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The Diagnostic Value of Transthoracic Echocardiography for Pulmonary Hypertension: A Systematic Review and Meta-Analysis

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Purpose

Pulmonary hypertension (PH) is an important cause of morbidity and mortality. A commonly proposed non-invasive method in the diagnosis and assessment of PH is Transthoracic Echocardiography (TTE). In this systematic review and meta-analysis, our aim was to assess the accuracy of echocardiography in the diagnosis of PH.

Methods

The search was done up to the 31st of January 2023 using MEDLINE, Scopus, CENTRAL, and Web of Sciences databases. The studies were included if they were randomized controlled trials or observational in design and evaluated the diagnostic performance of TTE in diagnosing PH in comparison to right-sided heart catheterization as a reference method. The diagnostic performance measures included sensitivity, specificity, Diagnostic Odds Ratio (DOR), Positive Likelihood Ratio (PLR), and Negative Likelihood Ratio (NLR).

Results

The total number of the included patients was 4,523 from 38 articles. The overall sensitivity and specificity of echocardiography in diagnosing pulmonary hypertension were 54.8% (95%CI: 45.7%-63.6%) and 52.1% (95%CI: 39.0%-64.9%), respectively. Moreover, the pooled DOR was 1.321 (95%CI: 0.695-2.51). The pooled PLR and NLR were 1.145 (95%CI: 0.830-1.579) and 0.867 (95%CI: 0.628-1.197), respectively. The highest diagnostic performance of TTE was among group 1 and 3 PH patients.

Conclusion

Our analysis revealed that TTE had low diagnostic sensitivity, specificity, and accuracy. Due to the overall poor diagnostic performance of TTE, the diagnosis of PH and the assessment of response to therapies require right-sided heart catheterization. Future prospective studies to improve the diagnostic performance of TTE in the diagnosis of PH are needed.

INTRODUCTION

The prevalence of Pulmonary Hypertension (PH) is around 1% in the general population, yet it is much higher among the elderly population (people>65 years), approaching 10%.[1] To improve the patient's outcomes, early detection and accurate assessment in follow ups are considered crucial.[2] The gold standard for the diagnosis of PH is right sided heart catheterization.[3,4] The superiority of catheterization over other methods stems from its ability to measure flow, gradients, and resistance which are considered major determinants of pulmonary hypertension prognosis.[5] However, it is considered invasive and expensive, which may limit its frequent and repeated use.[3,4] Additionally, right sided heart catheterization was associated with a rate of ad-

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verse events of around 1.1% in the most experienced centers.[4]

On the other hand, echocardiography is considered noninvasive and readily available.[6] In addition, many echocardiographic parameters are closely related to pulmonary hemodynamics.[6] These echocardiographic parameters that can be used to assess pulmonary hypertension include right heart cavities and cardiac dimensions, right ventricular diastolic dysfunction, right ventricular systolic dysfunction, and myocardial strain.[6] To improve the assessment of parameters among patients with PH, multiple techniques were considered, one of which is exercise as studies showed that during exercise some parameters change among patients with PH compared to controls which enhances the ability of echocardiography to diagnose PH.[6]

Multiple systematic reviews were done to assess the diagnostic accuracy of transthoracic echocardiography between 2010-2019.[7-10] However, these studies only included studies before 2019.[7-10] In addition, they included a small number of studies, performed a simple diagnostic analysis and did not assess detailed subgroup analysis especially for World Health Organization (WHO) pulmonary hypertension groups.[7-10] In the recent years multiple original studies were conducted.[6] In the view of right sided heart catheterization drawbacks, limitations of the previously conducted meta-analyses, and the need to accommodate the rapidly growing literature, we decided to conduct this systematic review and meta-analysis to assess the accuracy of echocardiography in the diagnosis of PH.

METHODS

This review was registered at the International Prospective Register of Systematic Reviews (PROSPERO) under the protocol number (CRD42023395408). We report this review in accordance with Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.

SEARCH STRATEGY

The search was done on the 31st of January 2023 independently by TNA and AAT using MEDLINE, Scopus, The Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Sciences databases. The search strategy combined terms about pulmonary hypertension and echocardiography, where we used the medical subject heading (MeSH) database to optimize keyword selection. The following terms were used in conducting the search: (Pulmonary Hypertension) AND (Echocardiography OR 2D Echocardiography OR Contrast Echocardiography OR Cross-Sectional Echocardiography OR Transthoracic Echocardiography OR M-Mode Echocardiography OR Two-Dimensional Echocardiography). No time or language restrictions were applied. Any discrepancy was resolved by a third senior researcher (DD).

STUDY SELECTION

The studies were included in this systematic review meta-analysis if they were:

- Observational studies that evaluated the diagnostic value of 2-dimensional TTE in diagnosing pulmonary hypertension compared to right sided heart catheterization as a reference (gold standard).
- Randomized Controlled Trials investigating the diagnostic value of 2-dimensional TTE in diagnosing pulmonary hypertension compared to right sided heart catheterization as a reference (gold standard).

