Contents lists available at ScienceDirect

Respiratory Investigation

journal homepage: www.elsevier.com/locate/resinv

Original article

Noninvasive assessment of pulmonary vascular resistance by echocardiography in chronic thromboembolic pulmonary hypertension

Hajime Kasai[a,*], *Akane Matsumura*[a], *Toshihiko Sugiura*[a], *Ayako Shigeta*[a,b], *Nobuhiro Tanabe*[a,b], *Ryogo Ema*[a], *Yoriko Sakurai*[a], *Misuzu Yahaba*[a], *Yukiko Matsuura*[a], *Naoko Kawata*[a], *Seiichiro Sakao*[a], *Koichiro Tatsumi*[a]

[a]*Department of Respirology, Graduate School of Medicine, Chiba University, Chiba 260-8670, Japan*
[b]*Department of Advanced Medicine in Pulmonary Hypertension, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuou-ku, Chiba 260-8670, Japan*

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form
23 March 2015
Accepted 31 March 2015
Available online 1 June 2015

Keywords:
Pulmonary vascular resistance
Chronic thromboembolic pulmonary hypertension
Echocardiography
noninvasive

ABSTRACT

Background: Pulmonary vascular resistance (PVR) is an important parameter in the management of patients with chronic thromboembolic pulmonary hypertension (CTEPH), and numerous noninvasive methods for PVR prediction have been proposed. However, a systematic evaluation of the methods that are specific for CTEPH has not been conducted. We compared a variety of echocardiography-derived prediction indices with direct right heart catheterization (RHC) to identify the most reliable noninvasive indicator of PVR in patients with CTEPH.

Patients and methods: Echocardiography and RHC were performed sequentially in 40 patients (mean age: 62.4±11.4 years; 30 females) with CTEPH. We measured the peak flow velocity of tricuspid regurgitation (TRV), tricuspid regurgitation pressure gradient (TRPG), right ventricular outflow tract (RVOT) time–velocity integral (TVI_{RVOT}), left ventricular outflow tract (LVOT) time–velocity integral (TVI_{LVOT}), cardiac output at RVOT (CO_{RVOT}), and the LVOT (CO_{LVOT}) using echocardiography. The parameters TRV/TVI_{RVOT}, TRV/TVI_{LVOT}, TRV/CO_{RVOT}, TRV/CO_{LVOT}, $TRPG/TVI_{RVOT}$, $TRPG/TVI_{LVOT}$, $TRPG/CO_{RVOT}$, and $TRPG/CO_{LVOT}$ were then calculated to predict the PVR. Finally, correlations between these echocardiographic predictors of PVR and the PVR data obtained from RHC (PVR_{RHC}) were assessed.

Results: The mean pulmonary arterial pressure and PVR_{RHC} were 32.1±11.4 mmHg and 5.4±2.9 Wood units, respectively. TRV/TVI_{RVOT}, TRV/TVI_{LVOT}, TRV/CO_{LVOT}, $TRPG/TVI_{RVOT}$, $TRPG/TVI_{LVOT}$, $TRPG/CO_{RVOT}$, and $TRPG/CO_{LVOT}$ were all significantly correlated with the PVR_{RHC}, and $TRPG/CO_{LVOT}$ was the most strongly correlated with the PVR_{RHC} ($r=0.807$, $p<0.001$).

Conclusions: Echocardiographic measurement of $TRPG/CO_{LVOT}$ is a reliable noninvasive predictor of PVR in CTEPH patients.

*Correspondence to: *Department of Respirology, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuou-ku Chiba 260-8670, Japan.* Tel.: +81 43 222 7171x71014; fax: +81 43 226 2176.
E-mail address: daikasai6075@yahoo.co.jp (H. Kasai).

http://dx.doi.org/10.1016/j.resinv.2015.03.002
2212-5345/

1. Introduction

Chronic thromboembolic pulmonary hypertension (CTEPH) is caused by nonresolving thromboembolisms of the pulmonary arteries and pulmonary vascular remodeling, which results in right heart failure unless treatment is effective [1]. Hemodynamic evaluation is important in the management of CTEPH; therefore, pulmonary vascular resistance (PVR) and the pulmonary arterial pressure (PAP) must be accurately assessed. PVR is a strong predictor of reduced survival in medically treated patients, and higher PVR is associated with increased mortality following pulmonary endarterectomy (PEA) [2–4].

