Original Article

Relationship of pericardial effusion thickness and volume measurement by non-ECG gated computed tomography

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Abstract

Background: An accurate estimation of pericardial fluid volume could improve communication between radiologists and the multidisciplinary team.

Objective: To find the correlation between the volume and thickness of pericardial effusion measured by CT scan.

Materials and Methods: The chest CT scans of 38 patients with pericardial effusion were measured for volume using manual segmentation and for thickness on axial and 3-chamber planes from the anterior and posterior aspects. The correlation between volume and thickness was evaluated using Pearson's correlation coefficient (r). The reliability of the measurements was tested using intraclass correlation coefficient (ICC) and Bland-Altman analysis.

Results: There was a fair to moderately strong correlation between the volume and thickness of pericardial effusion (r= 0.435-0.625, p= <0.01). An ICC of 0.452-0.703 indicated moderate inter-observer agreement. The best measurement is the sum of the anterior and posterior thicknesses on the axial plane (ICC of 0.703) that correlates well with the volume (r= 0.624). A linear regression equation demonstrating the relationship between pericardial effusion thickness and the effusion volume was computed as; Volume (mL) = 73 + 71*(the sum of anterior and posterior thicknesses on axial view in cm). The equation was applied: a value of approximately 3 cm = small, 6 cm = moderate, and 9 cm = large pericardial effusion.

Conclusion: There is a moderate correlation between the sum of the anterior and posterior pericardial thicknesses and the pericardial volume. Our preliminary formula enables a rapid estimation of the effusion volume. Further validation and refinement of the formula in a larger, prospective study is needed.

Keywords: Computed tomography, Estimation of pericardial effusion volume, Pericardial effusion.

Introduction

The diagnosis of pericardial effusion is usually made by echocardiography. (1) An estimation of the size of the effusion and its important hemodynamic is the first step in clinical management. Large pericardial effusions have the potential risk for cardiac tamponade [1]. An estimation of the pericardial effusion size is done by measuring the distance of the anechoic space between the epicardium and the parietal pericardium during end-diastole [2]. An echocardiographic quantitative assessment of pericardial effusion with a 3-dimensional disk method has a strong correlation with drained pericardial fluid [3]. However, echocardiography has limitations such as a poor acoustic window and loculated fluid [4].

Pericardial effusion is detected incidentally by computed tomography (CT) in up to 5% of patients [5]. Various methods to quantify the amount of pericardial effusion with CT have been reported. In 2012, Ebert et al. proposed that measuring the fluid volume in the phantom by using the segmentation technique was highly accurate [6]. Other studies have reported that the pericardial effusion volume estimated from CT was moderately correlated with the actual volume drained from aspiration [7,8]. However, due to leakage during incision or retained unmeasured hematoma, the drained fluid volume is usually less than that estimated by CT [6], suggesting that even surgically drained fluid does not accurately measure the pericardial effusion volume.

Therefore, we aimed to determine if the pericardial effusion thickness in the axial plane and the 3-chamber plane can be used to precisely estimate the pericardial effusion volume. We also aimed to identify the specified position or plane that could best represent the pericardial effusion volume and to calculate an equation demonstrating the relationship between the pericardial effusion thickness and the pericardial effusion volume. An accurate estimation of the fluid volume using pericardial wall thickness could reduce interpretation time and improve communication between radiologists and the multidisciplinary team.

Materials and methods

Study Population

We searched the picture archive and communication system (PACS) of a tertiary hospital in Bangkok, Thailand using the terms "moderate amount of pericardial effusion", "moderate pericardial effusion", and "large amount of pericardial effusion" from January to December 2019. The query returned 59 cases. Non-ECG gated CTs of the chest with contrast media administration were included. Patients with other pericardial pathology such as pericardial mass, pericardial calcification, or loculated pericardial effusion were excluded. Images with artifacts that caused evaluation limits, such as motion or metallic artifacts, were excluded. Finally, 38 cases (14 males) were included with a median age of 60 years. This retrospective study was approved by the Siriraj Hospital's institutional review board. (SIRB Protocol No. 828/2563 IRB3).

Imaging Technique

All CT studies were performed by one of three multidetector CT scanners (MDCT) at our institution, including Lightspeed VCT 64-slice (GE Healthcare, Milwaukee, USA), Discovery 750HD 64-slice (GE Healthcare, Milwaukee, USA), and Revolution CT 256-slice (GE Healthcare, Milwaukee, USA). Scanning parameters included three protocols; A) CT chest with contrast, B) CT pulmonary artery (CTPA), and C) CTA thoracoabdominal aorta. All protocols used 120 kVp tube voltage. However, the tube current and rotation time depended on each machine. The scanning volume for all studies included the entire chest from lung apex to base, in the supine position with a one-breath-hold at the end-inspiration phase.

