Original Research Article

Estimation of right atrial and ventricular hemodynamics by CT coronary angiography

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BACKGROUND: Computed tomography coronary angiography (CTCA) provides an accurate noninvasive alternative to the invasive assessment of coronary artery disease. However, a specific limitation of CTCA is inability to assess hemodynamic data.

OBJECTIVE: We hypothesized that CTCA-derived measurements of contrast within the superior vena cava (SVC) and inferior vena cava (IVC) would correlate to echocardiographic estimations of right atrial and right ventricular pressures.

METHODS: Medical records of all patients who underwent both echocardiography and CTCA in our center were reviewed (n = 32). Standard CTCA was performed with a 64-detector CT using test-bolus method for image acquisition timing and iso-osmolar contrast injection through upper extremity vein. The length of the column of contrast reflux into the inferior vena cava (IVC) was correlated to echocardiographically determine tricuspid regurgitation jet velocity (TRV). SVC area change with contrast injection at the level of the bifurcation of the pulmonary artery was also correlated with IVC sniff response by echocardiogram.

RESULTS: The reflux column length was interpretable in 27 of 32 patients with a mean length of 10.1 ± 1.1 mm, and a significant bivariate correlation was observed between reflux column length and the tricuspid regurgitant jet velocity ($r = 0.84$; $P < .0001$). Mean SVC distensibility ratio was 0.63 ± 0.03; mean IVC sniff response ratio was 0.53 ± 0.03. SVC distensibility correlated to IVC sniff response with a Pearson r of 0.57 ($P = .04$).

CONCLUSION: Quantification of IVC and SVC contrast characteristics during CTCA provides a feasible and potentially accurate method of estimating right atrial and ventricular pressure.
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Introduction

Computed tomography coronary angiography (CTCA) provides an accurate noninvasive alternative to the invasive assessment of coronary artery disease. However, a specific limitation of CTCA is the lack of hemodynamic data such

as can be obtained by echocardiography with the use of measures such as tricuspid regurgitation jet velocity (TRV) for the estimation of right ventricular systolic pressure (RVSP).[1,2] One proposed qualitative indicator of right heart disorders, such as pulmonary hypertension, tricuspid regurgitation and right ventricular systolic dysfunction, is the reflux of iodinated contrast material into the inferior vena cava (IVC) during chest or abdominal CT,[3,4] but the variability of these CT methods in regard to image acquisition, contrast injection, and respiration timing prevents this IVC contrast reflux from being a quantitative parameter.

Through standardization of the imaging parameters and gating of imaging to the diastasis period of the cardiac cycle, CTCA may enable a more quantitative assessment of right heart pressures from the finding of contrast reflux into the IVC. We hypothesized that the degree of reflux of contrast into the IVC measured on CTCA would be proportional to the TRV as measured on standard transthoracic echocardiography. Thus, IVC contrast reflux could be used to assess RVSP with CTCA. Furthermore, we hypothesized that right atrial pressure could be also be estimated by CTCA by measuring the degree of superior vena cava (SVC) dilation. These hypotheses were assessed in a series of 32 patients undergoing clinically directed CTCA and echocardiography.

Methods

Study cohort

We conducted a retrospective analysis of patients who underwent both echocardiography and CTCA at the George Washington University between April 2007 and May 2009. Charts selected for review were limited to those with no documented change in clinical status between echocardiography and CT (n = 32). If multiple echocardiograms were present for the same patient, the echocardiography in closest temporal proximity to the CT was chosen. Charts were reviewed for demographic information, including age, sex, race, height, weight, pertinent medical history, medications, and the CTCA indication. The institutional review board at the George Washington University Medical Center approved the study, and the need for written informed consent was waived.

CTCA protocol

Patients underwent clinically indicated CTCA performed with 64-row multidetector CT (GE Lightspeed VCT; GE Healthcare, Waukesha, WI) with the use of a test-bolus method for image acquisition timing. All patients were in sinus rhythm and were treated with metoprolol tartrate to achieve a resting heart rate <65 beats/min. Patients were also premedicated with 0.4 mg of sublingual nitroglycerin before image acquisition. Iodixanol contrast was injected through an upper extremity peripheral intravenous catheter

with the use of a biphasic administration protocol (mean contrast volume, 115 ± 4 mL; range, 100–145 mL), including an initial phase of 5.5 mL/s for 16–18 seconds, a second phase of 3.5 mL/s for 4 seconds, followed by saline flush. Image acquisition was timed to peak contrast enhancement in the aortic root during end-inspiratory breathhold. Retrospectively gated CCTA (0.625-mm collimation) was performed with a tube voltage of 120 kVp and a weight-based determination of milliAmperes.

