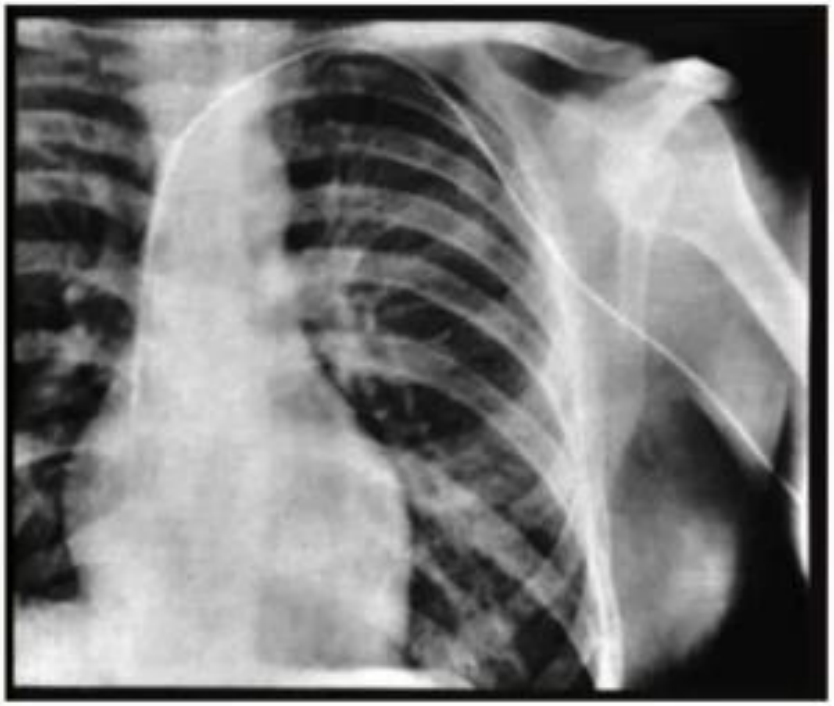
가톨릭대학교
의정부성모병원

Hemodynamic of PH
: 우심도자술

가톨릭대학교 의정부성모병원
안 효 석

History of heart catheterization

- 1929 – Werner Forssmann



History of heart catheterization

- 1956 Nobel laureates in Physiology or Medicine
- "for their discoveries concerning heart catheterization and pathological changes in the circulatory system"

1956		André Frédéric Cournand	United States
		Werner Forssmann	West Germany
		Dickinson W. Richards	United States

History of heart catheterization

- 1964 Ronald Bradley

  - First person to describe the use of a pulmonary-artery catheter in man

  - Miniature catheter (extreamly narrow portex catheter (0.63mm diam)) having no balloon

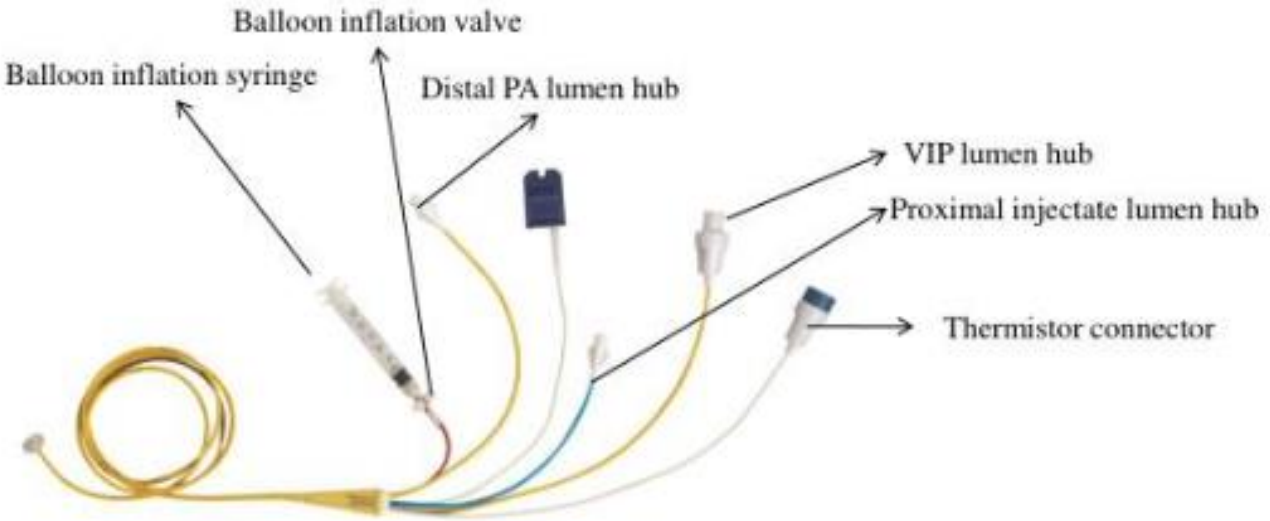
- 1970 Jeremy Swan & William Ganz

  - Balloon floatation catheter

  - Ballon tip was a modification of the simple portex tubing method developed by Bradley

Definition

- Cardiac catheterization implies the insertion of flexible tube into one or more heart chambers usually under fluoroscopic guide for diagnostic or therapeutic purpose



Indications

Diagnostic

- Evaluation of pulmonary hypertension

- Differentiation of variation etiologies of shock and pulmonary edema

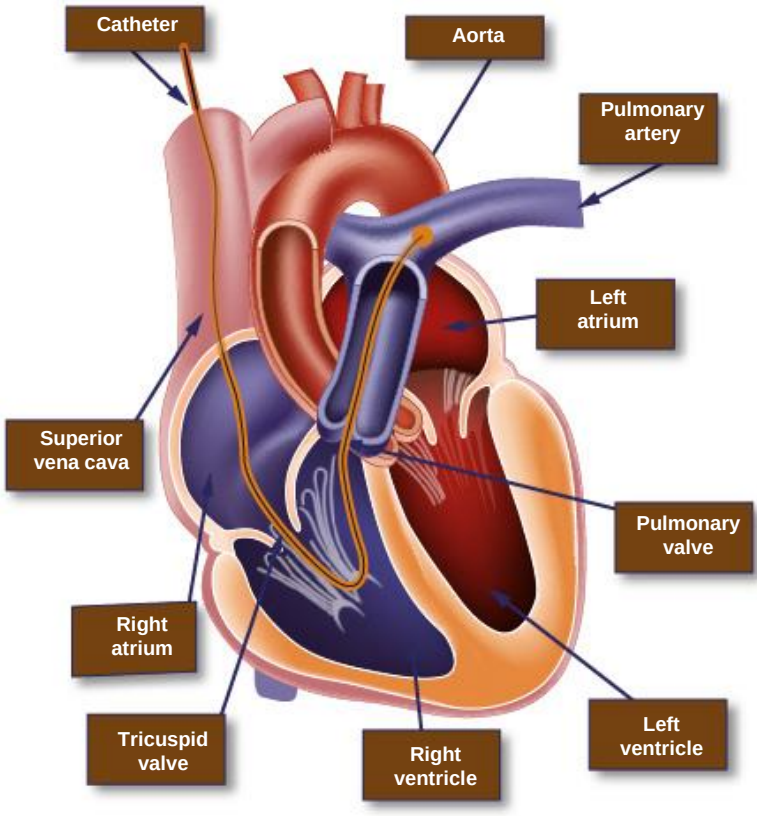
- Differentiation of pericardial tamponade from constrictive pericarditis and restrictive cardiomyopathy

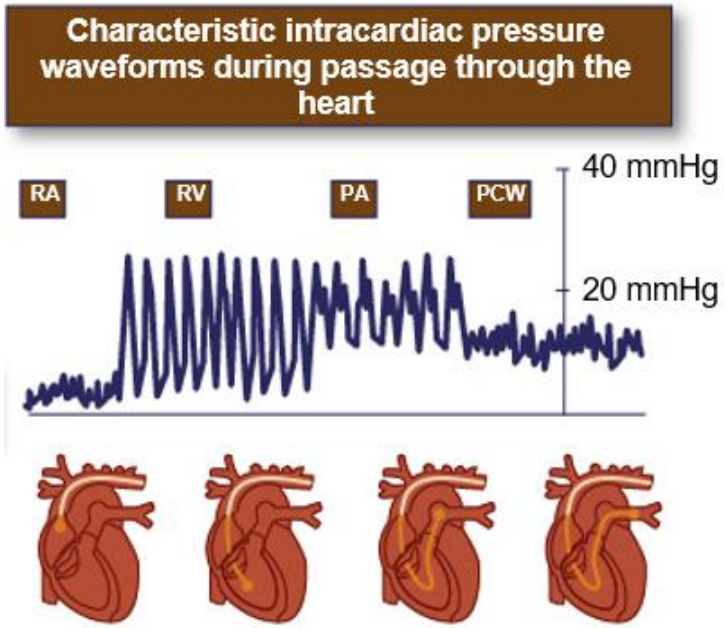
- Diagnosis of left to right intracardiac shunts

Therapeutic

- Guide to fluid management and hemodynamic monitoring of patients after surgery, complicated myocardial infarction, patients in shock, heart failure, etc.

Diagnosis of PAH_Right Heart Catheterization (RHC)





Normal Range

Site	Normal Value (mmHg)	Mean Pressure (mmHg)	Saturation
RA (orr CVP)	0-5		75%
RV	25/5		75%
PA	25/10	10-20	75%
PAWP	7-12		95-100%
LV	120/10		95-100%
Aorta	120/80		95-100%

Cardiac Output

- Fick Method

  - Fick cardiac output

    = (oxygen consumption) / (10 × arteriovenous oxygen difference)

  - Oxygen consumption is either measured by exhaled breath analysis or estimated from a nomogram that is based upon age, sex, height, and weight.

  - Arteriovenous oxygen difference

    = 1.34 × Hb × (SaO2 – MvO2)

Cardiac Output

- Indicator Thermodilution Method

- Bolus injection of saline into the proximal port

- Change in temperature is measured by thermistor in the distal portion of the catheter

- the thermistor records the temperature change over time and can electronically display a temperature-time curve

- The area under this curve is inversely proportional to the flow rate in the pulmonary artery, which is determined by the cardiac output of the left ventricle.

