META-ANALYSIS

Value of Thoracic Echocardiography in the Diagnosis of Acute Heart Failure: Systematic Review and Meta-analysis

Cuihuan Xie, BM; Yingying Qi, MM; Di Li, MM

ABSTRACT

Context • For patients with acute heart failure (AHF), the methods of clinical diagnosis of pulmonary edema mainly include clinical symptoms, laboratory results, and an imaging examination. The common diagnostic methods, such as chest X-rays and computerized tomography (CT) scanning, haven't been completely satisfactory.

Objective • The study intended to systematically, quantitatively, and comprehensively evaluate the value of a lung (pulmonary) ultrasound, performed at a patient's bedside, in the diagnosis of acute heart failure (AHF), to provide an objective basis for its clinical application and further research.

Design • The research team searched PubMed, Excerpta Medica Database (EMBASE), ScienceDirect, Cochrane Library, China Journal Full-text Database (CNKI), VIP Full-text Database, Wanfang Database, and China Biomedical Literature Database (CBM) for relevant literature, from January 2010 to the present, about the use of a lung ultrasound for diagnosis of AHF patients. The team used keywords to search literature: ultrasound, AHF diagnosis, cardiogenic pulmonary edema, ultrasonic examination, AHF diagnosis, and cardiogenic pulmonary edema. The research team then conducted a meta-analysis of the collected data according to the Cochrane Handbook 5.3 with RevMan 5.3 statistical software.

Setting • The study took place at Jinan

Outcome Measures • The research team: (1) evaluated the quality of the included studies; (2) examined the accuracy of a lung ultrasound in the diagnosis of AHF compared to computerized tomography (CT) as well as to the conventional ultrasonic cardiogram (echocardiogram) that a cardiologist performs; (3) determined the sensitivity, specificity, and predictive value of lung ultrasound using data from two of the included studies; (4) evaluated the data by drawing funnel charts; and (5) examined the publication bias of the included studies.

Results • The research team selected six controlled clinical studies, with 345 data samples, for the meta-analysis. The team performed heterogeneity tests for the included research data. For the first test, the team compared the accuracy of lung ultrasound and CT in diagnosing AHF and found obvious heterogeneity, with $\chi^2 = 11.40$, df = 3, $P = .010$, and $I^2 = 74\%$. Based on an analysis using a random effects model, the team found no significant differences between the two methods in the diagnosis of AHF ($P = .35$). For the second test, the team compared the accuracy of lung ultrasound and an ultrasonic cardiogram in diagnosing AHF and found that the data didn't differ significantly, with $\chi^2 = 0.08$, df = 1, $P = .78$, $I^2 = 0\%$. Based on an analysis using a fixed effects model, the team found that the accuracy of the lung ultrasound in diagnosing AHF was significantly higher than that of ultrasonic cardiogram ($P = .01$). In the two studies, the sensitivity and specificity were high. The majority of the funnel charts were symmetrical, but a few were asymmetrical, suggesting a publication bias, which the heterogeneity in the studies and the limited number of examined examples may explain.

Conclusions • Lung ultrasound is of great value in the diagnosis of AHF. It's highly efficient, has prospects for broad clinical application, and is worth popularizing, benefiting patients. Scholars need to verify the current study's findings in follow-up studies and in more high-quality case-control trials. (*Altern Ther Health Med.* 2023;29(6):322-327).

Cuihuan Xie, BM, Ultrasound Department, Shandong Provincial Third Hospital, Jinan, Shandong, China. **Yingying Qi,** MM, and **Di Li,** MM, Ultrasound Department, Central Hospital Affiliated with Shandong First Medical University, Jinan, Shandong, China.

Corresponding author: Di Li, MM
E-mail: 592740966@163.com

Heart failure (HF) is heart disease in which the heart isn't able to meet the metabolic needs of organs and tissues. It's a clinical syndrome with typical symptoms and is the last stage in the development of heart disease.

