Original Article

Diagnostic Accuracy of the Multi-Organ Ultrasound Performed by the Novice Emergency Medicine Residents for Diagnosis of Acute Heart Failure in Thailand

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Background: Multi-organ ultrasound including inferior vena cava, lung, and cardiac ultrasound improved diagnostic accuracy for diagnosis of acute heart failure (AHF). However, ultrasound from previous studies were performed by experts.

Objective: To ascertain the diagnostic accuracy of multi-organ ultrasound performed by the emergency medicine (EM) residents.

Materials and Methods: The prospective observational study was conducted in the emergency department of Siriraj Hospital, a large tertiary hospital in Bangkok, Thailand. The patients were enrolled if they were older than 18 years and had acute shortness of breath with AHF as one of differential diagnoses. EM residents who were blinded to the patient's information performed multi-organ ultrasound in the enrolled patients. The final diagnosis was determined by two emergency physicians by reviewing patient's medical record and admission summary.

Results: Sixty-two patients were enrolled. Of these patients, 40 (64.5%) were diagnosed as AHF. EM residents performed multi-organ ultrasound for diagnosis of AHF with sensitivity of 60%, specificity of 72.7%, positive predictive value (PPV) of 80.0%, and negative predictive value (NPV) of 50%. When correlated clinical data with multi-organ ultrasound, sensitivity was 50%, specificity was 77.3%, PPV was 87.2%, and NPV was 73.9%.

Conclusion: Emergency medicine residents can perform multi-organ ultrasound for diagnosis of AHF with moderate diagnostic value.

Keywords: Multi-organ ultrasound, Emergency medicine residents, Acute heart failure

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Acute heart failure (AHF) is one of the most common cause of emergency department (ED) visit. Diagnosis of AHF was previously based on history taking, physical examination, chest X-ray, and blood chemistry such as NT-pro BNP. However, using only clinical data and chest X-ray might be difficult to differentiate AHF from other dyspnea conditions such as pneumonia, asthma, or chronic obstructive pulmonary disease. Previous studies have found that physical signs and chest X-ray might not be reliable tools for diagnosing AHF(1-3).

Point-of-care ultrasound has been increasingly applied to help differentiate the cause of dyspnea in ED. The change in diameter of inferior vena cava (IVC) during respiratory cycle can be used to predict volume status(4-7). Lung ultrasound that showed multiple B-lines on bilateral lung fields was associated with extravascular lung water(8,9). Moreover, cardiac ultrasound can help to evaluate low left ventricular (LV) ejection fraction, which is one of the causes of AHF(10). Many previous studies demonstrated that multi-organ ultrasound, which consisted of IVC, lung, and cardiac ultrasound, could increase sensitivity and specificity for differentiating AHF from other dyspnea conditions(11,12). Furthermore, multi-organ ultrasound combined with clinical gestalts has also been shown to improve diagnostic accuracy of AHF and change management of patients with dyspnea(13,14).

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However, sonographers from all previous studies were highly experienced in ultrasound. The authors hypothesized that emergency medicine (EM) residents who had less experience could also perform multi-organ ultrasound to diagnose AHF with high accuracy. The present study was aimed to ascertain the diagnostic performance of multi-organ ultrasound performed by the EM residents for diagnosis of AHF.

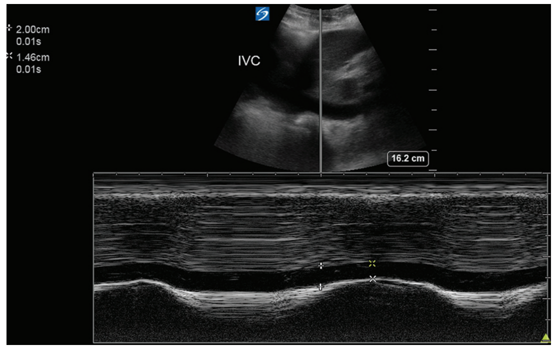

Figure 1. Inferior vena cava image in M-mode.

