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Prognostic Value of Tricuspid Annular Dilatation Assessed by Three-Dimensional Transesophageal Echocardiography☆

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ABSTRACT

Background: This study aimed to evaluate the relationship between tricuspid annular dilatation (TAD) and tricuspid regurgitation (TR), and the prognostic value of TAD using three-dimensional transesophageal echocardiography (3D TEE).
Methods: Tricuspid annular area (TAA) was measured in 116 patients using 3D TEE. Patients were classified into three groups (mild TR: n = 77, moderate TR: n = 26, severe TR: n = 13). Moreover, patients were classified into two groups based on rehospitalization for heart failure (HF); HF (+) group (n = 18) and HF (−) group (n = 98).
Results: TAA in the severe TR group was significantly larger than that in the mild and moderate TR groups (18.4 ± 3.8 cm^2 vs. 11.7 ± 3.2 cm^2, 12.3 ± 3.4 cm^2, $p < 0.05$). TAA in the HF (+) group was significantly larger than that in the HF (−) group (16.8 ± 4.3 cm^2 vs. 11.8 ± 3.3 cm^2, $p < 0.001$). In receiver operating characteristics curve assessing the ability of TAA to predict hospitalization for HF, the area under the curve was 0.84. TAA ≥ 15 cm^2 best predicted hospitalization for HF with 77.8% sensitivity and 84.6% specificity. The incidence of hospitalization for HF during 3 years was significantly higher in the TAD (+) group (TAA ≥ 15 cm^2) than the TAD (−) group (48.3% vs 4.6%, $p < 0.001$).
Conclusions: The results of this study suggested a possible association between TAD and the TR severity. TAD estimated using 3D TEE may predict hospitalization for prospective HF.

1. Introduction

Functional tricuspid regurgitation (TR) with no deformation of the tricuspid valve (TV) commonly occurs in patients with left-sided valve disease and left ventricular (LV) dysfunction. TR severity can considerably influence long-term outcome [1]. Several studies have suggested that changes in TV geometry in patients with functional TR, including annular dilatation and tethering of the leaflets, might gradually and negatively influence TR [2]. The tricuspid annulus (TA) is a component of both the TV and right ventricle (RV). Both the RV and TA must be dilated for surgery to be indicated [2,3]. Because high postoperative morbidity and mortality are associated with TR [4], tricuspid annuloplasty (TAP) for functional TR is recommended in patients with left-sided heart disease. However, residual regurgitation often persists after TAP [4–8]. These unsatisfactory results may be related to an incomplete knowledge of TA dilatation (TAD). Preoperative evaluation of TV using two-dimensional (2D) echocardiography is difficult. Recently, three-dimensional transesophageal echocardiography (3D TEE) was developed to provide superior image quality. Studies have revealed the advantages of this modality for assessing LV volume, mass, and output [9–11] and elucidating the 3D geometry of the mitral valve and annulus [12]. In this study, 3D TEE was utilized to provide fast, noninvasive, and accurate estimations of TV morphology. The purpose of this study was to evaluate the relationship between TAD and TR, and the prognostic value of TAD by 3D TEE.

2. Materials and Methods

2.1. Study patients and transthoracic echocardiography

We performed a retrospective analysis of 144 consecutive patients in whom 3D TEE was performed at Hiroshima City Hospital from April 2009 to April 2011. Among these, patients in whom 3D TEE was

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performed within 48 h after two-dimensional transthoracic echocardiography (2D TTE) and was not accompanied with congenital heart disease were enrolled in this study. All patients included in this study had functional TR. There were no patients with organic TR in whom TV deformation or flail motion was detected, those in whom previous TAP or TV repair had been performed or those with pacemaker wires across the TV. For patients with heart failure (HF), 3D TEE was performed after stabilization of hemodynamic conditions, treatment with intravenous and oral drugs, and full recovery, to exclude the influence of volume and pressure overload on TR. Estimated glomerular filtration rate was calculated using the Japanese equations for estimating glomerular filtration rate from serum creatinine; patients were diagnosed with CKD if glomerular filtration rate was <60 ml/min per 1.73 m^2. TTE was performed using i33 instruments (Philips Technology, Amsterdam, The Netherlands). Images were obtained after the gain, compression controls, and time gain compensation settings were optimized to ensure image quality. Left atrial and ventricular diameters were measured from M-mode tracing. Left ventricular ejection fraction (LVEF) and right ventricular ejection fraction (RVEF) were obtained by Simpson's method using apical 2- and 4-chamber views. LV and RV dysfunctions were defined as ejection fraction ≤ 40% [13]. TA dimensions were defined as the distance between the insertion sites of septal and anterior TV leaflets and obtained at an end-diastolic still frame using the apical 4-chamber view. Right ventricular end-diastolic dimension (RVDd) and right ventricular end-systolic dimension (RVDs) were obtained using the apical 4-chamber view. Using 2D Doppler echocardiography, pulmonary artery systolic pressure (PASP) was estimated from the TR jet velocity using a modified Bernoulli equation: $4 \times (\text{velocity})^2 + \text{right atrial pressure}$ [13,14]. Right atrial pressure was estimated at 5 mmHg if the inferior vena cava (IVC) was not dilated (<1.7 cm) and the diameter decreased by 50% during inspiration, at 10 mmHg if the IVC was dilated with normal inspiratory collapse, and at 15 mmHg if the IVC was dilated and did not collapse with inspiration [15]. The severity of TR was graded as follows: mild, moderate and severe based on 2D TTE findings of regurgitation on color Doppler (jet vena contracta, PISA radius, regurgitant orifice area, and the relative size of the regurgitant jet) using the apical 4-chamber view and hepatic venous flow pattern [16]. Patients were classified into three groups according to TR grade. All parameters were assessed and compared among the three groups. Moreover, patients were classified into two groups based on rehospitalization for HF after discharge from the hospital. Clinical follow-up was performed for up to 3 years.