The following study types were excluded: editorials, unstructured narrative review articles or other publications which did not report any primary data or did not present new analyses of existing data. In addition, studies which evaluated the diagnostic value of echocardiography in diagnosing pulmonary hypertension in comparison to methods other than right sided heart catheterization, or which used another method as an adjunct to echocardiography and compared it to right sided heart catheterization, were also excluded.

The study selection was performed using Rayyan (https://www.rayyan.ai/). The articles retrieved from the search were screened using title/abstract then the remaining studies were screened using their full-text form. The study selection was done by two independent investigators (TNA and AAT) and any disagreement was resolved by a third senior researcher (DD).

MAIN OUTCOMES

The topic of interest is the diagnostic value of 2-dimensional TTE in diagnosing PH compared to right sided heart catheterization (gold standard). The included diagnostic value measures are sensitivity, specificity, Diagnostic Odds Ratio (DOR), Positive Likelihood Ratio (PLR), and Negative Likelihood Ratio (NLR). In addition, we investigated these diagnostic values if the echocardiography was performed during exercise. PH was defined as pulmonary artery pressure higher than 25 mmHg while exercise PH was defined as pulmonary artery pressure higher than 30 mmHg during exercise.[11] The included studies measured pulmonary artery pressure through echocardiography using the Bernoulli equation by adding peak tricuspid regurgitation velocity to the estimate of right atrial pressure. Moreover, to evaluate the diagnostic value of the 2-dimensional echocardiography across the World Health Organization (WHO) PH groups, a sub-group analysis was done for each of the 5 WHO groups. Group 1 includes patients with idiopathic PH and PH due to connective tissue diseases, hereditary, drug induced and congenital heart disease while group 2 includes patients with PH due to left-sided heart disease. Groups 3, 4 and 5 include patients with pulmonary hypertension due to lung disease, chronic pulmonary thromboembolism, and miscellaneous causes, respectively.

DATA EXTRACTION AND QUALITY ASSESSMENT

We developed a spreadsheet for data extraction. The following variables were extracted; title, year of publication, study design, country of origin (defined as the country in which the study was located), sample size, number of patients with PH, WHO pulmonary hypertension groups that were included in the studies, primary outcome measure, type of 2-dimensional TTE (exercise vs resting), as well as True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN) values. The data extraction was performed by the same two independent researchers (TNA and AAT) and any discrepancy was resolved by a senior researcher (DD). The risk of bias in the included studies was assessed using Newcastle-Ottawa Scale (NOS) for observational studies. NOS is composed of 3 components including selection, comparability, and outcome. The selection component includes sampling methods and representativeness while the comparability component includes adjustment for confounding variables. The outcome component involves the appropriateness of the outcome definition. The highest score which can be achieved in NOS is 9.

STATISTICAL ANALYSIS

For all the studies, we constructed 2 x 2 contingency table, then the sensitivity, specificity, DOR, PLR and NLR were calculated for each study. When more than one threshold was used by any of the included studies, the threshold with the largest Youden index was used in the analysis. The mentioned diagnostic parameters were pooled using the random effects model. In addition, the Summarized Receiver Operating Characteristic (SROC) curve was constructed using these diagnostic parameters. All the mentioned analysis except the SROC was conducted using Meta XL, version 5.3 (EpiGear International, Queensland, Australia). The SROC was generated using MetaDTA: Diagnostic Test Accuracy Meta-Analysis v2.01.[12]

RESULTS

The search yielded 1,553 articles, 75 of which were duplicates. The remaining 1,478 articles were screened using their title/abstract and 1,135 articles were excluded because they were reviews, case reports, editorials, laboratory studies and cadaveric studies. The rest of the articles (343 articles) were screened using their full-text form and 305 were excluded due to not using right sided heart catheterization as a reference (gold standard) for comparison, using other types of echocardiography (such as transesophageal echocardiography), combining another method with echocardiography, or not reporting the data regarding the diagnostic value of echocardiography. Finally, 38 articles were included in the analysis.[13-49] Supplementary figure 1 describes the study selection process.

THE DIAGNOSTIC VALUE OF ECHOCARDIOGRAPHY

Thirty eight studies were included in the analysis of investigating the diagnostic value of echocardiography (Figure 1). The overall sensitivity and specificity of echocardiography in diagnosing PH were 54.8% (95%CI: 45.7%-63.6%) and 52.1% (95%CI: 39.0%-64.9%), respectively. Moreover, the pooled DOR was 1.321 (95%CI: 0.695-2.51). The pooled PLR and NLR were 1.145 (95%CI: 0.830-1.579) and 0.867 (95%CI: 0.628-1.197), respectively. Supplementary table 2 summarizes the diagnostic value measures of echocardiography. The overall accuracy of echocardiography in establishing the diagnosis was 53.4%. Supplementary figure 2 demonstrates the SROC curve of echocardiography.

