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Venae Cavae Anatomic Characteristics in Severe Tricuspid Regurgitation: Implications for Transcatheter Interventions

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Transcatheter tricuspid valve interventions (TTVIs) are rapidly expanding with new technologies being developed and investigated to address the unmet clinical need of severe tricuspid regurgitation (TR), a condition with significant morbidity and mortality, and relatively high associated surgical risk.[1] These technologies either target the valve (repair, replacement, annular remodeling) to address the TR or the venae cavae (VC) to prevent the downstream complications of the reflux. For valve therapies, VC are the main access route to deliver the equipment, ideally in a coaxial fashion, to the tricuspid valve (TV). This may be challenging and depends on the angulation, distance, and offset between the VC axes (access) and the TV axis (target). For heterotopic valve therapies, caval valve implantation (CAVI) is used in patients with right heart failure and unsuitable anatomy for orthotopic TV replacement or transcatheter edge-to-edge repair, who are at high or prohibitive surgical risk for TV surgery. However, little is known about the normal VC dimensions and how they change in patients with severe TR, important data for device sizing and anchoring.

We included 71 patients with isolated severe TR and none to mild mitral regurgitation (MR), referred to the Cleveland Clinic between 2017 and 2022 who had undergone multiphase cardiac computed tomography (CT) with right-sided contrast. Comparator groups included patients with isolated severe MR and none to mild TR, matched by age and gender (caliper 0.1) and patients without any valvular dysfunction (normal coronary CT), matched by gender (caliper 0.1). We evaluated VC diameter and area at the junction with the right atrium (RA), junction with supra-hepatic veins for inferior VC (IVC) and at the level of the pulmonary artery (PA) for superior VC (SVC). These measurements were done at systole and diastole and were stratified based on TR severity. We measured the angle between VC and the TV annulus, the height between these structures and the offset to the TV as previously described by Harb et al.[2] All measurements were indexed to body surface area. Variables are presented as mean ± standard deviation. We used analysis of variance (ANOVA) test for comparison between groups. This study was approved by the Institutional Review Board of the Cleveland Clinic.

Of 206 included patients, mean age was 77 years for the TR and MR groups and 38 years for the control group with 58%, 64%, and 56% females, respectively. Mean TV effective regurgitant orifice area was 0.66 ± 0.32 cm^2 in the TR group, with 30% having torrential TR, and mitral valve effective regurgitant orifice area being 0.42 ± 0.23 cm^2 in the MR group. VC dimensions were significantly larger in the severe TR cohort (Table 1), although no significant differences in systole versus diastole were observed (area of IVC at supra-hepatic veins junction mean 3.91 vs 3.87 cm^2/m^2; $p = 0.53$, and area of SVC at level of PA mean 2.67 vs 2.43 cm^2/m^2; $p = 0.161$). The IVC offset was increased in patients with severe TR compared to the MR and control group (mean 9.79, 7.08, and 5.87 mm/m^2, respectively; $p < 0.001$). On the contrary, while the SVC to TV angle was smaller in patients with severe TR compared to the other groups, the IVC angle was larger.

Abbreviations: CAVI, Caval valve implantation; TR, Tricuspid regurgitation; TTVI, Transcatheter tricuspid intervention; TV, Tricuspid valve; VC, Venae cavae.

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Table 1
Cardiac CT angiography VC dimensions between groups

