LVAD and the failing right heart

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Introduction

- Right heart failure in LVAD patients

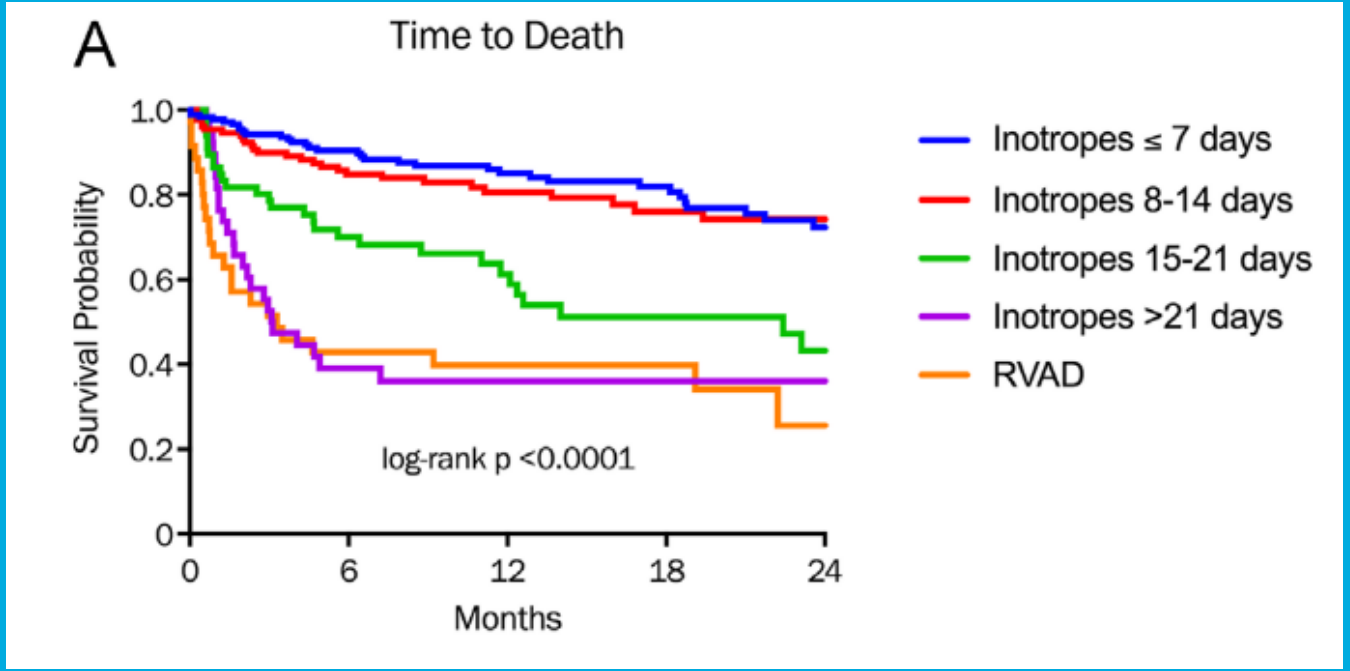
Pre-operative

Peri-operative

Post-operative

Incidence of peri-operative RV failure

- Peri-operative: 5 – 46%
  - Mild
  - Moderate
  - Severe



LaRue S, et al. Clinical outcomes associated with INTERMACS-defined right heart failure after left ventricular assist device implantation **J Heart Lung Transplant 2017; 36(4):475-477**.

Definition of RHF after LVAD

TABLE 2 | 2014 INTERMACS definition for right heart failure.

Definition: Symptoms or findings of persistent right heart failure characterized by BOTH of the following:

1. Documentation of elevated central venous pressure by:
   - Direct measurement with right atrial pressure > 16 mmHg OR
   - Findings of significantly dilated inferior vena cava with absence of inspiratory variation by echocardiography OR
   - Clinical findings of elevated jugular distention at least halfway up the neck in an upright patient
2. Manifestations of elevated central venous pressure characterized by:
   - Clinical findings of peripheral edema (>2+ either new or unresolved) OR
   - Presence of ascites or palpable hepatomegaly on physical examination or diagnostic imaging OR
   - Laboratory evidence of worsening hepatic congestion (total bilirubin > 2.0 mg/dl) or renal dysfunction (creatinine > 2.0 mg/dl)
3. If the patient meets definition of both criteria above then a severity scale for right heart failure will be graded utilizing post implant inotropes, inhaled nitric oxide or intravenous vasodilators, need for right ventricular assist device and timing from surgery.

Teuteberg J. et al Early Right Ventricular Assist Device Use in Patients Undergoing Continuous-Flow Left Ventricular Assist Device Implantation: Incidence and Risk Factors From the Interagency Registry for Mechanically Assisted Circulatory Support **J Heart Lung Transplant 2017; 36:356. doi 10.1016/j.healun.2017.01.368**

Definition of RHF after LVAD

TABLE 3 | 2020 Academic Research Consortium definition for right heart failure.

