Pitfalls in Measuring Hemodynamic Data and Pulmonary Vasoreactivity Test in the cath lab.

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Measurement, interpretation and use of hemodynamic parameters

Lopes , Cardiol Young 2009;19:8-12

"Calculation of blood flow and vascular resistance using the Fick principle requires attention to several possible sources of errors."

Inappropriate hemodynamic and respiratory conditions

Inadequate blood sampling and processing for blood gas analysis

Inappropriate assumptions – mixed venous and pulmonary venous O2 saturation, the value of oxygen consumption

Pitfalls

- **Pressure measurement**
- **Inadequate blood sampling for blood gas analysis**
- **Dissolved O_2 in total O_2 content**

  dissolved + oxyHgb O2

  0.003 ml/dl/torr + 1.36ml/g * Hgb g/dl * % O2
- **Inappropriate assumptions**

  mixed venous and pulmonary venous O2 saturation, oxygen consumption

Example

Hgb = 12g/dl, VO2 = 200, TPG = 6mmHg
PA = 70%
PV= 100%, 500mmHg

1. Dissolved O2 = 0.003*500 = 15 ml O2 /L
   Qp = 200/(15+49) = 3.1 Rp = 6/3.1 = 1.9 wu
   cf) Qp=4.1, Rp=1.5 wu
2. VO2 = 200 →170 ---- Rp=2.3wu
3. PA= 70 →65% ----- Rp=2.2wu
4. 2&3 ---------- Rp=2.5wu
5. TPG= 6 →9 ------- Rp=2.9wu