Limitation

Fick

- Oxygen consumption is often estimated by body weight (indirect method) rather than measured directly

- Large errors possible with small differences in saturations and hemoglobin

Thermodilution

- Not accurate in tricuspid regurgitation

- Overestimated cardiac output at low output states

Vascular Resistance

- Pulmonary Vascular Resistance

  = meanPAP-PAWP / Cardiac Output (WU)

- Systemic Vascular Resistance

  = meanAP-RAP / Cardiac Output (WU)

Qp/Qs

- Qs (systemic flow; L/min)

  - Fick cardiac output

    = (oxygen consumption) / (10 × arteriovenous oxygen difference)

  - Arteriovenous oxygen difference

    = 1.34 × Hb × (SaO2 – MvO2)

- Qp/Qs (shunt fraction)

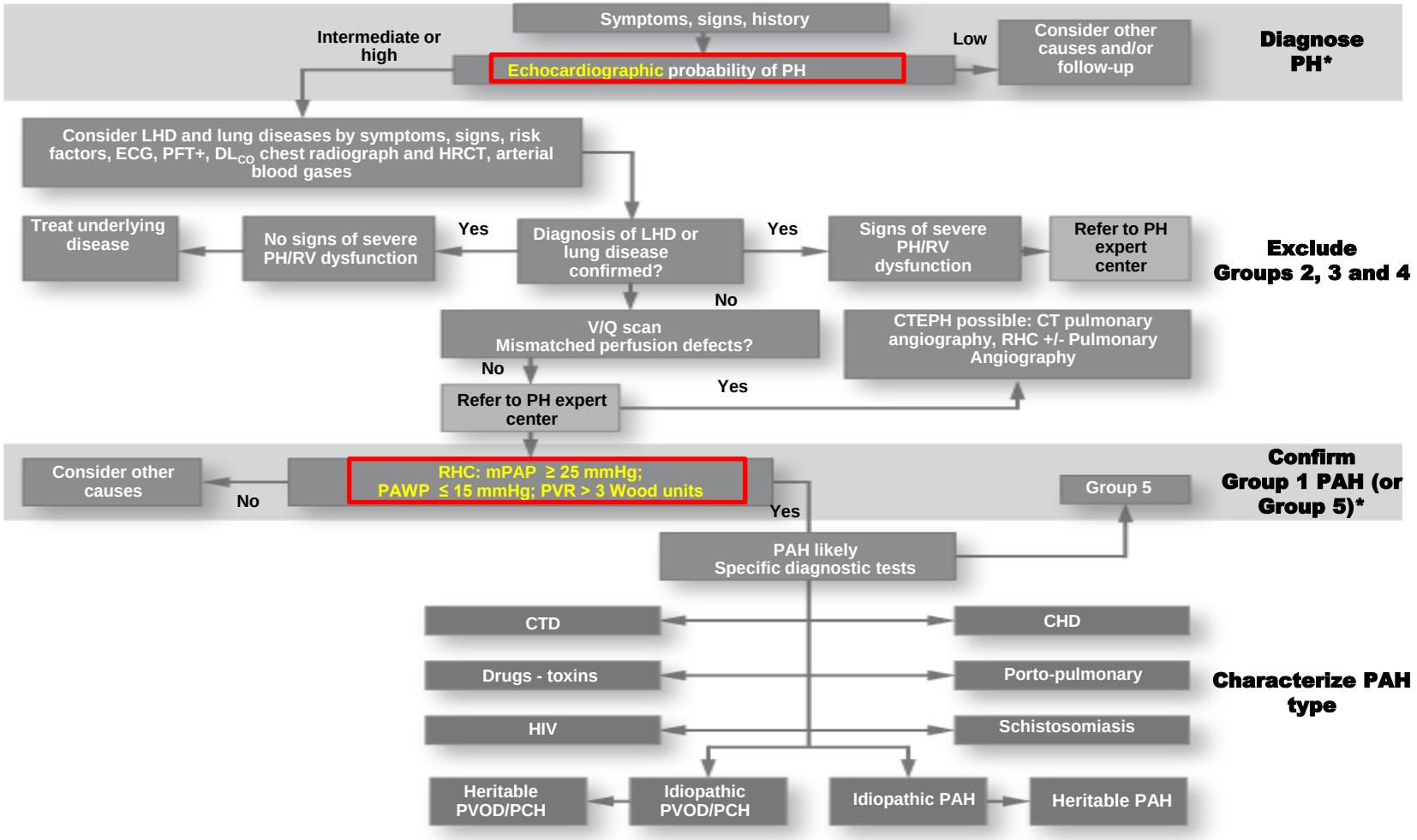
  = (SaO2 - MvO2) / (PvO2 - PaO2)

Procedure related complications

	PCI patients without STEMI (n = 787,980)	Diagnostic catheterization only patients without STEMI (n = 1,091,557)
Complications (%)		
Any adverse event	4.53	1.35
Cardiogenic shock	0.47	0.24
Heart failure	0.59	0.38
Pericardial tamponade	0.07	0.03
CVA/stroke	0.17	0.17
Percent of total strokes that were hemorrhagic	15.6	9.16
New requirement for dialysis	0.19	0.14
In-hospital mortality		
Non–risk-adjusted	0.65	0.72
Non–risk-adjusted excluding CABG patients	0.62	0.60

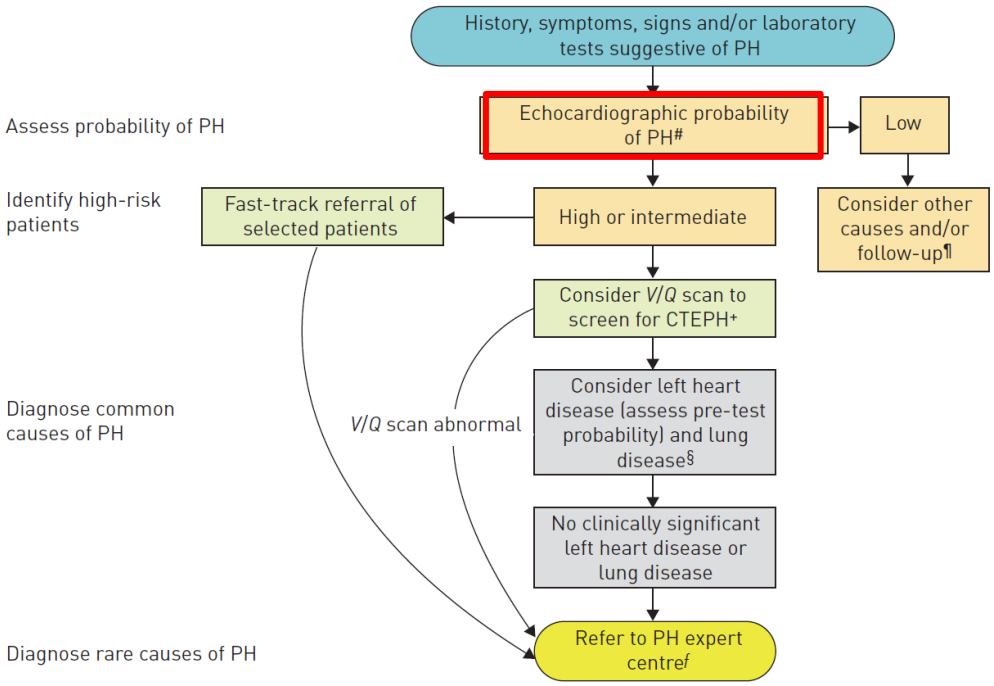
J Am Coll Cardiol 2012;60:2017.

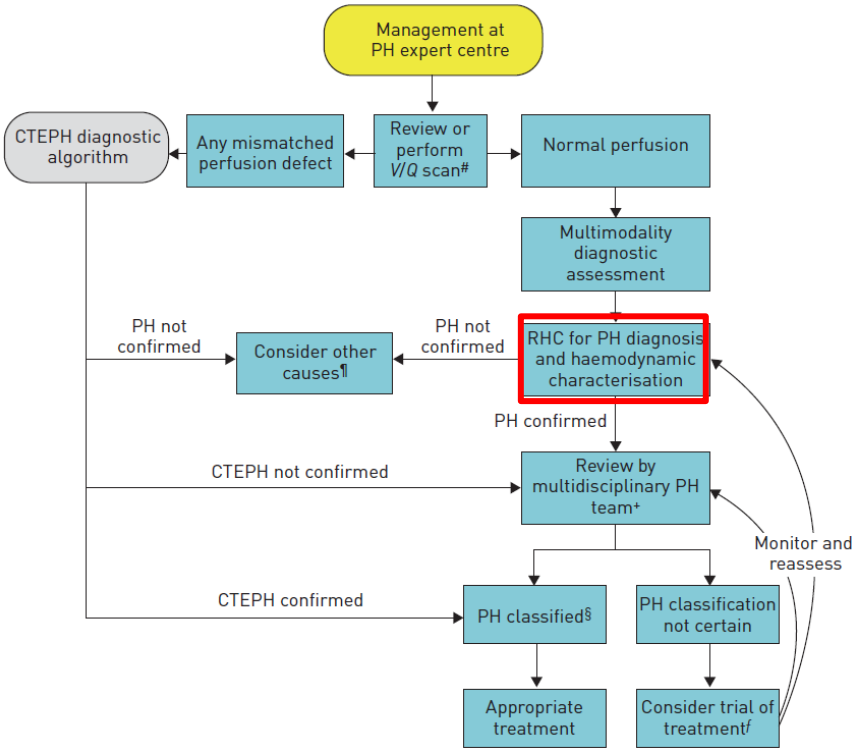
Diagnosis algorithm_2015 ESC/ERS Guidelines



Adapted from Galiè et al. Eur Heart J. 2016 Jan 1;37(1):67-119

Diagnostic approach to PAH_6th WSPH





Frost et al. Eur Respir J. 2019 Jan 24;53(1):1801904

The role of echocardiography in PH

- Key screening and diagnostic tool for detecting pre-clinical stage of PAH
- Rules out secondary causes of pulmonary hypertension
- Prognostic information
- Useful as a monitor for therapeutic interventions

Gaile N, et al. Eur heart J. 2016;37:67-119

The role of echocardiography _2020 Korean PH Guidelines

4.1.5 심초음파검사

경흉부 심초음파검사는 심장에 대한 폐고혈압의 영향을 평가하고, 삼첨판역류 혈류속도 측정을 통해 폐동맥압을 추정하기 위해 시행된다. 심초음파검사는 폐고혈압이 의심되는 환자에서 반드시 시행되어야 하며, 여러 종류의 심초음파 지표를 측정함으로써 폐고혈압의 유무와 원인을 진단하는 데 도움을 준다. 그러나, 심초음파만으로는 폐고혈압의 확진과 치료방침을 결정하는 데 충분하지 않으며 우심도자술이 꼭 필요하다.

Diagnostic Evaluation of PAH: Pivotal Tests

- Medical history
- Exam
- Chest X-ray
- Electrocardiogram
- **Echocardiogram**
- V/Q scan
- PFTs
- Overnight oximetry
- HIV test
- ANA
- LFTs
- Functional test (eg, 6MWT)
- **Right heart catheterization**

Frost et al. Eur Respir J. 2019 Jan 24;53(1):1801904

Echocardiographic probability of PH in symptomatic patients

표 7-2. 폐고혈압 의심 증상이 있는 환자에서 심초음파검사 결과에 따른 폐고혈압 가능성

① 최대 삼첨판역류속도 (m/s)	② 심초음파검사에서 '①' 이외에 다른 '폐고혈압 징후'의 유무[a]	③ 폐고혈압 가능성
≤ 2.8 또는 측정이 안됨	없음	낮음
≤ 2.8 또는 측정이 안됨	있음	중간
2.9~3.4	없음	
2.9~3.4	있음	높음
> 3.4	필요하지 않음	

표 7-1. 최대 삼첨판역류속도 측정 이외에 심초음파검사에서 폐고혈압을 시사하는 소견

A: 심실[a]	B: 폐동맥[a]	C: 하대정맥과 우심방[a]
우심실/좌심실 기저부의 직경 비율 > 1.0	우심실 유출로 도플러 속도증가 시간(acceleration time) < 105 msec 및/또는 수축기 중 도플러 신호 패임(midsystolic notching)	하대정맥 직경 > 21 mm 및 호흡시 하대정맥 직경감소(심호흡시 < 50% 또는 안정 호흡시 < 20%)
폐고혈압으로 인한 우심실 압력 상승으로 심실중격이 좌심실 쪽으로 눌림(수축기 및/또는 이완기 시 좌심실 편심률(eccentricity) 지수 > 1.1)	초기 이완기 폐동맥판막 역류 혈류속도 > 2.2 m/sec	우심방면적(수축기 말) > 18 cm^2
	폐동맥 직경 > 25 mm	

[a]'심초음파로 추정한 폐고혈압의 가능성' 단계(표 7-2)를 변경하기 위해서는 최소한 두 개 이상 다른 범주(A/B/C)의 심초음파 이상 소견이 확인되어야 한다.