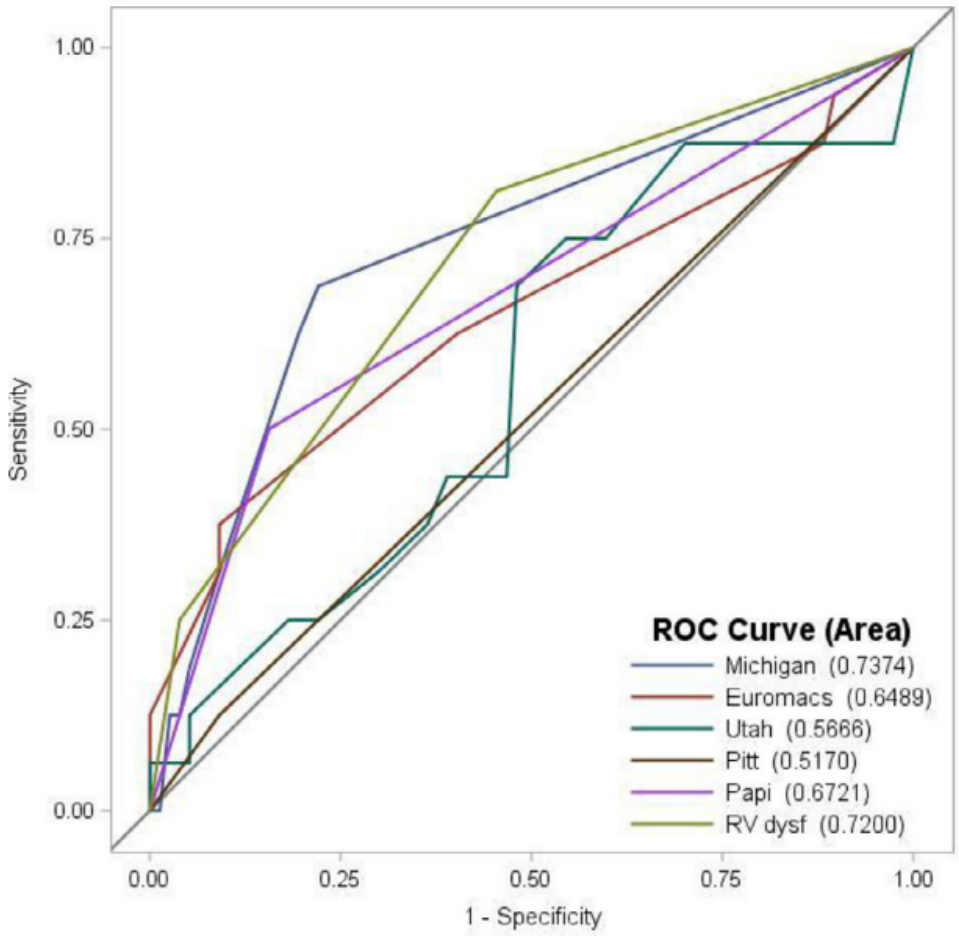
Early acute right heart failure	Early post-implant right heart failure
Need for implantation of right ventricular assist device at time of left ventricular assist device implantation	(A) Need for implantation of right ventricular assist device <30 days of left ventricular assist device implantation OR (*B) Failure to wean from inotropic support or inhaled nitric oxide within 14 days following LVAD implantation or having to initiate this support within 30 days of implant for a duration of at least 14 days OR (C) Death occurring in patients within 14 days of LVAD implant who have not received an RVAD but who remain on inotropes or vasopressors at the time of death and meet criteria for the diagnosis of Right Heart Failure on the basis of the above clinical findings * For Criteria B: At least two of the following must be present: - Ascites - Peripheral edema (>2+) - Elevated central venous pressure (>16 mmHg) - Elevated jugular venous pressure atleast half way up the neck in an upright patient OR At least one of the following must be present: - Renal failure with creatinine > 2 × baseline value - Liver injury with at least 2× upper limit normal in AST/ALT - Total bilirubin > 2.0 - SVO2 < 50% - Cardiac index < 2.2 liter/min/m^2 - Elevated lactate > 3.0 mmol/liter - Reduction in pump flow of >30% from previous baseline in absence of cardiac tamponade, tension pneumothorax or other mechanical causes.

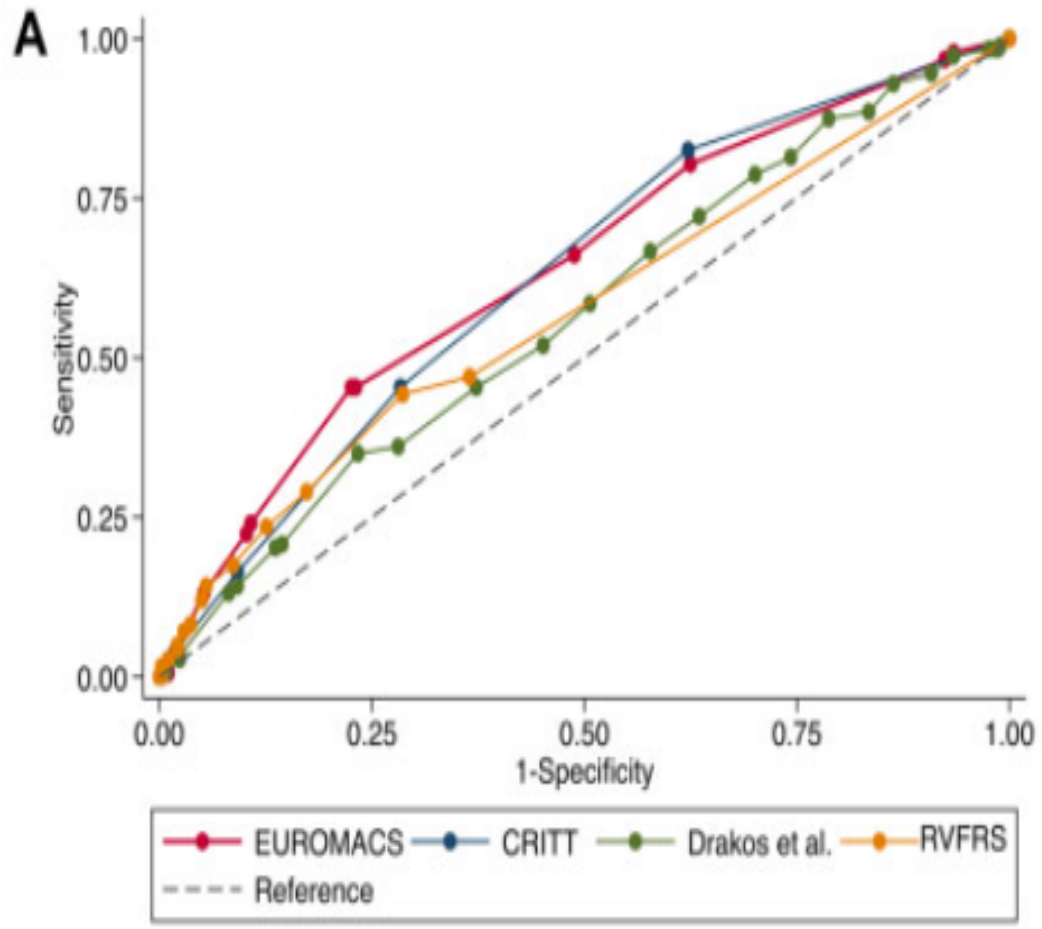
Hall S. et al The "Right" Definition for Post-Left Ventricular Assist Device Right Heart Failure: The More We Learn, the Less We Know. **Front. Cardiovasc. Med. 2022 9:893327. doi: 10.3389/fcvm.2022.893327**.

