European Journal of Radiology 86 (2017) 213–220

Contents lists available at ScienceDirect

European Journal of Radiology

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

Multi-parametric quantification of tricuspid regurgitation using cardiovascular magnetic resonance: A comparison to echocardiography

Diego Medvedofsky[a], Javier León Jiménez[b], Karima Addetia[a], Amita Singh[a], Roberto M. Lang[a], Victor Mor-Avi[a,*], Amit R. Patel[a]

[a] Department of Medicine, University of Chicago Medical Center, Chicago, IL, USA
[b] Complejo Hospitalario Universitario de Huelva, Huelva, Spain

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form
27 September 2016
Accepted 22 November 2016

Keywords:
Tricuspid regurgitation
Quantification
Cardiac magnetic resonance imaging
Cardiac imaging
Valvular heart disease

ABSTRACT

Background: Velocity-encoding is used to quantify tricuspid regurgitation (TR) by cardiovascular magnetic resonance (CMR), but requires additional dedicated imaging. We hypothesized that size and signal intensity (SI) of the cross-sectional TR jet area in the right atrium in short-axis steady-state free-precession images could be used to assess TR severity.

Methods: We studied 61 patients with TR, who underwent CMR and echocardiography within 24 h. TR severity was determined by vena contracta: severe (N = 20), moderate or mild (N = 41). CMR TR jet area and normalized SI were measured in the plane and frame that depicted maximum area. ROC analysis was performed in 21/61 patients to determine diagnostic accuracy of differentiating degrees of TR. Optimal cutoffs were independently tested in the remaining 40 patients.

Results: Measurable regions of signal loss depicting TR jets were noted in 51/61 patients, while 9/10 remaining patients had mild TR by echocardiography. With increasing TR severity, jet area significantly increased (15 ± 14 to $38 \pm 20\,mm^2$), while normalized SI decreased (57 ± 27 to 23 ± 11). ROC analysis showed high AUC values in the derivation group and good accuracy in the test group.

Conclusion: TR can be quantified from short-axis CMR images in agreement with echocardiography, while circumventing additional image acquisition.

1. Introduction

Tricuspid regurgitation (TR) is increasingly being recognized as an important independent predictor of prognosis in various cardiovascular conditions [1–4]. Today, two-dimensional (2D) echocardiography is the reference standard for the assessment of severity of TR. Although cardiovascular magnetic resonance (CMR) imaging is an important tool for the assessment of most types of heart disease, little attention has been given to the evaluation of TR using CMR. Although velocity-encoded phase-contrast imaging is a well-validated CMR method for quantifying left-sided regurgitant valvular lesions [5,6], it has not been as extensively validated with TR, and the level of agreement with echocardiography has yet to be established. This approach requires the acquisition of additional images to measure right ventricular stroke volume and determine pulmonary flow using velocity-encoded phase-contrast images. Acquisition of these images is not routinely performed in clinical exams and requires specialized CMR sequences, which are associated with additional costs. Furthermore, this technique is subject to different sources of errors. Although TR is often qualitatively assessed in the long-axis view, its severity may be underestimated because the jet may be incompletely visualized in planes that do not cut through the center of the jet. However, in short-axis views, TR jets are readily visualized as regions of signal loss in the right atrium (RA) due to the outflow of excited spins from the imaging plane with the regurgitant jet and dephasing by turbulent flow.

We aimed at studying the agreement between echocardiography and the above described CMR methodology for the evaluation of TR severity and testing an alternative approach that might be less prone to errors. Accordingly, we hypothesized that measuring the size and signal intensity of the cross-sectional jet area in the short-axis view on cine CMR could provide quantitative information on TR severity. This pilot study was designed to test this hypothesis by comparing these two quantitative TR severity indices to those determined by standard echocardiographic methodology.

* Corresponding author at: Section of Cardiology, University of Chicago Medical Center, 5841 South Maryland Avenue, MC5084, Chicago, IL 60637, USA.
E-mail address: vmoravi@bsd.uchicago.edu (V. Mor-Avi).

http://dx.doi.org/10.1016/j.ejrad.2016.11.025
0720-048X/

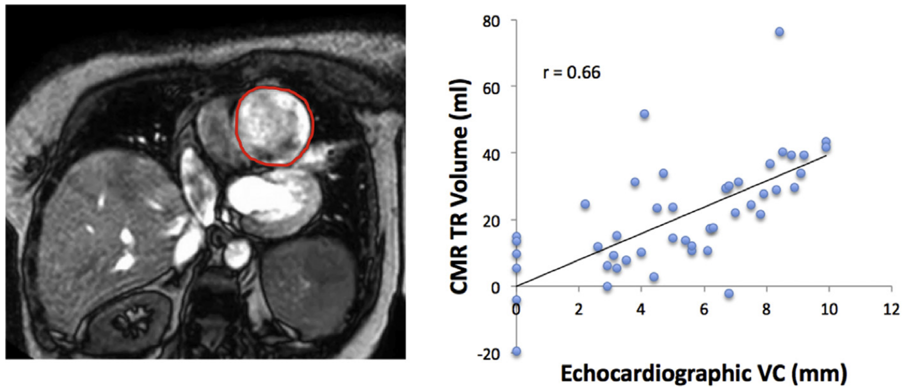

Fig. 1. An example of a velocity-encoded phase contrast image of the pulmonic valve plane, shown with the tracing of the pulmonic valve (red line) used to calculate the absolute forward flow volume (left). The relationship between TR volume calculated by subtracting trans-pulmonic forward flow volume from right ventricular stroke volume and echocardiographic TR vena contracta (VC).