Suggested Work-up based on Echocardiographic Probability of PH

가톨릭대학교 의정부성모병원

표 8. 폐고혈압에 부합하는 증상이 있는 환자에서 심초음파검사 결과에 따른 '폐고혈압 가능성' 단계별 진단검사 시행 전략

심초음파 검사에 따른 폐고혈압 가능성	폐동맥고혈압 또는 만성혈전색전폐고혈압의 위험인자 또는 관련된 상태가 없을 경우[a]	권고 수준	근거 수준	폐동맥고혈압 또는 만성혈전색전폐고혈압의 위험인자 또는 관련된 상태가 있을 경우	권고 수준	근거 수준
낮음	다른 진단을 고려	IIa	C	심초음파 추적검사를 고려	IIa	C
중간	심초음파 추적검사 및 다른 진단을 고려	IIa	C	우심도자술을 포함한 추가적인 폐고혈압 검사를 고려[b]	IIa	B
	폐고혈압 여부에 대한 추가검사를 고려[b]	IIb				
높음	우심도자술을 포함한 추가적인 폐고혈압 검사를 권고[b]	I	C	우심도자술을 포함한 추가적인 폐고혈압 검사를 권고[b]	I	C

[a] 폐실질을 전반적으로 침범한 폐질환 또는 좌심장질환을 가진 환자에게는 적용되지 않음

[b] 폐고혈압 2, 3 또는 5군과 관련한 위험인자 유무에 따라 추가검사 전략이 달라질 수 있음

2020년 폐고혈압 진료지침

Pitfalls in the estimation of sPAP by echocardiography

- Estimation of RA pressure …

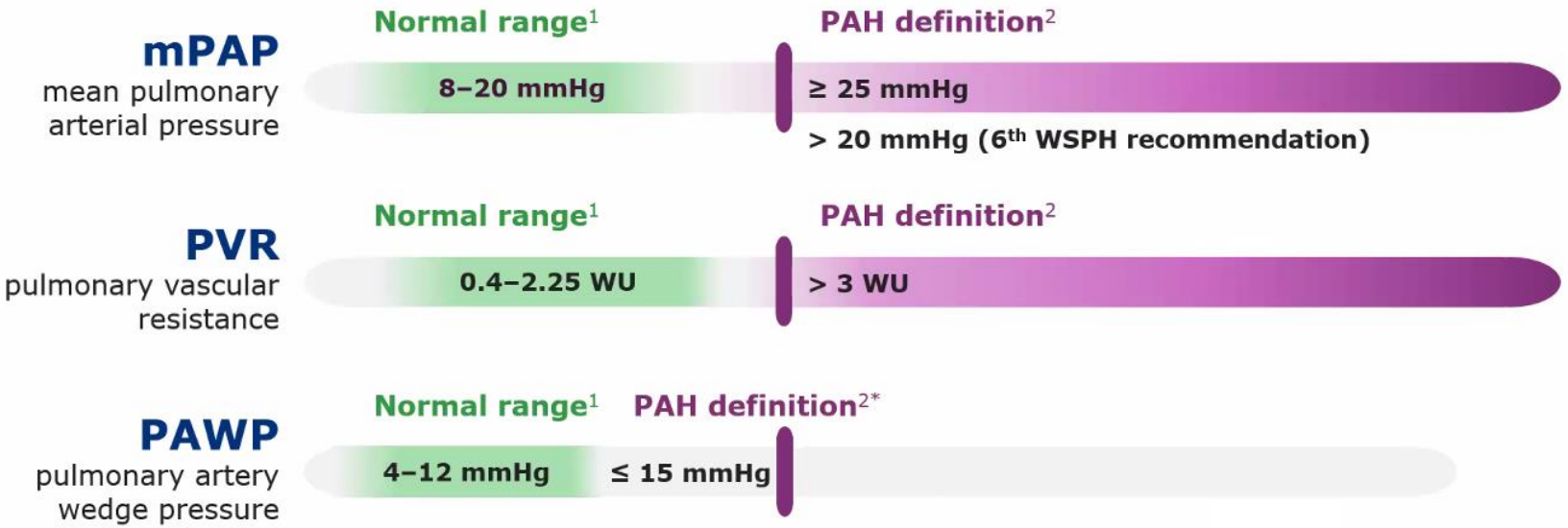
Table 3 Estimation of RA pressure on the basis of IVC diameter and collapse

Variable	Normal (0-5 [3] mm Hg)	Intermediate (5-10 [8] mm Hg)		High (15 mm Hg)
IVC diameter	≤2.1 cm	≤2.1 cm	>2.1 cm	>2.1 cm
Collapse with sniff	>50%	<50%	>50%	<50%
Secondary indices of elevated RA pressure				• Restrictive filling • Tricuspid E/E′ > 6 • Diastolic flow predominance in hepatic veins (systolic filling fraction < 55%)

- No TR…
- RVOT obstruction / pulmonary stenosis
- Bad alignment

Rudski LG, et al. J Am Soc Echocardiogr 2010;23:685-713

PAH should be defined by hemodynamic parameters assessed by Right Heart Catheterization (RHC)



* The presence of pre-capillary PH is characterized by PAWP ≤ 15 mmHg with an mPAP ≥ 25 mmHg[2].
mPAP: mean pulmonary arterial pressure; PAWP: pulmonary artery wedge pressure; PH: pulmonary hypertension; PVR: pulmonary vascular resistance; RHC: right heart catheterization; WU: Wood units.
1. Rosenkranz S and Preston IR. *Eur Respir Rev* 2015; 24:642-52; 2. Galiè N, *et al. Eur Heart J* 2016; 37:67-119.

Gaile N, et al. Eur heart J. 2016;37:67-119

The role of RHC_2020 Korean PH Guidelines

표 9. 폐고혈압에서 우심도자술에 대한 권고사항

권고사항	권고 수준	근거 수준
폐동맥고혈압 진단(폐고혈압 1군)과 치료 결정을 위해 우심도자술이 권고된다.	I	C
폐고혈압 환자는 심각한 합병증의 발생위험과 기술적인 측면을 고려하여 전문센터에서 우심도자술을 시행하는 것이 권고된다.	I	B
폐동맥고혈압(폐고혈압 1군)의 약물치료 효과를 평가하기 위해 우심도자술의 시행이 필요하다(표 15).	IIa	C
선천심장병을 가지고 있는 환자에게는 단락 교정 여부를 결정하기 위해 우심도자술이 필요하다(표 24).	I	C
장기이식을 고려하고 있는 좌심장질환(폐고혈압 2군) 또는 폐질환(폐고혈압 3군)으로 인한 폐고혈압 환자에게는 우심도자술이 필요하다.	I	C
폐동맥쐐기압 측정이 불가능할 경우, 좌심도자술을 통해 좌심실 이완기압을 측정해야 한다.	IIa	C
좌심장질환 또는 폐질환으로 인한 폐고혈압이 의심되는 환자에게는 감별 진단 및 치료방법에 대한 결정을 위해 우심도자술을 고려할 수 있다.	IIb	C
만성혈전색전폐고혈압(폐고혈압 4군)에 대한 진단 및 치료방법에 대한 결정을 위해 우심도자술이 권고된다.	I	C

- ✓ 폐동맥고혈압 및 CTEPH 확진에 반드시 필요
- ✓ 심초음파 소견과 함께 해석 필요
- ✓ 가능한 폐고혈압 평가를 위한 다른 검사를 모두 완료한 후 시행

PAH should be confirmed by Right Heart Catheterization (RHC)

RHC is suggested by 2015 ESC/ERS Guidelines as a gold standard of diagnostic tool for PAH

Gaile N, et al. Eur heart J. 2016;37:67-119

Confirmation by RHC
_2015 ESC/ERS Guidelines vs 6th WSPH

2015 ESC/ERS Guidelines

Confirmation of PAH:[1]

- mPAP ≥ **25** mmHg (normal < 20 mmHg)
- Normal PAWP (≤ 15 mmHg)
- Increased PVR (**>** 3 Wood units)

Other findings:

- Increased right atrial pressure
  - normal right atrial pressure 2–7 mmHg
- Normal/decreased cardiac output
  - normal cardiac output 4–8 liters/minute
- Decreased cardiac index
  - normal cardiac index 2.5–4.0 liters/min/m^2

6th WSPH

Confirmation of PAH:[2]

- mPAP > **20** mmHg (normal < 20 mmHg)
- Normal PAWP (≤ 15 mmHg)
- Increased PVR (**≥** 3 Wood units)

Other findings:

- Increased right atrial pressure
  - normal right atrial pressure 2–7 mmHg
- Normal/decreased cardiac output
  - normal cardiac output 4–8 liters/minute
- Decreased cardiac index
  - normal cardiac index 2.5–4.0 liters/min/m^2

1. Galiè et al. Eur Heart J. 2016 Jan 1;37(1):67-119; 2. Frost et al. Eur Respir J. 2019 Jan 24;53(1):1801904

Risk assessment in PAH

Determinants of prognosis[a]	Low risk < 5%	Intermediate risk 5-10%	High risk > 10%
Clinical signs of right heart failure	Absent	Absent	Present
Progression of symptoms	No	Slow	Rapid
Syncope	No	Occasional syncope[b]	Repeated syncope[c]
WHO functional class	I, II	III	IV
6MWD	> 440 m	165-440 m	< 165 m
Cardiopulmonary exercise testing	Peak VO_2 > 15 ml/min/kg (> 65% pred.) VE/VCO_2 slope < 36	Peak VO_2 11-15 ml/min/kg (35-65% pred.) VE/VCO_2 slope 36–44.9	Peak VO_2 < 11 ml/min/kg (< 35% pred.) VE/VCO_2 ≥ 45
NT-proBNP plasma levels	BNP < 50 ng/l NT-proBNP < 300 ng/ml	BNP 50-300 ng/l NT-proBNP 300-1400 ng/l	BNP > 300 ng/l NT-proBNP > 1400 ng/l
Imaging (echocardiography, CMR imaging)	RA area < 18 cm^2 No pericardial effusion	RA area 18-26 cm^2 No or minimal, pericardial effusion	RA area > 26 cm^2 Pericardial effusion
Haemodynamics	RAP < 8 mmHg CI ≥ 2.5 l/min/m^2 SvO_2 > 65%	RAP 8-14 mmHg CI 2.0-2.4 l/min/m^2 SvO_2 60-65%	RAP > 14 mmHg CI < 2.0 l/min/m^2 SvO_2 < 60%

[a]Estimated 1-year mortality. [b]Occasional syncope during brisk or heavy exercise, or occasional orthostatic syncope in an otherwise stable patient. [c]Repeated episodes of syncope, even with little or regular physical activity.

