JACC: CASE REPORTS VOL. 3, NO. 18, 2021

CASE REPORT

ADVANCED

CLINICAL CASE

Invasive Cardiomechanics During Transcatheter Edge-to-Edge Repair for Massive Tricuspid Regurgitation Using Biventricular Pressure-Volume Loop Monitoring

Antoon J.M. van den Enden, MD, Marcello B. Bastos, MD, Jan J. Schreuder, MD, PhD, Joost Daemen, MD, PhD, Nicolas M. Van Mieghem, MD, PhD

ABSTRACT

Invasive pressure-volume loop analysis allows direct monitoring of changing intraventricular cardiac mechanics during structural heart interventions. Our aim was to illustrate changes in right and left ventricular mechanics during transcatheter edge-to-edge tricuspid repair for severe tricuspid regurgitation. (**Level of Difficulty: Advanced.**)

HISTORY OF PRESENTATION

An 84-year-old woman with known right ventricular (RV) heart failure secondary to severe tricuspid valve insufficiency presented to a peripheral hospital reporting reduced exercise tolerance and progressive reports of dyspnea (New York Heart Association functional class IV), despite optimal medical therapy.

LEARNING OBJECTIVES

- To understand changes in biventricular loading and intraventricular cardiac mechanics during TEETR.
- To interpret ventricular tolerance of changing loading conditions during structural heart interventions, using PVL monitoring.

On physical examination, she was normotensive with bimalleolar edema. Transthoracic and transesophageal echocardiography showed normal left ventricular (LV) and reduced RV function (adequate longitudinal contraction but severely reduced radial contraction), in the presence of atrial dilatation and severe tricuspid regurgitation with a massive central jet without any further significant valvular disease (**Figure 1**). The patient was referred to our center (Thorax Center, Erasmus University Medical Center, Rotterdam, the Netherlands) for endovascular tricuspid valve repair.

PAST MEDICAL HISTORY

The patient's medical history included hypertension, chronic obstructive pulmonary disease, transient ischemic attack, and atrial fibrillation.

From the Department of Cardiology, Thorax Center, Erasmus University Medical Center, Rotterdam, the Netherlands.
The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received June 2, 2021; revised manuscript received July 9, 2021, accepted July 12, 2021.

ISSN 2666-0849 https://doi.org/10.1016/j.jaccas.2021.07.030

JACC: CASE REPORTS, VOL. 3, NO. 18, 2021
DECEMBER 15, 2021:1883-1887

ABBREVIATIONS AND ACRONYMS

E_a = effective arterial elastance

E_{es} = end-systolic elastance

LV = left ventricular

PVA = pressure-volume area

PVL = pressure-volume loop

RV = right ventricular

SW = stroke work

TEETR = transcatheter edge-to-edge tricuspid repair

DIFFERENTIAL DIAGNOSIS

Not applicable.