SUB-GROUP ANALYSIS

SUB-GROUP ANALYSIS FOR THE DIAGNOSTIC VALUE OF EXERCISE ECHOCARDIOGRAPHY

Four studies evaluated the diagnostic value of exercise echocardiography in diagnosing PH (Supplementary figure 3). The model that pooled these studies showed that the pooled sensitivity and specificity were 60.9% (95%CI: 39.4%-78.8%) and 32.8% (95%CI: 15.9%-55.8%), respectively. The false positive rate was 67.2% (95%CI: 44.2%-84.1%). Supplementary table 3 demonstrates the summary of diagnostic measures of exercise echocardiography in diagnosing PH. The overall accuracy of exercise echocardiography was 46.3%. Supplementary figure 4 shows the SROC curve of exercise echocardiography.

SUB-GROUP ANALYSIS FOR THE DIAGNOSTIC VALUE OF ECHOCARDIOGRAPHY AMONG PATIENTS WITH GROUP 1 PH

The model that evaluated the diagnostic value of echocardiography in diagnosing patients with group 1 PH included 8 studies (Supplementary figure 5). This model demonstrated that the pooled sensitivity and specificity were 68.5% (95%CI: 38.5%-88.4%) and 62.8% (95%CI: 24.8%-89.6%), respectively. The pooled diagnostic odds ratio was 3.684 (95%CI: 0.275-49.368). The pooled PLR and NLR were 1.844 (95%CI: 0.500-6.801) and 0.501 (95%CI: 0.134-1.872), respectively. Supplementary table 4 shows the summary measures of diagnostic value of echocardiography among patients with group 1 PH. The overall accuracy of echocardiography in diagnosing group 1 PH was 65.5%. Supplementary figure 6 demonstrates the SROC for echocardiography among patients with group 1 PH.