Transthoracic echocardiography

Echocardiographic images (Philips IE-33; Philips, Andover, MA) were analyzed on an Agfa Heartlab (Ridgefield Park, NJ) workstation. Echocardiography data recorded for analysis included peak TRV, IVC diameter, and IVC diameter with sniff.

Study measurement methods

CT images were analyzed for the presence and distance of contrast reflux into the IVC, change in SVC and IVC area with contrast injection, pulmonary artery diameter, and IVC attenuation values. CTCAs were analyzed by 2 readers (1 cardiologist and 1 radiologist) to determine whether coronary anatomy was interpretable. The caudal displacement of contrast into the IVC measured from the plane subtended by the right atrium-IVC junction was measured in millimeters and recorded as the IVC reflux column length with the use of standard subcostal views (Fig. 1). The SVC area change in response to contrast injection was measured in short axis at the level of the bifurcation of the pulmonary artery (Fig. 2). CTCA and echocardiography were read by independent observers blinded to the results of the other test. The interreader and intrareader variability of the reflux column length and SVC distension ratio were determined (n = 32).

Statistical analysis

Demographic data are reported as a mean ± standard error. Pearson correlation coefficients with 2-tailed P values were calculated for the relationship between the reflux column length and TRV in all patients and in only the subset with interpretable reflux column length. Pearson correlation coefficients were evaluated for the bivariate relationships between TRV and other echocardiography measures (pulmonary artery diameter, IVC and SVC distension with and without sniff), and IVC attenuation values. Linear regression for the relationship between reflux column length and TRV were completed on all studies. We derived a formula for the estimation of RVSP on the basis of the relationships between TRV and the length of the IVC contrast reflux column, including a semiquantitative term for right atrial pressure on the basis of the SVC distention ratio. Right atrial pressure was assumed to be 5 mm Hg when the SVC distention ratio was >0.4, and 10 mm Hg when
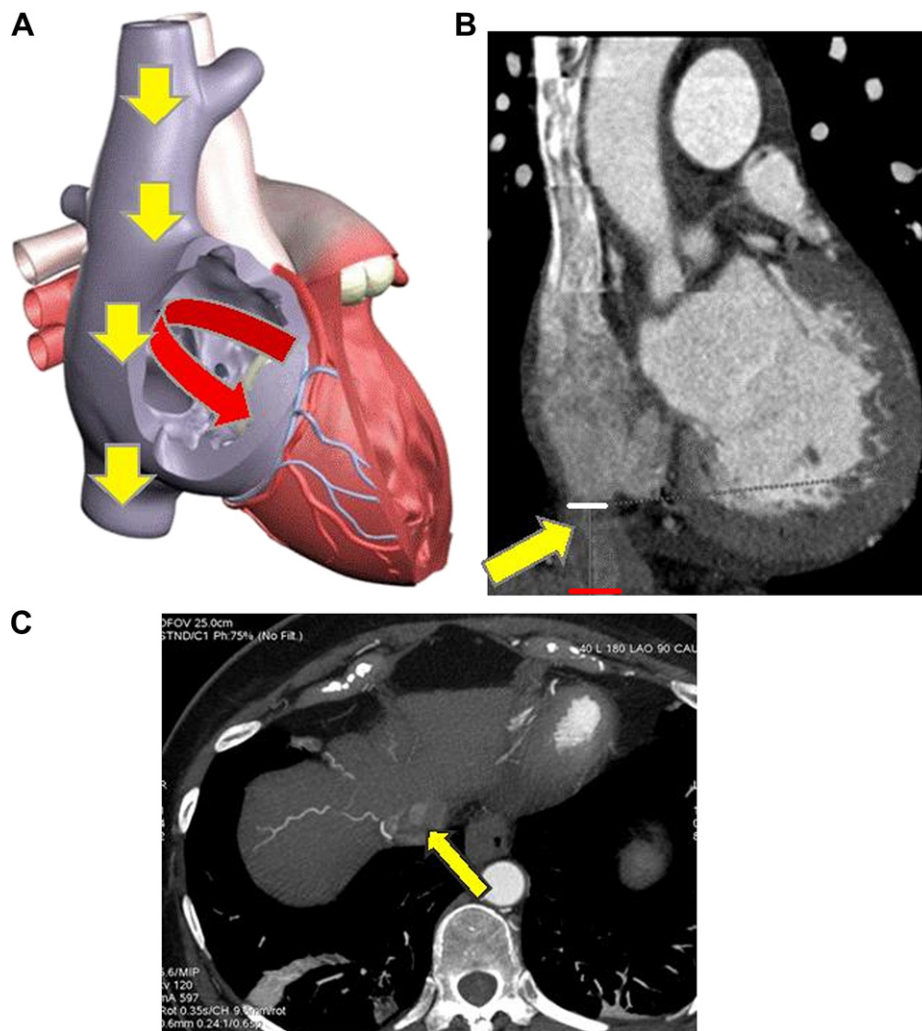
Figure 1 (**A**) Proposed pathophysiology of IVC contrast column length with contrast (depicted as the *yellow arrow*) directed around turbulent flow within the right atrium (*red arrow*) into the IVC. Figure used with permission of University of Minnesota (http://www.umn.edu/atlas). (**B**) Representative CTCA coronal image showing reflux of contrast into the IVC (*yellow arrow*). The reflux column length is calculated as the distance between the IVC-right atrial junction (*white horizontal line*) and its most caudal displacement (*red line*). (**C**) Representative CTCA axial image showing flux of contrast into the IVC (*yellow arrow*).

