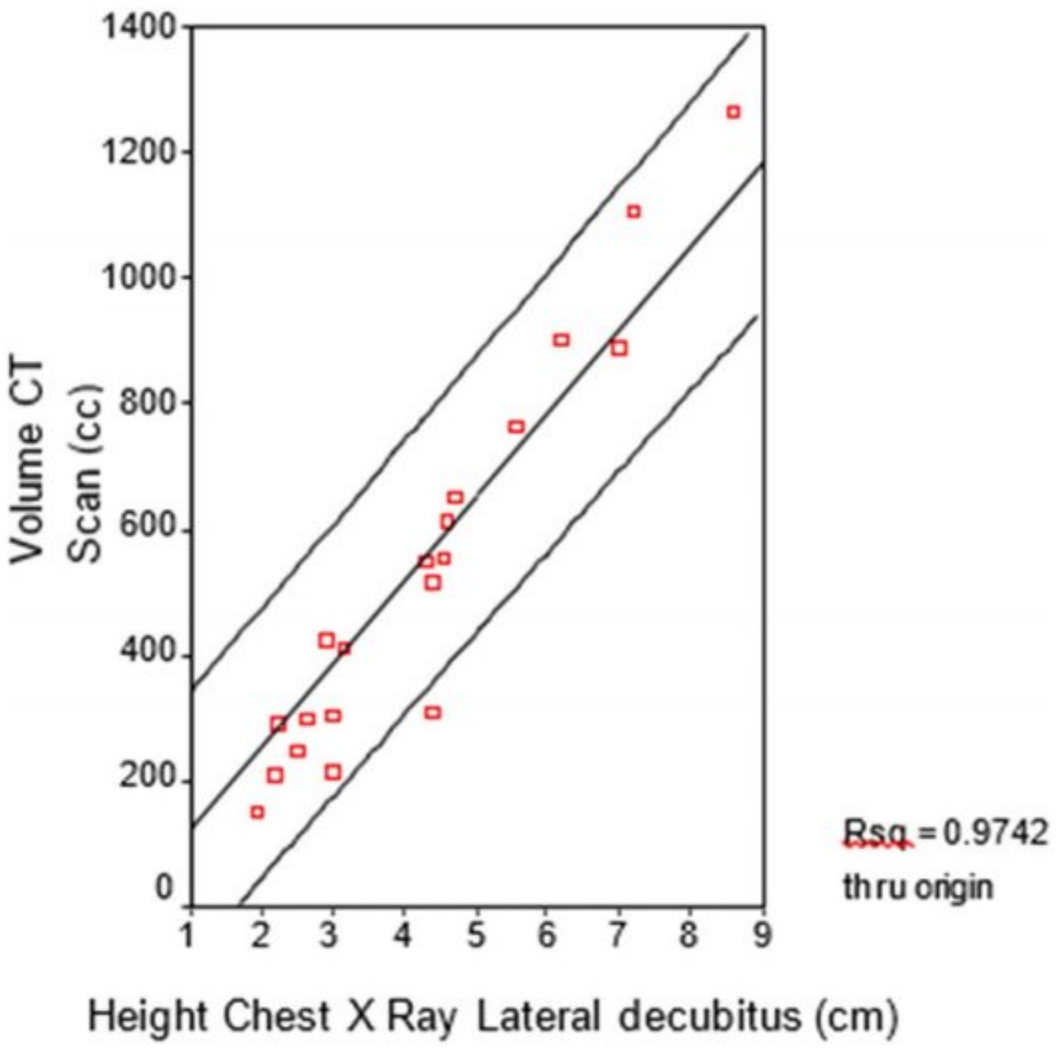

Figure 4. Graph of the correlation between the estimated results of PEV in patients as a function of pleural effusion image height with 95% CI.

