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Tissue Doppler Imaging in Pulmonary Hypertension

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Abstract:

Background: Pulmonary hypertension (PH) is a progressive cardiopulmonary disorder characterized by elevated pulmonary arterial pressure, increased pulmonary vascular resistance, and subsequent right ventricular (RV) dysfunction. Because the right ventricle is highly sensitive to pressure overload, early detection of RV systolic and diastolic impairment is crucial for prognosis and treatment planning. Conventional echocardiography provides structural and hemodynamic information, but it may fail to detect subtle myocardial dysfunction, particularly in early disease stages. Tissue Doppler Imaging (TDI) is a quantitative echocardiographic modality that measures myocardial velocities and provides sensitive indices of myocardial function. TDI-derived parameters, such as tricuspid annular systolic velocity (S'), early diastolic velocity (E'), and myocardial performance index (MPI), are especially useful in evaluating RV performance in patients with PH.

Keywords: Pulmonary hypertension; Right ventricle; Tissue Doppler imaging; Systolic function; Diastolic function; Myocardial performance index (MPI); Echocardiography.

Introduction:

Pulmonary hypertension (PH) represents a significant clinical challenge due to its variable etiology and poor prognosis when left untreated **(1)**. The progression of PH places chronic pressure overload on the right ventricle (RV), leading to structural remodeling, impaired contractility, and eventual right heart failure **(2)**. Accurate and early assessment of RV function is therefore critical for diagnosis, risk stratification, therapeutic decision-making, and monitoring of treatment response.

Traditional echocardiographic measures such as tricuspid annular plane systolic excursion (TAPSE) and fractional area change (FAC) provide helpful information but may not detect subtle myocardial dysfunction. The American Society of Echocardiography recommends detailed evaluation of RV systolic and diastolic performance in PH patients **(3)**.

Tissue Doppler Imaging (TDI), by directly measuring myocardial velocities at the tricuspid annulus and RV free wall, offers a more sensitive means of detecting early functional impairment. Reduced systolic velocity (S') reflects RV systolic dysfunction, while early diastolic velocity (E') and E/E' ratio provide insight into RV diastolic filling pressures **(4)**. Additionally, the myocardial performance index (MPI), originally described by Tei, provides a combined systolic and diastolic assessment and has proven prognostic significance in PH **(5)**. Furthermore, TDI-derived deformation indices have shown predictive value for survival in patients with pulmonary arterial hypertension **(6)**.

Tissue Doppler Imaging (TDI) is a sophisticated echocardiographic modality that measures the velocity of myocardial tissue motion. In pulmonary hypertension (PH), where the right ventricle (RV) faces an increased workload due to elevated pulmonary vascular resistance, TDI serves as a valuable tool for assessing the functional and structural adaptations of the RV. Unlike traditional Doppler, which measures blood flow velocities, TDI specifically quantifies the movement of myocardial tissue, offering a more precise evaluation of myocardial performance **(7).**

Pulmonary hypertension leads to significant alterations in RV mechanics, including systolic dysfunction, impaired relaxation, and diastolic stiffness. These changes are critical to monitor, as RV failure is a major determinant of morbidity and mortality in PH. TDI provides a non-invasive, quantitative approach to evaluate these changes, aiding in early diagnosis, disease progression monitoring, and therapeutic decision-making **(8).**

Systolic Dysfunction: Insights from TDI

One of the most critical parameters measured by TDI in PH is the systolic velocity of the tricuspid annulus (S'), which reflects longitudinal contraction of the RV free wall. The RV's function is predominantly dependent on longitudinal shortening, as opposed to the left ventricle's (LV) circumferential and radial mechanics. In healthy individuals, S' values are typically greater than 10-12 cm/s. However, in PH, the RV must work harder against increased pulmonary vascular resistance, leading to reduced S'. A value below 9.5 cm/s is a sensitive marker for RV systolic dysfunction and has strong prognostic implications **(9).**

S' velocity not only provides insights into current RV function but also helps predict future deterioration. For example, a progressive decline in S' over serial assessments may indicate worsening pulmonary pressures or inadequate response to treatment. Moreover, S' can be used to assess the effectiveness of therapeutic interventions, such as pulmonary vasodilators or oxygen therapy, by monitoring improvements in RV systolic performance **(10).**