Can we predict the RV failure?

- Risk scores:
  - Utah RVF
  - Pittsburgh decision tree
  - Michigan RVF
  - CRITT
  - Penn
  - EUROMACS right-sided heart failure risk score
  - …

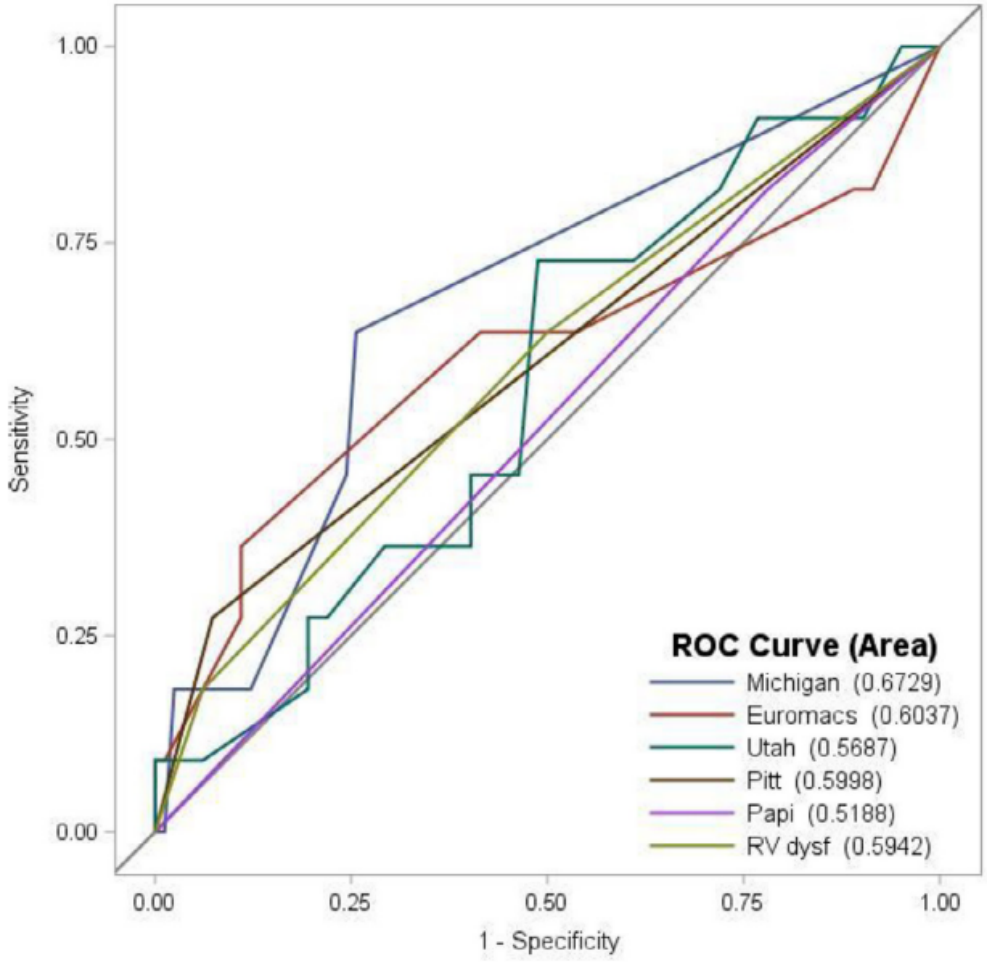
Can we predict the RV failure?