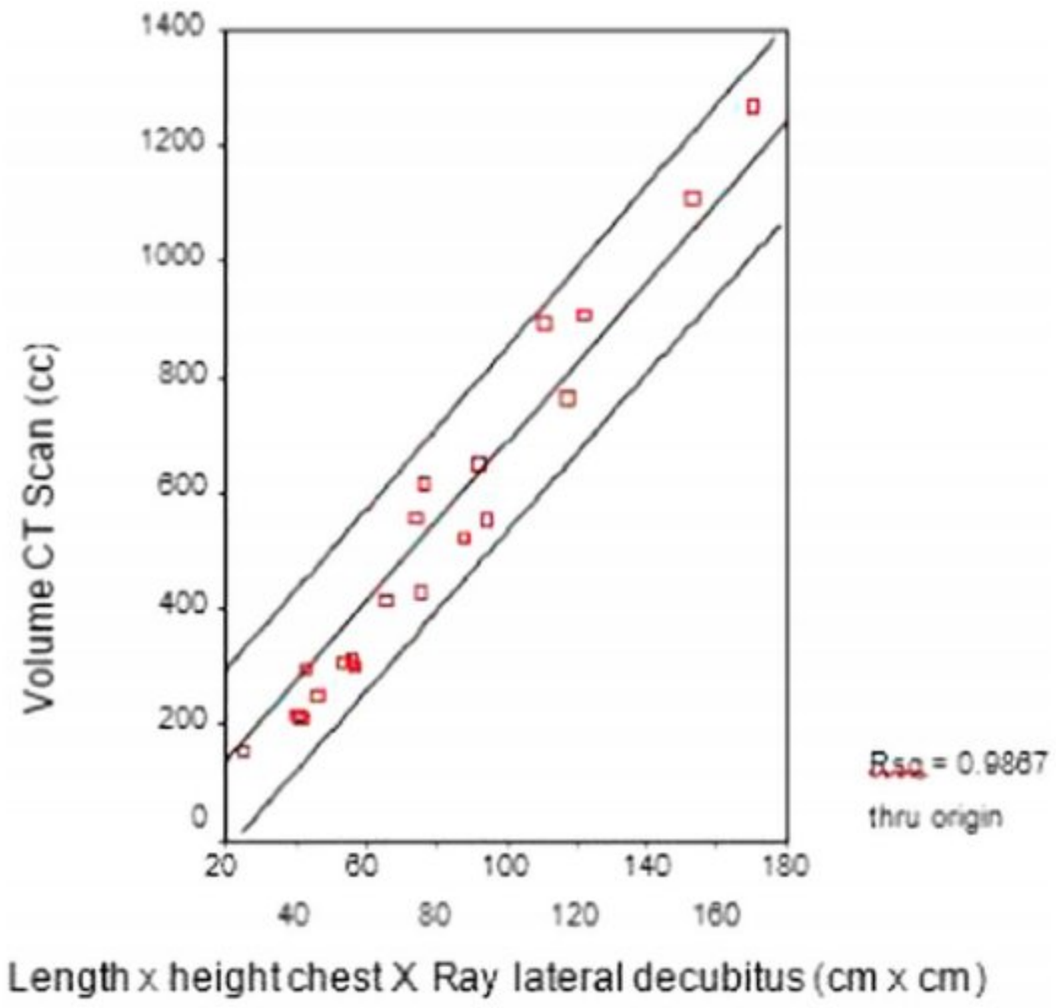

Figure 5. Graph of the correlation between the estimated results of PEV in patients as a function of height times the length of pleural effusion images with 95% CI.

between the estimated results of pleural effusion volume in patients as a function of height times the length of pleural effusion images with a 95% CI, it appears that all measured values are within the determined limits. Assessment of PEV calculation on CT scans compared with formula of PEV = 6.584 × (height × length) which based on chest x-ray with lateral decubitus position has a very significant correlation value, namely: 0.982, sig 0,000. There is a significant correlation between the volume calculated on CT scan with the volume calculated with the equation of 6.584 multiply (h × l) pleural effusion in patients with lateral decubitus chest x-ray examination.

Results of PEV Estimation Based on Area on the Lateral Decubitus Chest x-ray Images.