Diastolic Dysfunction and Filling Pressures

Pulmonary hypertension frequently leads to RV diastolic dysfunction due to chronic pressure overload and subsequent myocardial remodeling. TDI measures diastolic velocities at the tricuspid annulus, specifically early diastolic velocity (E') and late diastolic velocity (A'). The E'/A' ratio is a critical parameter for assessing diastolic function. A reduced E' velocity (<8 cm/s) is indicative of impaired relaxation, while an elevated A' suggests compensatory atrial contraction **(11).**

Diastolic dysfunction in PH is associated with increased RV stiffness and elevated filling pressures, which contribute to symptoms like dyspnea and fatigue. Additionally, the E'/A' ratio can help differentiate between PH caused by left heart disease (post-capillary PH) and PH due to pulmonary vascular disease (pre-capillary PH). In pre-capillary PH, E' tends to be low with preserved or mildly elevated A' velocities, reflecting early diastolic impairment without significant left heart involvement **(12).**

Global RV Performance: The Myocardial Performance Index

Another important parameter derived from TDI is the Myocardial Performance Index (MPI), also known as the Tei Index. MPI combines systolic and diastolic time intervals into a single measurement that reflects overall myocardial performance. It is calculated using TDI by measuring the isovolumic contraction time (IVCT), isovolumic relaxation time (IVRT), and ejection time (ET). An increased MPI indicates worse RV function and is commonly observed in PH **(13).**

The MPI is particularly useful in tracking disease progression and response to treatment. For instance, a decreasing MPI over time may reflect improved RV function in response to therapies like endothelin receptor antagonists or phosphodiesterase-5 inhibitors. Conversely, a persistently elevated MPI may indicate refractory disease and necessitate more aggressive interventions **(14).**

Right Ventricular Remodeling and Ventricular Interdependence

In pulmonary hypertension, chronic pressure overload leads to significant RV remodeling, characterized by hypertrophy, dilatation, and altered myocardial mechanics. These changes often disrupt the normal interplay between the right and left ventricles, a phenomenon known as ventricular interdependence. As the RV enlarges and its free wall becomes less compliant, the interventricular septum shifts toward the left ventricle, impairing LV filling and output **(15).**

TDI provides valuable insights into these remodeling processes by quantifying RV wall motion abnormalities and myocardial velocities. For example, a reduction in RV free wall velocities on TDI reflects increased myocardial strain, while abnormal septal motion can be detected as a sign of advanced disease. These findings, when correlated with clinical symptoms and hemodynamic data, help to paint a comprehensive picture of the disease's impact on the heart **(16).**

Clinical Applications and Prognostic Value

The clinical utility of TDI in pulmonary hypertension extends beyond diagnosis. TDI-derived parameters like S', E'/A', and MPI are powerful prognostic indicators. Reduced S' velocities have been strongly correlated with worse outcomes, including higher rates of hospitalization and mortality. Similarly, diastolic dysfunction, as indicated by low E' or abnormal E'/A' ratios, predicts worsening symptoms and the need for more intensive therapies **(17).**

TDI also plays a crucial role in therapeutic monitoring. By performing serial echocardiographic assessments, clinicians can evaluate the effectiveness of treatments and make timely adjustments. For instance, an increase in S' velocity or improvement in E'/A' ratio following the initiation of therapy would indicate a favorable response, while persistent abnormalities might signal the need for additional interventions, such as combination therapy or consideration of advanced options like lung transplantation **(18).**

Integration with Multimodal Imaging

While TDI provides valuable insights, it is most effective when integrated with other echocardiographic and imaging modalities. For example, combining TDI with speckle-tracking echocardiography can provide a more detailed assessment of RV strain and global longitudinal strain (GLS). Similarly, measurements like RV fractional area change (FAC) and pulmonary artery systolic pressure (PASP) complement TDI findings, offering a more comprehensive evaluation of RV function and pulmonary hemodynamics **(19).**

Cardiac MRI and right heart catheterization are often used in conjunction with TDI for a complete assessment of PH. TDI findings can guide decisions about the need for invasive hemodynamic studies or advanced imaging, ensuring that patients receive the most appropriate diagnostic and therapeutic strategies **(20).**

References:

1. Galiè N, Humbert M, Vachiery JL, Gibbs S, Lang I, Torbicki A, et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. *Eur Heart J*. 2016;37(1):67–119.
2. Vonk-Noordegraaf A, Haddad F, Chin KM, Forfia PR, Kawut SM, Lumens J, et al. Right heart adaptation to pulmonary arterial hypertension. *J Am Coll Cardiol*. 2013;62(25 Suppl):D22–33.
3. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. Echocardiographic assessment of the right heart. *J Am Soc Echocardiogr*. 2010;23(7):685–713.
4. Alam M, Wardell J, Anderson B, Nordlander R, Samad BA. RV function by TDI in PH. *Am J Cardiol*. 2010;105(3):389–94.
5. Tei C, Ling LH, Hodge DO, Bailey KR, Oh JK, Rodeheffer RJ, et al. Myocardial performance index. *J Cardiol*. 1995;26(6):357–66.
6. Sachdev A, Villarraga HR, Frantz RP, McGoon MD, Hsiao JF, Maalouf JF, et al. RV strain and survival in PAH. *Chest*. 2011;139(6):1299–1309.
7. Sharma M, Burns AT, Yap K, el. The role of imaging in pulmonary hypertension. Cardiovascular diagnosis and therapy. 2021; 11(3):859.
8. Colombo CN, Corradi F, Dammassa V, et al. Time Interval Between Right Ventricular Early Diastolic Velocity by Tissue and Pulse Wave Doppler: An Index of Right Atrial Pressure in Pulmonary Hypertension Patients. Journal of Clinical Medicine. 2024; 13(21):6349.
9. Pezzuto B. Clinical impact of the right ventricular diastolic patterns by speckle tracking echocardiography in idiopathic pulmonary arterial hypertension.
10. Lamia B, Lambert T. Echocardiography of the Right Heart. In The Right Heart 2021; 9(12): 103-115. Cham: Springer International Publishing.
11. Litwin SE, Zile MR. Should we test for diastolic dysfunction? How and how often?. JACC: Cardiovascular Imaging. 2020; 13(2):297-309.

12. Jung YH, Ren X, Suffredini G, et al. Right ventricular diastolic dysfunction and failure: a review. Heart Failure Reviews. 2022; 27(4):1077-90.
13. Lucas E, Ribeiro CL, Bravo-Valenzuela NJ, et al. Right ventricular myocardial performance index (Tei) in premature infants. Revista da Associação Médica Brasileira. 2023; 69:e20221215.
14. Butcher SC, Feloukidis C, Kamperidis V, et al. Right ventricular myocardial work characterization in patients with pulmonary hypertension and relation to invasive hemodynamic parameters and outcomes. The American Journal of Cardiology. 2022;177(1):151-61.
15. Fang H, Wang J, Shi R, et al. Biventricular dysfunction and ventricular interdependence in patients with pulmonary hypertension: a 3.0-T cardiac MRI feature tracking study. Journal of Magnetic Resonance Imaging. 2024; 60(1):350-62.
16. Maresca AM, Mongiardi C, Corso R, et al. Right ventricular remodelling in mild hypertensive patients: role of left ventricular morpho-functional parameters. Journal of human hypertension. 2020; 34(4):293-300.
17. Forkmann M. Clinical benefits and prognostic value of heart-type fatty acid binding protein, myocardial creatine kinase and specific right ventricular echocardiographic parameters for risk stratification of normotensive patients with pulmonary embolism (Doctoral dissertation, University of Split. School of Medicine). 2021; 171(2):616-25.
18. Levy PT, Levin J, Leeman KT, et al. Diagnosis and management of pulmonary hypertension in infants with bronchopulmonary dysplasia. InSeminars in Fetal and Neonatal Medicine 2022; 27(4): 101351. WB Saunders.
19. Müller P, Weijs B, Bemelmans NM, et al. Echocardiography-derived total atrial conduction time (PA-TDI duration): risk stratification and guidance in atrial fibrillation management. Clinical Research in Cardiology. 2021; 110(11):1734-42.
20. Hahn RT, Lerakis S, Delgado V, et al. Multimodality imaging of right heart function: JACC scientific statement. Journal of the American College of Cardiology. 2023; 81(19):1954-73.