HF can result in venous-system congestion and heart-circulation disorder. An increase in mechanical pressure on the pulmonary capillaries can lead to their ultrastructural damage and an increase in extravascular lung water.

If patients don't receive treatment in time, they can easily develop pulmonary circulation congestion, also called cardiogenic pulmonary edema. Edema can result from the filling of the jugular vein with fluid, lung rales, an abnormal heart structure and/or function, or decreased cardiac output and/or increased heart-filling pressure.[1-2]

Acute Heart Failure (AHF)

According to an epidemiological survey conducted in 2003, 0.9% of adults aged 35 to 74 in China suffer from HF. The most common cause of hospitalization among patients over 65 worldwide is acute heart failure (AHF). Most patients with chronic HF have an acute exacerbation, accounting for about 75% of patients hospitalized with HF.

Pulmonary edema is a complication from such an exacerbation. It's a common, clinically critical disease and is the main reason for hospitalization of HF patients. It's usually characterized by high, left-ventricular filling pressure and systemic vascular resistance.[5] Xu and Hu found that some patients with left HF can develop edema. [21]

Edema's main cause is ejection fraction retention heart failure (HFpEF),[7] which refers to HF with a left ventricular ejection fraction (LVEF) of ≥50%. When the heart can't meet the body's circulatory needs due to various factors, the cost is an increase in the left-ventricular filling pressure.

When the filling pressure increases, the stress on the left atrium and the pulmonary capillaries increases. With that increase in the capillaries' hydrostatic pressure, the tension in the capillary walls increases, thus increasing the speed of liquid passing through those walls.

At the same time, the increase in systemic venous pressure can hinder the drainage of lymphatic vessels to the venous system. Eventually, when the lymphatic system reaches the point at which it removes fluid from the matrix at a slower rate than it produces it, the fluid accumulates in the interstitial and alveolar cavities.[6]

With the decrease in myocardial compliance and the increase in myocardial stiffness in HF, the ventricular filling pressure gradually increases, leading to pulmonary or systemic blood stasis. Dysfunction of left-ventricular diastolic functionis an important feature of HF with ejection fraction retention.[8,9]

Diagnostic Methods

Cardiac enlargement, pleural effusion, interstitial or alveolar edema, and pulmonary congestion are typical clinical manifestations of AHF. At present for AHF patients, the methods of clinical diagnosis of pulmonary edema mainly include clinical symptoms, laboratory results, and an imaging examination. Conventional diagnostic methods include pulmonary auscultation, pulse continuous cardiac output monitoring (PICCO), plasma b-type natriuretic peptide (BNP), chest X-ray, computerized tomography (CT) scanning, and ultrasonic cardiogram (echocardiogram).

Pulmonary auscultation. This method assesses the airflow through the trachea-bronchial tree. A diagnosis using it requires a consensus among experienced doctors, making it an unsatisfactory method for diagnosing pulmonary edema.

PICCO. Medical practitioners have widely used PICCO technology, which employs an analysis of the pulse-wave profile and lung-heat dilution technology. It changes hemodynamic monitoring into volume monitoring and can accurately monitor the lung's blood volume and the extravascular water in the lungs.[23] However, pneumonectomy and local pulmonary vasoconstriction can affect the PICCO monitoring method, which can cause more trauma and quickly lead to a catheter-related infection. Also, the price of a puncture kit for PICCO monitoring is high as is the cost of each examination, about 7000-8000 yuan in China. These costs greatly increases patients' medical burden and seriously limit the method's clinical application.

Chest X-ray. A chest X-ray examination can be an effective diagnostic method for AHF patients. It's the clinical standard for evaluating extravascular lung water. The method has the advantages of simple operation and economy. However, while a chest X-ray examination is almost routine for about 20% of AHF patients, the value of a supine chest X-ray in AHF is limited. It has low resolution; it has difficulty in clearly showing some small lung lesions; and it can reduce the rate of clinical diagnosis, creating a limited clinical application.