Gaile N, et al. Eur heart J. 2016;37:67-119

Suggested follow-up plan for PAH patients

	At baseline	Every 3-6 months[a]	Every 6-12 months[a]	3-6 months after changes in therapy[a]	In case of clinical worsening
Medical assessment and determination of WHO FC	+	+	+	+	+
Electrocardiogram	+	+	+	+	+
6MWT/Borg dyspnea score	+	+	+	+	+
Cardiopulmonary exercise testing	+		+		+[b]
Echocardiography	+		+	+	+
Basic lab	+	+	+	+	+
Extended lab	+		+		+
Blood gas analysis	+		+	+	+
Right heart catheterization	+		+[c]	+[b]	+[b]

[a]Intervals to be adjusted according to patient needs.
[b]Should be considered; [c]Some centers perform RHCs at regular intervals during follow-up

Gaile N, et al. Eur heart J. 2016;37:67-119

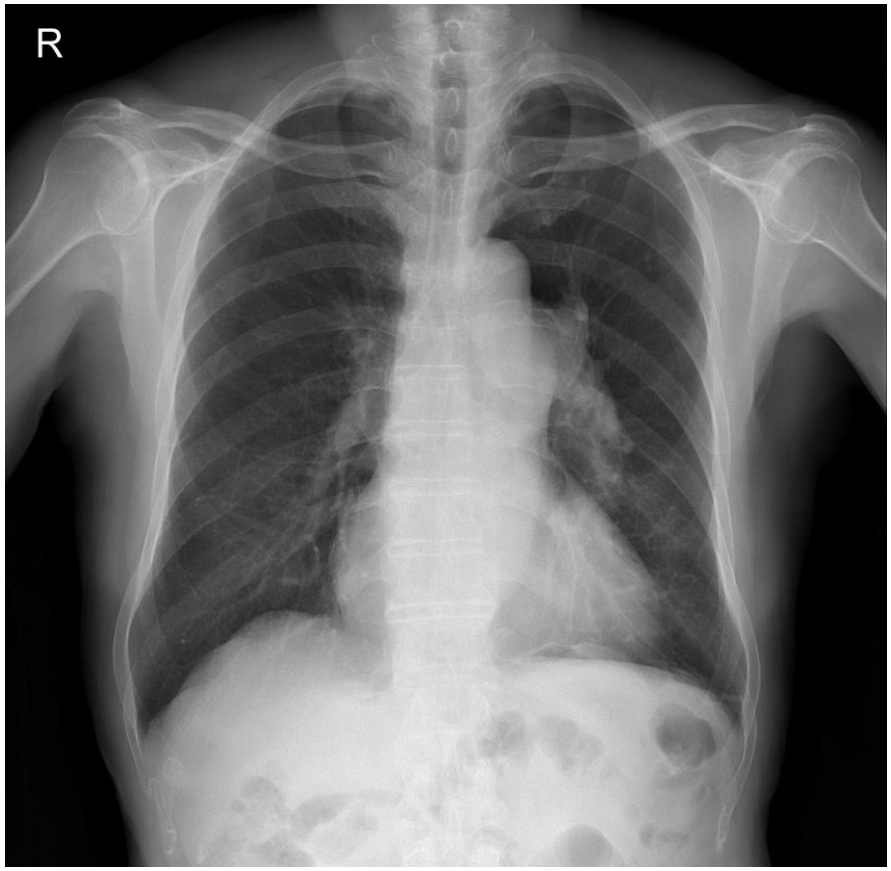
Case

- M / 81
- C.C : exertional dyspnea

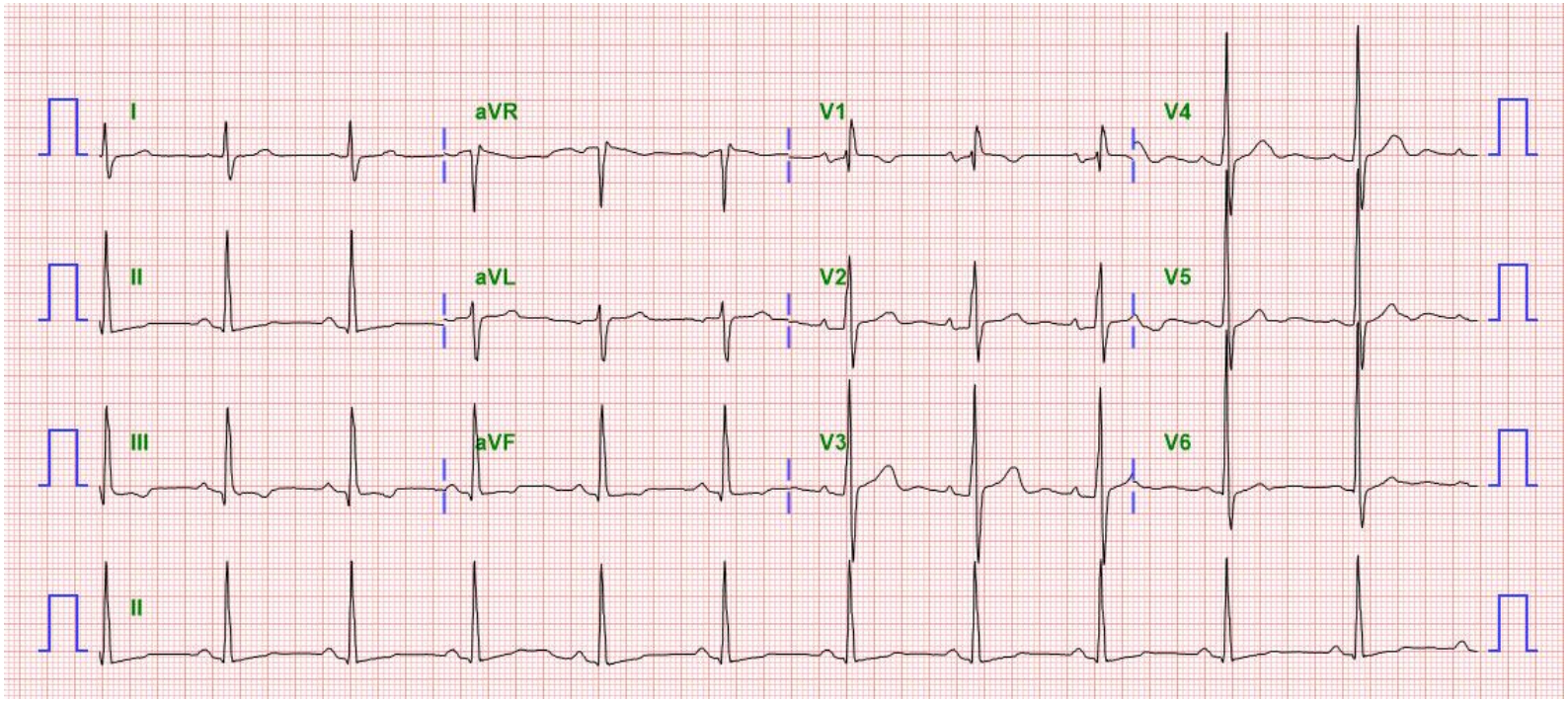
- P.I : 외과에서 Rt inguinal hernia 수술 예정으로
  평소 숨찬 증상 있어 순환기내과 외래 방문