For Protocol A, iodinated contrast was administered at 2 ml/kg of body weight, followed by 20 ml of saline at 3 ml/sec. For Protocol B, < 50 ml of iodinated contrast was administered at 4 ml/sec, then a mixture of contrast and saline (50:50 ratio) 5-10ml at a rate of 5 ml/sec, followed by 40 ml of saline at 5 ml/sec. For Protocol C, < 100 ml of iodinated contrast was administered followed by 40 ml of saline at a rate of 4 ml/sec.

Image Analysis

The images were reviewed using PACS for thickness evaluation and GE AW VolumeShare 5 for volume evaluation. Post contrast or delayed chest phase (approximately 45 sec after contrast injection) images were used. The window width and level were changed according to the reviewer preferences. The CT data were reconstructed with 1.25-mm slice thicknesses and reformatted into the 3-chamber plane. Each CT image was reviewed separately by three radiologists (K.P., J.W., and J.S., with 5, 15, and 4 years of experience in diagnostic radiology, respectively).

The pericardial effusion thicknesses were measured by K.P and J.W. with a one-week interval between readings. Pericardial effusion thicknesses were measured at two locations on two planes; maximal thickness at anterior to the right ventricle and maximal thickness at posterior to the free wall of the left ventricle on the axial and the 3-chamber planes (Figure1). Measurements of the pericardial fluid volume were measured twice by J.S. with a 1-week interval between readings and once by K.P, by drawing the region of interest (ROI) of the pericardial effusion area of every slice of CT with 2.5 mm thickness (Figure 2) using GE AW VolumeShare 5 software.

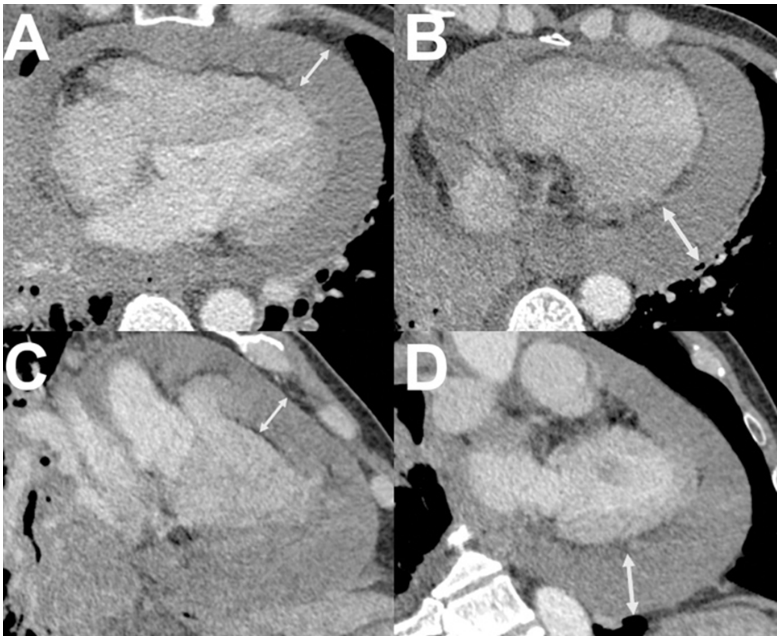

Figure 1. *Imaging planes used for measurement of pericardial effusion thickness*
A and B: axial plane images for measurement of anterior and posterior thickness,
C and D: 3-chamber plane for measurement of anterior and posterior thickness.