Figure 6 shows the graph of the correlation between the estimated results of pleural effusion

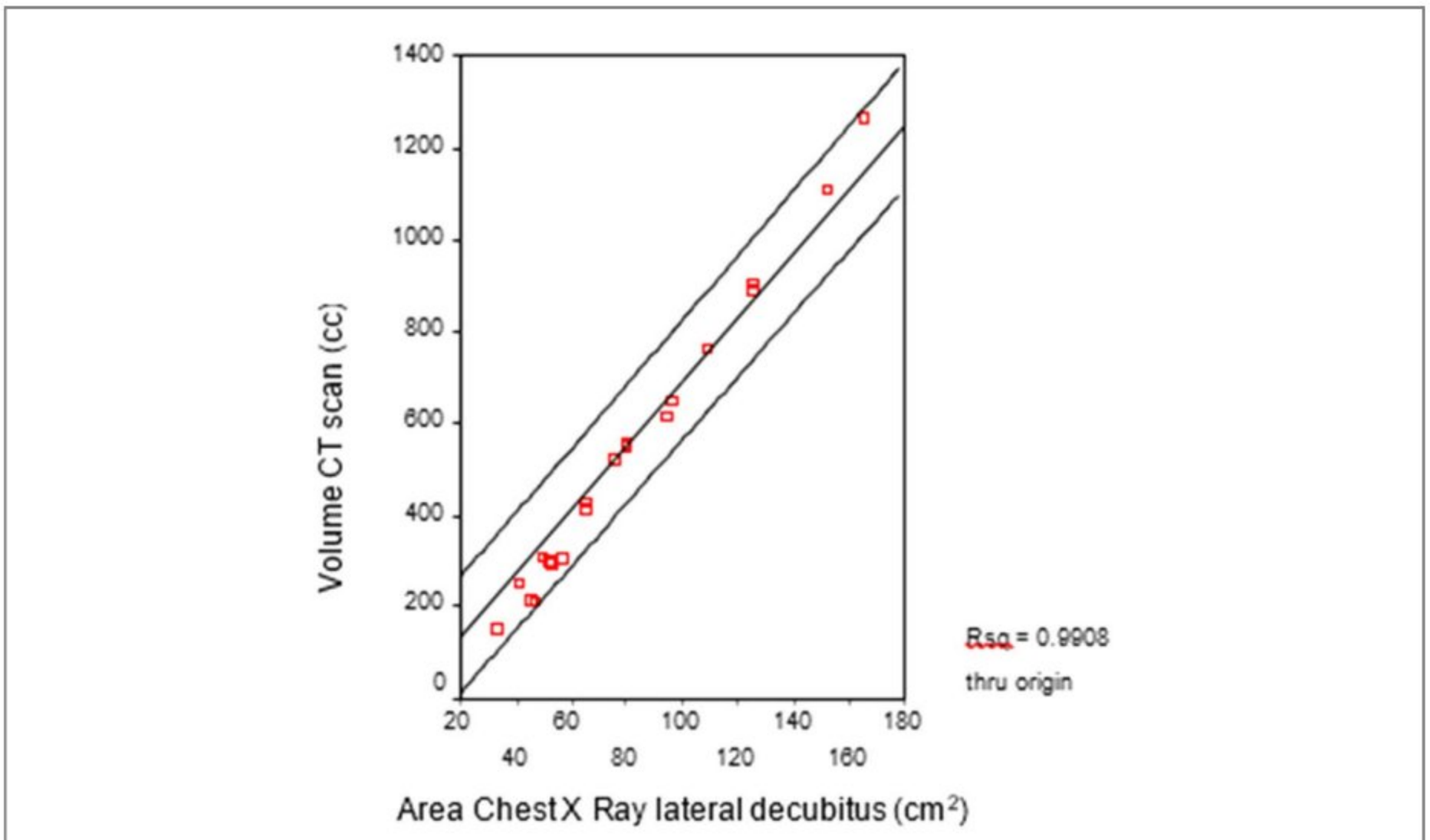

Figure 6. Graph of the correlation between the estimated results of PEV in patients as a function of area of pleural effusion images with 95% CI.