- 159.5 cm 54.2 kg
- BP: 138/76 mmHg 65 bpm

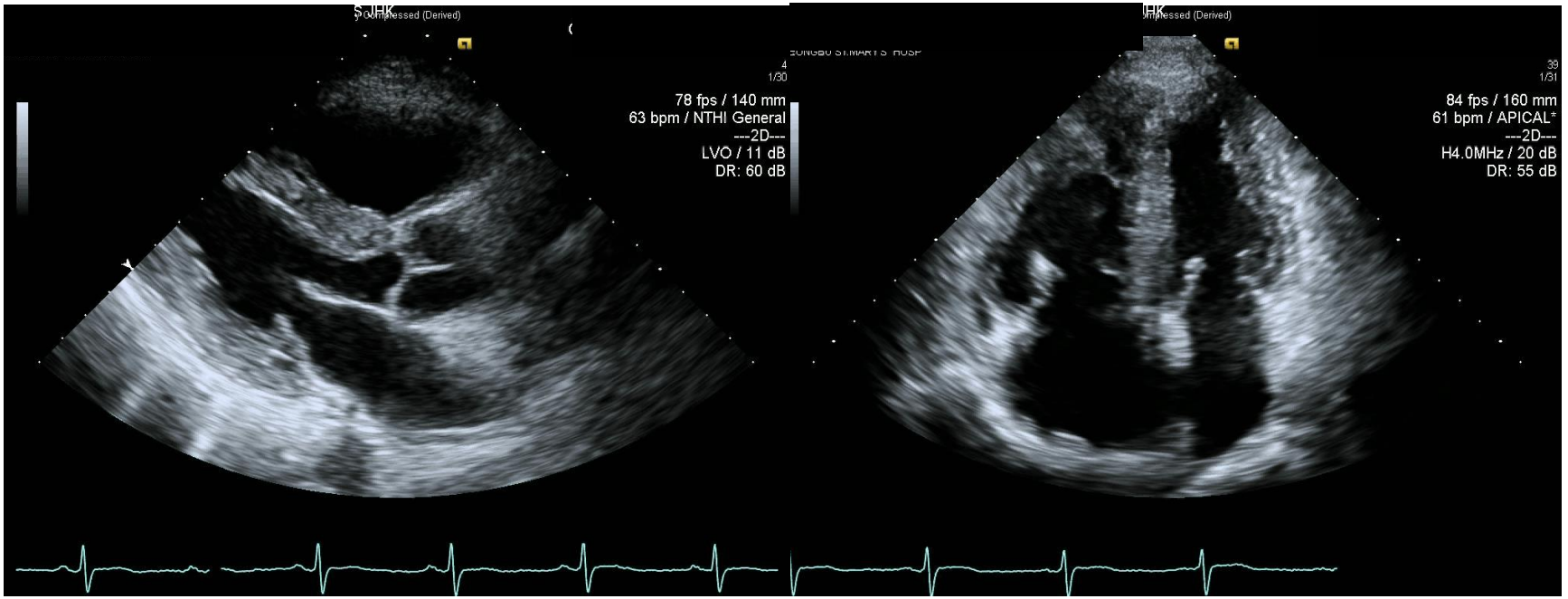
Chest PA



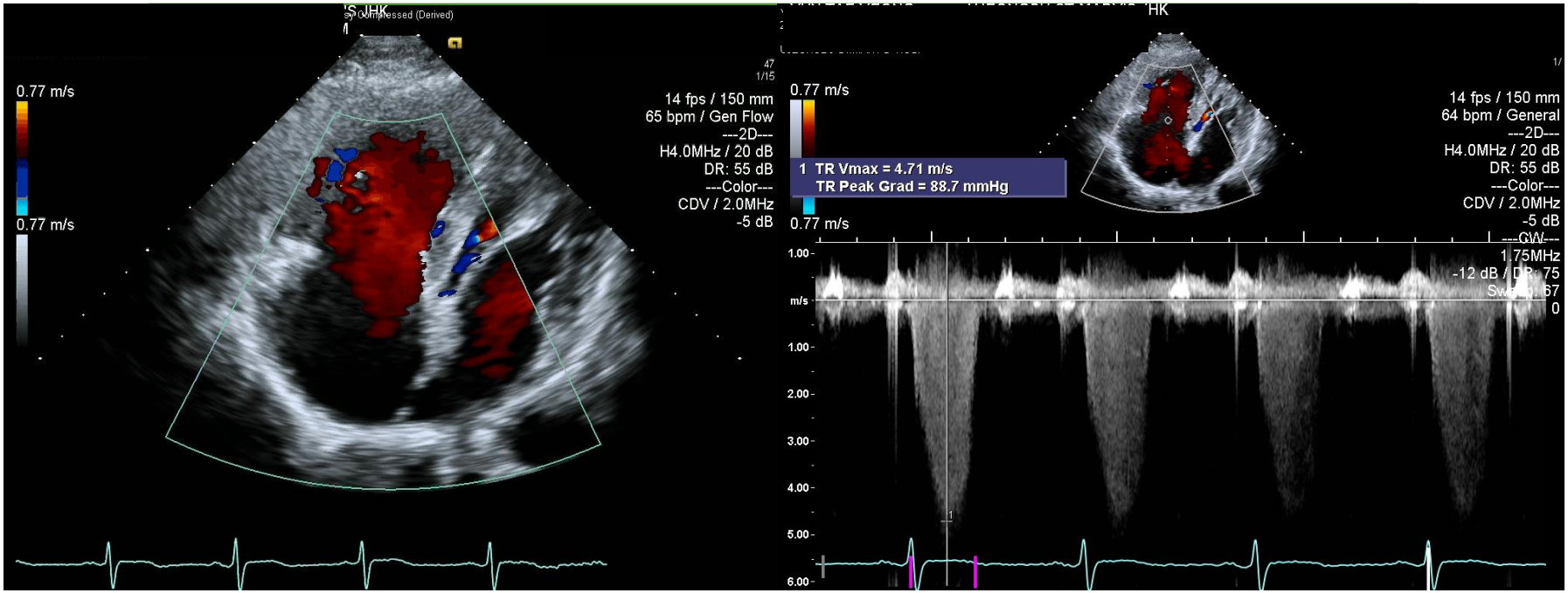
ECG



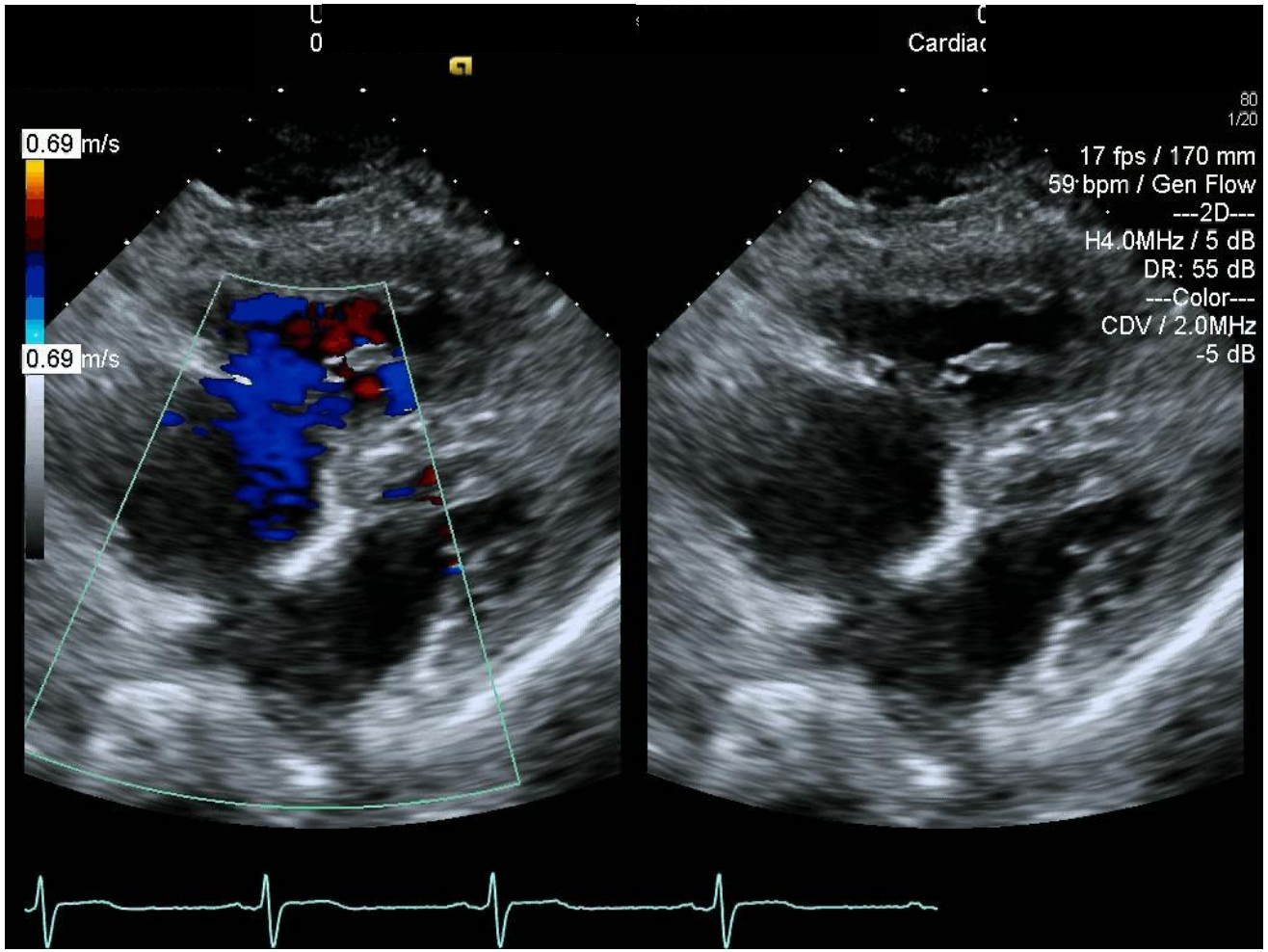
Echo


78 fps / 140 mm
63 bpm / NTHI General
---2D---
LVO / 11 dB
DR: 60 dB
84 fps / 160 mm
61 bpm / APICAL*
---2D---
H4.0MHz / 20 dB
DR: 55 dB

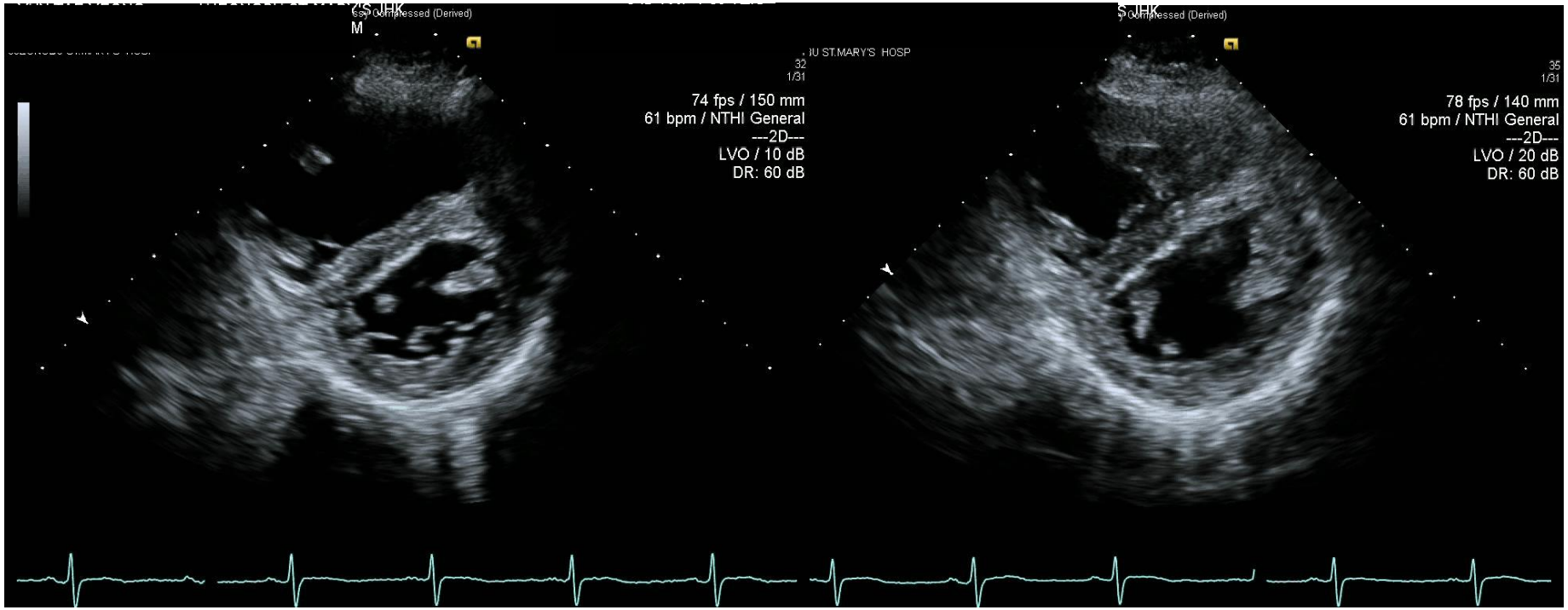
Echo


0.77 m/s
0.77 m/s
14 fps / 150 mm
65 bpm / Gen Flow
---2D---
H4.0MHz / 20 dB
DR: 55 dB
---Color---
CDV / 2.0MHz
-5 dB
0.77 m/s
1 TR Vmax = 4.71 m/s
TR Peak Grad = 88.7 mmHg
0.77 m/s
14 fps / 150 mm
64 bpm / General
---2D---
H4.0MHz / 20 dB
DR: 55 dB
---Color---
CDV / 2.0MHz
-5 dB
1.75MHz
-12 dB
m/s
1.00
1.00
2.00
3.00
4.00
5.00
6.00

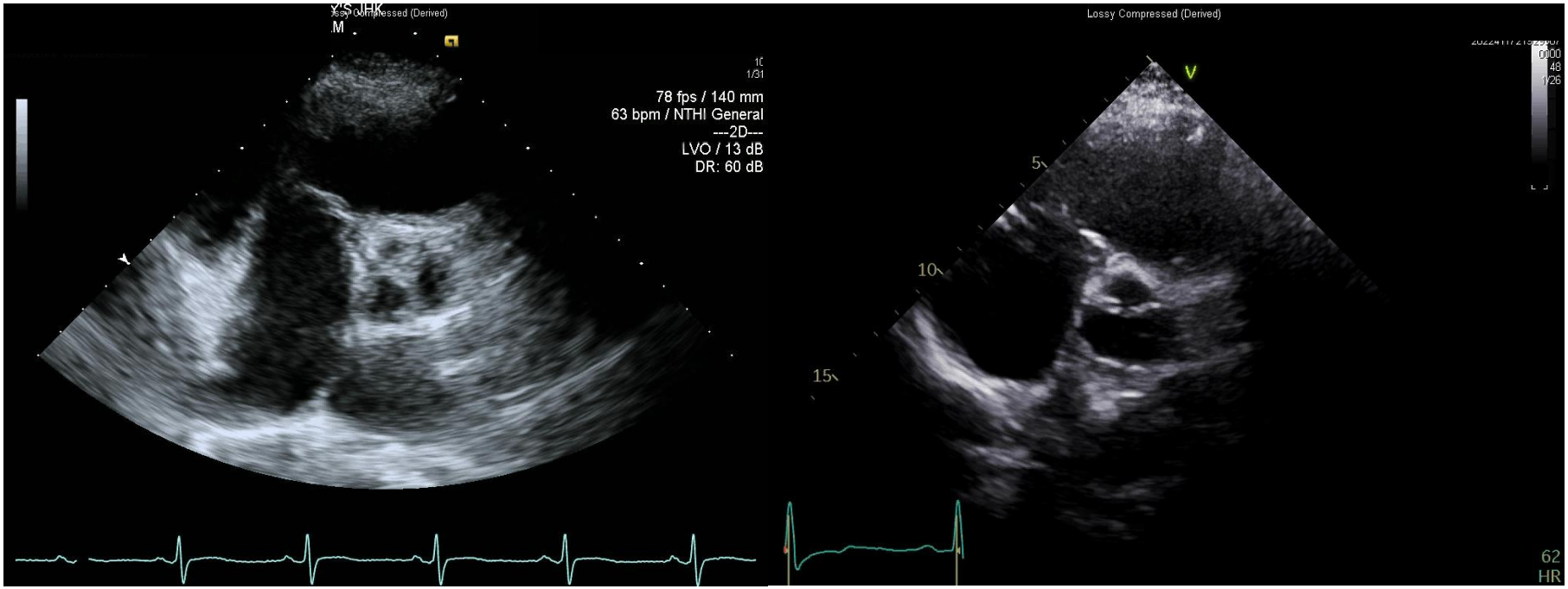
Echo


0.69 m/s
0.69 m/s
17 fps / 170 mm
59 bpm / Gen Flow
---2D---
H4.0MHz / 5 dB
DR: 55 dB
---Color---
CDV / 2.0MHz
-5 dB