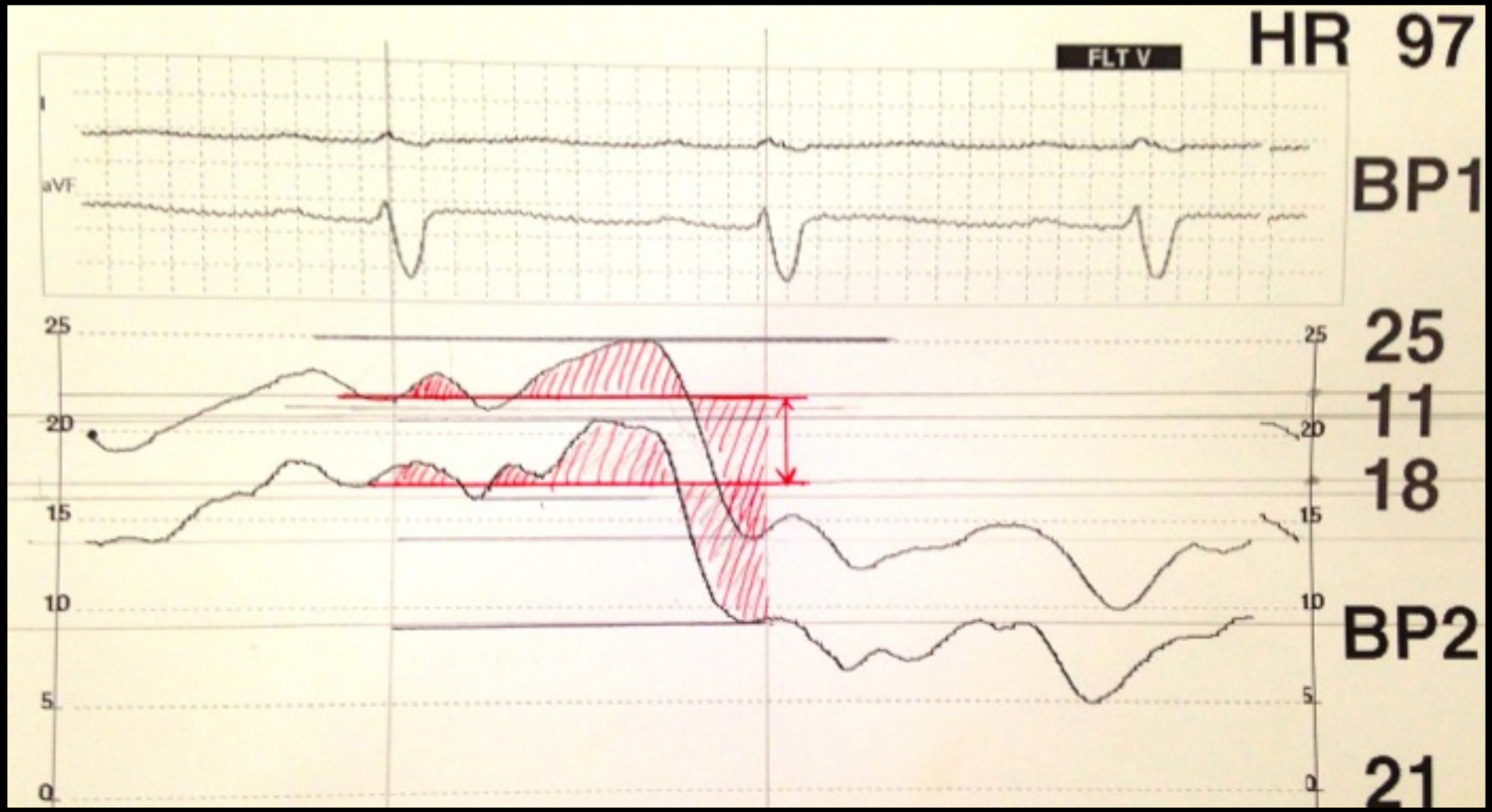
Pressure measurement

- **avoid ketamine in sedation**
- **adjust to zero**
  - setting zero at the mid-thoracic level

    (5th World symposium on PHT, Nice, 2013)
- **PAWP should be measured at end-expiration,** where the effects of intrathoracic pressure swings are minimal
- **Simultaneous tracing of PAP and PVP**

Routine Pressure Measurement

1. Zero & 100 mmHg settings
2. Routine double tracing
   AO-RA, AO-RV, RPCW-LV, RPA-LV,
   MPA-LV, RV-LV, RA-LV, LPCW-LV,
   LPA-LV, LV-AAO-DAO
3. TPG (PA-PV), switch transducers
4. Respiration - endexpiration


FLT V
HR 97
aVF
BP1
25
20
15
10
5
0
25
11
18
BP2
21

Definition of PAH

- m PAP ≥ 25mmHg (at rest)
  ≥ 30mmHg (with exercise)
- PCWP ≤ 15mmHg
- PVR ≥ 3 Wood units
- sPAP ≥ 50% of systemic pressure (children)
- 5-10% of all pts with CHD