it was <0.4. Two-tailed t test was performed for analysis for intraobserver and interobserver variability. Statistical calculations were performed with the MedCalc Version 11.3 (Mariakerke, Belgium) software package.

Results

The mean time between echocardiography and CTCA was 10 ± 3 days (range, 0–59 days). Patient characteristics are shown in Table 1. The mean TRV was 1.74 ± 0.2 m/s, and the severity of tricuspid regurgitation was graded as trace in all patients (Table 2). Five patients had pulmonary hypertension, and 2 patients had right atrial enlargement. Mean left ventricular ejection fraction was 62% ± 2%.

Five of the 32 CTCA studies showed no evidence of IVC contrast reflux. In the other 27 patients, the mean IVC reflux column length was 10.1 ± 1.1 mm. A direct

correlation was observed between the reflux column length and the TRV ($r = 0.84$, $P < .0001$) (Fig. 3). Additional correlations between CTCA and echocardiography variables are summarized in Table 3. Pulmonary artery diameter weakly correlated to TRV ($r = 0.31$, $P = .08$).

The mean SVC dispensability ratio was 0.63 ± 0.03, whereas mean IVC sniff response ratio was 0.53 ± 0.03. A modest correlation was observed between the SVC distensibility ratio and the IVC sniff response ($r = 0.57$, $P = .04$; Fig. 4). On the basis of these calculations, right ventricular systolic pressure could be estimated in the same fashion as in echocardiography with the use of a modified Bernoulli equation[1]: RVSP = 4(TRV)^2 + right atrial pressure; RVSP = 4 (0.11 × reflux column length + 0.67)^2 + right atrial pressure; RVSP = 0.048 (reflux column length)^2 + 0.59 (reflux column length) + 1.8 + right atrial pressure.