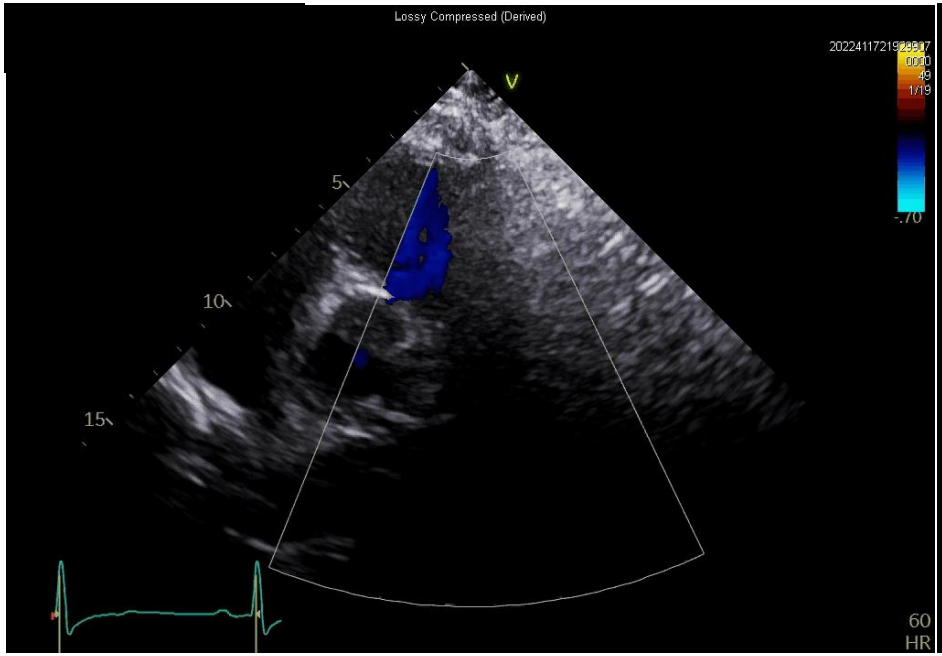
Echo

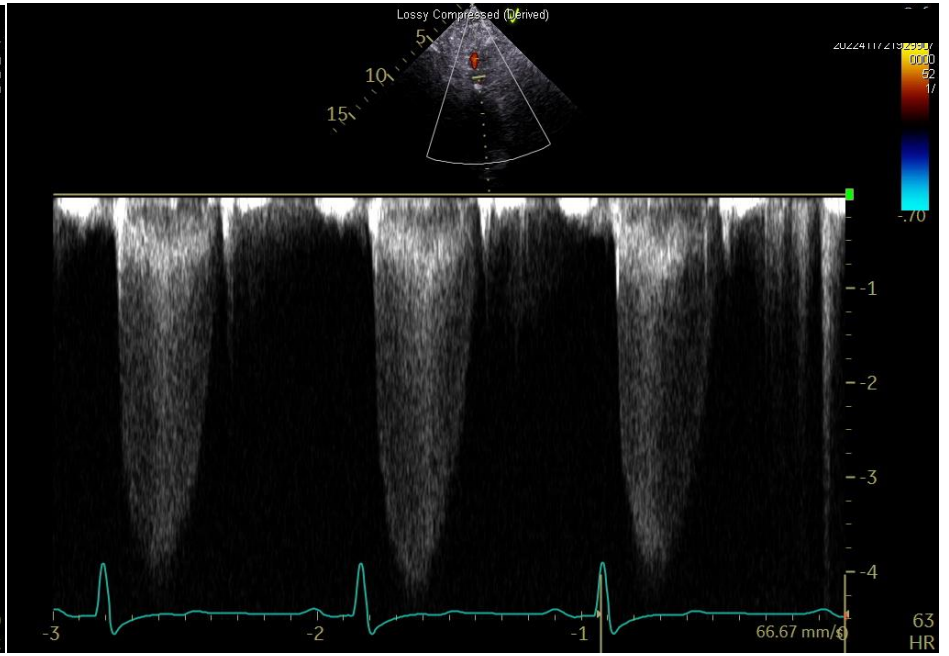

M
74 fps / 150 mm
61 bpm / NTHI General
---2D---
LVO / 10 dB
DR: 60 dB
78 fps / 140 mm
61 bpm / NTHI General
---2D---
LVO / 20 dB
DR: 60 dB

Echo

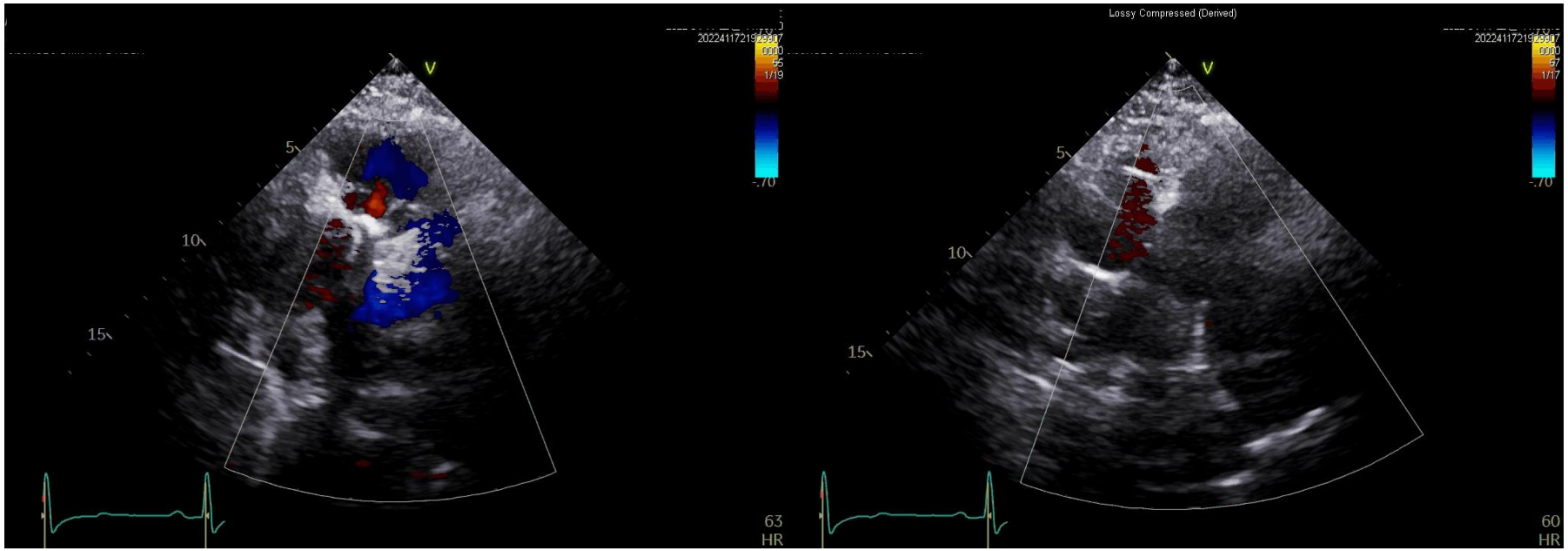

Lossy Compressed (Derived)
M
78 fps / 140 mm
63 bpm / NTHI General
---2D---
LVO / 13 dB
DR: 60 dB
Lossy Compressed (Derived)
V
5
10
15
62
HR