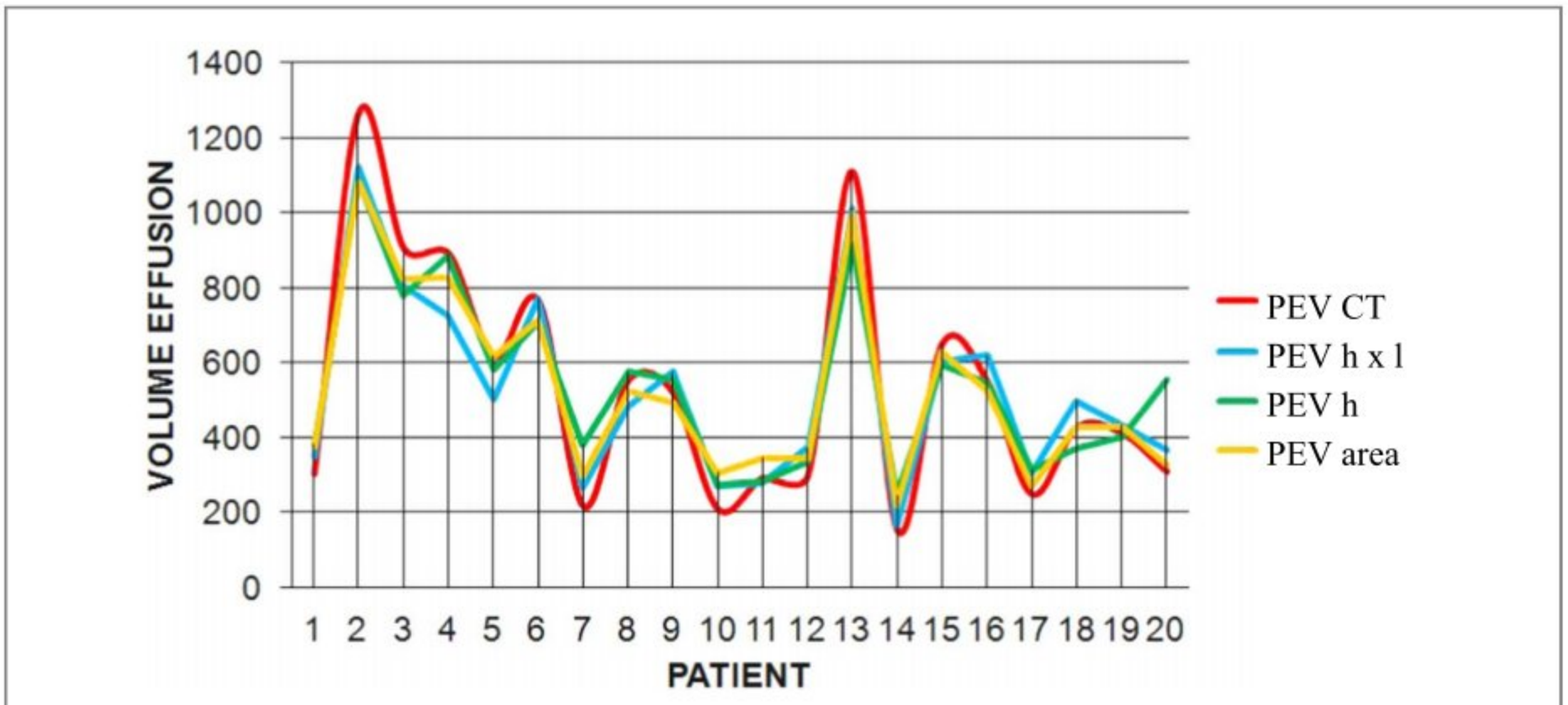

Figure 7. Graph of pleural effusion volume on CT Scans and chest x-ray of lateral decubitus position by measuring height, height times length, and area of image of the patient.

volume in patients as a function of the area of pleural effusion images with a 95% CI, it appears that all measured values are within the determined limits. Assessment of PEV calculation on CT scan compared with formula of PEV = 6.574 × area(A) (area, based on chest x-ray with lateral decubitus position) has a very significant correlation value, namely: 0.997, sig 0,000. There is a significant correlation between the volume calculated on CT scan with the volume calculated with the equation of 6.574 multiply the area of pleural effusion in patients with chest x-ray examination in the lateral decubitus position

Results of effusion volume using the 3 models and CT are compared and shown in figure 7.