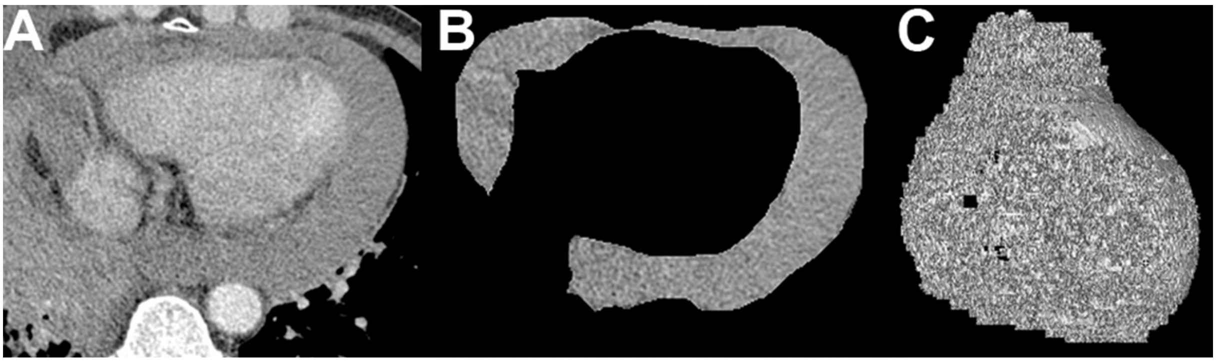

Figure 2. *Pericardial effusion volume measurement*
A: Axial CT shows pericardial effusion,
B: Image after manually drawn region of interest for pericardial effusion,
C: Volume-rendered image after drawing ROI of every slice demonstrates pericardial effusion volume.

Statistical Analysis

The statistical analysis was performed using SPSS version 23 and Medcalc. Intra- and inter-observer reliability were calculated to express the reproducibility, using the intraclass correlation coefficient (ICC) to assess the agreement of measurements and Bland-Altman analysis to present the bias and limits of agreement. An ICC <0.50 is considered poor, 0.50-0.75 moderate, 0.75-0.90 good and >0.90 excellent [9].

Validity was assessed by comparing the volume and thickness measured by both observers using Pearson's correlation coefficient. A linear equation was derived for the best thickness (best ICC). A correlation coefficient at least 0.80 is considered very strong, 0.60 up to 0.80 moderately strong, 0.30 to 0.50 fair, and less than 0.3 poor [10]. A P value of < 0.05 was considered statistically significant. For validity testing, a sample size of 38 provided 90% power to detect a correlation of 0.8 with an α value of 0.05.

Results

Pericardial effusion

The median pericardial effusion volume (n=38) measured by drawing the ROI technique was 203.50 ml (range 50 – 635 ml). There were 28 patients (73.6%) who had a pericardial effusion volume < 300 ml and 10 patients who had a pericardial effusion volume between 300 – 700 ml. No amount exceeding a volume of 700 ml was manifest in any patient.

Reliability of the measurements

There were excellent interobserver and intra-observer agreements of pericardial effusion volume measurement. The ICC of interobserver and intra-observer agreements were 0.902 and 0.968, respectively. The Bland-Altman analysis revealed a mean bias of -20.6 mL (95% limits of agreement between -128.8 mL to 87.5 mL) for interobserver agreement and -3.3 mL (95% limits of agreement between -67.6 mL to 61.0 mL) for intra-observer agreement (Table 1). Inter-observer agreements

(ICC 0.535-0.703) were moderate for thickness measurement in all locations, except for poor agreement in the posterior thickness on the 3-chamber plane (ICC 0.452). The strongest ICC was the sum of the anterior and posterior thicknesses on the axial plane (ICC = 0.703). Intra-observer agreement was moderate for the 1st reviewer and excellent for the 2nd reviewer. The sum of anterior and posterior thicknesses on the axial plane showed the strongest ICC (ICC = 0.997) (Table 2).

Table 1. *Intra- and inter-observer agreement of pericardial volume measurement.*

	Intraclass correlation coefficient (ICC)	Bland-Altman (mL)
Inter-observer agreement	0.902	-20.6 (-128.8, 87.5)
Intra-observer agreement	0.968	-3.3 (-67.6, 61.0)

Table 2. *Intra- and inter-observer agreement of pericardial thickness measurement.*

	Axial plane			3-chamber plane		
	Anterior	Posterior	Sum	Anterior	Posterior	Sum
Correlation for R1	0.435	0.599	0.613	0.505	0.523	0.625
P-value	0.006	0	0	0.001	0.001	0
Correlation for R2	0.404	0.578	0.624	0.381	0.596	0.63
P-value	0.012	0	0	0.018	0	0

Correlation between volume and thickness measurements

The correlation between thickness measurements and the pericardial volume for the sum of anterior and posterior thicknesses was moderately strong on both the axial and 3-chamber planes. The most robust Pearson's correlation coefficient was the sum of anterior and posterior thicknesses on the 3-chamber plane (r = 0.625 and 0.630) (Table 3).