Echo

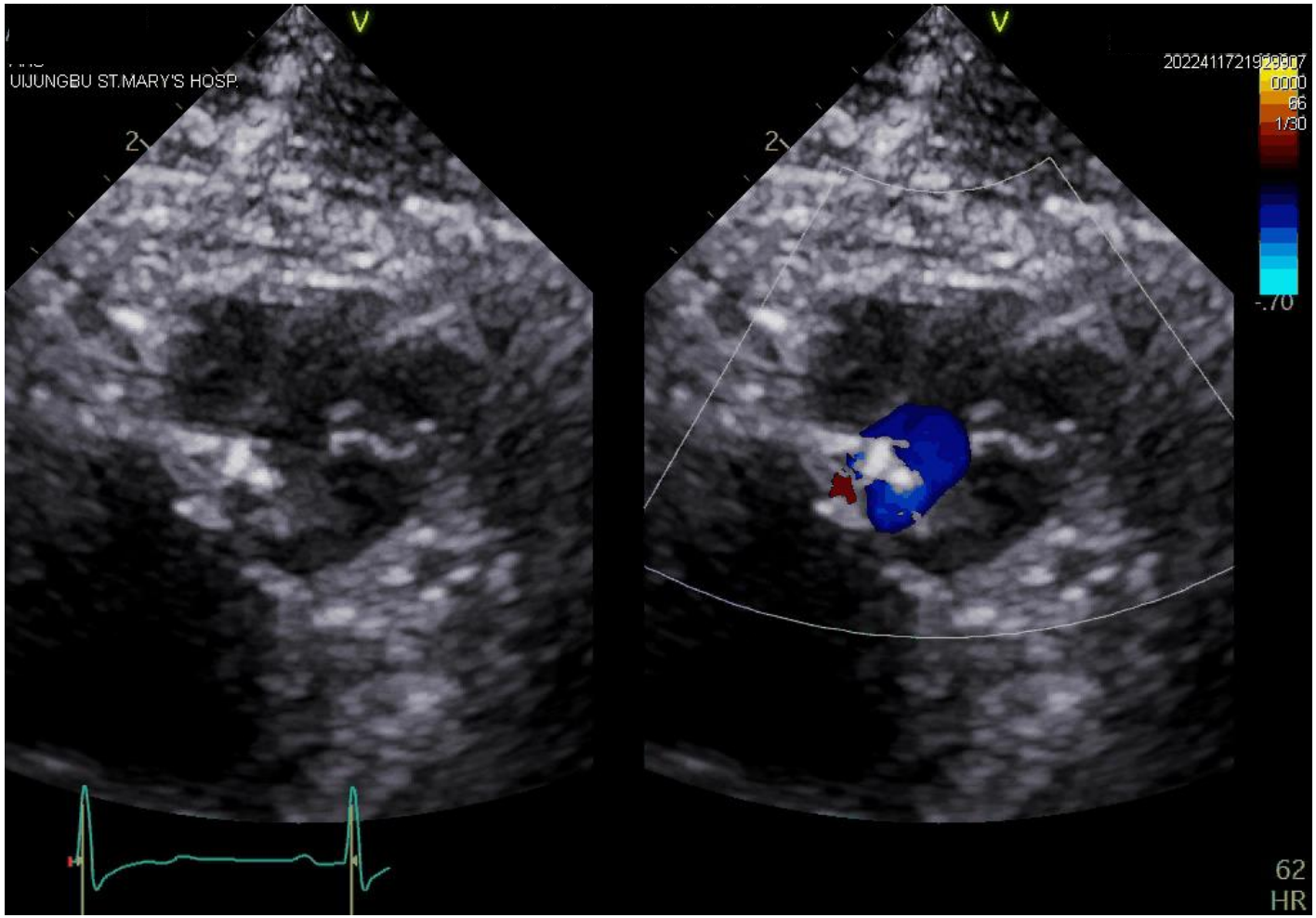

Lossy Compressed (Derived)
5
10
15
60
HR


Lossy Compressed (Derived)
5
10
15
-1
-2
-3
-4
-3
-2
-1
66.67 mm/s
63
HR

Echo

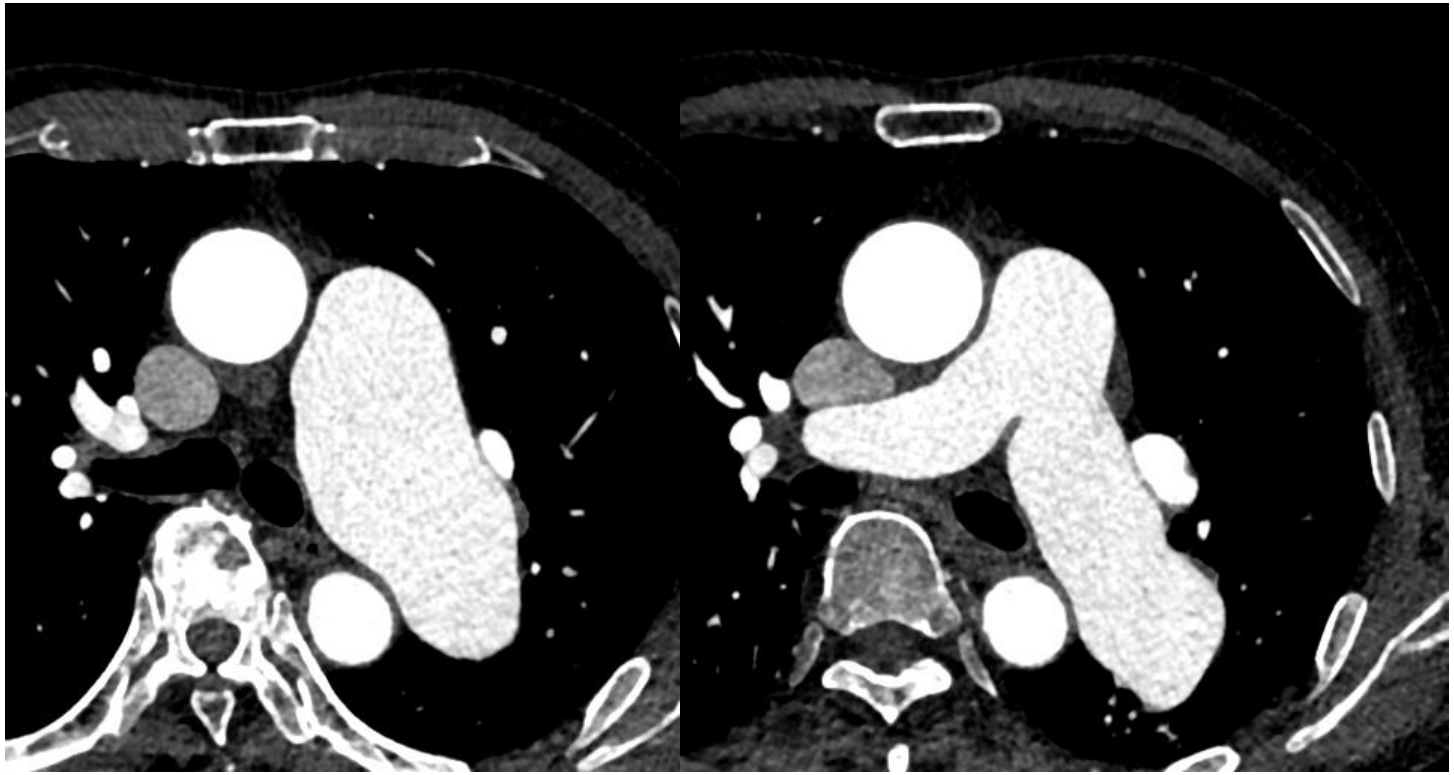


Echo

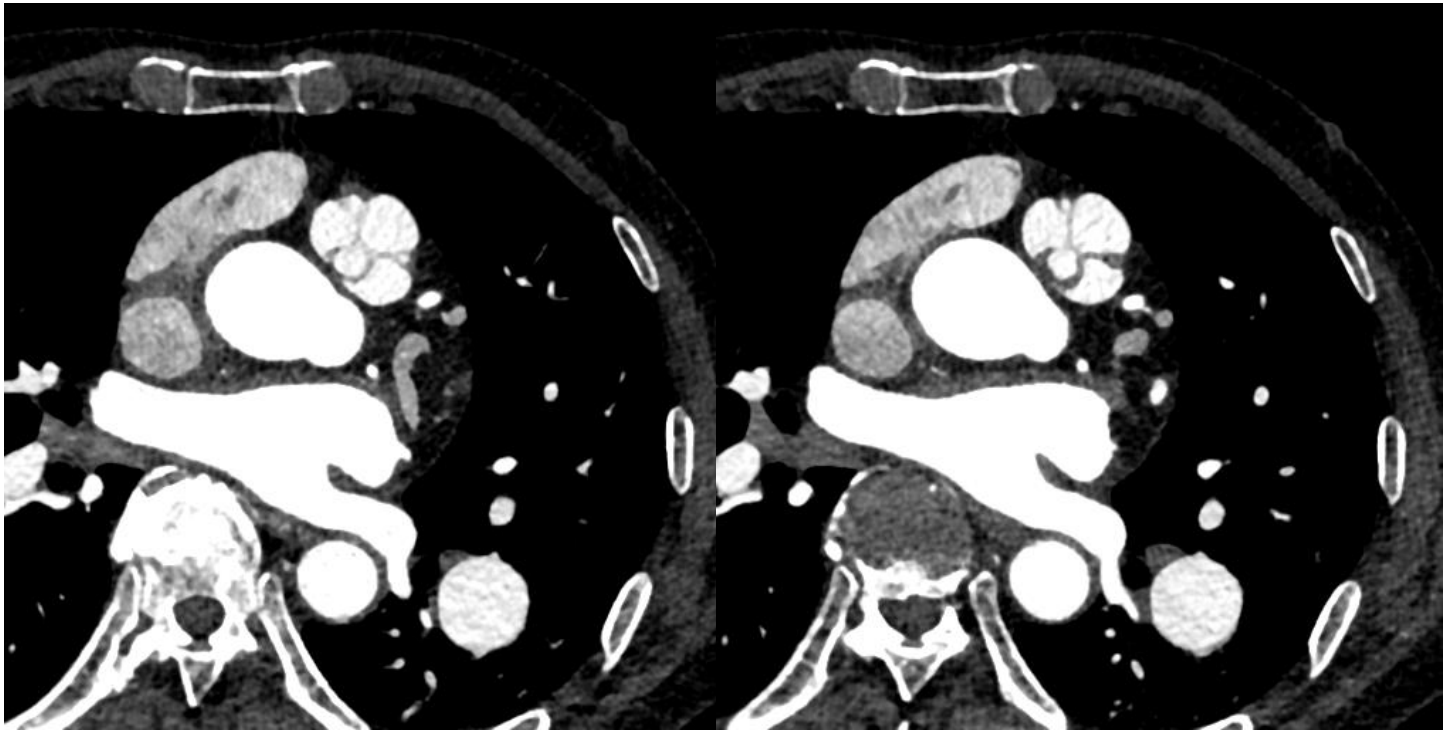


CT

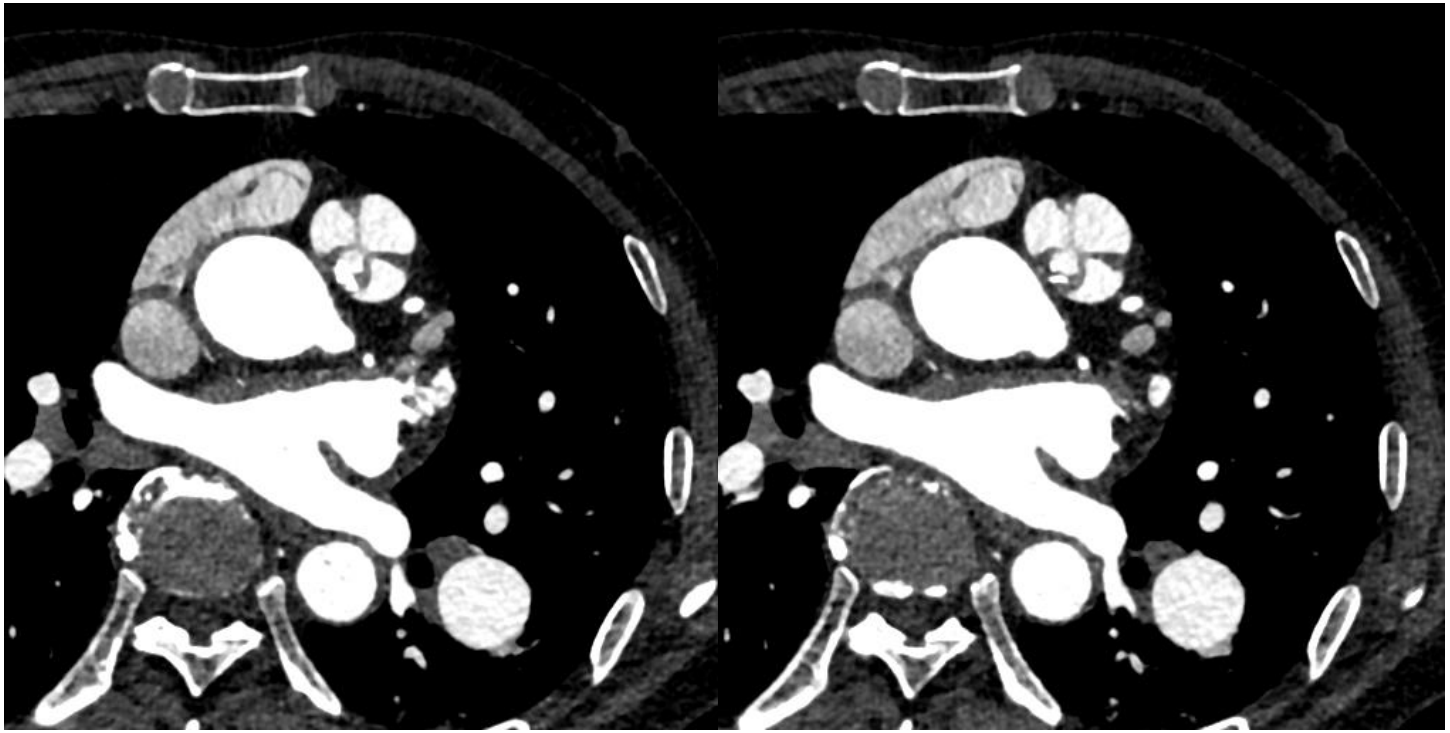
CT



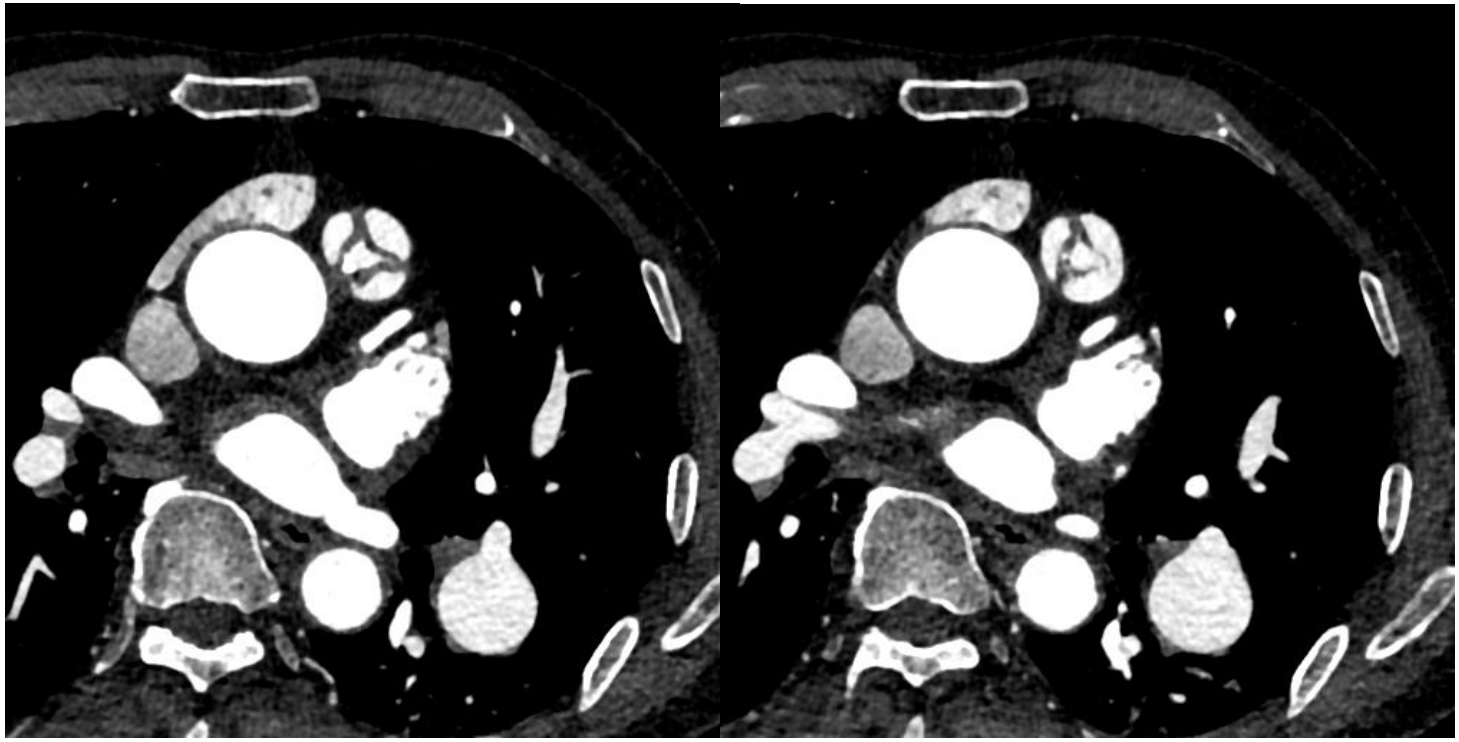
CT



CT



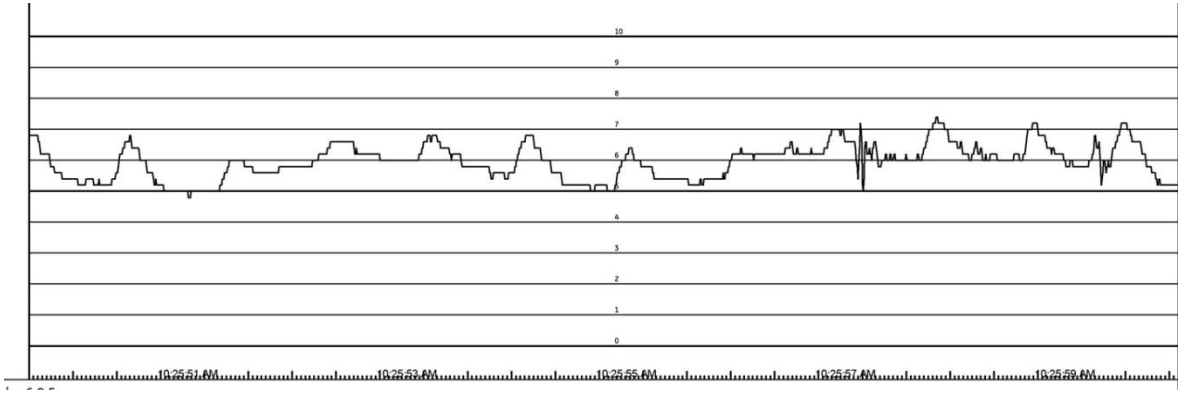
CT



Rt heart catheterization

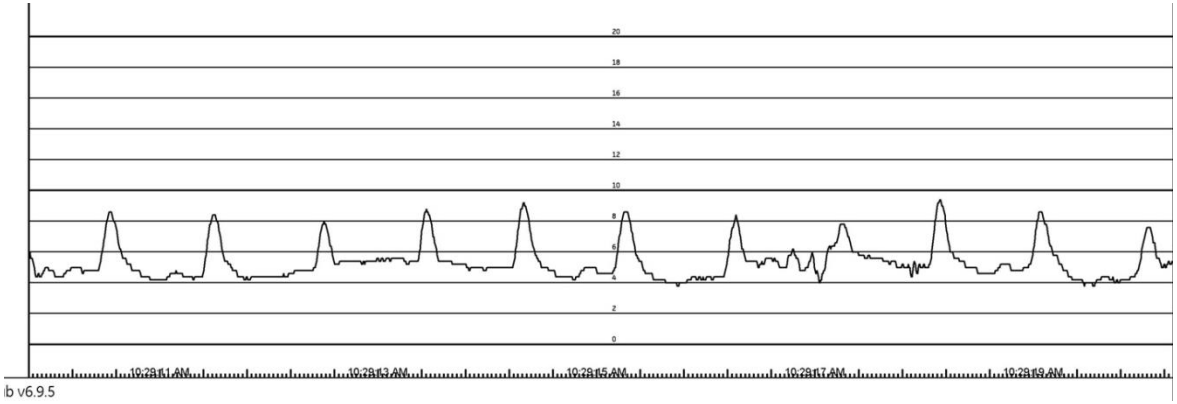
IVC

6mmHg