PEV CT is the pleural effusion volume that measured in the phantom; PEV h × l is the pleural effusion volume on lateral decubitus thoracic x-examination using the equation of PEV = 6.584 × (h × l); PEV h is the pleural effusion volume on lateral decubitus thoracic x-examination using the equation of PEV = 126.9 × h; PEV area is the pleural effusion volume on lateral decubitus thoracic x-examination using the equation of PEV = 6.574 × A.

Paired T-test results for the volume value of the equation by measuring the height, height times length and area of pleural effusion on chest x-ray lateral decubitus with volume of pleural effusion on CT scan were

Table 1. Paired T-test results.

Models	Value
PEV = 126.9 × h	0.892
PEV = 6.584 × (h × l)	0.611
PEV = 6.574 × A	0.647

respectively sig 0.892, sig 0.611, and sig 0.647, shown in table 1.

Discussion

Initially there were 25 patients included in this study, with 5 patients later excluded, because of their health condition. Subjects with lobulated effusion, massive effusion and unmeasured of effusion image were excluded from the study. Use of the three equations has limitation that all patients in this study were examined in the right lateral decubitus position, to avoid superposition with the heart contour that occur if the patient was positioned in the left lateral decubitus position. This calculation cannot be used if patient is in an examination position other than the right lateral decubitus. In addition, the three equation also can not be applied to patients with condition such as post lung surgery, massive subpulmonic/supradiaphragmatic pleural effusion, empyema, an atypical pleural effusion such as septated, encapsulated, loculated pleural effusion and anatomical deformity, scoliosis, or abnormalities of thoracic cavity, and anatomical abnormalities of thoracic cavity. In these condition it will be difficult to determine the measurement limit so that the result of the volume calculation will not be accurate.

The average age of subjects was 49.9 ± 11.3 years, with the youngest age being 20 years and the oldest being 69 years. The average age of male subjects was older compared to female subjects. There was no significant difference of number between men an women. Those finding is in accordance with research that states that there is no difference in incidence of pleural effusion based on sex although some causes of pleural effusion have sex predilection [6, 7].

In this study, pleural effusion is relatively more common in young adults and older people. There is no difference with the previous studies because the etiology of pleural effusion comes from several diseases in adults. The study found that men experience more malignant effusion than women. Lung cancer itself was more commonly found in men than women [8]. Another study assessed chest x-ray images of patients with radiological diagnosis of pleural effusion, found that pleural effusion was obtained most of the age of 45–59 years, male more often than female, and pleural effusion location mostly on the right side compared to the left and bilateral lungs. [9–12]

In a previous study using a unique thoracic phantom [3], a model for estimating fluid volume in phantom has been obtained which represents the case of pleural effusion based on the size of the x-ray radiograph. The model obtained in the form of three equations that connect in a row, the pleural effusion volume as a height function of radiograph image, volume as a function of length times the height of the image and volume as an area function of the image. Those three models of estimation have high linearity with ratio value more than 0.988 [4], higher than the modelling measurement using ultrasonography modality that use balik formula [5]. The pleural effusion volume can be estimated with ultrasonography, by measuring the maximal distance between parietal and visceral pleura (Sep) in end-expiration, where the patient was positioned supine with mild trunk elevation at 15°, probe was moved upwards in posterior axillary line and transverse section perpendicular to the body axis with pleural separeation visible at the lung base, evaluation in ultrasonography use balik formula: V (ml) = 20 × Sep (mm) that we can see in figure 8 [13]. Also the value of linearity when use USG is 95%.

The new three equations model or formulas developed using the unique phantom in the previous study, but now in this work already applied to real human patients so that proves that the formulas could be applied for measurement the pleural effusion volume of the human. This equation could be applied even in the hospital with limited equipment such as only used a conventional x ray, due the models is simple but has high linearity. Comparation measurement results of pleural effusion volume of the human by these models that only use conventional x-ray with measurement using CT-scan as the gold standard to calculate using an area of pleural effusion image are in accordance.