Indexed variables	≥ Severe TR (n = 71)	Stratified TR severity				Severe MR (n = 64)	Controls (n = 71)	p val[†]
		Severe TR	Massive TR	Torrential TR	p val[*]			
Indexed IVC dimensions, mean/BSA (SD)								
RA junction area at systole, cm^2/m^2	4.89 (1.9)	4.94 (1.99)	4.74 (1.74)	5.22 (1.35)	0.703	3.56 (1.3)	2.92 (0.9)	**< 0.001**
RA junction area at diastole, cm^2/m^2	4.72 (1.7)	4.80 (2.03)	4.54 (1.52)	5.13 (1.34)	0.521	3.33 (1.0)	2.92 (0.9)	**< 0.001**
RA junction diameter at systole, mm/m^2	15.61 (3.2)	18.25 (4.08)	17.59 (3.27)	19.44 (2.61)	0.247	15.61 (3.2)	13.71 (2.9)	**< 0.001**
RA junction diameter at diastole, mm/m^2	17.82 (3.2)	18.16 (3.87)	17.27 (3.09)	19.09 (2.46)	0.201	15.06 (2.5)	13.77 (2.7)	**< 0.001**
SHV junction area at systole, cm^2/m^2	3.91 (1.2)	3.97 (1.14)	3.53 (1.13)	4.74 (1.10)	**0.015**	3.03 (0.9)	2.81 (0.9)	**< 0.001**
SHV junction area at diastole, cm^2/m^2	3.87 (1.2)	3.84 (1.30)	3.64 (1.18)	4.62 (1.09)	0.07	3.05 (0.9)	2.91 (0.9)	**< 0.001**
SHV junction diameter at systole, mm/m^2	16.34 (2.8)	16.59 (2.47)	15.29 (2.84)	18.53 (2.46)	**0.006**	15.17 (3.6)	13.47 (2.9)	**< 0.001**
SHV junction diameter at diastole, mm/m^2	16.24 (2.6)	16.47 (2.48)	15.51 (2.92)	18.05 (2.29)	**0.034**	14.55 (2.4)	13.7 (2.9)	**< 0.001**
Length from RA junction to SHV junction at systole, mm/m^2	9.44 (6.4)	9.19 (9.83)	10.04 (6.19)	8.35 (6.16)	0.783	9.06 (3.7)	9.12 (4.8)	0.934
Length from RA junction to SHV junction at diastole, mm/m^2	9.8 (6.7)	10.60 (10.20)	10.47 (6.22)	6.93 (4.54)	0.29	9.17 (3.5)	9.5 (5.0)	0.839
Offset, mm/m^2	9.79 (5.6)	10.83 (4.59)	10.03 (5.99)	7.98 (4.67)	0.367	7.08 (4.4)	5.87 (2.9)	**< 0.001**
Angle to TVA, degrees/m^2	51.36 (9.9)	6.34 (4.71)	4.83 (4.48)	8.36 (4.70)	0.07	48.45 (11.3)	46.8 (10.7)	**0.038**
Height to TVA, mm/m^2	27.98 (8.7)	53.61 (8.72)	50.52 (9.88)	51.32 (9.24)	0.683	21.69 (8.1)	16.84 (5.5)	**<0.001**
Indexed SVC dimensions, mean/BSA (SD)								
Level of PA area at systole, cm^2/m^2	2.67 (0.9)	2.84 (0.98)	2.41 (0.80)	3.31 (0.90)	**0.012**	1.71 (0.7)	1.26 (0.5)	**< 0.001**
Level of PA area at diastole, cm^2/m^2	2.43 (0.9)	2.51 (1.01)	2.26 (0.65)	2.83 (0.82)	0.085	1.97 (1.5)	1.22 (0.5)	**< 0.001**
Level of PA diameter at systole, mm/m^2	13.46 (2.7)	13.94 (2.65)	12.63 (2.48)	15.41 (2.26)	**0.006**	10.58 (2.8)	9.03 (2.3)	**< 0.001**
Level of PA diameter at systole, mm/m^2	12.89 (2.7)	13.14 (2.64)	12.23 (2.14)	14.31 (3.09)	**0.049**	10.89 (2.5)	8.89 (2.0)	**< 0.001**
RA junction area at systole, cm^2/m^2	3.72 (1.6)	4.16 (1.63)	3.36 (1.42)	4.48 (1.56)	0.076	1.66 (0.7)	1.23 (0.5)	**< 0.001**
RA junction area at diastole, cm^2/m^2	3.34 (1.4)	3.75 (1.78)	3.13 (1.21)	3.62 (1.53)	0.394	1.85 (1.4)	1.11 (0.4)	**< 0.001**
RA junction diameter at systole, mm/m^2	15.84 (3.7)	16.84 (3.50)	14.79 (3.83)	17.88 (3.27)	0.038	10.68 (2.7)	8.92 (2.3)	**< 0.001**
RA junction diameter at diastole, mm/m^2	14.97 (3.5)	15.94 (3.98)	14.38 (3.48)	15.81 (3.61)	0.351	10.72 (2.6)	8.5 (1.9)	**< 0.001**
Length from RA junction to PA level at systole, mm/m^2	14.3 (4.9)	13.29 (5.05)	15.12 (5.41)	12.93 (5.18)	0.407	14.27 (4.9)	13.7 (5.6)	0.817
Length from RA junction to PA level at diastole, mm/m^2	14.8 (5.3)	14.73 (6.50)	15.44 (5.55)	12.62 (5.00)	0.303	13.98 (4.5)	13.5 (5.2)	0.312
Offset, mm/m^2	5.84 (4.8)	6.34 (4.71)	4.83 (4.48)	8.36 (4.70)	0.07	6.13 (4.8)	3.43 (2.6)	**< 0.001**
Angle to TVA, degrees/m^2	58.34 (12.0)	53.61 (8.72)	50.52 (9.88)	51.32 (9.24)	0.683	63.83 (10.4)	59.11 (11.9)	**0.017**
Height to TVA, mm/m^2	28.02 (7.4)	59.79 (9.68)	55.80 (12.4)	60.72 (10.02)	0.355	20.89 (6.2)	15.58 (4.4)	**< 0.001**