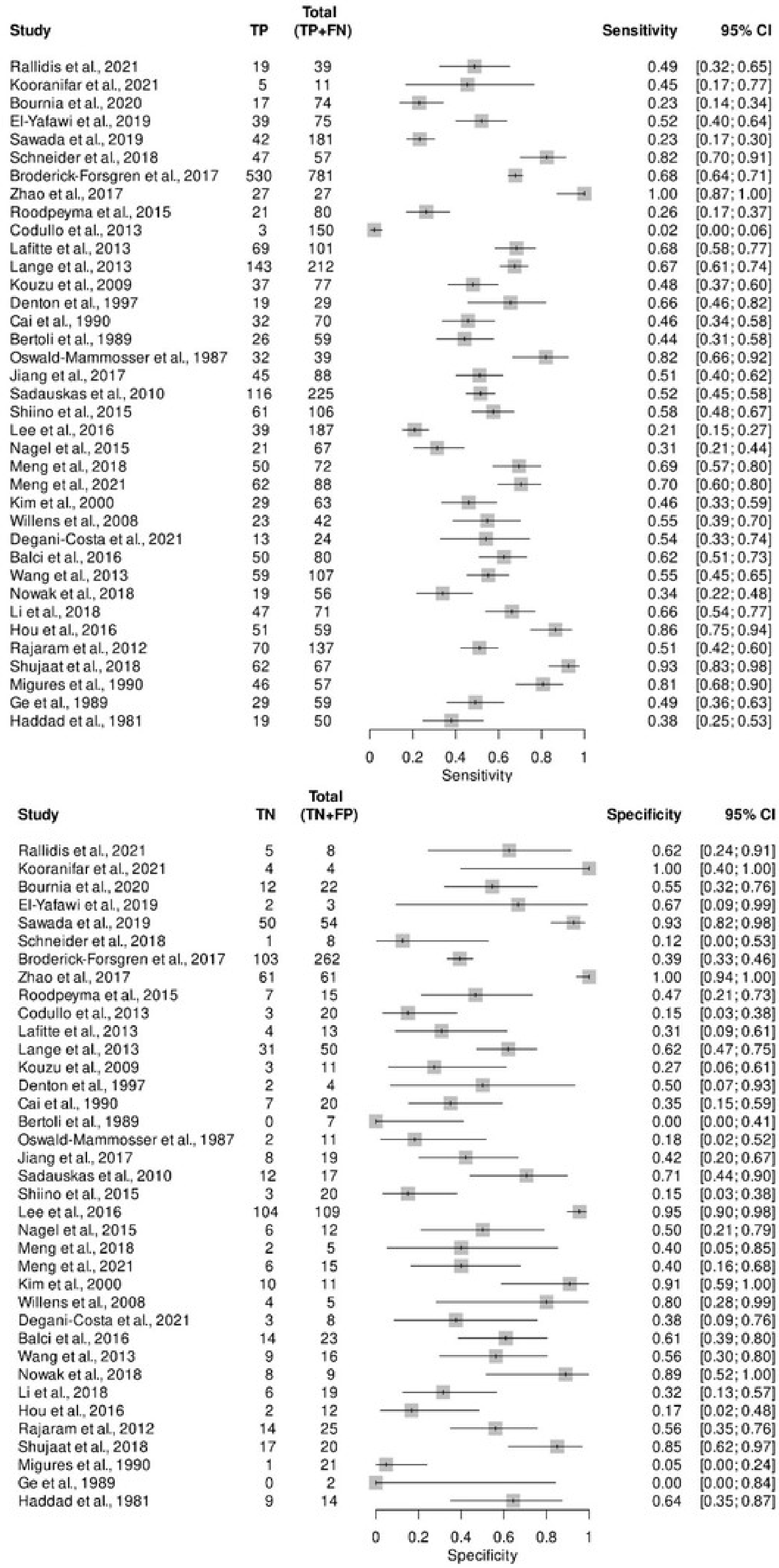

Figure 1. Meta-analysis for studies that were included in the Main Analysis.

SUB-GROUP ANALYSIS FOR THE DIAGNOSTIC VALUE OF ECHOCARDIOGRAPHY AMONG PATIENTS WITH GROUP 2 PH

Three studies evaluated the diagnostic value of echocardiography of group 2 PH (Supplementary figure 7). The model that pooled these studies revealed that the pooled sensitivity and specificity were 43.4% (95%CI: 3.4%-94.4%) and 53.0% (95%CI: 16.9%-86.2%). Furthermore, the pooled PLR and NLR were 0.924 (95%CI: 0.068-12.585) and 1.068 (95%CI: 0.129-8.82). Supplementary table 5 demonstrates the summary measures of the diagnostic value of echocardiography among patients with group 2 PH. The overall accuracy was 48.4%. Supplementary figure 8 shows the SROC curve of echocardiography in diagnosing patients with group 2 PH.

SUB-GROUP ANALYSIS FOR THE DIAGNOSTIC VALUE OF ECHOCARDIOGRAPHY AMONG PATIENTS WITH GROUP 3 PH

Eight studies investigated the diagnostic value of echocardiography of group 3 PH (Supplementary figure 9). The model that pooled these studies showed that the pooled sensitivity and specificity were 47.1% (95%CI: 35.3%-59.1%) and 65.3% (95%CI: 44.8%-81.3%), respectively. The overall DOR was 1.672 (95%CI: 0.906-3.086). The PLR and NLR were 1.356 (95%CI: 0.897-2.05) and 0.811 (95%CI: 0.656-1.002), respectively. Supplementary table 6 presents the summary measures of the diagnostic values of echocardiography in diagnosing group 3 PH. The pooled accuracy of echocardiography in diagnosing group 3 PH was 56.5%. Supplementary figure 10 demonstrates the SROC curve of echocardiography among patients with group 3 PH.

SUB-GROUP ANALYSIS FOR THE DIAGNOSTIC VALUE OF ECHOCARDIOGRAPHY AMONG PATIENTS WITH GROUP 4 PH

The model that evaluated the diagnostic value of echocardiography in diagnosing group 4 PH included 4 studies (Supplementary figure 11). This model showed that the pooled sensitivity and specificity were 55.4% (95%CI: 23.1%-83.7%) and 44.5% (95%CI: 4.8%-92.8%), respectively. The pooled PLR and NLR of echocardiography among patients with group 4 PH were 0.998 (95%CI: 0.478-2.081) and 1.003 (95%CI: 0.400-2.514) (Supplementary table 7). The overall accuracy of echocardiography in diagnosing patients with group 4 PH was 49.8% (Supplementary figure 12).

CHARACTERISTICS OF THE INCLUDED STUDIES

The total number of the included patients was 4,523 from 38 articles. The prevalence of PH in the included patients was 48.2% (2,181/4,523). The majority of the studies investigated the diagnostic value of resting echocardiography (89.5%) while 10.5% (4/38) evaluated the diagnostic value of exercise echocardiography. Moreover, 21.1% of the studies included patients with group 1 PH while 7.9%, 21.1%, and 7.9% of the studies included patients with group 2, group 3, and group 4 pulmonary hypertension, respectively. Supplementary table 1 shows the characteristics of the included studies.

QUALITY ASSESSMENT OF THE INCLUDED STUDIES

The majority of the included studies (76.3%) had a good score in the NOS (>5). The highest score (9/9) was achieved by 18.4% of the included studies (7/38). On the other hand, 7.9% of the included studies had the lowest score (4/9). The detailed results of NOS assessment of the included studies are described in Supplementary table 1.