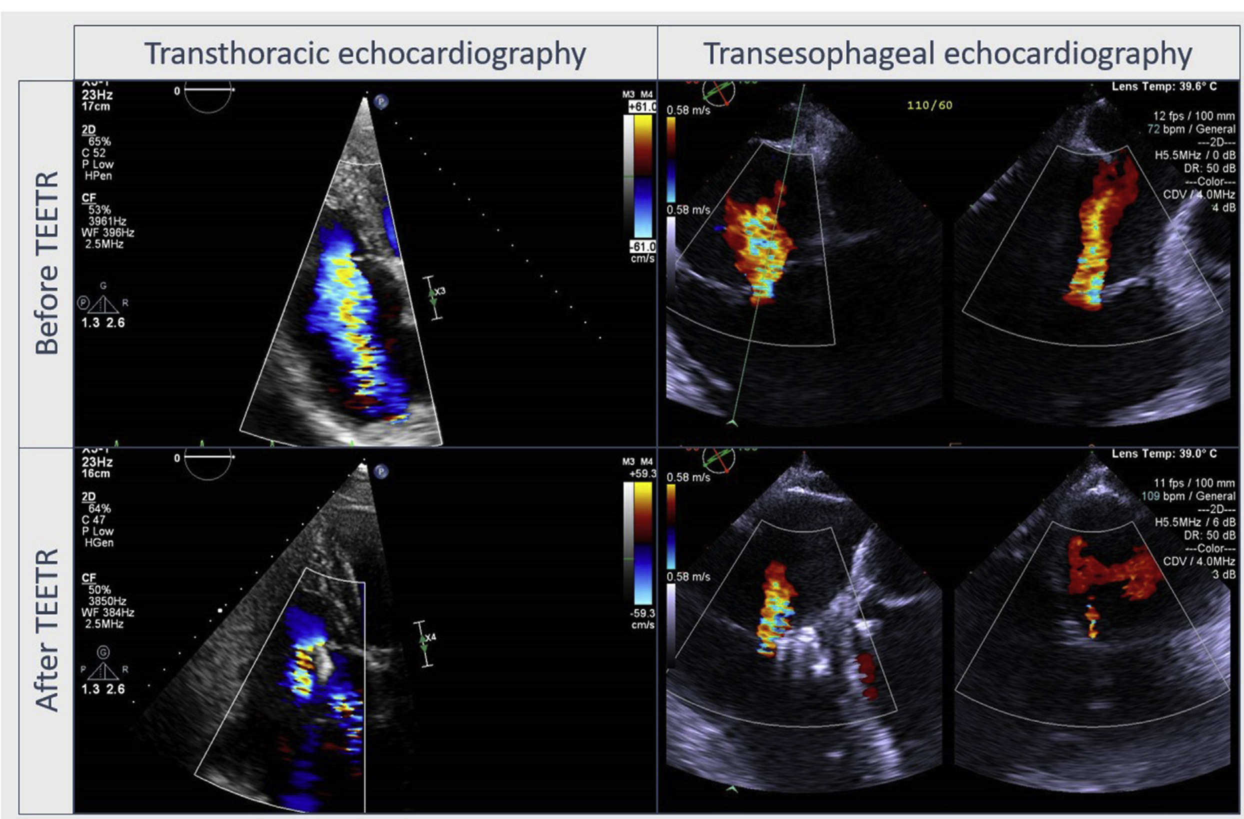
INVESTIGATIONS

After heart team consensus, the patient was turned down for surgical tricuspid valve replacement because of her age and frailty (The Society of Thoracic Surgeons score, 3.7%) and was subsequently scheduled for transcatheter edge-to-edge tricuspid valve repair (TEETR) with extensive periprocedural hemodynamic monitoring.