CT scan. Transporting critical patients to a CT room can increase the risk of symptoms' aggravation, and the long time required for image processing can lead to a delay in clinical decision-making. It's not easy to transport patients with cardiogenic pulmonary edema frequently due to their severe conditions. If physicians use CT, the examination cost is high, and patients' radiation exposure is high. Chen et al indicate that physicians still need to evaluate patients using an imaging examination, requiring a more acceptable method.[29]

Lung Ultrasound

In recent years, scientists have developed a new method for observing the lungs, the lung (pulmonary) ultrasound, which occurs at a patient's bedside.[10,11] Compared with other methods, lung ultrasound uses no radiation and is safe, repeatable, and low in cost, and more important, its use at the bedside provides convenient application and quick results.

In the past, medical practitioners have regarded the lungs as a unsatisfactory area for ultrasonic medical examination because they're organs filled with air, which can produce a large number of reflections and artifacts at the interface between the gas and other tissues, which isn't conducive to ultrasonic penetration into deep tissues.

Therefore, previously the method wasn't conducive to the formation of ultrasound images of tissues, which led practitioners to the idea that air is the enemy of ultrasound. In the past few years, the artifacts that ultrasound causes by the imbalance of the gas-liquid ratio in lung tissue and the change in extravascular lung water have become the basis of ultrasound imaging of the lung, regardless of whether the

technique is a lung (pulmonary) ultrasound or an ultrasonic cardiogram. The method can sensitively reflect pulmonary interstitial edema.

Xu found that the clinical diagnosis of pulmonary edema using lung ultrasound was equivalent to that using a chest CT scan,[12] and Mojoli et al found that it was superior to that using a chest X-ray.[13] Lichtenstein et al performed a prospective comparison of pulmonary auscultation, lung ultrasound, chest X-ray, and CT scanning in the diagnosis of pulmonary edema with 32 patients who had acute respiratory distress syndrome (ARDS) and 10 healthy volunteers.[22]

Platz et al found that the number of B lines in an lung ultrasound was a good indicator for evaluation of extravascular lung water (EVLW).[24] Shrestha et al and Yang et al found that the accuracy of the clinical diagnosis of pulmonary edema using lung ultrasound was equivalent to that using a chest CT scan and superior to that using a chest X-ray.[25,26]

The latest consensus guideline of the European Heart Association (ESC) supports the use of a lung ultrasound to diagnose and treat AHF.[27] Glockner et al found that the sensitivity and specificity of a lung ultrasound in the diagnosis of AHF were 54.2% and 97.6%, respectively.[28] Lung ultrasound has become a simple, noninvasive, rapid, and semiquantitative tool to detect pulmonary edema.

Current Study

However, significant differences exist among research designs in studies evaluating lung ultrasound, including the use of different outcome measures. High-quality research about the effectiveness of lung ultrasound, as well as standardization in the use of specific outcome measures, can support the value of the clinical application of lung ultrasound in the treatment of AHF patients. Researchers need to demonstrate the value of lung ultrasound in the clinical diagnosis of AHF by more authoritative scientific research.

The current study intended to systematically, quantitatively, and comprehensively evaluate the value of a lung ultrasound in the diagnosis of AHF to provide an objective basis for its clinical application and further research.

METHODS

Procedures

The study took place at Jinan.

Sources and retrieval methods. The research team searched PubMed, Excerpta Medica Database (EMBASE), ScienceDirect, Cochrane Library, China Journal Full-text Database (CNKI), VIP Full-text Database, Wanfang Database, and China Biomedical Literature Database (CBM) for relevant literature, from January 2010 to the present, about the use of lung ultrasound for diagnosis of AHF patients. The team also searched relevant Chinese and foreign periodicals, conference papers, degree papers, news, and manual-search contents. The team used keywords to search literature: ultrasound, AHF diagnosis, cardiogenic pulmonary edema, ultrasonic examination, AHF diagnosis, and cardiogenic pulmonary edema.

