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LETTER TO THE EDITOR

Artificial Intelligence-Based Assessment of Left Ventricular Filling Pressures From 2-Dimensional Cardiac Ultrasound Images

The estimation of left ventricular (LV) filling pressure from the ratio of transmitral and annular velocities (E/e′) is used commonly for identifying diastolic dysfunction in patients who complain of exertional dyspnea (1). We have recently illustrated that LV and left atrial speckle tracking echocardiography (STE)-derived measurements have similar information content as do conventional 2-dimensional and Doppler methods for characterizing LV diastolic dysfunction (2). Therefore, an alternative approach could be to use an automated approach in which myocardial deformation variables with machine learning (ML) models deliver a rapid decision support system from just 2-dimensional cardiac ultrasound images for deriving the same level of information regarding left ventricular filling pressures (LVFP) as provided by E/e′.

We explored the development and validation of an ML model for assessing LVFP in 174 patients. The details regarding these subjects have been previously described (2). The study sample size was split into an ML training group of 130 patients (75%) and an ML testing group of 44 (25%) who also had the pulmonary capillary wedge pressure invasively measured using right cardiac catheterization. Patients were classified as elevated or reduced LVFP, as suggested by the echocardiographic ratio between early diastolic mitral flow velocities to early diastolic mitral annular velocity averaged from the septal and lateral positions (E/e′) ≥13. An ensemble model of ML algorithms was then applied to the STE data for the prediction of elevated LVFP. The models output in the testing sets were also verified for identification of elevated pulmonary capillary wedge pressure (≥18 mm Hg) (3).

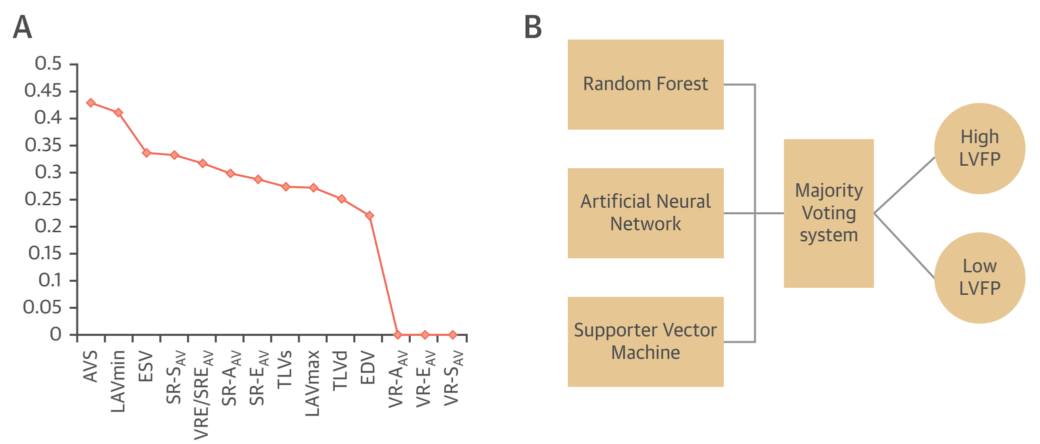
Fourteen STE variables derived from parameters of the atrioventricular (AV) deformation, chamber volume, and volume expansion (**Figure 1A**) were used to build the ML model. The model was developed using a "majority voting" method combined from random forests, artificial neural networks, and support vector machines so that a patient was assigned the diagnosis of elevated LVFP if ≥2 ML models show this diagnosis (**Figure 1B**). To assess sample-induced bias and error rates; the final results are reported based on 10-fold cross-validation.

Feature relevance for STE parameters used in the ML algorithm was derived using information gain criterion and ranked using Ranker method (**Figure 1A**). Receiver-operating characteristic curves were compiled to evaluate the models. The overall accuracy of our model was based on area under the curve. Statistical analyses were performed using R: a language and environment for statistical computing (version 3.1.2, R Foundation, Vienna, Austria). ML algorithms and feature selection methods were implemented using R packages and Weka (Open source software issued under the GNU General Public License).

Using the full set of STE features ($n = 14$), a 10-fold cross-validation showed a strong predictive ability of ML model for elevated LVFP (areas under the curve: training cohort = 0.847, testing cohort = 0.868). Based on the information gained, 11 features were found to best predict LVFP. Consistent with theoretical estimations, our ML models were found to perform better using this reduced set of features ($n = 11$), yielding areas under the curve of 0.853 and 0.881 for training and testing sets, respectively. In the testing set, the output defined as elevated LVFP as suggested by E/e′, was found to correctly identify 80% of patients with pulmonary capillary wedge pressure ≥18 mm Hg (kappa = 0.51; $p < 0.001$).

Our work here is an extension of previous attempts of the application of ML to aid in the interpretation of cardiac imaging and clinically actionable phenotypic classifications (4). The use of automated STE analysis has been suggested to improve reproducibility (5). Our data further suggests that noninvasive assessment of LVFP using STE is feasible and suggests a method that can be used to accommodate the large amount of parameters found within the STE data for enhancement of the currently used methods. In the future, it would be worthwhile to assess whether such a decision support system can be used to completely fulfill all the steps recommended currently in guideline documents for assessing diastolic function (1). Development of such automated algorithms may be significant in the setting of the growing burden of cardiovascular disease in the community, the increased costs of sophisticated diagnostics, and the projected workforce shortage in the field. Finally, it is important to note that, while our model was developed based on E/e′, this Doppler-based method is known to have some limitations (1). A direct

FIGURE 1 Development of ML Model of the Assessment of LVFP



(A) Speckle tracking echocardiographic-derived parameters performance using information gain parameters. **(B)** The machine learning (ML) prediction model was developed using a "majority voting" method from a combined random forests, artificial neural networks, and support vector machines, so that a patient was assigned the diagnosis of elevated left ventricular filling pressure (LVFP) if ≥2 ML models show this diagnosis. Atrioventricular (AV) strain is expressed as a percentage. AV strain rate at systole ($SR\text{-}S_{AV}$), early diastole ($SR\text{-}E_{AV}$), and late diastole ($SR\text{-}A_{AV}$) are expressed in s^{-1}. Left atrial volume maximal (LAVmax) and minimal (LAVmin) are expressed in milliliters. LV end diastolic volume (EDV) and end systolic volume (ESV) are expressed in milliliters. TLVd = the combined total left heart volume at diastole; TLVs = the combined total left heart volume at systole; $VR\text{-}A_{AV}$ = left ventricular volume expansion at late diastole; $VR\text{-}E_{AV}$ = left ventricular volume expansion at early diastole, $VR\text{-}S_{AV}$ = left ventricular volume expansion at peak systole.

comparison between our STE-based model and E/e′ against directly measured pressures is required to test the potential ability of STE to overcome such limitations.

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