JACC: CARDIOVASCULAR IMAGING
VOL. ■, NO. ■, 2017

ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER
http://dx.doi.org/10.1016/j.jcmg.2016.12.021

Unraveling the RV Ejection Doppler Envelope

Insight into Pulmonary Artery Hemodynamics and Disease Severity

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ABSTRACT

OBJECTIVES The purpose of this study was to characterize the profiles of right ventricular outflow tract (RVOT) Doppler flow velocity envelopes in patients with pulmonary arterial hypertension (PAH) and to establish whether changes in the RVOT flow profile related to patient outcome.

BACKGROUND The RVOT systolic flow profile is frequently abnormal, with findings of a mid-systolic flow deceleration and notching, previously proposed as an indicator of elevated pulmonary vascular resistance (PVR).

METHODS We reviewed RVOT systolic flow profiles recorded by pulsed-wave Doppler from 159 consecutive patients with PAH and measured deceleration time (DT) of mid-systolic deceleration slope (mid-systolic DT) and the peak velocity of pre- and post-notching flow. Concurrent right-heart catheterization was available in all (41 of 41) incident patients and in 39 of 118 established patients. Outcomes, defined as time to all-cause mortality or need for lung transplantation, were assessed during 3 years of follow-up.

RESULTS Notched envelopes were identified in 150 of 159 patients. The presence of a notched pattern and a decrease in the mid-systolic DT were associated with higher PA pressures; higher PVR; and, at a threshold of a mid-systolic DT of <120 ms, worse outcome. Those patients with a shorter DT were further subdivided based on the post-notch systolic flow velocity. In these patients, a decline in the post-notch flow velocity to less than 62% of the pre-notch flow velocity defined a cohort with a marked reduction in systolic function and the worst outcome.

CONCLUSIONS In PAH, the notched profile of RVOT Doppler flow velocity envelope appears to integrate indicators of pulmonary vascular load and RV function and serves as a marker for adverse outcomes. (J Am Coll Cardiol Img 2017;■:■–■) © 2017 by the American College of Cardiology Foundation.

In patients with pulmonary hypertension (PH), conventional echocardiographic measurements include tricuspid and pulmonary regurgitant flows to evaluate pulmonary artery (PA) hemodynamics and measurements of right ventricular (RV) systolic function. The RV outflow tract (RVOT) systolic Doppler flow velocity envelope is frequently abnormal, with findings of a notched envelope, previously suggested as an indicator of elevated PA pressure or pulmonary vascular resistance (PVR) (1-3). Prior studies have suggested that notching of the RVOT systolic flow profile corresponds to reflected waves from the abnormal pulmonary vascular bed (4,5) and is present in most patients with pulmonary arterial hypertension (PAH) (6). Recent guidelines from the American Society of Echocardiography have suggested "the notch" as a complementary index to suggest an elevation in PVR (7). Others have suggested that the timing in which the notch occurs in the profile may reflect the severity of the pulmonary vascular disease (5,8). However, the factors that underlie the changes seen in the RVOT Doppler profile and whether these changes are linked to prognosis are not well established. Our aim was to

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Manuscript received December 12, 2016; revised manuscript received December 16, 2016, accepted December 21, 2016.

ABBREVIATIONS AND ACRONYMS

DT = deceleration time

LDT = longer mid-systolic deceleration time (≥120 ms)

NN = RVOT flow profiles with no notching

PAH = pulmonary arterial hypertension

PVR = pulmonary vascular resistance

RVOT = right ventricular outflow tract

SH = shorter mid-systolic deceleration time (<120 ms) and higher V_{post}/V_{pre} (>62%)

SL = shorter mid-systolic deceleration time (<120 ms) and higher V_{post}/V_{pre} (≥62%)

V_{notch} = velocity of acceleration flow at the time of notching

V_{pre} = peak velocity of pre-notching acceleration flow

V_{post} = peak velocity of post-notching acceleration flow

characterize the RVOT Doppler profiles in a large sequential series of patients with PAH and to establish whether changes in the RVOT systolic flow profile related to patient outcome.