2. Methods

2.1. Population and study design

We studied 61 adult patients (12 males; age 51 ± 16 years; BSA 1.84 ± 0.26 m^2) who underwent CMR and transthoracic 2D echocardiography on the same day to minimize the changes in loading conditions, and were diagnosed with more than trace TR. Of these patients, 47 (77%) had pulmonary hypertension, 12 (20%) cardiomyopathy and 2 (3%) no known cardiac pathology. The study was approved by the Institutional Review Board with a waiver of consent.

Echocardiographic color Doppler images were used to measure TR vena contracta (VC) and classify TR as mild or moderate versus severe. In a subgroup of 46/61 patients, in whom velocity-encoded phase-contrast images were available, we evaluated TR severity using the current CMR methodology [7–9], and compared the results to echocardiography. Additionally, short-axis CMR images were used to measure cross-sectional TR jet area and signal intensity. These novel CMR indices were also compared to echocardiographic VC measurements. Subsequently, receiver-operating characteristics (ROC) analysis was performed in a derivation group of 21 patients (including randomly selected 7 patients from the severe TR group and 14 from the non-severe TR group) for each CMR parameter, in order to determine its diagnostic accuracy for discriminating severe from non-severe TR and identify the optimal cutoff. These optimal cutoffs were tested prospectively in the remaining 40 patients (test group) to determine their sensitivity, specificity and accuracy in an independent group of patients.

2.2. 2D echocardiography

2D and Doppler echocardiographic images were acquired using iE33 imaging system (Philips, Andover, MA). Presence of TR was initially determined qualitatively using color Doppler images and patients with no or trivial TR were excluded. Then TR severity was quantified by the highest VC value measured in the four-chamber and right ventricular (RV) inflow views. Patients were classified into two groups according to TR severity: mild or moderate for VC < 7 mm, and severe for VC ≥ 7 mm.

2.3. CMR imaging

CMR imaging was performed on a 1.5T scanner (Philips, Best, Netherlands) with a 5-channel cardiac coil. Steady-state free-precision short-axis cine images (~30 phases per cardiac cycle) were obtained from the apex to above the ventricular base. Imaging parameters were: echo time: 1.25msec, repetition time: 2.5msec, flip angle: 60°, slice thickness: 6 mm with 4 mm gaps, resolution varying from 1.25 × 1.25 to 1.79 × 1.79 mm. Velocity-encoded phase-contrast images were acquired in the pulmonic valve plane (Fig. 1, left) using the following settings: retrospective ECG gating; slice thickness 10 mm; flip-angle 15°; in-plane resolution 1.2 × 1.2 mm; repetition/echo time (TR/TE) 4.28/2.63 ms; phase-encoding velocity 200 cm/s; temporal resolution 28 ms.

2.4. Standard CMR analysis of TR

Short-axis images were analyzed to obtain RV stroke volume using the method of disks. Velocity-encoded phase-contrast images were analyzed using commercial software (Medis, Leiden, Netherlands) to measure absolute forward flow volume trough the pulmonic valve (Fig. 1, left), which was then subtracted from the RV stroke volume, in order to obtain TR volume (TRV). Patients were classified into two groups according to the severity of TR: severe (TRV either ≥30 ml, or in a separate analysis, ≥40 ml), moderate or mild (TRV < the above threshold).

2.5. New CMR analysis of TR

The new CMR analysis included: (1) identification of the plane and frame where TR jet area was maximal; (2) counting the number of slices where TR jet was seen; and (3) manual delineation of region of interest of the visualized jet cross-section to measure jet area and mean signal intensity (SI) within the jet, which was normalized to SI measured in the RA cavity away from the jet in the same plane.

2.6. Statistical analysis

Inter-technique comparison between CMR-derived TRV and echocardiographic VC included linear regression with Pearson's correlation. Inter-technique agreement for TR severity classification was performed using kappa (k) statistics. The calculated kappa coefficients were judged as: 0–0.20 low, 0.20–0.40 fair, 0.40–0.60 moderate, 0.60–0.80 good, and >0.80 excellent.

The TR jet area (JA) and normalized signal intensity (NSI) were first compared between the two groups of patients with different TR degrees using unpaired student's *t*-tests. P-values <0.05 were considered significant. Similar to CMR-derived TRV, inter-technique comparisons for JA and NSI against VC also included linear regression (in the entire study group) and k-statistics for TR severity (in 46 patients with velocity-encoded images to facilitate inter-technique comparisons).