Inclusion and exclusion criteria. The research team included studies if: (1) they were published in China or abroad about the diagnosis of AHF using lung ultrasound; (2) participants were adult patients with AHF symptoms; (3) a cardiologist or experienced physician had diagnosed AHF using a patient's medical history and related clinical examinations, (4) the diagnostic criteria were those from the European College of Cardiology guidelines[14]; (5) the diagnostic method for AHF was a chest X-ray, a chest CT, plasma b-type natriuretic peptide (BNP), lung ultrasound, and/or ultrasonic cardiogram,; (6) they included a control group—Group A was diagnosed as AHF by echocardiography; and (7) they reported use of more than one of the following outcome measures: diagnostic accuracy, sensitivity, and specificity.

The research team excluded studies if: (1) the reported data weren't complete, or the data weren't usable for the meta-analysis; (2) they followed the research content and take into account the latest research; (3) they had a sample size of fewer than 20 participants; or (4) the text was a meeting summary or minutes, a review, a meta-analysis, a correction of errors in a previous publication, a letter, or a case report.

Quality evaluation and data extraction. In the assessment of studies' effectiveness, the research team performed a bias-risk assessment using the bias-risk assessment tool from the Cochrane Systematic Evaluation Manual 5.3.

For the literature screening and data extraction, two members of the research team screened the literature and gathered data independently, assessed the results' quality, and crossed-checked the findings. The two team members discussed and tried to resolve disagreements. If they couldn't, they asked the third researcher to contribute to the judgment as well.

The two team members managed and extracted the research data using Note Express document-management software, and Microsoft Office software. The team contacted the articles' authors if the data were incomplete to obtain more information.

The extracted data included information: (1) about the authors, publication dates, and numbers of participants; (2) about the diagnostic methods; and (3) about the results.

Outcome measures. The research team: (1) evaluated the quality of the included studies; (2) examined the accuracy of a lung ultrasound in the diagnosis of AHF compared to computerized tomography (CT) as well as to the conventional ultrasonic cardiogram (echocardiogram) that a cardiologist performs; (3) determined the sensitivity, specificity, and predictive value of lung ultrasound using data from two of the included studies; (4) evaluated the data by drawing funnel charts; and (5) examined the publication bias of the included studies.

Outcome Measures

Quality evaluation. The research team examined the quality of the studies using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) scale, and

evaluating each of the quality item as Yes = a slight bias risk, Grade A; No = a high risk of bias, Grade B; or Unclear = a moderate bias risk. The scores of the high-quality studies were ≥3 and those of low-quality documents were ≤2.

Publication bias. According to the diagnosis rate of AHF using CT, lung ultrasound, and echocardiography, the research team drew funnel charts.

Statistical Analysis

The research team analyzed the data using the meta-analysis software RevMan 5.4, from the Cochrane cooperation network. The team entered the studies' data for analysis into RevMan 5.4 to evaluate the accuracy of the diagnosis of AHF using lung ultrasound compared to CT and using lung ultrasound compared to an ultrasonic cardiogram. The team used the degree of relative risk as an effective index and calculated the 95% confidence interval.

To determine whether the research data were heterogeneous, the team first used the Chi-square test (χ^2) test. If $P > .05$ and $I^2 < 50\%$, the team conducted the meta-analysis based on a revised impact model, which the team considered to be homogeneous. If $P < .05$ and $I^2 \geq 50\%$ and the team intended to judge homogeneity using the combined effect, they selected the random effects model. If $P < .05$ and heterogeneous sources couldn't be considered, the team didn't conduct a meta-analysis and instead used descriptive analysis.

RESULTS

Search Results

The research team found 1042 articles from the computer-database search (Figure 1). The team removed 419 articles by eliminating 250 duplicate studies, 103 studies that automation tools had marked as ineligible, and 86 for other reasons, with 623 articles remaining.

The team then eliminated 286 irrelevant studies, reviews, case reports, and studies with no control group, with 337 studies remaining. The team then excluded 253 studies with incomplete data or no primary outcome measures, with 84 studies remaining.