DISCUSSION

The aim of this study was to evaluate the sensitivity, specificity, PLR, NLR, DOR, and accuracy of TTE in comparison to right heart catheterization (reference). The overall sensitivity and specificity of echocardiography in diagnosing PH were 54.8% and 52.1%, respectively. The pooled DOR was 1.321 while the pooled PLR and NLR were 1.145 and 0.867, respectively. The overall accuracy of echocardiography in establishing the diagnosis of PH was 53.4%. Exercise echocardiography increased sensitivity to 60.9% but specificity decreased to 32.8%. The overall accuracy of exercise echocardiography was also lower than resting echocardiography (46.3%).

Previous meta-analyses showed that the sensitivity and specificity of TTE was around 80% and 70%, respectively.[3,10,50,51] In addition, these studies showed that the overall accuracy was higher than 70% in the main analysis. These findings contradict the results of our analysis models that demonstrated lower sensitivity, specificity, and accuracy. These contradictions can be explained by the fact that these meta-analyses included lower number of studies and patients which might have resulted in an overestimation of the diagnostic measures of echocardiography. The most recent meta-analysis conducted by the Cochrane collaboration only included 17 studies with total sample size of 3,656 patients[52] while the largest meta-analysis of the aforementioned ones included 27 studies.[48] In comparison, our study searched databases up to the end of January 2023 and included larger number of studies (38 studies) and sample size (4,523 patients). Thus, our results are considered more reliable and precise with lower confidence intervals.

The DOR is one of the indicators of test accuracy[53] which pools data from sensitivity and specificity into a single measure. Higher values of DOR indicate better discriminatory test performance. A DOR of 1 suggests that the test does not discriminate between patients with and those without the disease.[53] In our study, the pooled TTE DOR was low indicating low overall accuracy of the test. Although SROC and DOR are very important measures for diagnostic tools, they are not easily integrated into clinical practice.[54] Thus, we also presented PLR and NLR as diagnostic measures. Our analysis showed that the PLR was 1.145, indicating that patients with PH have a mere 1.15 fold higher likelihood of having a positive TTE compared to controls, which is considered a very low probability to confirm the diagnosis of PH. On the other hand, NLR was found to be 0.867 indicating that if the TTE result for any individual is negative, the probability that this individual has PH is higher than 85%. This can be explained by the fact that the population included in the studies comprised of a group of high-risk patients for having PH which indicates that TTE has low diagnostic performance among this group. Future studies are recommended to study the correlation between TTE and right sided heart catheterization among low-risk patients to study the performance of echocardiography among the population with a low probability of having PH.

TTE had the highest sensitivity, specificity, DOR and PLR as well as the lowest NLR among patients with group 1 PH, who were mainly patients with connective tissue diseases. The overall accuracy in this group of patients was 65.5% indicating that TTE is a relatively accurate method in diagnosing PH among this group. TTE had lower sensitivity but higher specificity in diagnosing group 3 PH patients. The pooled accuracy among this group of patients was 56.5%, which is still higher than the cut off point of 50% for evaluating the accuracy of diagnostic tools. On the other hand, the accuracy of TTE among group 2 and group 4 PH patients was very low (below 50%). Also, the NLR among these groups of patients was higher than the PLR. These findings were similar to previous studies that indicated that the accuracy of echocardiography in diagnosing PH among patients with lung diseases is low.[10,50] The plausible explanation behind these findings is that changes associated with chronic pulmonary diseases, including a marked increase in intrathoracic gas, consolidation of lung tissue, expansion of the thoracic cage and alteration in the position of the heart might decrease the imaging quality and the parameters measurement of TTE.[51] Consequently, the use of TTE to measure pulmonary pressure among this group of patients might not be a valid method. However, it is important to highlight that a lower number of studies included patients with group 2 and 4 PH compared to group 1 and 3 which emphasize the need for conducting further studies among patients in these two groups of PH. Previous meta-analyses did not perform subgroup analysis according to the PH WHO grouping.

Several limitations are present in our study. First, a systematic review and meta-analysis is a secondary research method based on original studies. Although the majority of the included studies had a good quality score according to NOS, the low quality of some of the included studies might impact our results. Second, echocardiography relies heavily on the operator's ability, experience, and operational discipline which might differ between the included studies. Another limitation is that we did not perform sensitivity analysis for parameters used to diagnose PH, yet a previous meta-analysis showed that using different parameters did not affect the performance of echocardiography.[10] Furthermore, despite conducting subgroup analyses on the level of PH groups, some of the included studies did not describe the basic disease and PH type in detail among the included patients. In addition, due to lack of data in the included studies, we were not able to conduct subgroup analyses according to pulmonary hypertension severity grading. Lastly, the low sensitivity and specificity found with TTE might be attributed to it being an operator dependent tool. The included studies did not investigate the inter-rater reliability; thus, we were not able to consider such factor in our analysis. Future studies are recommended to investigate this limitation of TTE in diagnosing pulmonary hypertension.

