Right ventricular pressure-volume loop produced with simultaneous application of three-dimensional echocardiography and high-fidelity micromanometry in a patient with pulmonary arterial hypertension

Running head: Right ventricular PV loop produced with 3D echo

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Abstract

Accurate assessment of right ventricular (RV) function has received a growing attention. Pressure-volume (PV) loop analysis is the gold standard method for evaluating RV function; however, it is not widely employed because of its invasive nature and complexity. The present report is the first to have drawn a RV PV loop in a patient with pulmonary hypertension, with a simultaneous recording of RV pressure and volume using high-fidelity micromanometry and three-dimensional echocardiography. This allows for less invasive and simple assessment of RV function, potentially promoting better understanding and management of pulmonary hypertension and other cardiovascular diseases.

Pressure-volume (PV) loop analysis is the gold standard for evaluating left/right ventricular (RV) function. Its application has become increasingly important in pulmonary arterial hypertension (PAH) because RV function critically affects PAH patients' outcome [1]. However, PV loop analysis is not used widely, as it is invasive and requires dedicated catheters and expertise. Recent advances in three-dimensional (3D) echocardiography have enabled non-invasive RV volume measurements, potentially replacing conductance catheters required for RV volume measurements.

The PV loop presented in **Figure 1** was created using data obtained from simultaneous 3D echocardiography for RV volume (**Movie 1**) and high-fidelity micromanometry for RV pressure (**Figure 2**) in a PAH patient. The triangular shape of the presented PV loop with a late systolic peak is representative of advanced PAH cases. Using PV data along with the single-beat method [2], end-systolic elastance (Ees) (1.22 mmHg/mL) and the Ees/(arterial elastance]Ea]) ratio (calculated as 1.27), which are representative indices of RV systolic function and RV-pulmonary arterial coupling, respectively, were measured. Reportedly, the normal range of Eed/Ea is 1.5-2.0; thus, the low Ees/Ea value (i.e., 1.27) calculated in this case indicated an impaired RV-pulmonary arterial coupling. The representative index of RV relaxation, tau, was calculated as 36.3 ms. In addition, 3D echocardiography allowed the estimation of the RV volume (end-diastolic volume, 105 mL; end-systolic volume, 66 mL) in this case. Using these

values, the pressure data, and the formula reported by Rain et al. [3], the RV stiffness/compliance index "β" was calculated to be 0.0412.

To the best of our knowledge, the PV loop image presented in this report is the first that has been created with a simultaneously obtained RV pressure and 3D echocardiography-derived volume. This method waives the conductance catheter use, thereby significantly lowering the examination time, cost, and dedicated expertise needed. With better temporal resolution of 3D echocardiography and by modifying the RV's pre/after-load, such as by using Valsalva maneuver, a more detailed and less invasive RV function assessment would become possible.

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Author contributions:

Toshitaka Nakaya created the PV loop shown in Figure 1. Junichi Nakamura recorded the RV pressure during the catheterization using a micromanometry. Yasuyuki Chiba and Hiroyuki Iwano recorded the 3D image, analyzed the data, and created the 3D movie clip. Ichizo Tsujino conceptualized the study and reviewed the manuscript.

References

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Figure 1. RV pressure–volume curve of a patient with pulmonary arterial hypertension

The image was created based on a dataset of RV pressure and volume that were simultaneously recorded using high-fidelity micromanometry and 3D echocardiography.

RV, right ventricular; 3D, three-dimensional

Figure 2. RV pressure curves recorded with a high fidelity micromanometer

RV pressure was recorded using a high-fidelity micromanometer (Mikro-Cath™ Pressure Cather, Millar Inc., TX, USA). The pressure catheter was connected to an AV converter (PowerLab®, ADInstruments, Dunedin, New Zealand) and to a personal computer, in which dedicated software (LabChart Pro®, ADInstruments) was installed. This software allowed pressure recording at 1,000 Hz and the data exportation, as a csv file. Zero level was determined while the tip of the catheter was placed just below the surface of warmed water in a cup. The RV pressure was recorded at the natural end-expiration, and the dataset of the first cardiac cycle was used for drawing the PV loop shown in Figure 1.