Materials and Methods

Study design and setting

The present study was a prospective observational study conducted in the non-trauma ED of Siriraj Hospital, which is a tertiary academic hospital with more than 130,000 ED visits per year. The subjects were enrolled between August and November 2017.

The Department of Emergency Medicine of Siriraj Hospital has started a 3-year residency training for 10 years with six residents per class per year. Ultrasound training has been formally implemented to residency curriculum for three years. The training includes a 1-day workshop that is annually held at the beginning of each academic year and self-practicing under experts' supervision while on duty in ED. The ultrasound workshop includes a 2-hour didactic session and a 2-hour hands-on session on cardiac, lung, and abdomen ultrasound. Every resident from first to third year must attend this workshop. The authors started enrollment after the workshop had been done for one month. The present study was approved by the Siriraj Institutional Review Board.

Participants selections

A convenience sample of patients were enrolled if they were older than 18 years old and had acute shortness of breath with more than one differential diagnosis in which AHF was considered one of them. The patients were enrolled upon the condition that the residents who were not on duty or not exposed to that patient were available to perform ultrasound. The exclusion criteria were ST-segment elevation myocardial infarction, shock, and positive pressure ventilation with either invasive or non-invasive methods.

Study protocols: After written informed consent were obtained, the residents who were blinded to the patients' condition would scan heart, lung, and IVC using the Sonosite X-Porte machine (Fujifilm SonoSite, Bothell, WA).

Cardiac ultrasound: With patients in supine position, a phased array probe (5-1 MHz) was used to scan the parasternal long axis view. LV function was evaluated visually by eyeball estimation. LV function was classified into three types, hyperdynamic, normal, and hypodynamic. Hypodynamic heart (impaired left ventricular systolic function) was considered as positive for AHF[15].

IVC ultrasound: A curvilinear probe (8-5 MHz) was used to scan IVC in longitudinal views. M-mode was used to evaluate the change of IVC diameter through respiration. IVC maximum (IVCmax) and IVC minimum (IVCmin) diameter were measured at 1 to 2 cm distal to the junction between right atrium and IVC (Figure 1). Inferior vena cava collapsibility index (IVC-CI) was calculated by (IVCmax – IVCmin / IVCmax) ×100. IVC-CI of less than 50% was considered as positive for AHF[5,6].

Lung ultrasound: A phased array or curvilinear probe was used to scan the lung in eight areas bilaterally. Each side of chest wall was divided into four areas. The boundary of the whole chest wall is determined longitudinally from clavicle to diaphragm and transversely from parasternum to posterior axillary line. The anterior axillary line was used to divide chest wall into anterior and lateral part, while the third intercostal space was used to separate the chest wall into upper and lower part. Evidence of more than three B-lines per intercostal space found in at least two from the eight areas bilaterally was considered as positive for AHF[12,16,17]. Picture of B-lines is shown in Figure 2.

The multi-organ ultrasound was considered as positive for AHF if IVC ultrasound was positive and either cardiac or lung ultrasound was also positive.

After performing ultrasound, the resident would assess the patient's clinical data and correlated it with the ultrasound finding to give the diagnosis. Baseline characteristics of patients including age, sex, comorbidities were also recorded. The final diagnosis was determined by two EM faculty members who

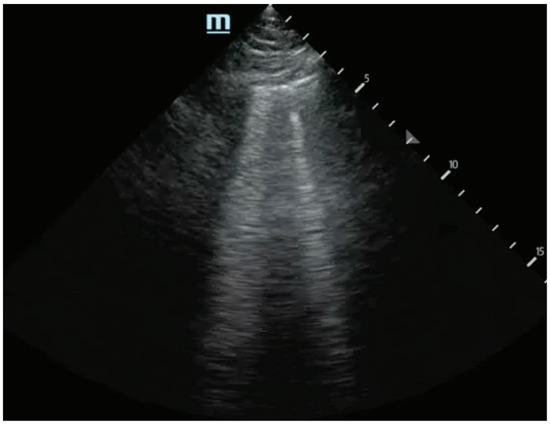

Figure 2. B-lines.

were blinded to the ultrasound results. The faculties gave final diagnosis based on Framingham criteria by reviewing out-patient medical record, admission summary, and all available investigation. If the opinions of the two faculty members were different, the third EM faculty member would determine the final diagnosis.