J Am Coll Cardiol 2009;54(1 suppl):S55

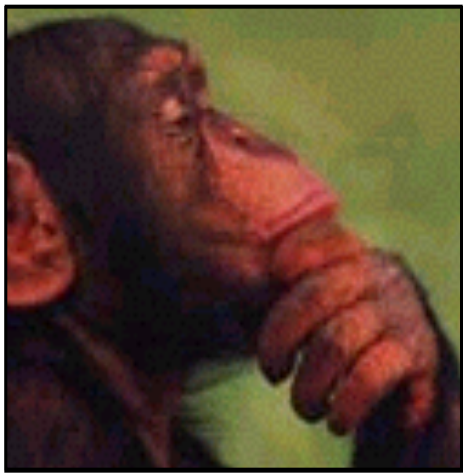
Myth

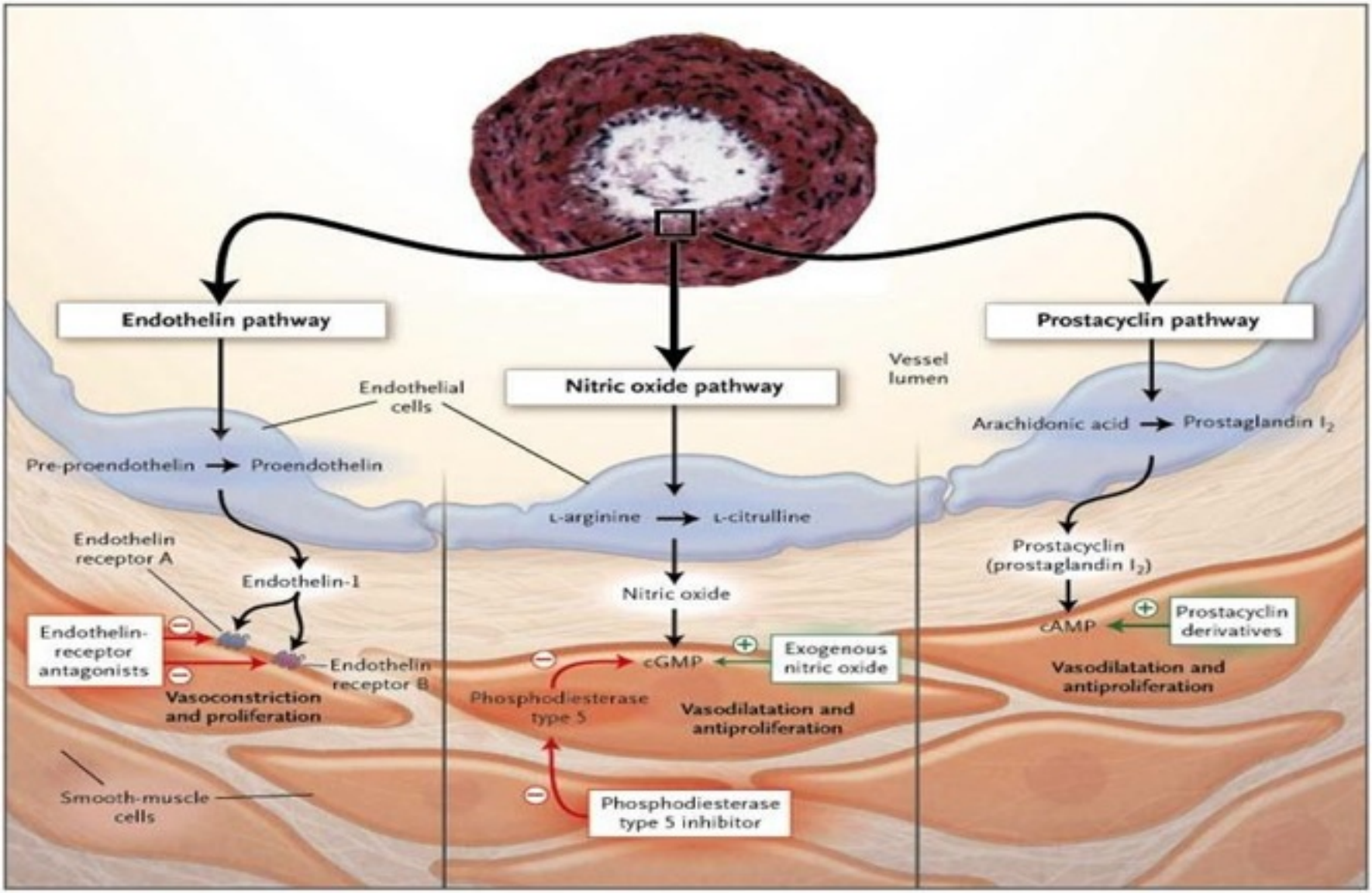
“Eisenmenger syndrome is a stable disease, not amenable to treatment”

Myth-busters

What is the cutoff value of Rp in closing ductus?

6WU? 8Wu? 10WU?