The team assessed the 84 articles for eligibility, and after carefully reading the full text, the team selected six controlled clinical studies, excluding 78 studies, again with incomplete data or no primary outcome measures.

To perform the meta-analysis, the team found 345 data samples in the six selected studies, two of which, Zhou et al[19] and Aggarwal et al,[20] analyzed the curative effects of lung ultrasound at patients' bedsides in the diagnosis of AHF. Table 1 shows the basic features of the included literature.

Quality Evaluation

Figures 2 and 3 show the analysis of the risks. All studies used random sequence generation.

Figure 1. Eligibility of Studies for Inclusion in Meta-analysis

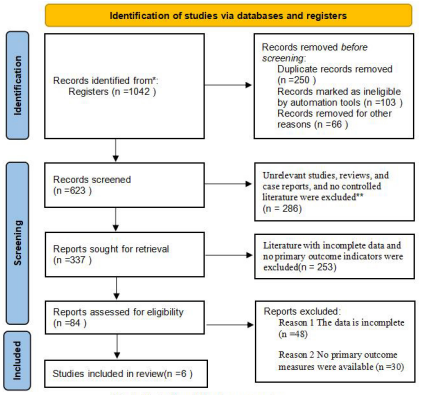


Figure 2. Risk Bias Chart

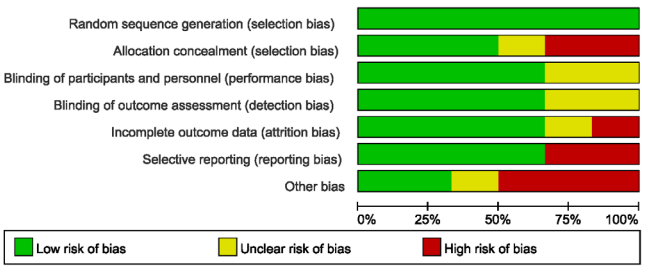


Table 1. Basic Characteristics of Selected Studies

Study	Sample Size	Inspection Mode		Research Type	Ultrasonic Scanner Model	Probe Type Frequency, MHz
		Control Group	Ultrasound Group			
Yu and Lan, 2020[15]	80	Chest CT	Ultrasonic cardiogram	Retrospective	GE VSCAN ultrasonic diagnostic apparatus	• Not described • 3-6 MHz
Ru et al, 2015[16]	61	Chest CT	Ultrasonic cardiogram	Retrospective	GE E9 color doppler ultrasonic diagnostic instrument	• Heart probe • 1.0-5 MHz
Su, 2018[17]	65	Thoracic CT, ultrasound	Ultrasonic cardiogram	Retrospective	Not described	• Heart probe • 1.0-5 MHz
Zhang and Jiang, 2020[18]	66	Thoracic CT, ultrasound	Ultrasonic cardiogram	Forward-looking	Not described	• Heart probe • 1.0-5MHz
Zhou et al, 2014[19]	31	Chest X-ray	Lung ultrasound	Retrospective	Philips IU 22 Netherlands	• Convex array probe • 5 MHz
Aggarwal et al, 2016[20]	42	Plasma BNP	Lung ultrasound	Forward-looking	Not described	• Not described

Abbreviations: BNP, brain natriuretic peptide; CT, computerized tomography

Lung Ultrasound and CT

Figure 4 shows that heterogeneity was evident in the data, with χ^2 = 11.40, df = 3, P = .010, and I^2 = 74%. The analysis using the random effects model found that no significant differences existed between the two methods in the accuracy of the AHF diagnosis (P = .35).

Lung Ultrasound and Ultrasonic Cardiogram

Figure 5 shows the included research data didn't appear to be heterogeneous, with χ^2 = 0.08, df = 1, P = .78, and I^2 = 0%. The analysis using the fixed effects model found that the accuracy of the diagnosis of AHF using lung ultrasound was significantly higher than that of an ultrasonic cardiogram (P = .01).