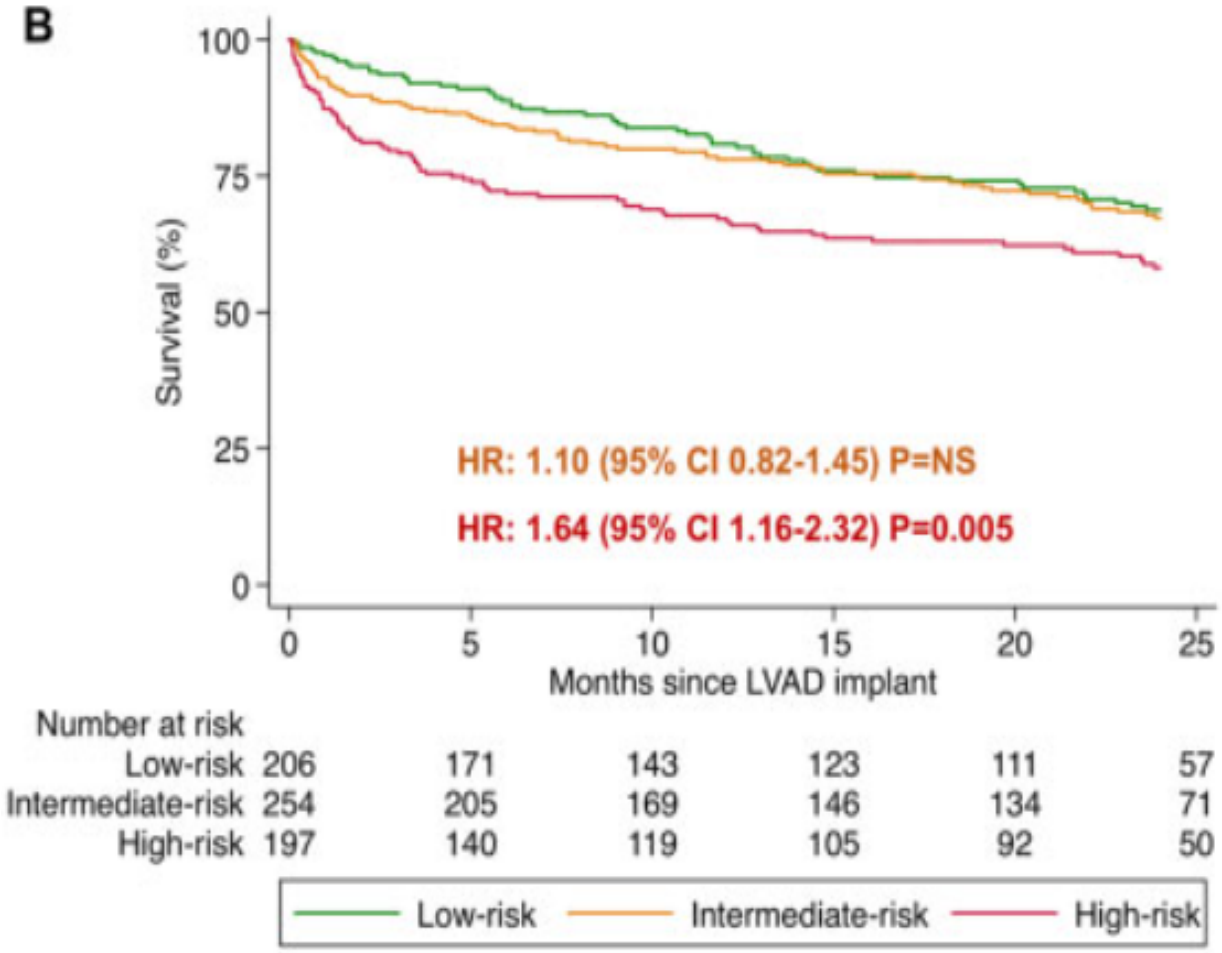




Peters A. et al Comparative Analysis of Established Risk Scores and Novel Hemodynamic Metrics in Predicting Right Ventricular Failure in Left Ventricular Assist Device Patients **J Card Fail 2019; 25(8):620-628**.
Rivas-Lasarte M. et al Prediction of right heart failure after left ventricular assist implantation: external validation of the EUROMACS right-sided heart failure risk score **Eur Heart J Acute Cardiovasc Care 2021; 10(7):723-732**.

Can we predict the RV failure?





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Are there risk factors?

	Model						
	Michigan (RVFRS)	EUROMACS	Penn (Fitzpatrick)	Utah (Drakos)	CRITT	Kormos (Heartmate II)	Pittsburgh Decision Tree
Model variables							
Demographic				Obesity			Age
Preoperative status	Vasopressor requirement	≥3 inotropes	Previous cardiac surgery	Inotrope dependency	Preoperative intubation	Need for ventilatory support	No. of inotropes
		INTERMACS class 1–3		IABP			
Hemodynamic		RAP/PCWP ≥0.54	CIn ≤2.2 L/min per m^2	PVR	CVP >15 mm Hg	CVP/PCWP >0.63	RAP
			RVSWI ≤0.25 mm Hg L/m^2		HR >100 bpm		TPG
			SBP ≤96 mm Hg				HR
Echocardiographic		Severe RV dysfunction	Severe RV dysfunction		Severe RV dysfunction		
					Severe TR		
Laboratory	AST ≥80 UI/L	Hb ≤10 g/dL	Cr ≥1.9 mg/dL			BUN >39 mg/dL	INR
	Bili ≥2 mg/dL						WBC
	Cr ≥2.3 mg/dL						ALT
Device indication				DT			
Medication				ACE inhibitor/ ARB			
				β-Blocker			

Frankfurter C. et al Predicting the Risk of Right Ventricular Failure in Patients Undergoing Left Ventricular Assist Device Implantation: A Systematic Review **Circ Heart Fail 2020; 13(10): E006994**.

Are there risk factors?

- Higher risk in patients with:
  - Mechanical ventilation, CRRT
  - Higher NT-proBNP, INR, WBC
  - Lower RVSWI, higher CVP

Frankfurter C. et al Predicting the Risk of Right Ventricular Failure in Patients Undergoing Left Ventricular Assist Device Implantation: A Systematic Review and meta-analysis of observational studies. **Circ Heart Fail 2020; 13(10): E006994**.

Can we prevent RV failure?