MANAGEMENT

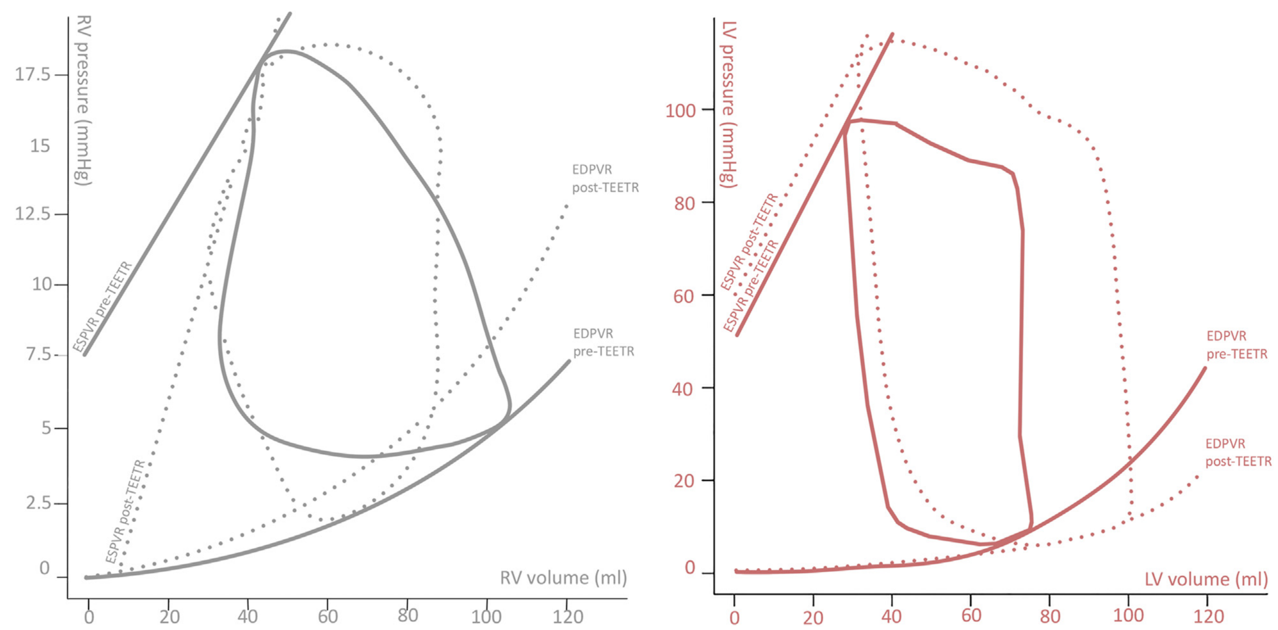
TEETR was performed with the patient under general anesthesia and using transesophageal echocardiographic guidance. Periprocedural hemodynamic monitoring was performed using both a pulmonary artery catheter and a conductance catheter allowing pressure-volume loop (PVL) monitoring (CD Leycom). Comprehensive invasive hemodynamic assessment was done directly before and immediately after TEETR, including PVL analysis of the right and left ventricles. During TEETR, the conductance catheter remained in the apex of the left ventricle. Thermodilution was used for volume calibration of the conductance catheter, and hypertonic saline was administrated to determine parallel conductance. Volume calibration and parallel conductance determination were repeated after conduction catheter exchange between the right and left ventricles. The conduction catheter was positioned in the ventricular apex under fluoroscopic guidance with visual inspection of segmental loops, thereby ensuring that the segments were in the same position within the respective chamber during data acquisition.

FIGURE 1 Echocardiographic Visualization Before and After TEETR



(Top) Tricuspid regurgitation before transcatheter edge-to-edge tricuspid repair (TEETR) during **(left)** transthoracic and **(right)** transesophageal echocardiography. **(Bottom)** Improved tricuspid regurgitation from massive to mild or moderate after transcatheter edge-to-edge tricuspid repair during **(left)** transthoracic and **(right)** transesophageal echocardiography.

FIGURE 2 Pressure-Volume Loop Plots



Pressure-volume loop shifts before and after transcatheter edge-to-edge tricuspid repair (TEETR) for both the **(left)** right ventricle (RV) and the **(right)** left ventricle (LV), presented with subsequent end-systolic pressure-volume relationship (ESPVR) and end-diastolic pressure-volume relationship (EDPVR) trendlines. The **solid line** reflects the pressure-volume loop before transcatheter edge-to-edge tricuspid repair, and the **dotted line** represents the pressure-volume loop after transcatheter edge-to-edge tricuspid repair.

Single-beat maximal pressure (P_{max}) was used for end-systolic elastance (E_{es}) calculation. Throughout the procedure, the patient had atrial fibrillation with minimal beat-to-beat irregularities. A total of 2 clips (TriClip XT, Abbott) were positioned along the septal-anterior commissure (Figure 1). LV and RV PVL plots with corresponding end-systolic pressure-volume and end-diastolic pressure-volume relationships, before and directly after TEETR, are summarized in Figure 2, with corresponding quantifications presented in Table 1.