Sensitivity, Specificity, and Predictive Value

As Table 2 shows, the lung ultrasounds in Zhou et al[19] and Aggarwal et al[20] had high sensitivity, at 80.60% and 91.90%, respectively, and high specificity, at 77.60% and 100.00%, respectively, in the diagnosis of AHF.

In Zou et al, lung ultrasound had a positive predictive value of 65.80% and a negative predictive value of 88.20% compared to the 56.10% and 83.30%, respectively, for a chest X-ray. In Aggarwal et al, lung ultrasound had a positive predictive value of 100.00% and a negative predictive value of 62.90% compared to the 4.90% and 100%, respectively, for a Plasma BNP.

Publication Bias

The funnel charts for most of the studies were symmetrical, but a few were asymmetrical, which indicates that publication bias existed, which the heterogeneity of the research and the limited number of samples included may explain. (Figures 6 and 7).

DISCUSSION

The current meta-analysis found no significant differences in the accuracy of diagnosis of AHF between lung ultrasound and CT. Medical practitioners can use lung ultrasound as a reliable method for the diagnosis of cardiogenic pulmonary edema.

The current meta-analysis also found that the accuracy of lung ultrasound in diagnosing AHF was significantly higher than that of ultrasonic cardiogram. The lung ultrasound was more effective in differentiating cardiogenic pulmonary edema.

Figure 3. Summary Chart of Risk Bias

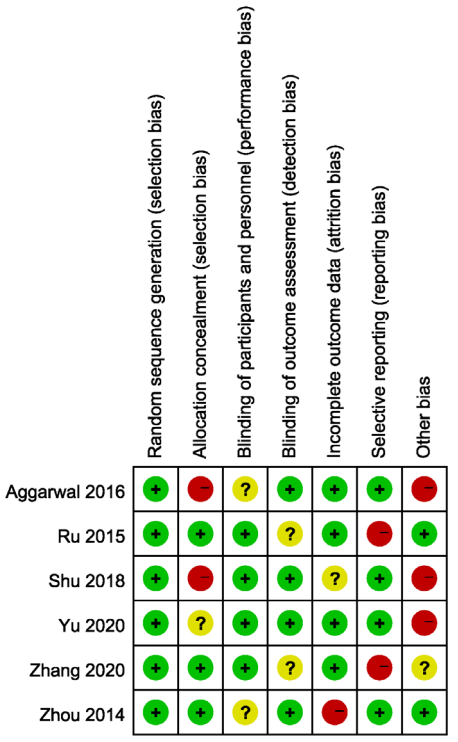


Figure 4. Comparison of the Diagnostic Rate for Acute Heart Failure (AHF) of Lung Ultrasound and Computerized Tomography (CT)

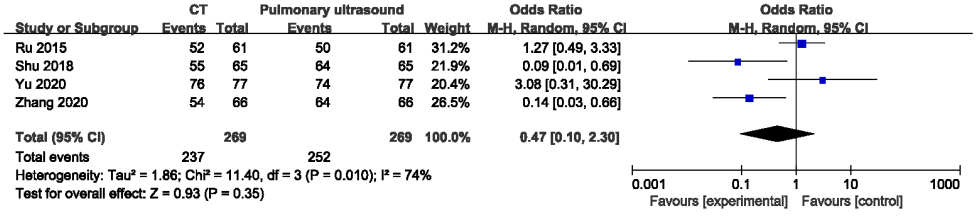


Figure 5. Comparison of the Diagnostic Rate for Acute Heart Failure (AHF) of Lung Ultrasound and Ultrasonic Cardiogram

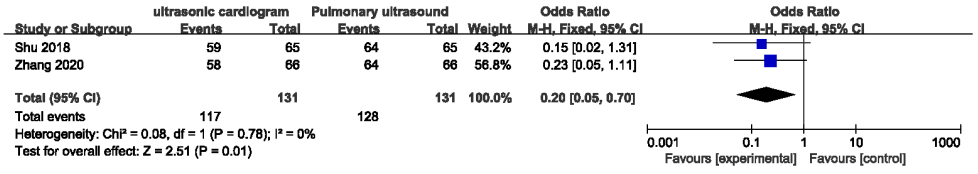


Table 2. Comparison of the Efficacy of Chest Ultrasound and Other Examinations in the Diagnosis of AHF

