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Original article

The utility of fully automated real-time three-dimensional echocardiography in the evaluation of left ventricular diastolic function

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ABSTRACT

Background: A novel real-time three-dimensional echocardiography (RT3DE) system allows fully automated quantification of the left ventricular (LV) volume throughout a cardiac cycle. This study aimed to investigate whether an LV time–volume curve, obtained using fully automated RT3DE, is useful in the evaluation of LV diastolic function.

Methods: First, 15 patients underwent simultaneous standard two-dimensional echocardiography (2DE), RT3DE, and cardiac catheterization to measure the time constant of the isovolumic-pressure decline (τ). From the LV time–volume curve obtained using RT3DE, peak early filling rate (PFR) during diastole was generated and indexed for LV end-systolic volume. Next 570 patients, who were scheduled for both 2DE and RT3DE examinations, were enrolled to investigate the association between PFR index and 2DE-evidenced diastolic dysfunction and clinical characteristics.

Results: Of the 585 patients, RT3DE analysis was adequate in 542 patients (feasibility 93%). In the 15 patients, PFR index showed significant correlation with τ ($r = -0.65$, $p = 0.009$). In the remaining 527 patients, PFR index was related to age ($r = -0.24$, $p < 0.001$) and e' ($r = 0.41$, $p < 0.001$). PFR index decreased in proportion to the grade of 2DE-evidenced diastolic dysfunction. All patients with normal diastolic function had a PFR index greater than 2.0.

Conclusions: This study demonstrated that a novel, fully automated RT3DE-derived PFR index was the diagnostic tool of choice for the assessment of LV diastolic function.

Introduction

Left ventricular (LV) diastolic dysfunction is an important determinant of clinical symptoms and outcomes in patients with cardiac diseases [1–3]. The traditional standard approach to characterize diastolic function has involved micromanometric assessment of ventricular pressure decay, i.e. a time constant of the isovolumic-pressure decline (τ) [4], although this method is impractical due to its invasive nature. In clinical practice, several less-invasive imaging techniques, such as radionuclide ventriculography, gated-single-photon emission computed tomography [5–7], and magnetic resonance imaging [8], have been used to obtain global LV time–volume curve and peak early filling rate (PFR), as an index of assessing diastolic physiology. Real-time three-dimensional echocardiography (RT3DE) is a non-invasive tool to obtain 3D information on the LV cavity with acceptable spatial and temporal resolution

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that would be more accurate and physiologic than those measured by conventional imaging techniques [9–14]. A recently introduced RT3DE algorithm enables fully automated detection of the LV cavity surface during a cardiac cycle and acquisition of LV time–volume curve, providing accurate assessment of LV volume and systolic function [15–17]. This study therefore aimed to investigate whether PFR derived from this fully automated RT3DE is useful in the evaluation of LV diastolic function.

Methods

Protocol

This study had two arms: (1) the validation arm included patients who were scheduled for invasive coronary angiography and was used to determine the relation between the variable τ, obtained by direct micromanometric measurement, and PFR index derived from RT3DE; (2) the clinical arm included a relatively large number of patients from four collaborating institutions and was used to determine the relation between PFR index and clinical characteristics, and the results of two-dimensional echocardiography (2DE). The study was approved by the ethics committee in each institution.

Study population

Validation arm

Fifteen consecutive patients (11 men; age, 66 ± 8 years) who were scheduled for diagnostic cardiac catheterization for the evaluation of coronary artery disease were enrolled in the Osaka Ekisaikai Hospital. The exclusion criteria included non-sinus rhythm, history of myocardial infarction, evidence of cardiomyopathy, significant valvular disease (moderate and severe), history of open heart surgery, or presence of other serious systemic diseases. RT3DE and 2DE were performed at the time of cardiac catheterization.

Clinical arm

The clinical arm consisted of 570 patients (413 men; age, 67 ± 12 years) who were scheduled for 2DE examinations. The primary reason for 2DE was coronary artery disease in 401 patients, arrhythmia in 59 patients, hypertension in 53 patients, pulmonary hypertension in 21 patients, and other conditions in 36 patients. Patients were recruited at the following collaborating institutions; 94 patients from the Osaka Ekisaikai Hospital, 49 patients from the University of Tsukuba, 409 patients from the Sakakibara Heart Institute, and 18 patients from the Nishinomiya Watanabe Cardiovascular Center. The exclusion criteria were the same as those in the validation arm. RT3DE images were acquired at the time of 2DE examinations.