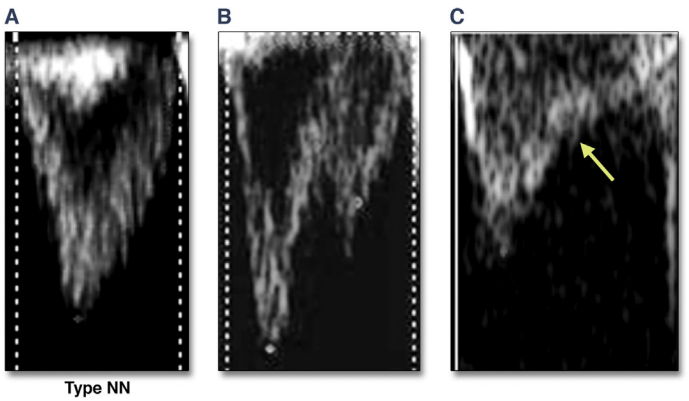
METHODS

STUDY PATIENTS AND RVOT SYSTOLIC FLOW PROFILE ANALYSIS. The study was approved by the Mayo Clinic Institutional Review Board (protocol 08-007824). We enrolled consecutive adult patients (≥18 years of age) at our institution who underwent imaging between January 1, 2008 and March 30, 2013 (n = 175), who fulfilled the contemporary diagnostic criteria for group 1 PH (mean PA pressure: ≥25 mm Hg, occurring in the setting of increases in pre-capillary pulmonary resistance) (9). One patient with congenital heart disease and another who developed PAH after liver transplantation and 7 with atrial fibrillation were excluded. Another 7 patients were excluded due to poor image quality of pulsed-wave Doppler interrogation of the RVOT. The final study cohort consisted of 159 subjects.

ECHOCARDIOGRAPHIC PARAMETERS AND HEMODYNAMIC EVALUATION. Transthoracic echocardiography was performed according to standard guidelines (7,10). Pulsed-wave Doppler interrogation of the RVOT was performed from a modified basal short-axis view from the left parasternal or subcostal window. The transducer position was adjusted to open up the RVOT, with the sample volume placed approximately 1 cm proximal to the pulmonic valve. Doppler tracings were recorded at end-expiration. Three contiguous signals were measured and averaged.

Patients who had RVOT systolic flow profiles without notching (Figure 1A) were categorized as no notch (NN). Regarding the RVOT systolic flow profiles with mid-systolic deceleration and notching (Figure 1B), 5 specific measurements were made (Figure 2): the notch position, the deceleration time (DT) of the mid-systolic deceleration slope (mid-systolic DT), the peak velocity of the pre-notching acceleration flow (V_{pre}), the flow velocity at notching (V_{notch}), and the peak velocity of the post-notching acceleration flow (V_{post}). The V_{notch}/V_{pre} and V_{post}/V_{pre} ratios were used in analyses to convert velocity to parameters of flow profiles. The notch position was defined as the time-to-notch ratio, calculated as the time between the onset of the ejection to the notch to the ejection time. Mid-systolic DT was calculated as the time duration of the slope from V_{pre} to baseline. For the RVOT systolic flow profile with an inflection point where flow deceleration rate decreased obviously and no post-notching acceleration flow as shown in Figure 1C, we defined the flow velocity at the inflection point as V_{notch} and V_{post}, and the time to the inflection point as time-to-notch. Representative examples of measurements of ejection flow envelope are shown in Figure 2. Measurements were made offline from digitally stored images, using ImageJ software (U.S. National Institutes of Health, Bethesda, Maryland) from 3 consecutive cardiac cycles, and the results were averaged. Tricuspid annular plane systolic excursion (TAPSE) was measured using the distance of systolic excursion of the RV annular segment along its longitudinal plane from an apical 4-chamber view. Cardiac index was calculated using Doppler-estimated stroke volume measured in the left ventricular outflow tract and heart rate. The severity of tricuspid regurgitation was assessed using color flow imaging and regurgitant jet area. Echocardiographic estimation of PA systolic pressure was obtained as the sum of tricuspid pressure gradient and right atrial pressure estimated in 5-mm Hg increments between 5 and 20 mm Hg on the basis of the size and collapsibility of the inferior vena cava (11). Tricuspid pressure gradient was calculated from the continuous-wave Doppler tricuspid valve regurgitant velocity, using the simplified Bernoulli equation. Right ventricular index of

FIGURE 1 Representative RVOT Flow Systolic Profiles



(A) Pattern without mid-systolic deceleration and notching (no notch [NN] pattern), whereas there is shortening of acceleration time, the flow pattern maintains a parabolic curve. **(B)** The pattern demonstrates mid-systolic deceleration and notching separating 2 distinct acceleration flows. **(C)** The pattern of rectilinear mid-systolic deceleration with an inflection point **(arrow)** and no post-notching acceleration flow. RVOT = right ventricular outflow tract.