2.2. 3D TEE analysis

3D TEE was performed within 48 h after 2D TTE using an iE33 system with an X7-2 t transducer (2–7 MHz) (Philips Technology). First, a 2D TEE image of the TV was obtained, and the best image with a good echocardiographic signal and a clear R-wave was utilized (Fig. 1A). It was taken at an angle of 45° in most cases. Second, full-volume imaging was performed at the same angle (Fig. 1B) and analyzed using the QLAB software. In Fig. 1C, the yellow frame was full-volume imaging. Short-axis plane of TV was obtained in the blue frame referring to full-volume imaging. In the cross-sectional image with blue frame, the red line was adjusted from the anteroseptal to the anteroposterior commissure, and the green line was adjusted vertical thinning from the anterior intercommissure to the posteroseptal commissure; the white dots were the three commissures. In the green and red frames, the blue line was adjusted at TV annulus. The TV in the cross-sectional image in the blue frame was measured in the end systolic phase (Fig. 1D). The tricuspid annular area (TAA) and 3 intercommissural distances (ICDs) (anterior, posterior, and septal ICD) were measured (Fig. 1E). Interobserver and intraobserver variability in TV measurement was determined by analysis of 10 random 3D images by 2 independent blinded observers and by the same observer at 2 different times. Informed consent was obtained from all patients. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the ethical committee of Hiroshima City Hospital.

2.3. Statistical analysis

Standard statistical methods were used in this study. Significant differences were tested using the χ^2 test for categorical variables. Normally distributed continuous variables are presented as mean and standard deviation (SD) or median and inter-quartile range (IQR). Unpaired Student's t test or Wilcoxon rank-sum test when appropriate was used for continuous variables. Kruskal–Wallis test was used for comparing more than two groups and post-hoc analyses were performed using Steel–Dwass's multiple comparison test. Event-free survival curves up to 3 years after 3D TEE were constructed using the Kaplan–Meier method and were compared using the log-rank test. Cox proportional hazard regression was used to identify independent predictors of rehospitalization for heart failure, adjusting echocardiographic variables. In addition, to adjust for selection bias, propensity scores for each patient were estimated with logistic regression, with HF (+) as the outcome. Twelve baseline clinical and echocardiographic variables were chosen for imputation and derivation of propensity scores, based on clinical and echocardiographic relevance and ability to correct for differences between HF (+) vs. HF (−) groups. The JMP statistical package (version 11.0, SAS Institute, Inc. Cary, NC, USA) was used for all statistical tests. A significance level of 0.05 was used and two-tailed tests were applied.

3. Results

Flow Chart in this study is shown in Fig. 2. From April 2009 to April 2011, 3D TEE was performed in 144 patients. Among these, 116 patients were enrolled in this study. Sixteen patients in whom 3D TEE was performed over 48 h after 2D TTE were not enrolled. Nine patients were not enrolled because of poor TV visualization (6 patients by 3D TEE and 3 patients by 2D TTE). Three patients were not enrolled because of congenital heart disease. Conditions for which 3D TEE was performed are summarized in Table 1. The mean LVEF was 58.4% ± 13.5%, ranging from 15% to 78%. To rule out the presence of left atrial thrombus, 3D TEE was performed on 60 patients with atrial fibrillation, 2 patients with atrial flutter, and 10 patients with cerebral infarction which did not have any severe valvular disease. Left atrial thrombus was not detected in them. Furthermore, 3D TEE was performed in 4 patients to rule out infective endocarditis. Mitral valve vegetation was detected in one of them, but he did not have severe mitral regurgitation. 3D TEE was performed in other patients to assess structural heart disease. Mild mitral regurgitation was observed in 42 patients (64%), moderate in 21 (32%), and severe in 3 (4%) patients. Patients were classified into three groups according to TR grade: the mild TR group ($n = 77$), moderate TR group ($n = 26$), and severe TR group ($n = 13$). Clinical characteristics by TR grades are shown in Table 2. No significant differences in age, gender, body mass index, body surface area, hypertension, dyslipidemia, diabetes mellitus, or chronic kidney disease were observed between the three groups. A significantly higher history of HF was found in patients with severe TR than in patients with mild and moderate TR (69% vs. 17%, 42%, respectively; $p < 0.05$), whereas no significant difference in the N-terminal pro B-type natriuretic peptide (NT-proBNP) was detected between groups. Table 3A displays 2D TTE findings by TR grades. No significant differences in LV end-diastolic dimension (LVDd), LV end-systolic dimension (LVDs), LVEF, or left atrial dimension (LAD) were observed between the three groups. RVDd, RVDs and RVEF in patients with severe TR were significantly larger than those in patients with mild and moderate TR (RVDd: 30.1 ± 10.5 mm vs. 20.9 ± 5.5 mm, 20.6 ± 4.6 mm, $p < 0.001$, RVDs: 25.1 ± 11.2 mm vs. 15.9 ± 4.3 mm, 15.6 ± 4.3 mm, $p < 0.001$, RVEF: 39.9 ± 13.5% vs. 52.6 ± 11.6%, 52.7 ± 9.9%, $p = 0.001$; respectively). TA dimension in patients with severe TR was significantly larger than those in patients with mild and moderate TR (32.9 ± 6.7 mm vs. 23.9 ± 6.0 mm, 22.1 ±