Outcome

The primary outcome was to ascertain the diagnostic value of multi-organ ultrasound for diagnosis of AHF performed by EM residents. The secondary outcome was to evaluate the diagnostic value of multi-organ ultrasound along with clinical data for diagnosis of AHF that was also performed by EM residents.

Statistical analysis

Based on previous studies[12], the authors estimated the diagnostic accuracy of multi-organ ultrasound for AHF to be 0.8 with 95% confident interval (CI) of 0.8±0.1. Therefore, the calculated number of enrolled populations was 62. Demographic data were described as percentage if it was categorical data, while mean with standard deviation was used if it was continuous data that was normally distributed, or median with interquartile range was used if it was continuous data that was non-normally distributed. The continuous data between AHF and non-AHF groups were compared using Student's t-test while the categorical data were compared using Chi-square or Fisher's exact test. The diagnostic value of multi-organ ultrasound was reported as sensitivity and specificity. Data analyses were performed using PASW 18.0 statistics for Windows (SPSS Inc., Chicago, IL, USA).

Results

Sixty-two patients were enrolled. Median age of all patients was 72 years. Other demographic data are shown in Table 1. Forty patients (64.5%) were diagnosed with AHF. The other diagnoses are shown in Table 2. Seventeen residents performed ultrasound. Among 62 patients, 17 (27.4%) were scanned by first year residents, 19 (30.6%) were scanned by second year residents, and 26 (41.9%) were scanned by third year residents.

Seventeen EM residents performed multi-organ ultrasound for diagnosis of AHF with sensitivity of 60% (95% CI 43.3 to 75), specificity of 72.7% (95% CI 49.8 to 89.3), positive predictive value (PPV) of 80.0% (95% CI 65.9 to 89.2), and negative predictive value (NPV) of 50% (95% CI 38.8 to 61.3). When correlated clinical data with multi-organ ultrasound, sensitivity was 50% (95% CI 38.8 to 61.3), specificity was 77.3% (95% CI 54.6 to 92.2), PPV was 87.2% (95% CI 75.7 to 93.7), and NPV was 73.9% (95% CI 56.7 to 85.9). The sensitivity and specificity of one-organ or two-organ ultrasound are shown in Table 3.

Discussion

Diagnosis of AHF in ED is challenging because it might be difficult to differentiate from other conditions such as pneumonia or COPD. Multi-organ ultrasound has been proved to efficiently assist physicians to guide diagnosis of AHF[11-14]. However, all images from the previous studies were performed by experts. The present study was the first to determine the diagnostic value of multi-organ ultrasound performed by EM residents. The authors found that with formal workshop at the beginning of each academic year together with self-practice while working in ED, EM residents could gain the ability to use multi-organ ultrasound to diagnose AHF with moderate accuracy.

Kajimoto et al[12] found that the sensitivity and specificity of multi-organ ultrasound performed by cardiologists were over 90%, whereas Anderson et al who studied on emergency ultrasound fellows reported high specificity (100%) but low sensitivity (16%)[11]. Nevertheless, the results of those previous studies were much higher than the present study. This might have been because of the different methods to evaluate or different criteria to make the diagnosis. For example, Kajimoto et al additionally searched for mitral regurgitation, and Anderson et al required all three organs to give positive results to diagnose AHF, which is different from the present study.