N Engl J Med 2004;351:1425-36

Case

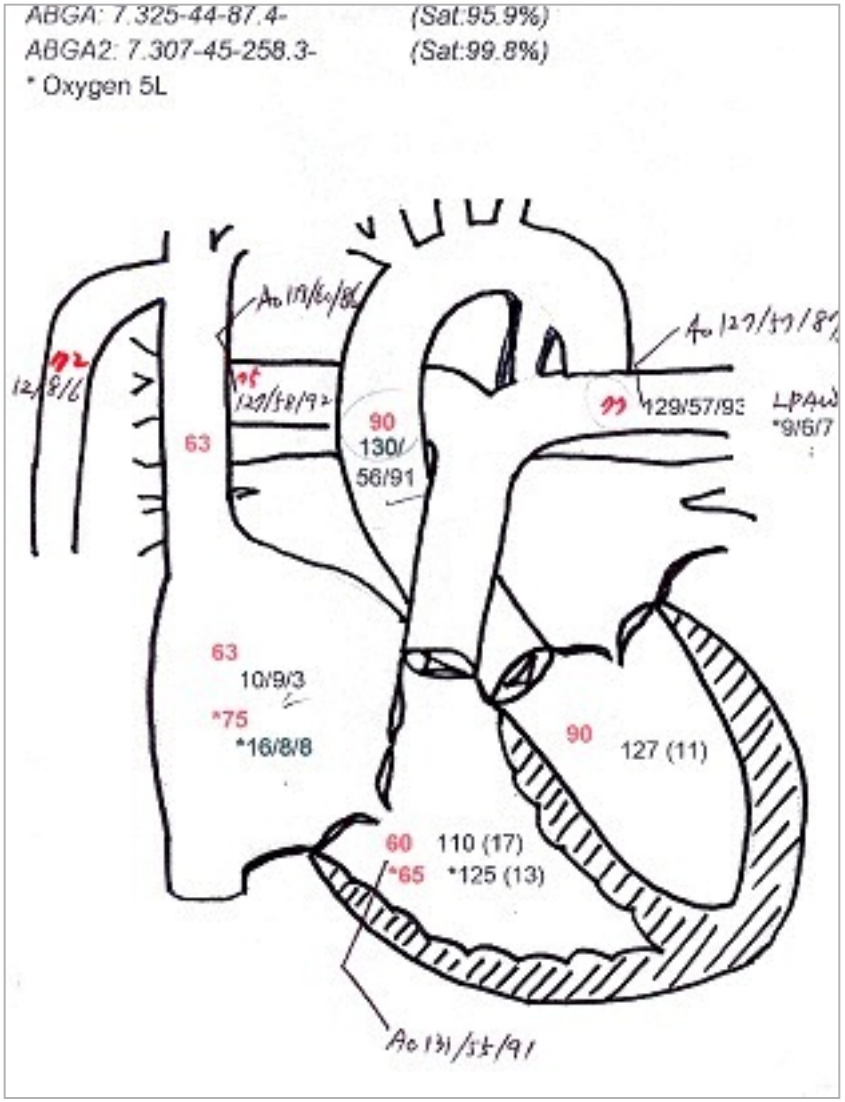
- 4Y/boy, Wt 11.5kg
- Mild CHF symptom
- Mild cardiomegaly on CXR
- Echo.

  Large PDA with severe PAH

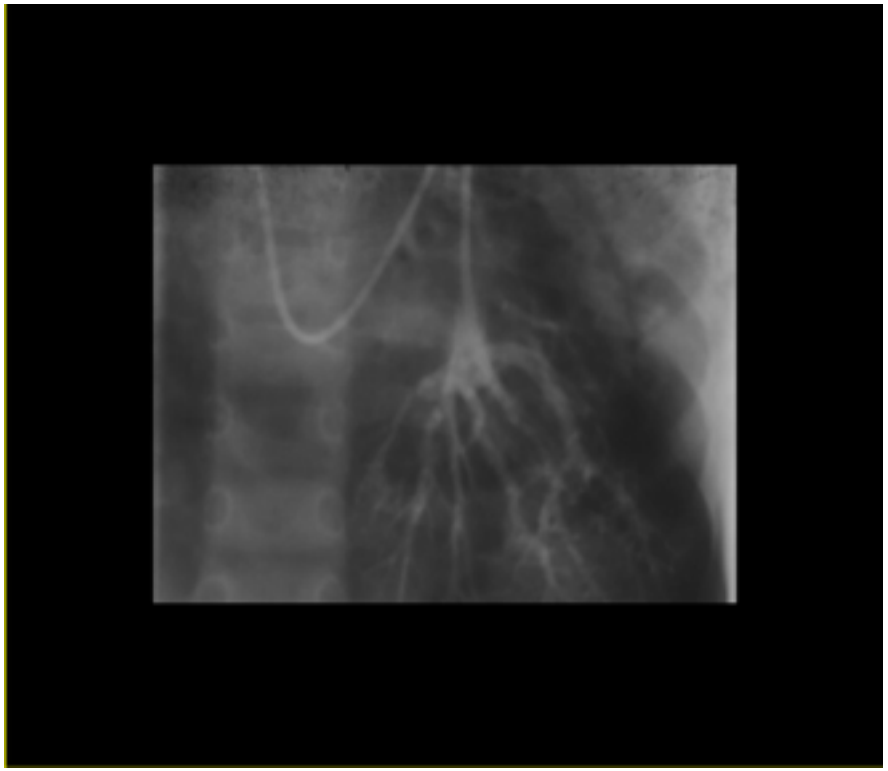
  d=7.1mm, bidirectional shunt

  Interrupted IVC

Cath. (99-6-4, 4Y)