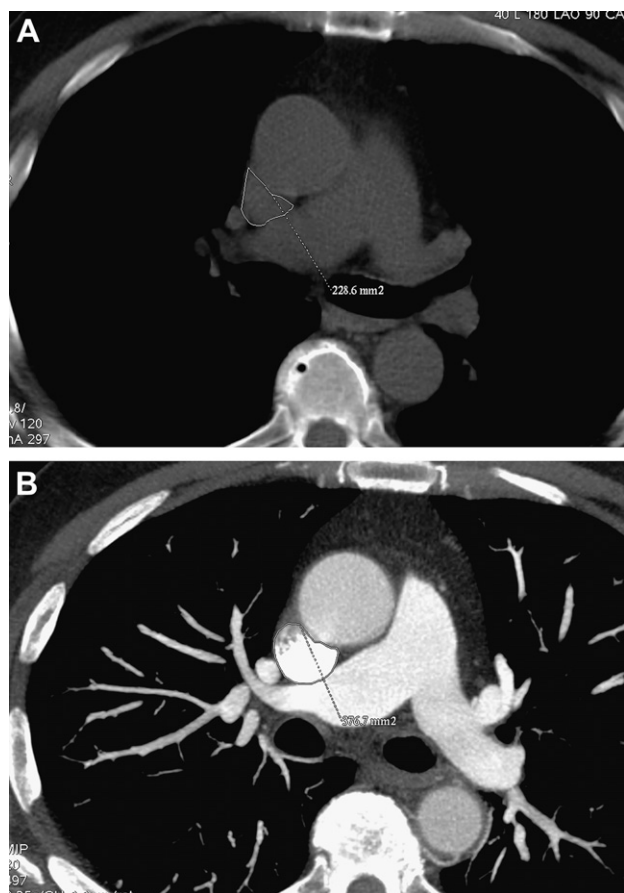Intraobserver variability was determined to be 0.89 and 0.96 by 2-tailed t test for IVC reflux column length and

Figure 2 (**A**) Representative noncontrast image of the SVC at the level of the bifurcation of the pulmonary artery (PA) on CTCA. (**B**) Representative contrast-enhanced image of the SVC at bifurcation of the pulmonary artery on CTCA. Note the marked distension with contrast power injection found with normal right atrial pressure.

Table 1 Characteristics of the study cohort

	Values
Sex	
Female, n (%)	11 (33)
Male, n (%)	21 (67)
Age, y, mean $\pm$ SD	58 $\pm$ 14
Body mass index, kg/m^2, mean $\pm$ SD	29 $\pm$ 5
Race	
White, n (%)	15 (47)
Black, n (%)	13 (40)
Other, n (%)	4 (13)
Indication for CTCA	
Chest pain, n (%)	17 (53)
Arrhythmia, n (%)	5 (16)
Dyspnea, n (%)	4 (12)
Abnormal stress test, n (%)	3 (9)
Syncope, n (%)	2 (7)
Other, n (%)	1 (3)
Hypertension, n (%)	17 (53)
Heart failure, n (%)	4 (13)
Rheumatologic disorders, n (%)*	1 (3)
Lung disorders, n (%)	6 (19)
Chronic obstructive pulmonary disease, n	1
Pulmonary embolism, n	3
Sarcoidosis, n	1
Interstitial lung disease, n	1
Congenital heart disease, n (%)	2 (6)
Hypertrophic cardiomyopathy, n	1
Repaired tetralogy of Fallot, n	1
Use of calcium channel blocker, n (%)	4 (13)
Amlodipine, n	2
Verapamil, n	1
Diltiazem, n	1

*Systemic lupus erythematosus.

SVC distension ratio. In addition, interobserver relationship was computed to be 0.76 and 0.91 for the reflux column length and SVC distension ratio, respectively.

Discussion

CTCA has been conventionally used solely for the evaluation of coronary anatomy. In this study, we have described a relationship between the length of the column of contrast into the IVC on CTCA and echocardiographically estimated RVSP among patients without significant tricuspid regurgitation.

Prior studies have described a relationship between the finding of IVC contrast reflux and tricuspid regurgitation. Several prior studies analyzed the presence and degree of reflux of contrast into the IVC during ungated CT studies and related it to the severity of tricuspid regurgitation on

Table 2 Echocardiographic findings (N = 32)

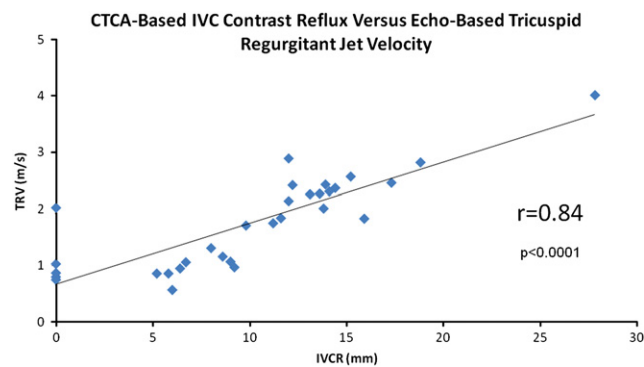|	Normal/trace, n (%)	Mild, n (%)	Moderate, n (%)	Severe, n (%)
Tricuspid regurgitation	32 (100)	0 (0)	0 (0)	0 (0)
Right atrial enlargement	30 (94)	1 (3)	1 (3)	0 (0)
Right ventricular systolic dysfunction	28 (88)	1 (3)	1 (3)	2 (6)
Right ventricular enlargement	28 (88)	1 (3)	3 (9)	0 (0)
Left ventricular systolic dysfunction	28 (88)	4 (12)	0 (0)	0 (0)
Pulmonary hypertension	27 (85)	4 (12)	0 (0)	1 (3)