In conclusion, this is the largest and most updated systematic review and meta-analysis to evaluate the diagnostic performance of TTE in diagnosing pulmonary hypertension compared to right sided heart catheterization as a reference method. Our analysis revealed that TTE had low diagnostic sensitivity, specificity, and accuracy. The highest diagnostic measures for TTE were among WHO group 1 and group 3 PH patients as the accuracy was higher than 50%. On the other hand, TTE had a poor diagnostic performance among WHO groups 2 and 4 PH patients, indicating that using it among these groups of patients may not be reliable or valid. Considering the limitations, echocardiography might be a useful and non-invasive modality for measuring pulmonary artery pressure among group 1 and 3 PH patients. Also, it may be useful for first line surveillance in patients with a low risk of PH. However, the diagnosis of PH and the assessment of response to therapies require right sided heart catheterization due to the overall poor diagnostic performance of TTE. Future prospective large scale well-conducted studies that aim to improve the diagnostic performance of TTE in the diagnosis of PH are needed.

CONTRIBUTION

TNA and DJD were involved in Conceptualization; AAT and TNA were involved in Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, and Writing the original draft; JPV and DJD was involved in Supervision and Reviewing & Editing the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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REFERENCES

1. Hoeper MM et al. A global view of pulmonary hypertension. *Lancet Respir Med*. 2016;4(4):306-322. doi:10.1016/S2213-2600(15)00543-3

2. Galiè N et al. Treatment of patients with mildly symptomatic pulmonary arterial hypertension with bosentan (EARLY study): a double-blind, randomised controlled trial. *Lancet*. 2008;371(9630):2093-2100. doi:10.1016/S0140-6736(08)60919-8

3. Galiè N et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. 2015;73(12):1127-1206. doi:10.5603/KP.2015.0242

4. Hoeper MM et al. Complications of right heart catheterization procedures in patients with pulmonary hypertension in experienced centers. *J Am Coll Cardiol*. 2006;48(12):2546-2552. doi:10.1016/j.jacc.2006.07.061

5. Chemla D et al. Haemodynamic evaluation of pulmonary hypertension. *Eur Respir J*. 2002;20(5):1314-1331. doi:10.1183/09031936.02.00068002

6. Topyła-Putowska W et al. Echocardiography in Pulmonary Arterial Hypertension: Comprehensive Evaluation and Technical Considerations. *J Clin Med*. 2021;10(15). doi:10.3390/jcm10153229

7. Janda S et al. Diagnostic accuracy of echocardiography for pulmonary hypertension: a systematic review and meta-analysis. *Heart*. 2011;97(8):612-622. doi:10.1136/hrt.2010.212084

8. Taleb M et al. The diagnostic accuracy of Doppler echocardiography in assessment of pulmonary artery systolic pressure: a meta-analysis. *Echocardiography*. 2013;30(3):258-265. doi:10.1111/echo.12061

9. Zhang RF et al. Diagnostic value of transthoracic Doppler echocardiography in pulmonary hypertension: a meta-analysis. *Am J Hypertens*. 2010;23(12):1261-1264. doi:10.1038/ajh.2010.188

10. Ni JR et al. Diagnostic accuracy of transthoracic echocardiography for pulmonary hypertension: a systematic review and meta-analysis. *BMJ Open*. 2019;9(12):e033084. doi:10.1136/bmjopen-2019-033084

11. Maron BA. Revised Definition of Pulmonary Hypertension and Approach to Management: A Clinical Primer. 2023;12(8):e029024. doi:10.1161/JAHA.122.029024

12. Patel A et al. Graphical enhancements to summary receiver operating characteristic plots to facilitate the analysis and reporting of meta-analysis of diagnostic test accuracy data. *Res Synth Methods*. 2021;12(1):34-44. doi:10.1002/jrsm.1439

13. Rallidis LS et al. The role of exercise doppler echocardiography to unmask pulmonary arterial hypertension in selected patients with systemic sclerosis and equivocal baseline echocardiographic values for pulmonary hypertension. *Diagnostics*. 2021;11(7). doi:10.3390/diagnostics11071200

14. Kooranifar S et al. Diagnostic value of chest spiral ct scan and doppler echocardiography compared to right heart catheterization to predict pulmonary arterial hypertension in patients with scleroderma. *Acta Biomedica*. 2021;92(1):1-6.

15. Bournia VK et al. Cardiac catheterization versus echocardiography for monitoring pulmonary pressure: A prospective study in patients with connective tissue disease-associated pulmonary arterial hypertension. *Diagnostics*. 2020;10(1). doi:10.3390/diagnostics10010049

16. El-Yafawi R et al. Pulmonary hypertension subjects exhibit right ventricular transient exertional dilation during supine exercise stress echocardiography. *Pulmonary Circulation*. 2019;9(2). doi:10.1177/2045894019851904

17. Schneider M et al. Multi-view approach for the diagnosis of pulmonary hypertension using transthoracic echocardiography. *International Journal of Cardiovascular Imaging*. 2018;34(5):695-700.