Qp/Qs	**1.6**
R_P	**15.1**
R_P/R_S	**0.6**
P(PA/Ao)	**1.0**



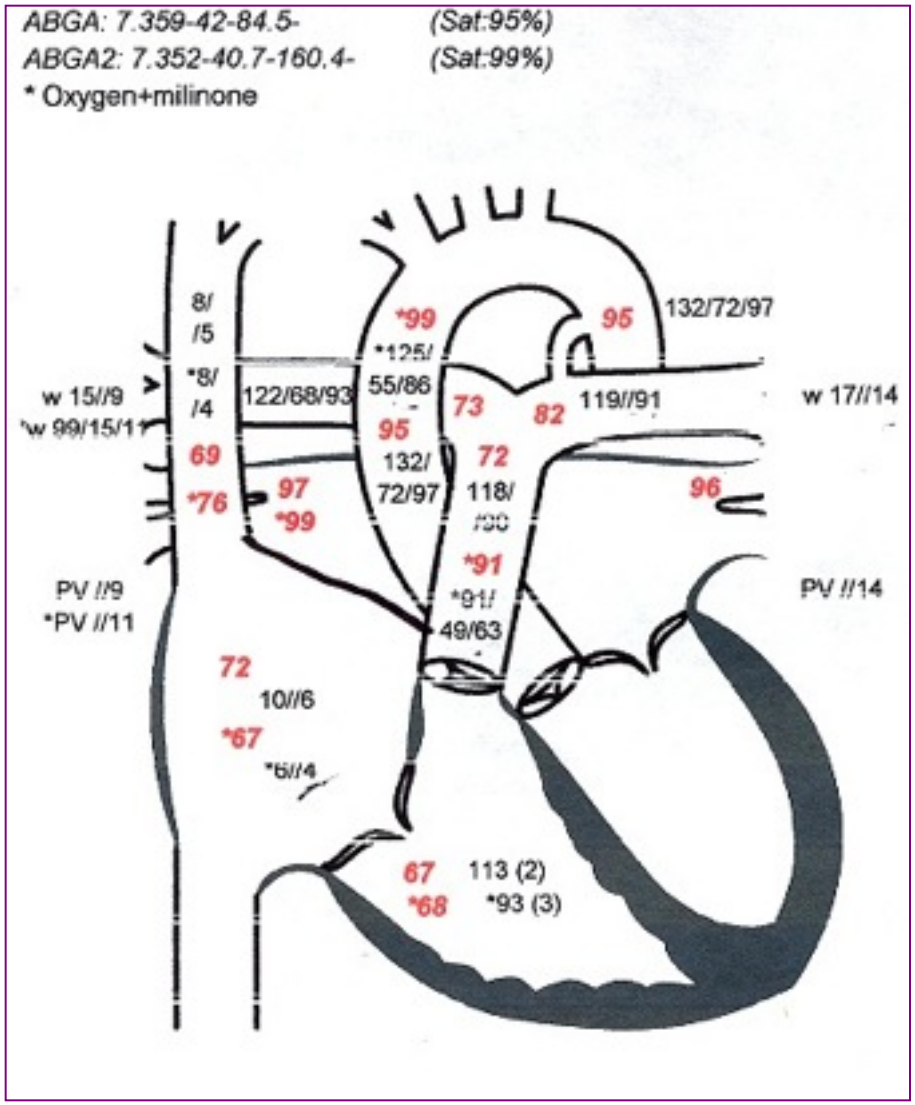
Management (99-6-30)

- **No closure of PDA**
- **Beraprost PO (2ug/kg/day)**
- ***Echo. (2001-3-13, 21months later)***

PDA PG=41mmHg (↑)