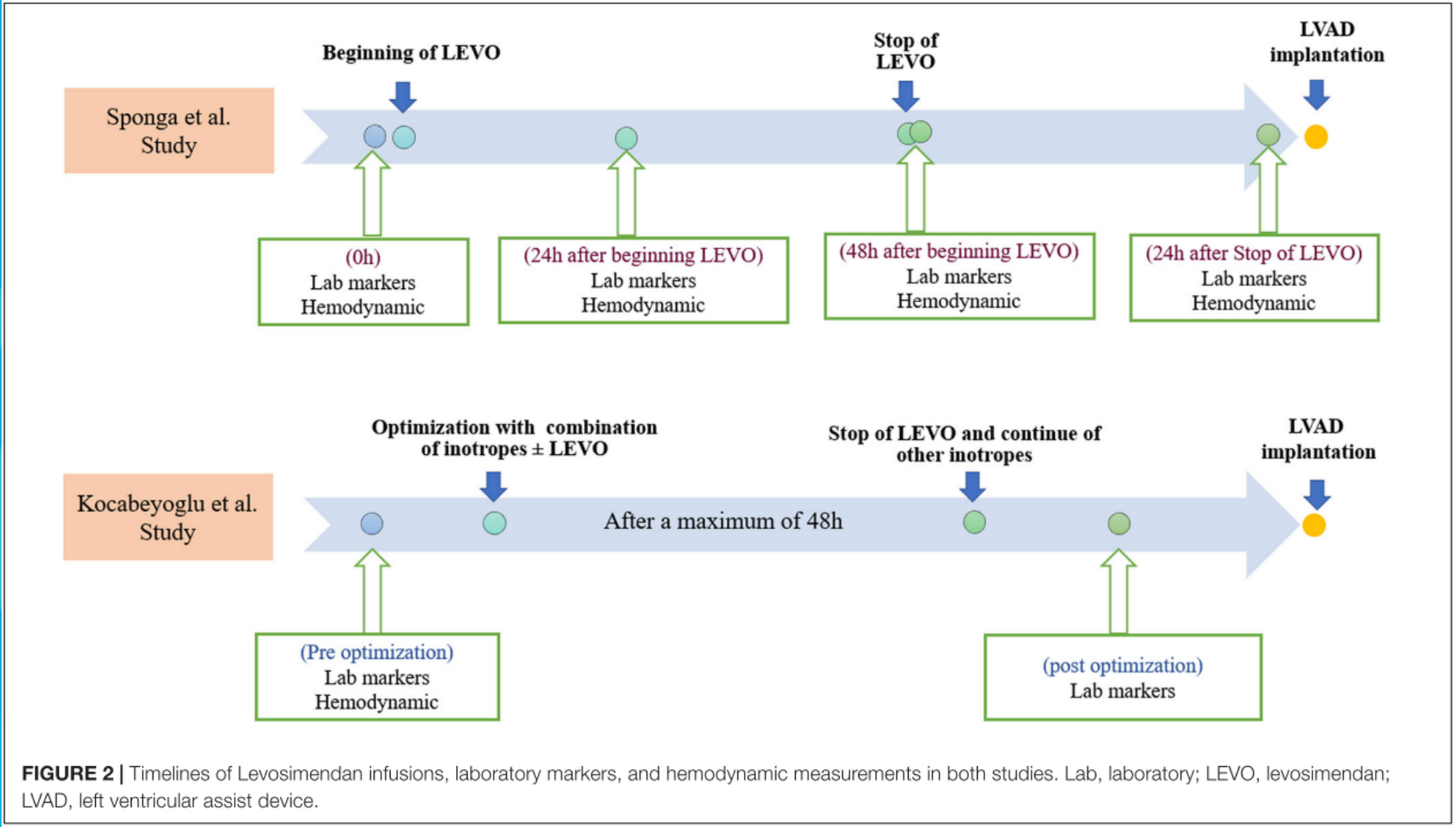
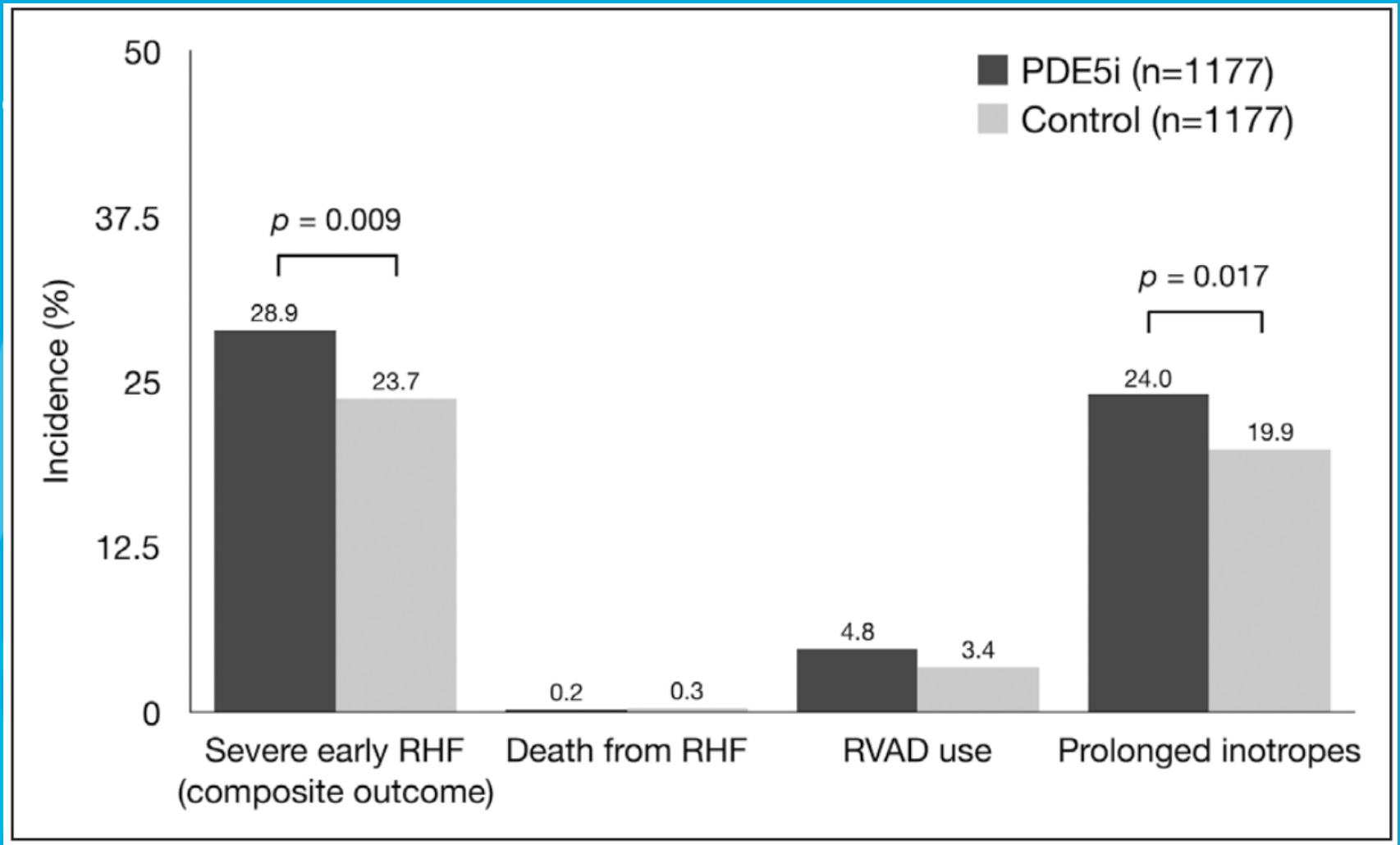


FIGURE 2 | Timelines of Levosimendan infusions, laboratory markers, and hemodynamic measurements in both studies. Lab, laboratory; LEVO, levosimendan; LVAD, left ventricular assist device.