Although right heart catheterization (RHC) is the gold standard for assessing pulmonary hemodynamics, it is invasive and costly. Therefore, noninvasive methods for predicting PVR are desirable, and many studies have assessed the use of echocardiography for this purpose [5–13]. The peak flow velocity of tricuspid regurgitation (TRV) and the right ventricular outflow tract (RVOT) time–velocity integral (TVI_{RVOT}) are most often used for this purpose. For example, Abbas et al. reported that using the ratio of TRV/TVI_{RVOT} was a reliable method for identifying patients with elevated PVR [10], and that the ratio of $(TRV)^2/TVI_{RVOT}$ provided an even better noninvasive estimate of PVR [9]. The influence of the heart rate (HR) could be neglected, and Haddad et al. reported that systolic PAP (sPAP)/($HR \times TVI_{RVOT}$) provided clinically useful estimations of PVR in pulmonary arterial hypertension (PAH) [11]. However, anatomical modifications of right ventricular structures in patients with severe pulmonary hypertension (PH) may make it difficult to measure TVI_{RVOT} accurately [7]. Hence, the left ventricular outflow tract (LVOT) time–velocity integral (TVI_{LVOT}) may be easier to measure in these patients. Indeed, the TVI_{LVOT} and the cardiac output (CO) at the LVOT (CO_{LVOT}) have also been used to estimate PVR [7].

There is currently no definitive method for the noninvasive estimation of PVR, possibly because previous comparative evaluations included subjects with multiple PH etiologies. Moreover, no systematic evaluations of echocardiographic PVR estimates have been conducted specifically for CTEPH patients. This study aimed to identify the most reliable noninvasive indicator of PVR in patients with CTEPH by comparing a variety of echocardiography-derived prediction indices with the PVR data obtained from RHC (PVR_{RHC}).

2. Patients and methods

2.1. Study population

This study was a single-center retrospective investigation of consecutive patients with a high clinical suspicion of CTEPH who underwent echocardiography and RHC from September 2012 to October 2014. This study was approved by the ethics committee of Chiba University (Approval date: June 1, 2009; Approval number: 826), and written informed consent was obtained from each patient before echocardiography and RHC. Patients with suspected CTEPH complicated by left heart disease such as ischemic heart disease or cardiomyopathy, or moderate or severe valvular disease of the aortic and mitral valves, intracardiac shunts, or patients who underwent PEA within 1 year of the study were excluded from the study. Patients complicated with severe tricuspid regurgitation (TR) were also excluded, because severe TR reduces the accuracy of the CO calculation using the thermodilution method. We defined severe TR as a regurgitation jet area that was more than two-thirds of the maximum right atrial area visible on color Doppler echocardiography in the apical view [14].

2.2. Echocardiography

Within 2 days of RHC, Doppler echocardiography using an Aplio™ 300 ultrasound (Toshiba Medical, Tochigi, Japan) with a PST-25BT transducer (2.5 MHz) was performed on all of the patients while they held their breaths at the end of expiration. The recordings were obtained from the left parasternal long axis, left parasternal short axis, apical four-chamber, and the apical five-chamber views. All of the results were the averages of three measurements, and the analyses were performed without knowledge of the patients' clinical statuses. No changes were made to the medication and oxygen therapy between RHC and echocardiography. The TRV was obtained using continuous wave Doppler from the apical four-chamber, parasternal, and subcostal views, and the highest peak value was recorded. The tricuspid regurgitation pressure gradient (TRPG) was determined from the velocity using a simplified Bernoulli equation.

The TVI_{RVOT} was determined from digitized Doppler signals. We traced the black/white interface of the flow profile from time × velocity traces (Fig. 1A) that were generated by positioning a pulsed wave Doppler sample volume in the range from just above to 1 cm distal to the pulmonary valve,

Abbreviations: CI, cardiac index; CO, cardiac output; CO_{LVOT}, cardiac output in left ventricular outflow tract; CO_{RVOT}, cardiac output in right ventricular outflow tract; CTEPH, chronic thromboembolic pulmonary hypertension; HR, heart rate; LVOT, left ventricular outflow tract; TVI_{LVOT}, left ventricular outflow tract time–velocity integral; mPAP, mean pulmonary arterial pressure; TRV, peak flow velocity of tricuspid regurgitation; dPAP, pulmonary arterial diastolic pressure; PAP, pulmonary arterial pressure; sPAP, pulmonary arterial systolic pressure; PAWP, pulmonary artery wedge pressure; PEA, pulmonary endarterectomy; PVR, pulmonary vascular resistance; PVR_{ECHO}, pulmonary vascular resistances derived from the tricuspid regurgitation pressure gradient/cardiac output in the left ventricular outflow tract; PVR_{RHC}, pulmonary vascular resistance measured by right heart catheterization; RHC, right heart catheterization; RVOT, right ventricular outflow tract; TVI_{RVOT}, right ventricular outflow tract time–velocity integral; TR, tricuspid regurgitation; TRPG, tricuspid regurgitation pressure gradient; WU, wood units