Moreover, the most important reason that the present results were less than expected might have

Table 1. Baseline characteristics

	Total (n = 62) n (%)	AHF (n = 40) n (%)	Non-AHF (n = 22) n (%)	p-value
Age (years), Mean±SD	68.4±17.0	67.3±18.0	75.5±15.2	0.473
Male	24 (38.7)	15 (37.5)	9 (40.9)	0.792
Comorbidities				
Hypertension	38 (61.3)	24 (60.0)	14 (63.6)	0.779
Diabetes mellitus	22 (35.5)	13 (32.5)	9 (40.9)	0.508
Ischemic heart disease	18 (29.0)	14 (35.0)	4 (18.2)	0.163
Valvular heart disease	7 (11.3)	7 (17.5)	0	0.044
Chronic kidney disease	14 (22.6)	7 (17.5)	7 (31.8)	0.219
Chronic obstructive pulmonary disease	9 (14.5)	6 (15.0)	3 (13.6)	1.000
Asthma	3 (4.8)	1 (2.5)	2 (9.1)	0.285
Pulmonary hypertension	8 (12.9)	5 (12.5)	3 (13.6)	1.000
Symptoms				
Dyspnea on exertion	31 (50.0)	21 (52.5)	10 (45.5)	0.596
Orthorpnea	35 (56.5)	27 (67.5)	8 (36.6)	0.018
Paroxysmal nocturnal dyspnea	31 (50.0)	22 (55.0)	9 (40.9)	0.288
Fever	11 (17.7)	4 (10.0)	10 (45.5)	0.042
Productive cough	15 (24.2)	5 (12.5)	10 (45.5)	0.004
Physical signs				
Unilateral rales	5 (8.1)	4 (10.0)	1 (4.5)	0.647
Bilateral rales	36 (58.1)	27 (67.5)	9 (40.9)	0.042
Wheezing	21 (39.9)	9 (22.5)	12 (54.4)	0.011
Lower extremities edema	22 (35.5)	16 (40.0)	6 (27.3)	0.316

AHF=acute heart failure; SD=standard deviation

Table 2. Final diagnosis

Diagnosis	n (%)
Acute heart failure	40 (64.5)
Pneumonia	13 (59.1)
Tracheobronchitis	3 (13.6)
Acute asthmatic attack	2 (3.2)
Pulmonary hypertension	2 (3.2)
Pulmonary embolism	1 (1.6)
Pericardial effusion	1 (1.6)

been because the lack of experience of EM residents. Although, they had learnt ultrasound since the very beginning of each academic year and had time to practice while they were on duty, they may not have gained enough competency to perform such complex scan of all heart-lung-IVC ultrasound. Previous studies suggested sonographers to repeatedly scan more than 11 to 25 times to gain high level of competency[18-20]. However, the authors did not collect the number of scans that EM residents experienced prior to the study. Therefore, the authors supposed that some residents did not achieve the suggested number of scans by the time of the present study.

The present results of one-system scanning also showed less sensitivity and specificity compared with the previous studies. This might inferred that the study's residents also required more practice in one-system ultrasound before using multi-organ ultrasound comparable with previous studies[11,12].

When correlating ultrasound finding with clinical data, the sensitivity and specificity increased to the level that was comparable to the previous studies[13,14]. However, the authors suspected that this might have

Table 3. Sensitivity and specificity of ultrasound for diagnosis of AHF performed by residents

Variables	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)
Lung US	35 (20.6 to 51.7)	72.7 (49.8 to 89.3)	70 (51.1 to 83.9)	38.1 (30.4 to 46.4)
IVC-CI <50%	87.5 (73.2 to 95.8)	22.7 (7.8 to 45.4)	67.3 (61.5 to 72.7)	50 (24.2 to 75.5)
Impaired LV systolic function	50 (33.8 to 66.2)	86.4 (65.1 to 97.1)	86.9 (69.0 to 95.2)	48.7 (40.1 to 57.5)
IVC-CI <50% & lung US	27.5 (14.6 to 43.9)	72.7 (49.8 to 89.3)	64.7 (43.9 to 81.1)	35.6 (28.6 to 43.2)
IVC-CI <50% & impaired LV systolic function	45 (29.3 to 61.5)	86.4 (65.1 to 97.1)	85.7 (66.5 to 94.8)	46.3 (38.4 to 54.5)
Lung US & impaired LV systolic function	12.5 (4.2 to 26.8)	86.4 (65.1 to 97.1)	62.5 (30.5 to 86.4)	35.2 (30.7 to 39.9)
Multi-organ US	60 (43.3 to 75.1)	72.7 (49.8 to 89.3)	80 (65.9 to 89.2)	50 (38.8 to 61.3)
Multi-organ US & clinical data	85 (70.2 to 94.3)	77.3 (54.6 to 92.2)	87.2 (75.7 to 93.7)	73.9 (56.7 to 85.9)