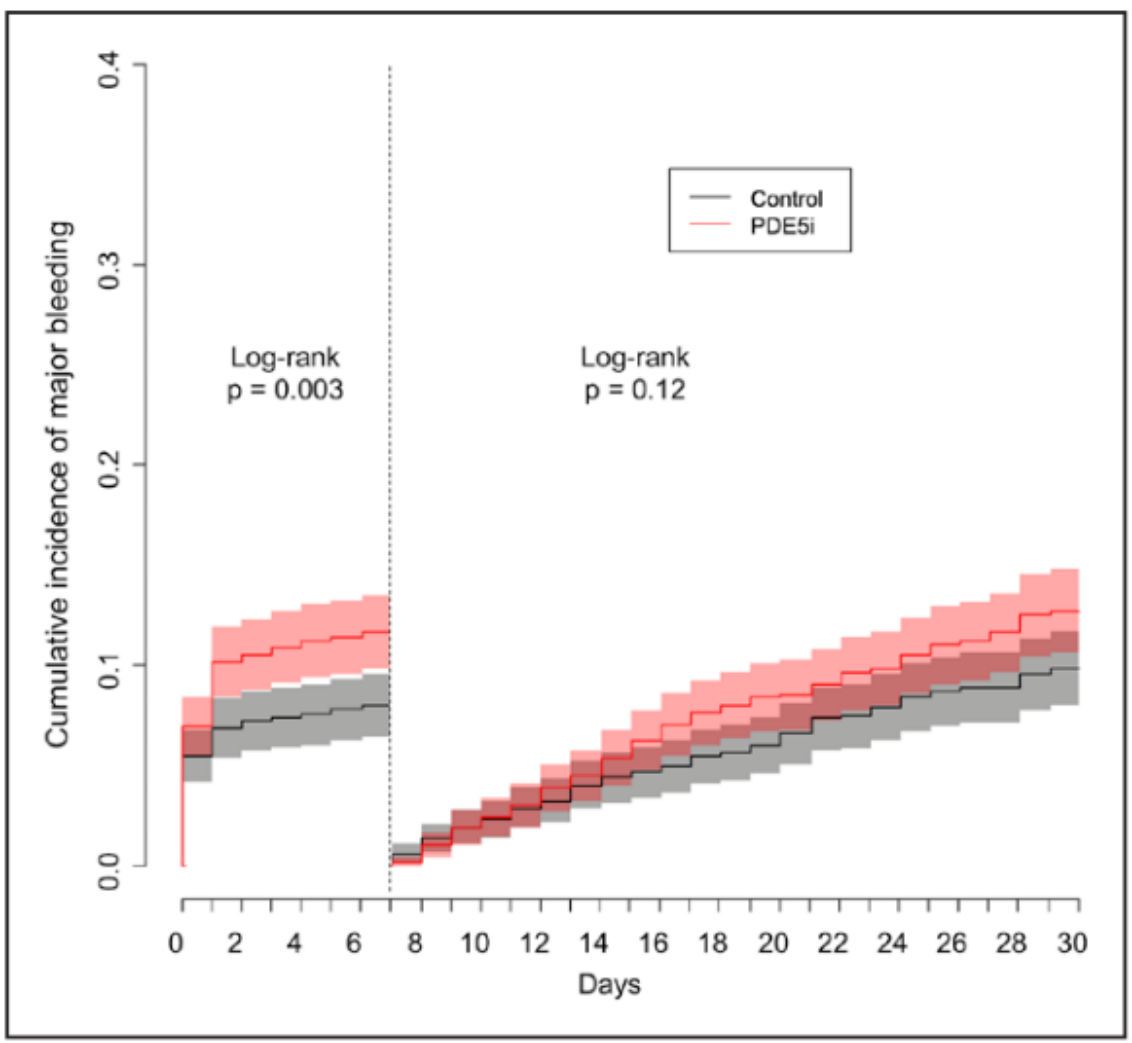
Abdelshafy M. et al Perioperative Levosimendan Infusion in Patients With End-Stage Heart Failure Undergoing Left Ventricular Assist Device Implantation **Front Cardiovasc Med 2022 Apr 28;9:888136**.

Can we prevent RV failure?



Gulati G. et al Preimplant phosphodiesterase-5 inhibitor use is associated with higher rates of severe early right heart failure after left ventricular assist device implantation an INTERMACS analysis **Circ Heart Fail 2019 Jun; 12(6):e005537**.

Can we prevent RV failure?



Gulati G. et al Preimplant phosphodiesterase-5 inhibitor use is associated with higher rates of severe early right heart failure after left ventricular assist device implantation an INTERMACS analysis **Circ Heart Fail 2019 Jun; 12(6):e005537**.

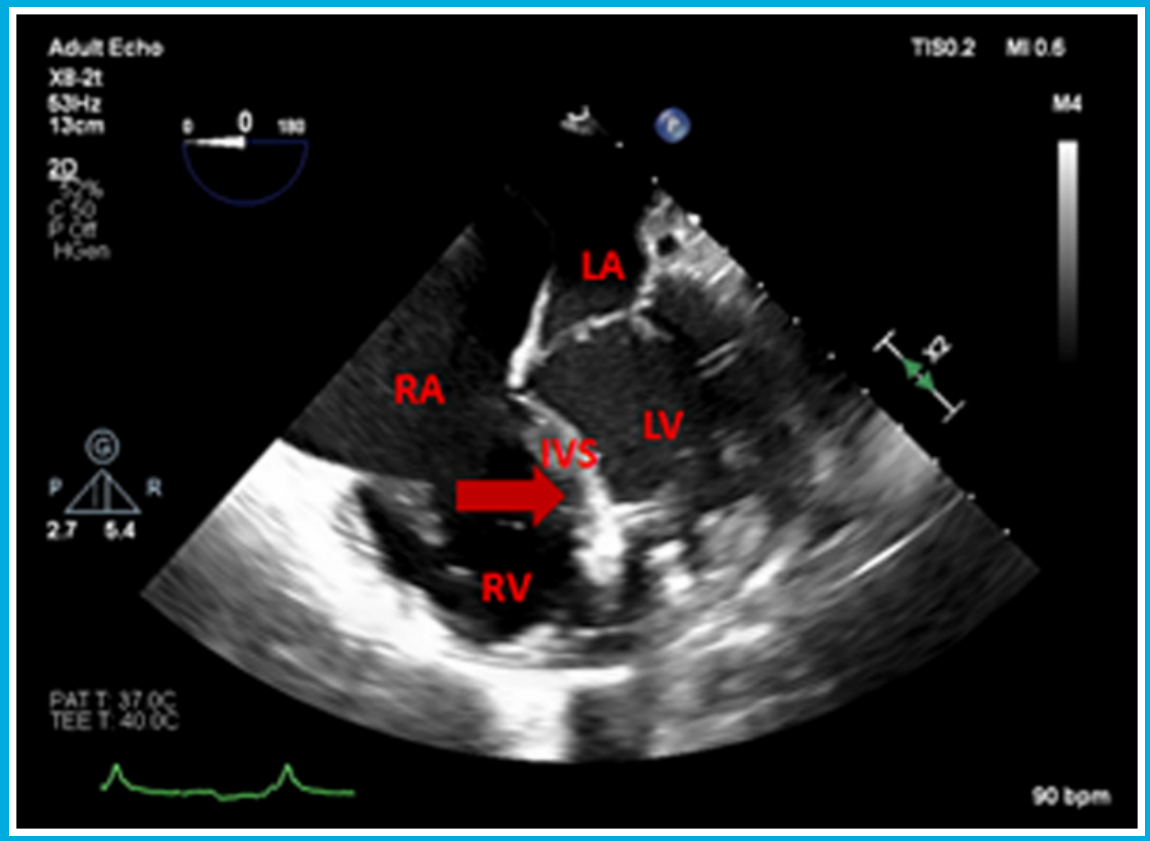
Surgical points of attention

- Use of carbon dioxide

- Carefull de-airing (Trendelenburg)

Surgical points of attention

- Start low, go slow
- Filling state!