Cardiac output improved from an average of 2.9 L/min before TEETR to 3.4 L/min after TEETR. LV PVL shifted in a right-upward fashion after TEETR with increased LV end-diastolic volume from 77.9 to 105.6 mL and LV stroke volume from 53.4 to 67.9 mL. RV end-diastolic volume decreased from 101.9 to 84.3 mL after TEETR. Tau, a constant reflecting the exponential decline in ventricular pressure during the early relaxation phase of diastole, decreased for the right ventricle from 187.7 to 70.7 ms after TEETR. RV stroke work (SW) and pressure-volume area (PVA) decreased after TEETR (with an increased SW/PVA ratio from 0.54 to 0.68), thus demonstrating improved mechanical efficiency. Moreover, RV systolic and diastolic intraventricular dyssynchrony improved after TEETR (32.6% to 10.0% and 28.8% to 12.4%, respectively). RV regurgitant volume decreased from 44 to 7 mL with the RV ratio of end-systolic elastance (E_{es}) to effective arterial elastance (E_a) (E_{es}/E_a) (reflecting right ventricular-pulmonary arterial coupling) increasing from 0.43 to 0.98. RV ejection fraction decreased after TEETR (60.4% to 47.0%). After TEETR, maximal RV dP/dt (rate of rise in ventricular pressure) halved, whereas E_{max} (maximal elastance) remained similar (0.44 to 0.41 mm Hg/mL).

DISCUSSION

The goal of TEETR is to alleviate the right ventricle from tricuspid regurgitation. Invasive PVL analysis can document biventricular hemodynamic effects of structural heart interventions in situ and thereby provide enhanced insights into cardiac mechanics. RV myocardial energetic demand decreased after TEETR, as reflected by an increased SW/PVA ratio. RV ejection fraction slightly decreased (47%), but

JACC: CASE REPORTS, VOL. 3, NO. 18, 2021
DECEMBER 15, 2021:1883–1887

TABLE 1 Changes in Left and Right Ventricular Hemodynamic and Cardiac Energetic Parameters on the Basis of PVL Monitoring Before and After TEETR

	Right Ventricle		Left Ventricle	
	Before TEETR	After TEETR	Before TEETR	After TEETR
Average heart rate (beats/min)	65	68	70	70
Average cardiac output (L/min)	2.9	3.4	3.1	3.8
Average stroke volume (SV, mL)	34.4	37.7	53.4	67.9
Stroke work (SW, mm Hg/mL)	845.0	737.0	4,273.9	6,274.9
Pressure-volume area (PVA single beat, mm Hg/mL)	1,561.2	1,088.9	7,509.9	10,838.8
SW/PVA ratio	0.54	0.68	0.57	0.58
Ejection fraction ([EDV − ESV] / EDV, %)	60.4	47.0	66.8	69.3
End-diastolic volume (EDV, mL)	101.9	84.3	77.9	105.6
End-diastolic pressure (EDP, mm Hg)	3.9	6.0	8.4	11.4
End-systolic volume (ESV, mL)	40.3	44.7	25.9	32.4
End-systolic pressure (ESP, mm Hg)	17.6	18.3	97.3	115.4
Tau (ms)	189.7	70.7	39.3	43.0
dP/dt max (mm Hg/s)	201.1	95.7	868.7	871.0
$V_{100mmHg}$ (mL)	421.4	216.4	27.8	21.8
V_{30mmHg} (mL)	207.5	146.9	120.2	145.8
V_{15mmHg} (mL)	28.3	37.7	−30.4	−36.4
End-systolic elastance (E_{es}, mm Hg mL)	0.22	0.48	1.46	1.46
V_O (mL)	−13.9	8.1	−42.0	−41.4
Effective arterial elastance (E_a, mm Hg/mL)	0.51	0.49	1.82	1.70
E_{es}/E_a ratio	0.43	0.98	0.80	0.86
Intraventricular dyssynchrony, systolic (%)	32.6	10.0	6.3	8.9
Intraventricular dyssynchrony, diastolic (%)	28.8	12.4	12.1	11.9

Values are the average numbers and therefore preclude 1:1 correlations.

dP/dt max = maximum rate of rise in ventricular pressure; PVL = pressure-volume loop; TEETR = transcatheter edge-to-edge tricuspid repair; V = volume.