From the calculation of the estimated volume of pleural effusion in patients, the calculation using an area of pleural effusion image has the value closest to the standard value of gold that is CT scan with the highest correlation value as well as the spread is 95% CI. This is in accordance with the definition of volume or can also be called capacity is the calculation of how much space can be occupied in an object. Measurement of area images using the freehand method has already exist in the CR software. For measurement of height times length is still below area due to irregulerity of thoracic cavity shape on phantoms or patients. Anatomically, a space between the parietal pleura and the visceral pleura are called pleural cavities [14]. In the chest cavity there are several organs that will affect the shape of the pleural space or pleural cavity. The parietal pleura limits the thoracic wall, covering the thoracic surface of the diaphragm and the lateral surface of the mediastinum, extending to the base of the neck to limit the surface of the suprapleural membrane to the superior thoracic apertura. The visceral pleura encloses the entire outer surface of the lungs and extends into the interlobar fissure [14].

On validation results, the data distribution on differences of PEV from CT scans with PEV using area on

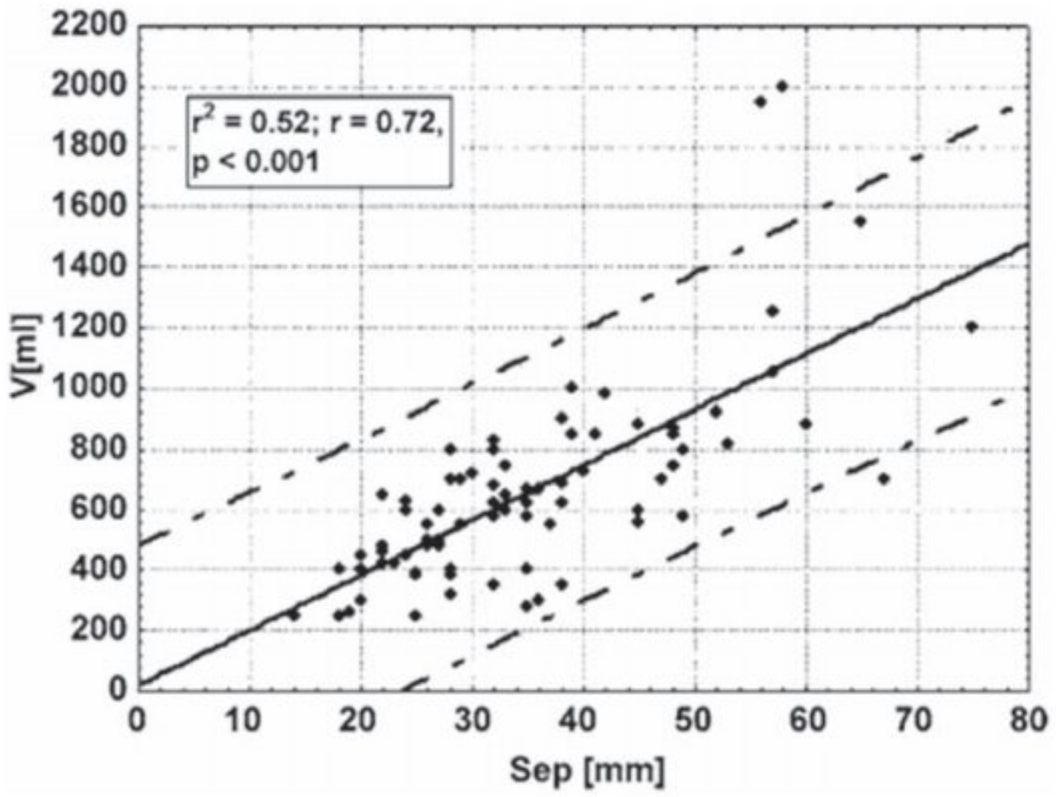

Figure 8. Graph of the relationship between volume of pleural effusion and maximum separation of pleural layers (Sep).

chest x-ray imaging is closer to mean value compared to using height or height times length. Based on the distribution in the graph at height there is one subject outside the lower boundary line of the CI 95% acceptable range. This supports the results of the conformity analysis, the PEV from the area equation is the closest approximation to PEV from the CT scan. In the paired T test for PEV by CT scans and PEV by chest x-ray lateral decubitus position with height, height times length, area, the value was significantly above 0.05, with sig value 0.892, 0.611 and 0.647 respectively.