18. Sawada N et al. Detection of pulmonary hypertension with systolic pressure estimated by doppler echocardiography comparison with invasive mean pulmonary artery pressure. *International Heart Journal*. 2019;60(4):836-844. doi:10.1536/ihj.18-453

19. Roodpeyma S et al. Accuracy of electrocardiography and echocardiography in the assessment of pulmonary arterial hypertension in patients with congenital heart disease. *Iranian Heart Journal*. 2015;15(4):20-25.

20. Codullo V et al. Stress doppler echocardiography in systemic sclerosis: Evidence for a role in the prediction of pulmonary hypertension. *Arthritis and Rheumatism*. 2013;65(9):2403-2411. doi:10.1002/art.38043

21. Lafitte S et al. Estimation of pulmonary pressures and diagnosis of pulmonary hypertension by doppler echocardiography: A retrospective comparison of routine echocardiography and invasive hemodynamics. *Journal of the American Society of Echocardiography*. 2013;26(5):457-463. doi:10.1016/j.echo.2013.02.002

22. Lange TJ et al. Qualitative echocardiography parameters for prediction of pulmonary hypertension. *International Journal of Clinical Practice*. 2013;67(SUPPL. 179):5-12. doi:10.1111/ijcp.12068

23. Kouzu H et al. Noninvasive Estimation of Pulmonary Vascular Resistance by Doppler Echocardiography in Patients With Pulmonary Arterial Hypertension. *American Journal of Cardiology*. 2009;103(6):872-876. doi:10.1016/j.amjcard.2008.11.039

24. Denton CP et al. Comparison of Doppler echocardiography and right heart catheterization to assess pulmonary hypertension in systemic sclerosis. *British Journal of Rheumatology*. 1997;36(2):239-243. doi:10.1093/rheumatology/36.2.239

25. Cai HR. Diagnosis of pulmonary hypertension secondary to obstructive lung disease by M-mode echocardiography contrasting with right cardiac catheterization. *Zhonghua jie he he hu xi za zhi = Zhonghua jiehe he huxi zazhi = Chinese journal of tuberculosis and respiratory diseases*. 1990;13(5):264-267.

26. Bertoli L et al. Value of two-dimensional echocardiography in the identification of pulmonary hypertension in chronic obstructive lung disease. *Respiration*. 1989;55(4):193-201. doi:10.1159/000195734

27. Oswald-Mammosser M et al. Non-invasive diagnosis of pulmonary hypertension in chronic obstructive pulmonary disease. Comparison of ECG, radiological measurements, echocardiography and myocardial scintigraphy. *European Journal of Respiratory Diseases*. 1987;71(5):419-429.

28. Shujaat A et al. Diagnostic accuracy of echocardiography combined with chest CT in pulmonary hypertension. *Clin Respir J*. 2018;12(3):948-952. doi:10.1111/crj.12610

29. Miguéres M et al. Pulsed Doppler echocardiography in the diagnosis of pulmonary hypertension in COPD. *Chest*. 1990;98(2):280-285. doi:10.1378/chest.98.2.280

30. Ge ZM, Zhang Y, Gao DC. [Diagnosis of pulmonary hypertension by pulsed Doppler echocardiography--comparison with cardiac catheterization]. *Zhonghua Nei Ke Za Zhi*. 1989;28(8):460-462.

31. Haddad KA, Lebeau R, Tremblay G. Use of echocardiography in the diagnosis of pulmonary hypertension. *Acta Cardiol*. 1981;36(1):21-34.

32. Jiang R et al. A novel scoring index by Doppler echocardiography for predicting severe pulmonary hypertension due to chronic lung diseases: a cross-sectional diagnostic accuracy study. *Int J Chron Obstruct Pulmon Dis*. 2017;12:1741-1751. doi:10.2147/COPD.S133854

33. Sadauskas S et al. Comparison of non-invasive methods–impedance cardiography and 2-dimentional transthoracic echocardiography applied for diagnostics of pulmonary artery hypertension. 2010;105(9):105-108.