Turner K. et al Right Ventricular Failure After Left Ventricular Assist Device Placement-The Beginning of the End or Just Another Challenge? **Journal of Cardiothoracic and Vascular Anesthesia 33 (2019) 1105?1121**.

Table 5 Primary and Secondary Outcome Measures in the Intent-to-Treat Population

Outcome Measure	iNO	Placebo	*p*-value
Patients meeting RVD criteria ≤48 hours			0.330
No. of total (%)	7/73 (9.6)	12/77 (15.6)	
95% CI	2.8–16.3	7.5–23.7	
Males, No. (%)	7/64 (10.9)	7/65 (10.8)	>0.99
Females, No. (%)	0/9 (0.0)	5/12 (41.7)	0.045
PVRI <270.5 dyne/sec/cm^{-5}	6/51 (11.8)	6/48 (12.5)	>0.99
PVRI ≥270.5 dyne/sec/cm^{-5}	1/7 (14.3)	5/7 (71.4)	0.103
Days on mechanical ventilation[a]	70	67	0.077
Mean (SD)	5.37 (7.72)	11.10 (24.81)	
Median (range)	2.0 (1–30)	3.0 (0–160)	
No. of ICU days[b]	60	58	0.630
Mean (SD)	20.52 (32.31)	19.90 (24.38)	
Median (range)	11.0 (3–194)	9.0 (3–115)	
No. of total hospital days[c]	58	58	0.979
Mean (SD)	40.57 (32.19)	40.76 (29.41)	
Median (range)	32.0 (11–194)	31.5 (10–156)	
Quantity of blood products used	73	77	
Mean, ml (SD)	4,232 (4675)	4,885 (7760)	0.226
Patients requiring RRT, No. (%)[d]	10/71 (14.1)	8/70 (11.4)	0.637
Non-survival at Day 28, No. (%)	8/71 (11.3)	8/70 (11.4)	0.924
Patients needing RVAD by Day 28, No. (%)	4/71 (5.6)	7/70 (10.0)	0.468

ICU, intensive care unit; iNO, inhaled nitric oxide; PVRI, pulmonary vascular resistance index; RRT, renal replacement therapy; RVAD, right ventricular assist device; RVD, right ventricular dysfunction; SD, standard deviation.

[a]Intent-to-treat population, extubated before study end (Day 28).

[b]Intent-to-treat population, discharged from ICU before study end (Day 28).

[c]Intent-to-treat population, discharged from hospital before study end (Day 28).

[d]Includes those patients in the intent-to-treat population for whom RRT information was available.

Potapov E. et al Inhaled nitric oxide after left ventricular assist device implantation: a prospective, randomized, double-blind, multicenter, placebo-controlled trial **J Heart Lung Transplant 2011; 30(8):870-878**.

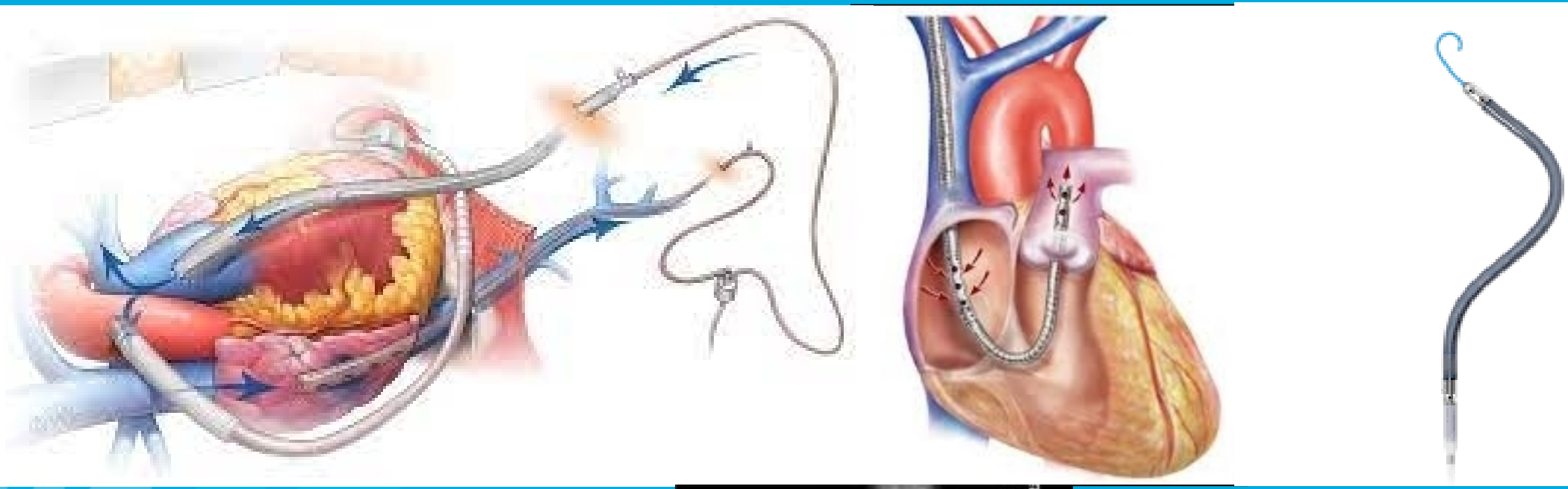
Can we treat RV failure?