Table 3. *Pericardial thicknesses and pericardial volume correlation.*

	Axial plane			3-chamber plane		
	Anterior	Posterior	Sum	Anterior	Posterior	Sum
Inter-observer agreement						
ICC	0.631	0.535	0.703	0.581	0.452	0.571
Bland-Altman (cm)	0.03 (-0.81, 0.88)	-0.2 (-1.7, 1.3)	-0.2 (-1.8, 1.5)	0.13 (-0.68, 0.93)	-0.35 (-1.58, 0.88)	-0.2 (-1.8, 1.4)
Intra-observer agreement (R1)						
ICC	0.806	0.702	0.774	0.732	0.678	0.716
Bland-Altman (cm)	-0.14 (-0.63, 0.36)	-0.28 (-1.22, 0.66)	-0.42 (-1.49, 0.66)	-0.18 (-0.74, 0.38)	-0.30 (-1.09, 0.50)	-0.48 (-1.48, 0.52)
Intra-observer agreement (R2)						
ICC	0.995	0.995	0.997	0.991	0.993	0.991
Bland-Altman (cm)	0 (-0.10, 0.10)	0.03 (-0.14, 0.20)	0.03 (-0.15, 0.21)	0.02 (-0.10, 0.13)	0.03 (-0.11, 0.17)	0.05 (-0.16, 0.26)

The summation of anterior and posterior thicknesses on the axial plane was selected to calculate a formula for the pericardial volume estimation with the best inter-observer agreement (ICC = 0.703 and correlation = 0.624). (Table 2 and 3) Using this correlation, we created a linear regression equation, from which we obtained the formula. The linear regression equation for summation of anterior and posterior thicknesses on axial view against the pericardial volume was simplified into the formula (Figure 3):

Volume (mL) = 73 + 71(the sum of anterior and posterior thicknesses on axial view in cm).*