34. Shiino K et al. Usefulness of right ventricular basal free wall strain by two-dimensional speckle tracking echocardiography in patients with chronic thromboembolic pulmonary hypertension. *Int Heart J*. 2015;56(1):100-104. doi:10.1536/ihj.14-162

35. Lee SE et al. Screening of Mechanical Complications of Dilated Pulmonary Artery Related to the Risk for Sudden Cardiac Death in Patients with Pulmonary Arterial Hypertension by Transthoracic Echocardiography. *J Am Soc Echocardiogr*. 2016;29(6):561-566. doi:10.1016/j.echo.2016.02.002

36. Rallidis LS et al. Low-Dose Dobutamine Stress Echocardiography for the Early Detection of Pulmonary Arterial Hypertension in Selected Patients with Systemic Sclerosis Whose Resting Echocardiography Is Non-Diagnostic for Pulmonary Hypertension. *J Clin Med*. 2021;10(17). doi:10.3390/jcm10173972

37. Nagel C et al. Stress Doppler echocardiography for early detection of systemic sclerosis-associated pulmonary arterial hypertension. *Arthritis Res Ther*. 2015;17(1):165. doi:10.1186/s13075-015-0673-7

38. Meng X et al. Three-dimensional echocardiography to evaluate right atrial volume and phasic function in pulmonary hypertension. *Echocardiography*. 2018;35(2):153-161. doi:10.1111/echo.13761

39. Meng H et al. Right Ventricular Diastolic Performance in Patients With Chronic Thromboembolic Pulmonary Hypertension Assessed by Echocardiography. *Front Cardiovasc Med*. 2021;8:755251.

40. Kim WR et al. Accuracy of Doppler echocardiography in the assessment of pulmonary hypertension in liver transplant candidates. *Liver Transpl*. 2000;6(4):453-458. doi:10.1053/jlts.2000.7573

41. Willens HJ et al. Noninvasive differentiation of pulmonary arterial and venous hypertension using conventional and Doppler tissue imaging echocardiography. *J Am Soc Echocardiogr*. 2008;21(6):715-719. doi:10.1016/j.echo.2007.10.003

42. Degani-Costa LH et al. Accuracy of echocardiography and chest tomography for pulmonary hypertension screening in patients awaiting lung transplantation. *Einstein (Sao Paulo)*. 2021;19:eAO5710. doi:10.31744/einstein_journal/2021AO5710

43. Balcı MK et al. Assessment of Pulmonary Hypertension in Lung Transplantation Candidates: Correlation of Doppler Echocardiography With Right Heart Catheterization. *Transplant Proc*. 2016;48(8):2797-2802. doi:10.1016/j.transproceed.2016.06.055

44. Wang B et al. Accuracy of Doppler echocardiography in the assessment of pulmonary arterial hypertension in patients with congenital heart disease. *Eur Rev Med Pharmacol Sci*. 2013;17(7):923-928.

45. Nowak J et al. Pulmonary hypertension in advanced lung diseases: Echocardiography as an important part of patient evaluation for lung transplantation. *Clin Respir J*. 2018;12(3):930-938. doi:10.1111/crj.12608

46. Li AL et al. The value of speckle-tracking echocardiography in identifying right heart dysfunction in patients with chronic thromboembolic pulmonary hypertension. *Int J Cardiovasc Imaging*. 2018;34(12):1895-1904. doi:10.1007/s10554-018-1423-0

47. Hou Y et al. Clinical Application of Superior Vena Cava Spectra in Evaluation of Pulmonary Hypertension: A Comparative Echocardiography and Catheterization Study. *Ultrasound Med Biol*. 2016;42(1):110-117. doi:10.1016/j.ultrasmedbio.2015.07.029

48. Rajaram S et al. Comparison of the diagnostic utility of cardiac magnetic resonance imaging, computed tomography, and echocardiography in assessment of suspected pulmonary arterial hypertension in patients with connective tissue disease. *J Rheumatol*. 2012;39(6):1265-1274. doi:10.3899/jrheum.110987

49. Zhao QH et al. Cardiopulmonary exercise testing improves diagnostic specificity in patients with echocardiography-suspected pulmonary hypertension. *Clinical Cardiology*. 2017;40(2):95-101. doi:10.1002/clc.22635

50. Arcasoy SM et al. Echocardiographic assessment of pulmonary hypertension in patients with advanced lung disease. *Am J Respir Crit Care Med*. 2003;167(5):735-740. doi:10.1164/rccm.200210-1130OC

51. Galderisi M et al. Standardization of adult transthoracic echocardiography reporting in agreement with recent chamber quantification, diastolic function, and heart valve disease recommendations: an expert consensus document of the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging*. 2017;18(12):1301-1310. doi:10.1093/ehjci/jex244

52. Tsujimoto Y et al. Doppler trans-thoracic echocardiography for detection of pulmonary hypertension in adults. *Cochrane Database of Systematic Reviews*. 2022;(5). doi:10.1002/14651858.CD012809.pub2

53. Glas AS et al. The diagnostic odds ratio: a single indicator of test performance. *J Clin Epidemiol*. 2003;56(11):1129-1135. doi:10.1016/S0895-4356(03)00177-X

54. Gallagher EJ. Clinical utility of likelihood ratios. *Ann Emerg Med*. 1998;31(3):391-397. doi:10.1016/S0196-0644(98)70352-X

SUPPLEMENTARY MATERIALS

Supplementary Material

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