Another advantage of developing the models measurement are it can be easy to used and fast for estimating the pleural effusion volume at health facilities that didn't have CT-scan modalities it can be evaluate with x-ray equipment for chest radiographs or if the health facilities doesn't have the software for calculating the pleural effusion volume.

Conclusions

Estimated pleural effusion volume in patient's thoracic cavity can be measured by measuring the height, length and area of the pleural effusion image on lateral decubitus position of chest x-ray with the PEV equation = 126.9 × height, PEV = 6.584 ×(height × length), PEV = 6,574 × A. From the three equations, measurement of estimated pleural effusion volume using function of area on chest x-ray lateral decubitus position is the most appropriate equation. Measurement of the height on chest x-ray lateral decubitus position is the fastest measurement and also to measure pleural effusion volume in its application. The three equations can not be applied to patients with condition such as post lung surgery, massive subpulmonic/supradiaphragmatic pleural effusion, empyema, an atypical pleural effusion such as septated, encapsulated, loculated pleural effusion and anatomical deformity, scoliosis, or abnormalities of thoracic cavity, and anatomical abnormalities of thoracic cavity.

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

ORCID iDs

Bambang Satoto https://orcid.org/0000-0001-6783-5895
Ali Khumaeni https://orcid.org/0000-0002-6907-7693

References

[1] Grimberg A, David C A, Alvaro N A, Sergio A and Wagner L 2010Diagnostic accuracy of sonography for pleural effusion: systematic review *Sao Paulo Med J* **128** 90–5
[2] Ramerand F, Mao Z and Ferrari F 2010 Multiplane ultrasound approach to quantify pleural effusions at the bedside *Intensive Care Med.* **36** 656–64
[3] Satoto B, Mohandas F S, Wahyu S B, Yuyun Y and Noor H 2018 Imaginary anatomy line measurements on the thorax *International Journal of Innovative Research in Advanced Engineering* **5** 6–9 (https://www.ijirae.com/volume-5-issue-01)
[4] Satoto B, Wahyu S B, Yuyun Y and Noor H 2017 Estimation of the volume of pleural effusion in the thoracic phantom by examination on the lateral position of the decubitus photo thoraks *Transylvaniaan Review* **XXV** 6170–4
[5] Balik M, Plasis P and Waldauf P 2006 Ultrasound estimation of volume of plural fluid in ventilated patients *Intensive care Med* **32** 318–21
[6] Selly J M and Ayyappan A P 2008 *Pleural Effusion. In Imaging of The Chest* Volume II ed L Nestor and S Isabella (Philadelphia: Saunders Elsevier) pp 1336–66
[7] Republic Indonesia Ministry of Health 2015 Cancer diseases situation *Buletin Jendela. Data and information of Health. Jakarta*

[8] Alberg A J and Samet J M 2013 Epidemiology of lung cancer *J Semin Interv Radiol.* **30** 173–7
[9] Melinda G L, Elvie L and Ramli H A 2016 Image of the chest radiograph on pleural effusion in Radiology Department, Medical Faculty of Sam Ratulangi University—Prof. Dr R.D. *Kandouw Manado Hospital, Periode November 2014—Oktober 2015. Jurnal e-Clinic (eCl)* **4** 272–4 (https://ejournal.unsrat.ac.id/index.php/eclinic/article/view/10966)
[10] Desalew M, Amanuel A, Addis A, Zewdu H and Jemal A 2012 Pleural effusion: presentation, causes and treatment outcome in a resource limited area *Ethiopia. Health.* **4** 15–9
[11] Mcgrath E E and Anderson B P 2011 Diagnosis of pleural effusion: a systematic approach *Am J Crit Care* **20** 119–28
[12] Khairani R, Syahruddin E and Partakusuma L G 2012 Pleural effusion characteristic in persahabatan hospital *J Respir Indo.* **32** 155–60
[13] Balik M, Plasil P, Waldauf P, Jpazout M, Fric M, Otahal J and Pachl 2006 Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients *Intensive Care Med* **32** 318–21
[14] Ferreira A, Filho F M and Braga T 2006 The role of ultrasound in the assesment of pleural effusion *Radiologia Brasileira.* **39** 2