Bold values indicate $p < 0.05$.
BSA, body surface area; CT, computed tomography; IVC, inferior vena cava; MR, mitral regurgitation; PA, pulmonary artery; RA, right atrium; SD, standard deviation; SHV, supra-hepatic veins; SVC, superior vena cava; TR, tricuspid regurgitation; TVA, tricuspid valve annulus.
[*] p value for ANOVA test comparing severe vs massive vs torrential TR.
[†] p value for ANOVA test comparing ≥ severe TR vs severe MR vs controls.

Understanding the VC anatomy, their dimensions (at various levels), and spatial relationship (angle, offset, distance) to the TV are crucial for TTVI procedural success, although these considerations remain not well studied, underappreciated, and often overlooked. To our knowledge, this is the first detailed report assessing the VC anatomic characteristics as they pertain to TTVI on cardiac CT, which is typically used for procedural planning.[3] Procedural evaluation for CAVI also requires the presence of significant caval reflux for proper valve function after implantation. Earlier heterotopic therapies mainly involved the IVC with complications including residual leaks, improper sizing, and device embolization and thrombosis.[4] Currently, TricValve (Products + Features) is the only dedicated CAVI system. The early experience of TricValve in 35 patients has demonstrated the procedure's feasibility (94% procedural success) and safety (no procedural deaths or conversions to surgery) as well as functional status and patient-reported quality of life (NYHA functional class and Kansas City Cardiomyopathy Questionnaire) benefits.[5] However, these findings are largely limited by the small sample size. With the increasing use of CAVI therapies, knowing how substantially larger the VC dimensions are in the severe TR group has important implications, particularly in terms of device sizing and catheter approach in advanced disease.

First, we present the VC dimensions at multiple levels for patients with severe TR and how they compare to normal younger patients (normal coronary CT) and age-matched and gender-matched patients with nonsevere TR (MR group). Second, since these dimensions were not significantly different across the cardiac cycle, a single-phase CT rather than a multiphasic acquisition may be used, significantly limiting the amount of radiation exposure associated with such scans. Finally, the angulation, distance, and offset required to reach the TV in a coaxial fashion from both the SVC and IVC are outlined, which have important implications in terms of designing TTVI delivery guides' physical properties and capabilities in terms of maneuverability. Careful understanding of the VC anatomic characteristics is key for TTVI procedural success, as they are either the access routes or the targets for these rapidly evolving therapies.

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Ethics Statement

This study was approved by the Institutional Review Board of the Cleveland Clinic, and written informed consent was waived.

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Disclosure Statement

The authors report no conflict of interest.

Supplementary Material

Supplemental data for this article can be accessed on the publisher's website.

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