intraventricular systolic and diastolic dyssynchrony improved. Further, RV E_{es}/E_a increased as a reflection of raised pulmonary flow resulting from TEETR. The load-independent E_{es} doubled and reflected an improved myocardial contractile state (1). The stable E_a was a marker of pulmonary vascular resistance and thus RV afterload. Interestingly, the RV maximal dP/dt dropped after TEETR but is a largely load-dependent parameter. Conversely, the RV volume at 15 mm Hg (V_{15mmHg}) and mechanical intraventricular dyssynchrony decreased, both suggesting improved myocardial intrinsic contractility. These characteristics, together with an improved SW/PVA ratio, indicate a clear gain in RV efficiency.

TEETR increased LV preload and LV myocardial metabolic demand represented by higher LV end-diastolic volume, SW, and PVA. However, these phenomena were well tolerated and were associated with improved overall cardiac output, increased LV stroke volume, and stable LV intraventricular dyssynchrony and E_{es}/E_a (ie, LV-aortic coupling). PVL observations of increased LV filling (reflected by increased LV end-diastolic volume and stroke volume) and reduced RV loading were in concordance with cardiac magnetic resonance-based visualizations by Rommel et al (2) in 18 patients up to 6 months after TEETR. PVL analysis in this case is characterized by several limitations. Cardiac output measurement by thermodilution in the presence of valvular insufficiency has intrinsic limitations and was not confirmed by an additional (eg, Fick) measurement. In addition, parallel conductance was determined using hypertonic saline; nonetheless, we cannot exclude clip material interference with RV or LV conductance.

FOLLOW-UP

Transthoracic echocardiography before discharge confirmed a significant reduction in tricuspid regurgitation from massive to mild or moderate after TEETR (**Figure 1**).

CONCLUSIONS

Invasive PVL analysis illustrated immediate favorable cardiomechanical effects of TEETR in a patient with massive isolated tricuspid regurgitation. TEETR resulted in the following: 1) RV unloading, increased pulmonary artery flow, and decreased RV myocardial metabolic demand; 2) improved intraventricular dyssynchrony; and 3) increased LV loading and LV myocardial metabolic demand.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

Dr Barros Bastos has received personal fees from PulseCath BV. Dr Schreuder has reported a working and financial relationship with CD Leycom. Dr Daemen has received institutional grant and research support from AstraZeneca, Abbott Vascular, Boston Scientific, ACIST Medical, Medtronic, Pie Medical, and ReCor Medical; and has received consulting and speaker fees from Abiomed ACIST Medical, Boston Scientific, ReCor Medical, PulseCath, Pie Medical, Siemens Health Care, and Medtronic. Dr Van Mieghem has received research grant support from Abbott Vascular, Boston Scientific, Edwards Lifesciences, Medtronic, PulseCath BV, Abiomed, Daiichi Sankyo, and Siemens. Dr van den Enden has reported that he has no relationships relevant to the contents of this paper to disclose.

ADDRESS FOR CORRESPONDENCE: Dr Nicolas M. Van Mieghem, Department of Cardiology, Thoraxcenter, Erasmus University Medical Center, Dr. Molewaterplein 40, 3015 GD, Rotterdam, the Netherlands (Office Nt-645). E-mail: n.vanmieghem@erasmusmc.nl. Twitter: @drnvanmieghem, @CathlabN.

REFERENCES

1. Bastos MB, Burkhoff D, Maly J, et al. Invasive left ventricle pressure-volume analysis: overview and practical clinical implications. *Eur Heart J*. 2020;41:1286–1297.

2. Rommel KP, Besler C, Noack T, et al. Physiological and clinical consequences of right ventricular volume overload reduction after transcatheter treatment for tricuspid regurgitation. *J Am Coll Cardiol Intv*. 2019;12:1423–1434.

KEY WORDS left ventricle, pressure-volume loop monitoring, right ventricle, transcatheter edge-to-edge tricuspid repair, tricuspid valve, valve repair