Figure 3   The bivariate relationship between inferior vena cava (IVC) contrast reflux column (IVCR) and tricuspid regurgitant jet velocity (TRV).
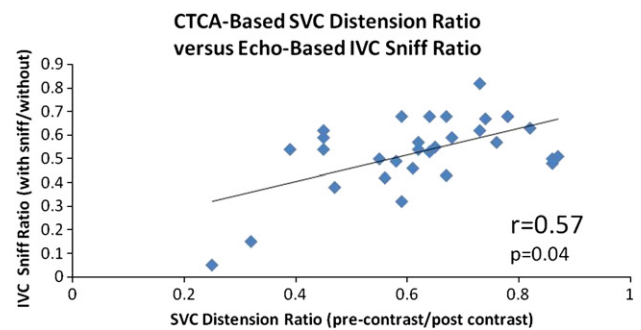

Figure 4   The correlation of CT-based SVC distension ratio (SVC area before contrast injection/SVC area after contrast bolus injection) and echo-based IVC sniff response (IVC diameter with sniff/IVC diameter without sniff maneuver).

transthoracic echocardiography, although a relationship with RVSP was not described.[3,4] CTCA provides an opportunity to extend these observations to a more quantitative assessment on the basis of method strengths, including generally uniform contrast delivery technique, temporal resolution and acquisition timing, and use of a breathhold. In contrast to our findings, LaBounty et al[5] analyzed tricuspid valvular regurgitation on transesophageal echocardiography with CTCA and showed no relationship. Further study is needed to determine whether quantitative assessments of RVSP with the use of CTCA can be extended to patients with mild or more-severe degrees of tricuspid regurgitation.

Other radiographic findings have been proposed for the assessment of pulmonary pressure. Pulmonary artery diameter has been reported to have good correlation with invasive measures of pulmonary artery pressure and have been proposed as a method for calculating pulmonary artery pressure.[6,7] Among our patients, we did not observe a significant relationship between pulmonary artery diameter and TRV; however, most of our patients had pulmonary artery pressures within the normal range. In contrast, we found a statistically significant correlation between distension of SVC in response to contrast injection to the echocardiography IVC sniff response, suggesting this may provide an estimation of right atrial pressure by CTCA.

Limitations

Our study has several limitations. The analysis was retrospective, and the CTCA and echocardiographic studies were not performed concurrently. Although there was no documented change in clinical status, we assume that volume status and blood pressure were comparable for both studies. In this study we have compared 2 noninvasive methods, and invasive measurement of right heart pressure provides the most accurate, "gold standard" assessment. Our findings are limited to patients without significant tricuspid regurgitation, and the number of patients with significant pulmonary hypertension was limited. Only a small number of patients in the cohort had right atrial enlargement, and right atrial size and compliance plays an integral role in hemodynamic assessment. Further study is needed in the use of newer triphasic contrast injection protocols and the lower contrast volumes that may be used with 256- or 320-row CT.

Conclusion

Quantification of IVC and SVC contrast characteristics during CTCA provides a feasible and potentially accurate method of estimating right atrial and ventricular pressures.

References

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Table 3   Bivariate correlations between cardiac CT angiography and echocardiographic variables

Cardiac CT	Echocardiography	Correlation coefficient	P
IVC distension	TRV	0.18	.46
SVC distension	TRV	0.33	.08
IVC distension	IVC sniff response	0.24	.27
IVC contrast attenuation	TRV	0.36	.08
Pulmonary artery diameter	TRV	0.31	.08

IVC, inferior vena cava; SVC, superior vena cava; TRV, tricuspid regurgitation velocity.

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