AHF=acute heart failure; CI=confident interval; PPV=positive predictive value; NPV=negative predictive value; US=ultrasound; IVC-CI=inferior vena cava collapsibility index; LV=left ventricle

been primarily from the effect of clinical information subsequently added rather than the initial ultrasound finding.

The present study also had some limitations. The study was conducted in a small single center in an academic hospital at which ultrasound curriculum for EM residents have been integrated for only a few years. Moreover, the formal evaluation of residents' competency has not yet been established, therefore, the number of scans performed by each resident before enrollment had not been collected. The authors also did not evaluate inter-rater reliability between residents. Furthermore, the present study enrolled a convenience sample of patients, therefore, there might be some sampling bias. In addition, the residents could not blind the surrounding environment of the patients such as intravenous fluid given to the patient at the time of ultrasound, thus, sonographers might have prejudged the diagnosis of the patients and performed ultrasound to match their impression. Finally, there was no record of the time taken since the patients arrived at ED to the start of ultrasound scan. The delay in ultrasound might lead to possible false negative scan because IVC-CI and number of B-line in patients with AHF changed after treatment[21-24].

Conclusion

EM residents performed multi-organ ultrasound for diagnosis of AHF with moderate diagnostic value. Improvement of ultrasound training curriculum should be required to enhance ultrasound competency of EM residents.

What is already known on this topic?

AHF is a common presentation in Emergency Department. Diagnosis of AHF by clinical information and chest X-ray is sometimes difficulty to differentiate AHF from other dyspnea causes. Multi-organ ultrasound included heart, lung, and inferior vena cava has been proved to increase diagnostic performance of AHF. However, the previous studies[11-13] were done by ultrasound experts.

What this study adds?

This study showed the diagnostic performance of multi-organ ultrasound for diagnosis of AHF performed by novice emergency medicine residents.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Stevenson LW, Perloff JK. The limited reliability of physical signs for estimating hemodynamics in chronic heart failure. JAMA 1989;261:884-8.
2. Elder A, Japp A, Verghese A. How valuable is physical examination of the cardiovascular system? BMJ 2016;354:i3309.
3. Collins SP, Lindsell CJ, Storrow AB, Abraham WT. Prevalence of negative chest radiography results in the emergency department patient with decompensated heart failure. Ann Emerg Med 2006;47:13-8.
4. Miller JB, Sen A, Strote SR, Hegg AJ, Farris S, Brackney A, et al. Inferior vena cava assessment in the bedside diagnosis of acute heart failure. Am J Emerg Med 2012;30:778-83.
5. Nagdev AD, Merchant RC, Tirado-Gonzalez A, Sisson CA, Murphy MC. Emergency department bedside ultrasonographic measurement of the caval index for noninvasive determination of low central venous pressure. Ann Emerg Med 2010;55:290-5.
6. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. Am J Cardiol 1990;