Study	Inspection Mode	Sensitivity %	Specificity Degree %	Positive Predictive Value %	Negative Predictive Value %
Zhou et al, 2014[19]	Chest X-ray	74.20	69.00	56.10	83.30
	Lung ultrasound	80.60	77.60	65.80	88.20
Aggarwal et al, 2016[20]	Plasma BNP	100.00	60.00	4.90	100.00
	Lung ultrasound	91.90	100.00	100.00	62.90

Abbreviations: AHF, acute heart failure; BNP, brain natriuretic peptide

Figure 6. Funnel Chart Based on the Diagnostic Rate of CT and Lung Ultrasound

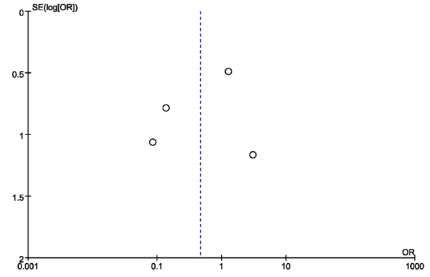
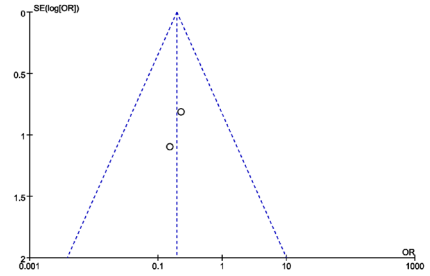


Figure 7. Funnel Chart Based on the Diagnostic Rate of Lung Ultrasound and Ultrasonic Cardiogram



In addition, two studies in the current meta-analysis analyzed the effectiveness of lung ultrasound in the diagnosis of AHF, and the sensitivity and specificity of lung ultrasound in the diagnosis of AHF were high, suggesting that lung ultrasound is a reliable means of distinguishing cardiogenic pulmonary edema.

However, in practical application, lung ultrasound still has some defects[30]: (1) if the patient is physically deformed or obese, the difficulty of the examination can increase; (2) the test results are subjective; and (3) if a patient has another lung disease, lung inflation can affect the results. The current research team intends those issue to also be the focus of follow-up, in-depth research.

Once a patient has received a diagnosis of cardiogenic pulmonary edema, he or can receive symptomatic nursing services at the hospital. If the edema is very serious, patients can stay in bed; if it's complicated by ascites or pleural effusion, it nurses can change the patient's position to semi-recumbent; and if the edema is in the lower extremities, nurses can raise the affected limb to promote venous reflux.

Physicians should advocate a low-sodium diet, foods that are easy to digest, and those with high protein levels, and instruct patients to avoid pickled foods, sodium drinks, and fermented pastry to avoid the aggravation of edema. Hospitals should scientifically control patients' fluid intake, change their body positions regularly, keep mattress clean and dry. Patients should wear soft or breathable clothes, use air-cushion beds and balloons to prevent pressure sores when necessary, and evaluate skin pressure areas in detail. Problems such as ulcer or infection should be dealt with in time. Physicians should deal with problems such as ulcers or infections in good time.

The current study had some limitations: (1) the inclusion and exclusion criteria were relatively strict; (2) no more-detailed subgroup analyses of heterogeneous studies could occur due to the relatively small number of included studies; (3) the diagnostic criteria used in various studies were inconsistent, which may have affected the reliability of the results.

CONCLUSIONS

Lung ultrasound is of great value in the diagnosis of AHF. It's highly efficient, has prospects for broad clinical application, and is worth popularizing, benefiting patients. Scholars need to verify the current study's findings in follow-up studies and in more high-quality case-control trials.

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