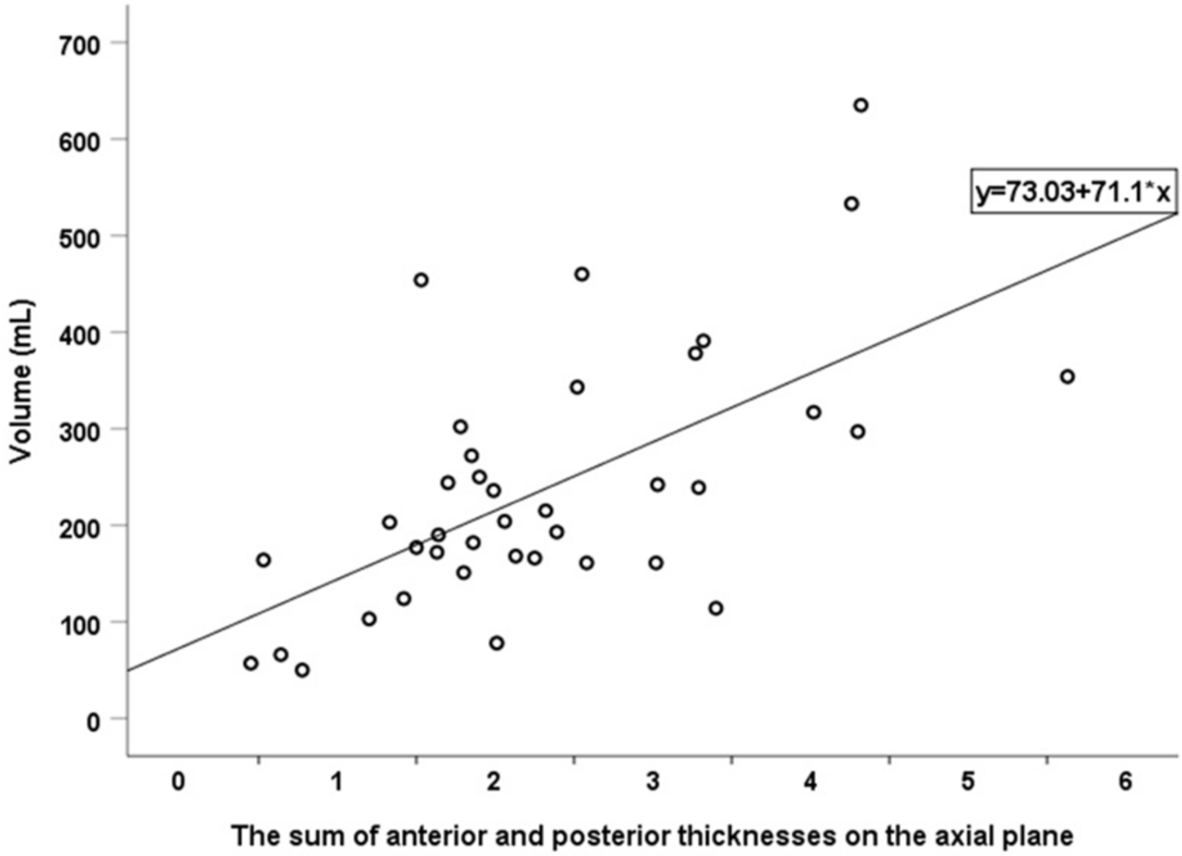

Figure 3. *The correlation between pericardial volume and thickness.*

Discussion

We found that the posterior thickness and the sum of the anterior and posterior thicknesses of both the axial and the 3-chamber planes had a moderately strong correlation, with Pearson's correlation coefficients of 0.613 and 0.624 for the axial plane and 0.625 and 0.630 for the 3-chamber plane. Therefore, the sum of the anterior and posterior thicknesses reveals a moderately strong correlation with the pericardial effusion volume.

Frank and colleagues suggested a thickness of the pericardial effusion anterior to the right ventricle of more than 5 mm represented a moderate amount of pericardial effusion [11]. We cannot find an explanation from the previous reports for why 5 mm would represent a moderate amount. However, we found anterior thickness to be poorly correlated with the volume which may be explained by the fact that gravity causes fluid to accumulate at the posterior aspect of the heart, making the anterior measurement alone a poor proxy for the volume.

Ohta et al. proposed that if a combination of anterior and posterior maximal thicknesses on the axial view exceeded 25.5 mm, this would indicate cardiac tamponade with an odds ratio of 12.7 [12]. Using our proposed equation would result in 254 mL of fluid, a small amount by echocardiography standards. However, the increment rate has more effect than the volume with respect to cardiac tamponade [13], and Ohta et al. did not evaluate the volume on CT or echocardiogram to compare with the mentioned thicknesses [12].

The intra-observer agreements for both thicknesses and volume measurements were excellent. However, the inter-observer agreements were moderate to weak, with the highest ICC for the sum of anterior and posterior thicknesses on the axial plane. This is different from a study by Groth et al. that reported excellent intra- and inter-observer agreement in a study of 20 patients with a different position for measurement than the one we used [14]. In our study, each reviewer scrolled through the entire scan/ set and selected the maximal anterior and posterior thicknesses.

The semiquantitative measurement from echocardiography is small (< 10 mm, representing 300 ml), moderate (> 10 mm, representing 500 ml), and large (> 20 mm, representing 700 ml [15]. When our formula is applied to calculate the thickness of pericardial effusion from CT scan for volumes of 300, 500 and 700 ml, the corresponding summation of anterior and posterior thicknesses is 3.19, 6.01 and 8.83 cm, respectively. To simplify the calculation, we round to the nearest whole number. Therefore, the sum of the anterior and posterior thicknesses on the axial plane of approximately 3 cm, 6 cm, and 9 cm represents small, moderate, and large pericardial effusion, respectively.

This equation can reduce the typical interpretation time using the drawing the ROI technique, which is normally between 40 and 50 minutes, to fewer than five minutes using thickness measured on the axial plane, which is almost always available in a routine practice. Our method may also help create a standard reference for what constitutes small, moderate, and large pericardial effusions on CT scan. Nonetheless, further validation is needed.

Limitations

There is currently no gold standard for the estimation of the volume of a pericardial effusion. Most patients with pericardial effusions are treated medically, and none of our patients were surgically drained. Moreover, post-mortem studies have showed that surgically drained fluid is often less than the volume estimated by CT, which can be explained by the inability to drain all of the pericardial effusion or errors during autopsy measurement [6,16]. Ebert et al. also validated volume measurement using CT compared with the phantom, which accurately measured the amount of pericardial effusion [6]. Thus, we used CT volume measured from every slice to be the standard to compare with thicknesses. Second, due to the variable size of pericardial effusion and although we used the key search terms “moderate amount”, “moderate” and “large amount” of pericardial effusion, 73.6% of our cases had a small pericardial effusion volume per echocardiography estimation [2,15]. As the present study is a retrospective, single-center experience with potential selection bias and the sample size of relatively small; hence, further prospective studies with larger recruited patients should be considered.

Conclusion

The sum of the anterior and posterior pericardial thicknesses and pericardial volume for both the axial and 3-chamber planes are moderately correlated. Our formula enables a rapid estimation of pericardial effusion volume and could help create a standard reference for what constitutes small, moderate, and large pericardial effusions on CT scan. Further validation and refinement of the formula in a larger, prospective study is needed.

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