- Drug therapy
  - Milrinone

Inotrope and vasopressor support			
Norepinephrine should be considered as a first-line vasopressor in case of postoperative hypotension or shock.	IIa	B	[9, 328, 329]
Dopamine may be considered in case of postoperative hypotension or shock.	IIb	B	[9, 328, 329]
The combination of norepinephrine and dobutamine should be considered instead of epinephrine in case of postoperative hypotension and low cardiac output syndrome with RV failure.	IIa	C	[9, 71, 330, 331]
Epinephrine may be considered in case of postoperative hypotension and low cardiac output syndrome with RV failure.	IIb	C	
Phosphodiesterase 3 inhibitors may be considered in patients with long-term mechanical circulatory support with postoperative low cardiac output syndrome and RV failure.	IIb	C	[332, 333]
The use of levosimendan in case of postoperative low cardiac output syndrome may be considered.	IIb	A	[334, 335]

Potapov E. et al 2019 EACTS Expert Consensus on long-term mechanical circulatory support **Eur J Cardiothorac Surg 2019 Aug 1; 56(2):230-270**.

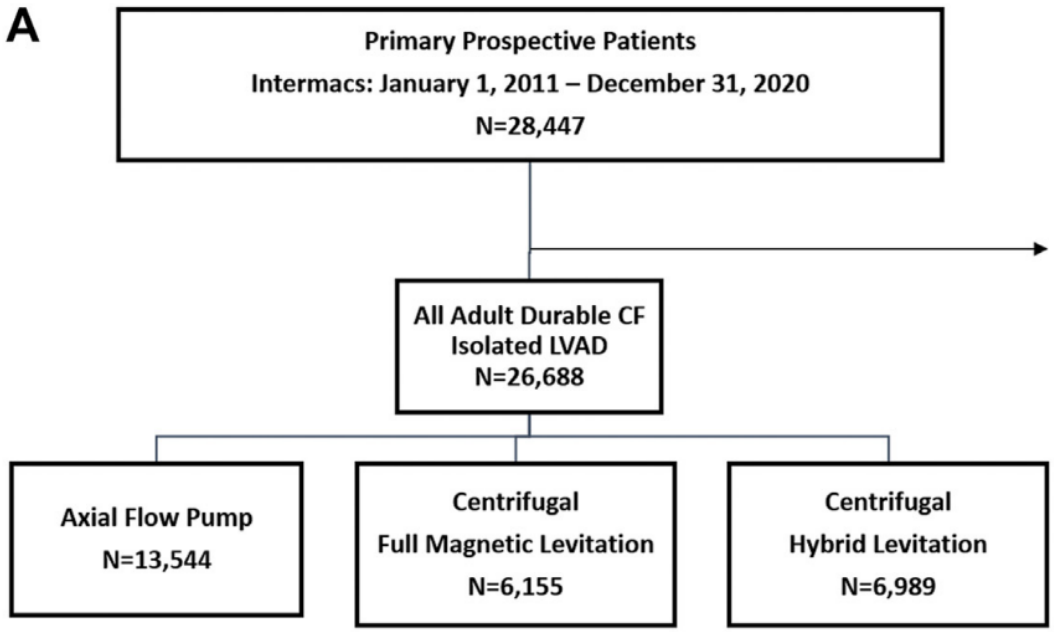
Mechanical RV support



- Long term:
  - BiVAD
  - *HTX*

Chronic RVAD and LVAD

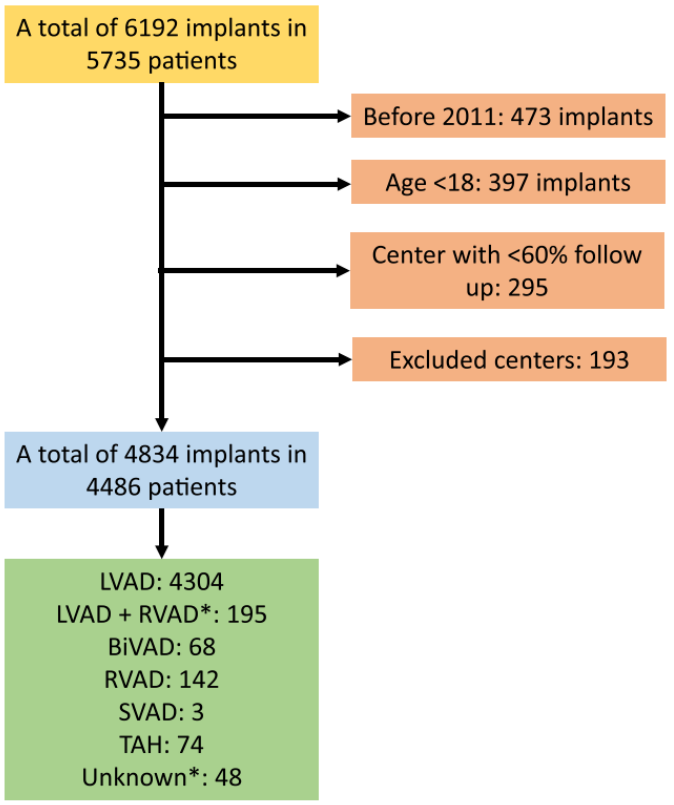
12th INTERMACS report



Exclude:	n
Isolated PF RVAD	19
Isolated CF RVAD	10
TAH	426
Isolated PF LVAD	30
PF BiVAD	138
CF BiVAD	1,136
Total	**1,759**

PF = pulsatile flow pump
CF = continuous flow pump
RVAD: right ventricular assist device
LVAD: left ventricular assist device
TAH: total artificial heart
BiVAD: biventricular assist device

3th EUROMACS report



The European Registry for Patients with Mechanical Circulatory Support of the European Association for Cardio-Thoracic Surgery: third report
De By T, et. al. Eur J of Cardthorac Surg 2022 Feb 12;ezac032. doi: 10.1093/ejcts/ezac032. Online ahead of print
Twelfth Interagency Registry for Mechanically Assisted Circulatory Support Report: Readmissions After Left Ventricular Assist Device
Shah P, et al. Annals of thoracic Surgery, 2022 113;3: 722-737

Leuven experience with RV failure

- BIVAD in Leuven
  - Long term: 0
  - Temporary RVAD: 14/252 (5,6%)
    - Urgent HTX: 4
    - Weaned: 9
    - Death: 1
    - In hospital mortality
      - HTX: 2
      - Weaned: 3

Conclusions

- RV failure is common after LVAD implantation
- RV failure is hard to predict
- A strugling RV benefits from:
  - Careful fluid and LVAD management
  - iNO
  - Vasopressors / inotropes
  - Temporary RV support