RA

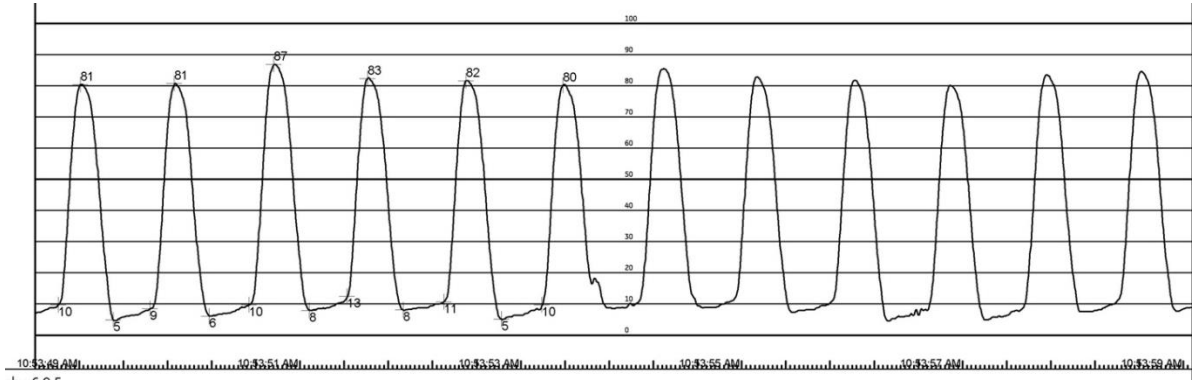
6mmHg



Rt heart catheterization

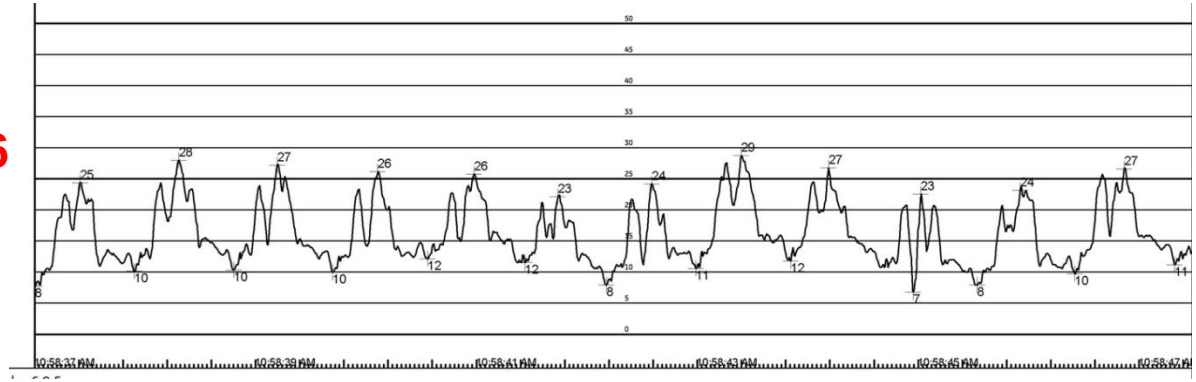
RV

83 /7 /11



PA

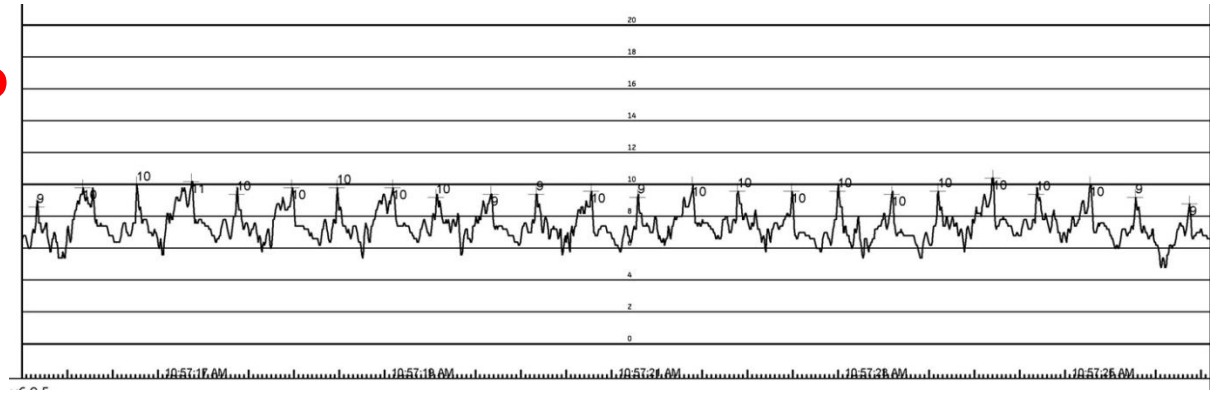
26/ 10 /16



Rt heart catheterization

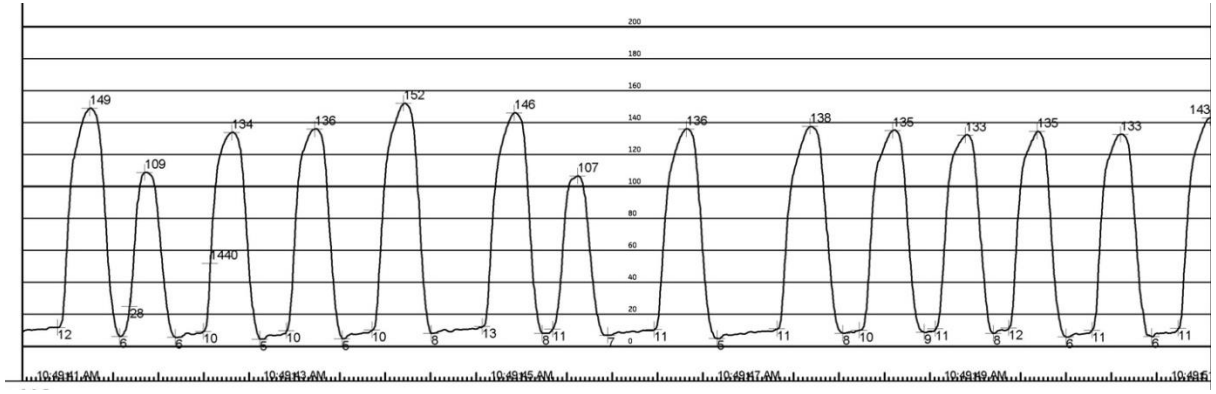
PAWP

8mmHg



LV

135 /7 /12



Rt heart catheterization

- Cardiac Output 3.13 L/min
- CO Index 2.01 L/min/m2
- PVR 2.23 WU
- SVR 27.8 WU
- Qp/Qs 1.29

Conclusion

- Moderate PS
- ASD
- No pulmonary hypertension

THANK YOU