66:493-6.
7. Gaskamp M, Blubaugh M, McCarthy LH, Scheid DC. Can bedside ultrasound inferior vena cava measurements accurately diagnose congestive heart failure in the emergency department? A Clin-IQ. J Patient Cent Res Rev 2016;3:230-4.
8. Picano E, Pellikka PA. Ultrasound of extravascular lung water: a new standard for pulmonary congestion. Eur Heart J 2016;37:2097-104.
9. Pivetta E, Goffi A, Lupia E, Tizzani M, Porrino G, Ferreri E, et al. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED: A SIMEU multicenter study. Chest 2015;148: 202-10.
10. Mancuso FJ, Siqueira VN, Moises VA, Gois AF, Paola AA, Carvalho AC, et al. Focused cardiac ultrasound using a pocket-size device in the emergency room. Arq Bras Cardiol 2014;103:530-7.
11. Anderson KL, Jenq KY, Fields JM, Panebianco NL, Dean AJ. Diagnosing heart failure among acutely dyspneic patients with cardiac, inferior vena cava, and lung ultrasonography. Am J Emerg Med 2013;31: 1208-14.
12. Kajimoto K, Madeen K, Nakayama T, Tsudo H, Kuroda T, Abe T. Rapid evaluation by lung-cardiac-inferior vena cava (LCI) integrated ultrasound for differentiating heart failure from pulmonary disease as the cause of acute dyspnea in the emergency setting. Cardiovasc Ultrasound 2012;10:49.
13. Mantuani D, Frazee BW, Fahimi J, Nagdev A. Point-of-Care multi-organ ultrasound improves diagnostic accuracy in adults presenting to the emergency department with acute dyspnea. West J Emerg Med 2016;17:46-53.
14. Russell FM, Ehrman RR, Cosby K, Ansari A, Tseeng S, Christain E, et al. Diagnosing acute heart failure in patients with undifferentiated dyspnea: a lung and cardiac ultrasound (LuCUS) protocol. Acad Emerg Med 2015;22:182-91.
15. Yancy CW, Jessup M, Bozkurt B, Butler J, Casey DE Jr, Drazner MH, et al. 2013 ACCF/AHA guideline for the management of heart failure: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol 2013;62:e147-239.
16. Cibinel GA, Casoli G, Elia F, Padoan M, Pivetta E, Lupia E, et al. Diagnostic accuracy and reproducibility of pleural and lung ultrasound in discriminating cardiogenic causes of acute dyspnea in the emergency department. Intern Emerg Med 2012;7:65-70.
17. Volpicelli G, Cardinale L, Garofalo G, Veltri A. Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD. Emerg Radiol 2008;15:145-51.
18. Gómez Betancourt M, Moreno-Montoya J, Barragán González AM, Ovalle JC, Bustos Martínez YF. Learning process and improvement of point-of-care ultrasound technique for subxiphoid visualization of the inferior vena cava. Crit Ultrasound J 2016;8:4.
19. Fields JM, Lee PA, Jenq KY, Mark DG, Panebianco NL, Dean AJ. The interrater reliability of inferior vena cava ultrasound by bedside clinician sonographers in emergency department patients. Acad Emerg Med 2011;18:98-101.
20. American College of Emergency Physicians. Emergency ultrasound guidelines. Ann Emerg Med 2009;53:550-70.
21. Yavaşi Ö, Ünlüer EE, Kayayurt K, Ekinci S, Sağlam C, Sürüm N, et al. Monitoring the response to treatment of acute heart failure patients by ultrasonographic inferior vena cava collapsibility index. Am J Emerg Med 2014;32:403-7.
22. Ramasubbu K, Deswal A, Chan W, Aguilar D, Bozkurt B. Echocardiographic changes during treatment of acute decompensated heart failure: insights from the ESCAPE trial. J Card Fail 2012;18:792-8.
23. Platz E, Merz AA, Jhund PS, Vazir A, Campbell R, McMurray JJ. Dynamic changes and prognostic value of pulmonary congestion by lung ultrasound in acute and chronic heart failure: a systematic review. Eur J Heart Fail 2017;19:1154-63.
24. Tchernodrinski S, Lucas BP, Athavale A, Candotti C, Margeta B, Katz A, et al. Inferior vena cava diameter change after intravenous furosemide in patients diagnosed with acute decompensated heart failure. J Clin Ultrasound 2015;43:187-93.