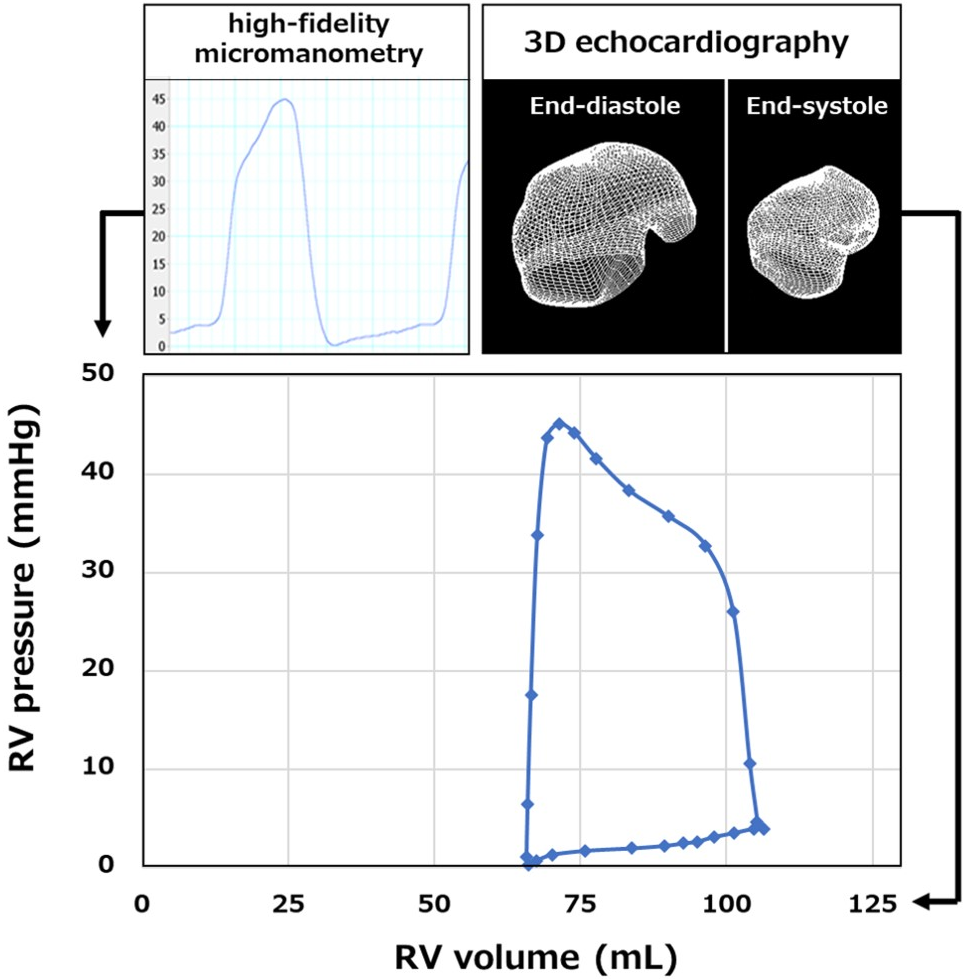
RV, right ventricular

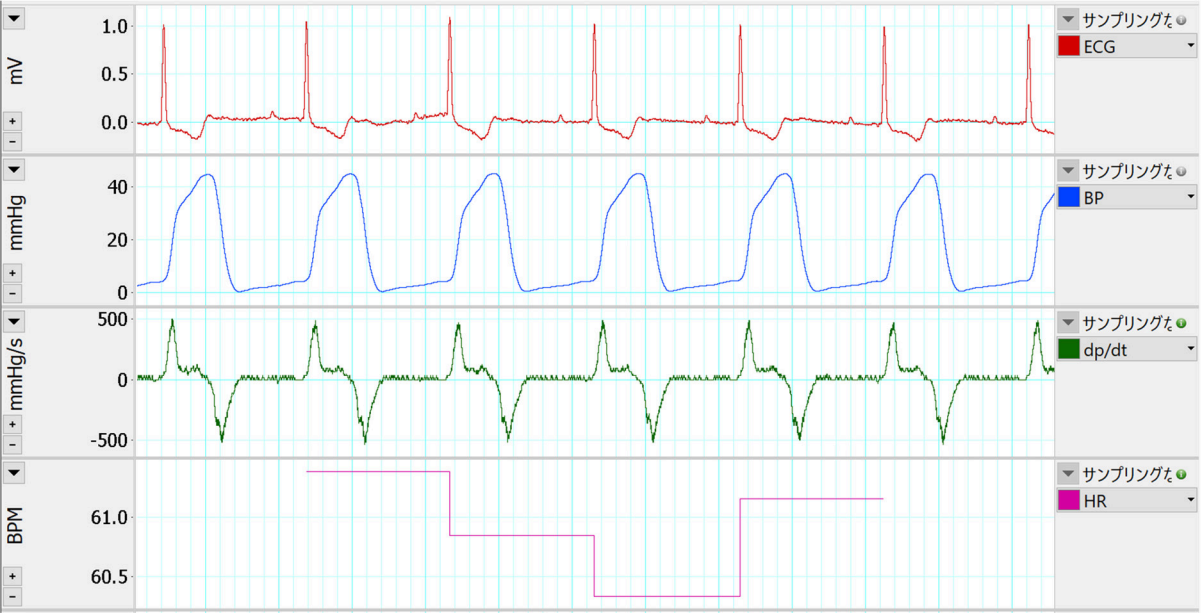
Supplementary material: The following supplementary material is available online (Codec ID: avc1)

- Movie Clip 1: Three-dimensional movie image of the right ventricle

RV images were recorded with a 3D echo (Aplio i800, Cannon Medical Systems, Tokyo) while the patient was asked to hold her breath at the natural end-expiration. Six consecutive beats were recorded to create a dataset of the RV volume of one cardiac cycle. The numerical data were exported afterward, as a csv file and then used, along with the pressure data, to draw an RV pressure–volume loop shown in Figure 1.

RV, right ventricular; 3D, three-dimensional


high-fidelity micromanometry
3D echocardiography
End-diastole
End-systole
RV pressure (mmHg)
RV volume (mL)
0
10
20
30
40
50
0
25
50
75
100
125


mV
1.0
0.5
0.0
サンプリングた
ECG
mmHg
40
20
0
サンプリングた
BP
mmHg/s
500
0
-500
サンプリングた
dp/dt
BPM
61.0
60.5
サンプリングた
HR