Three-dimensional echocardiography

Transthoracic RT3DE was performed using the SC2000 (Siemens, Mountainview, CA, USA) with a 4Z1c transducer (2.8 MHz). A 3D data set including the entire LV was acquired in a single beat during a breath hold. Gain and compression controls as well as settings for time gain compensation were optimized for the quality of 3D images. All 3D data sets were digitally stored and analyzed off-line.

The 3D volume of the LV during a cardiac cycle was analyzed using the SC2000 Workplace (eSie LVA) for visualization and analysis of 3D echocardiographic data (Fig. 1A and B). This software automatically detects the endocardial surface from knowledge gained from large, expert-annotated training databases of volume data combined with a 3D discriminative model, to match relevant image features of the given LV volume to the database [15–17].

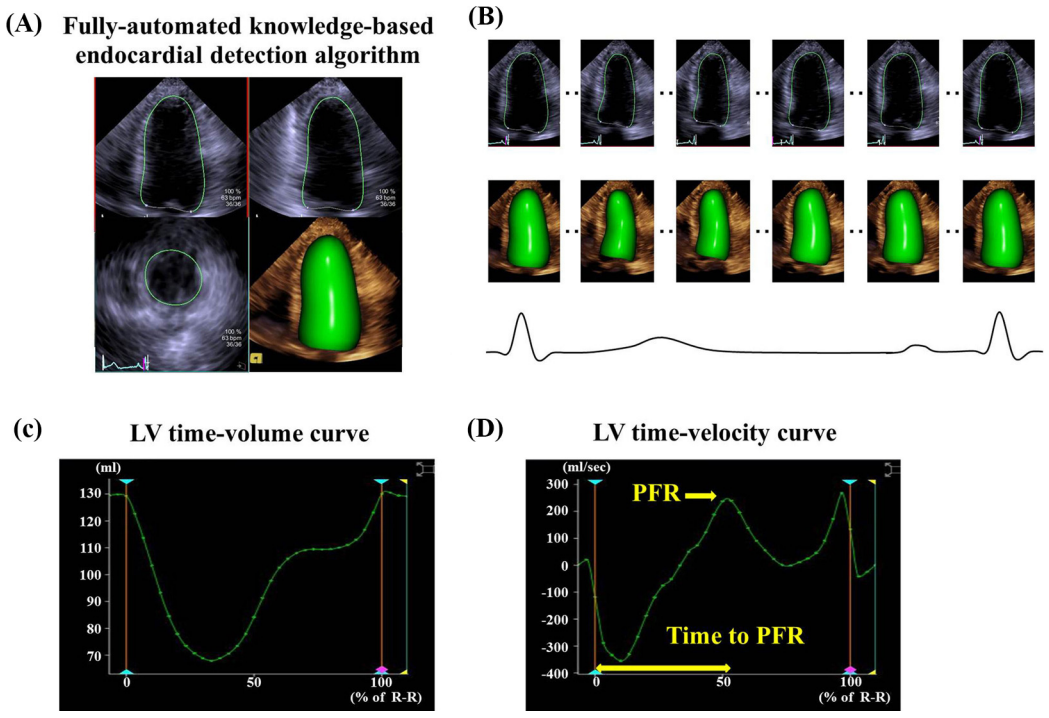

Fig. 1. RT3DE images, showing the process to obtain PFR index. (A and B) The software automatically identified the cavity wall interface in the 3D space throughout a cardiac cycle (green line). (C and D) From LV time–volume curve, LV time–velocity curve was automatically generated. PFR was identified as the first upward peak in diastole. PFR was then indexed to LV end-systolic volume. Time from the R-wave to the point at which PFR occurred was measured. LV, left ventricle; PFR, peak early filling rate; RT3DE, real-time three-dimensional echocardiography. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)