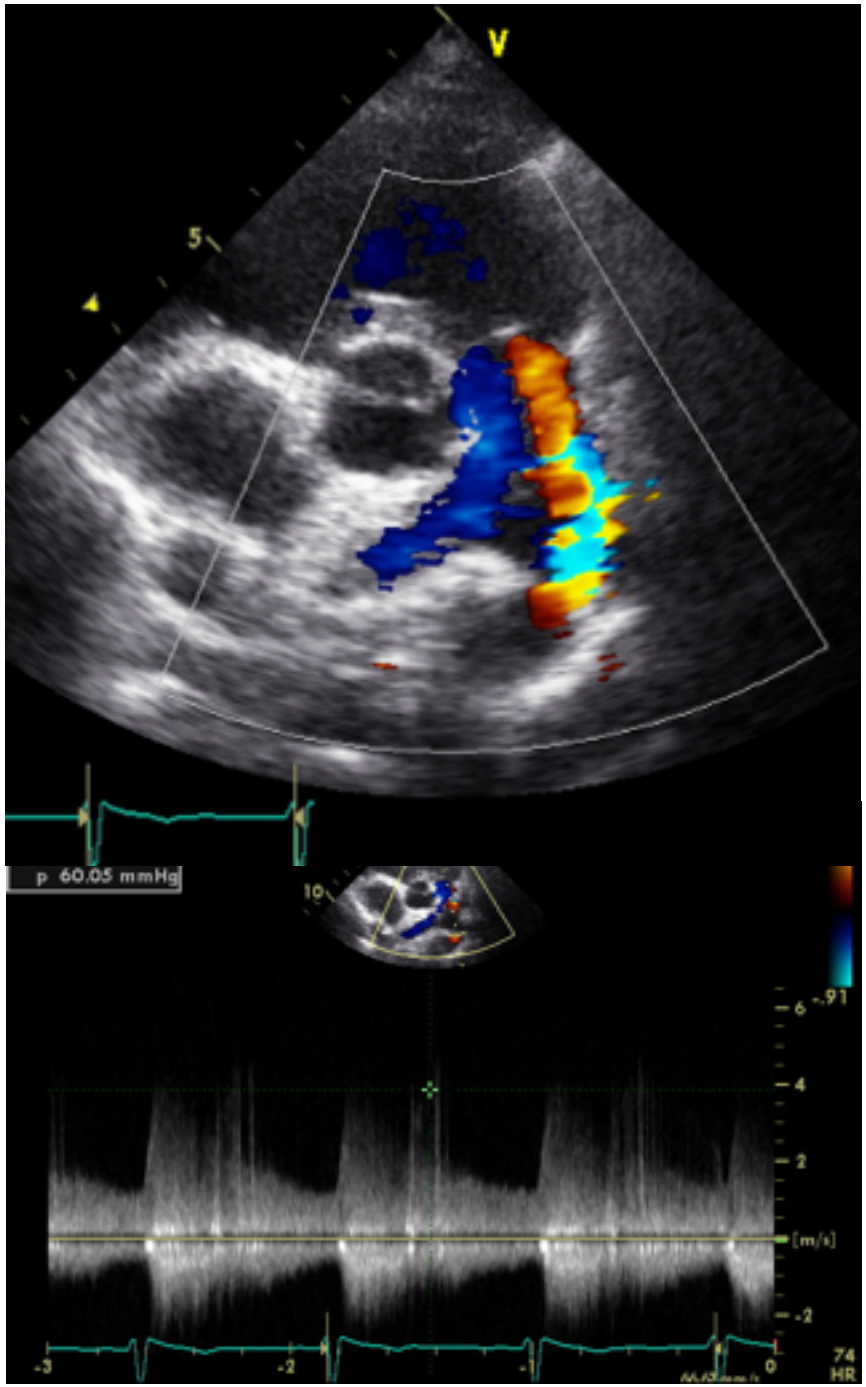
bidirectional shunt,
dominantly L to R shunt
Enlarged LA and LV (↑)

Cath. (2001-3-16, 6Y)



	Baseline	O2
Q_P	4.6	9.7
Q_S	3.4	3.8
Q_P/Q_S	1.4	2.6
R_P	16.5	5.3
R_P/R_S	0.6	0.3
P(PA/Ao)	0.9	0.7

High Rp(16)
Vasoreactivity(+)



Echo. (2006-7-11, 11y)

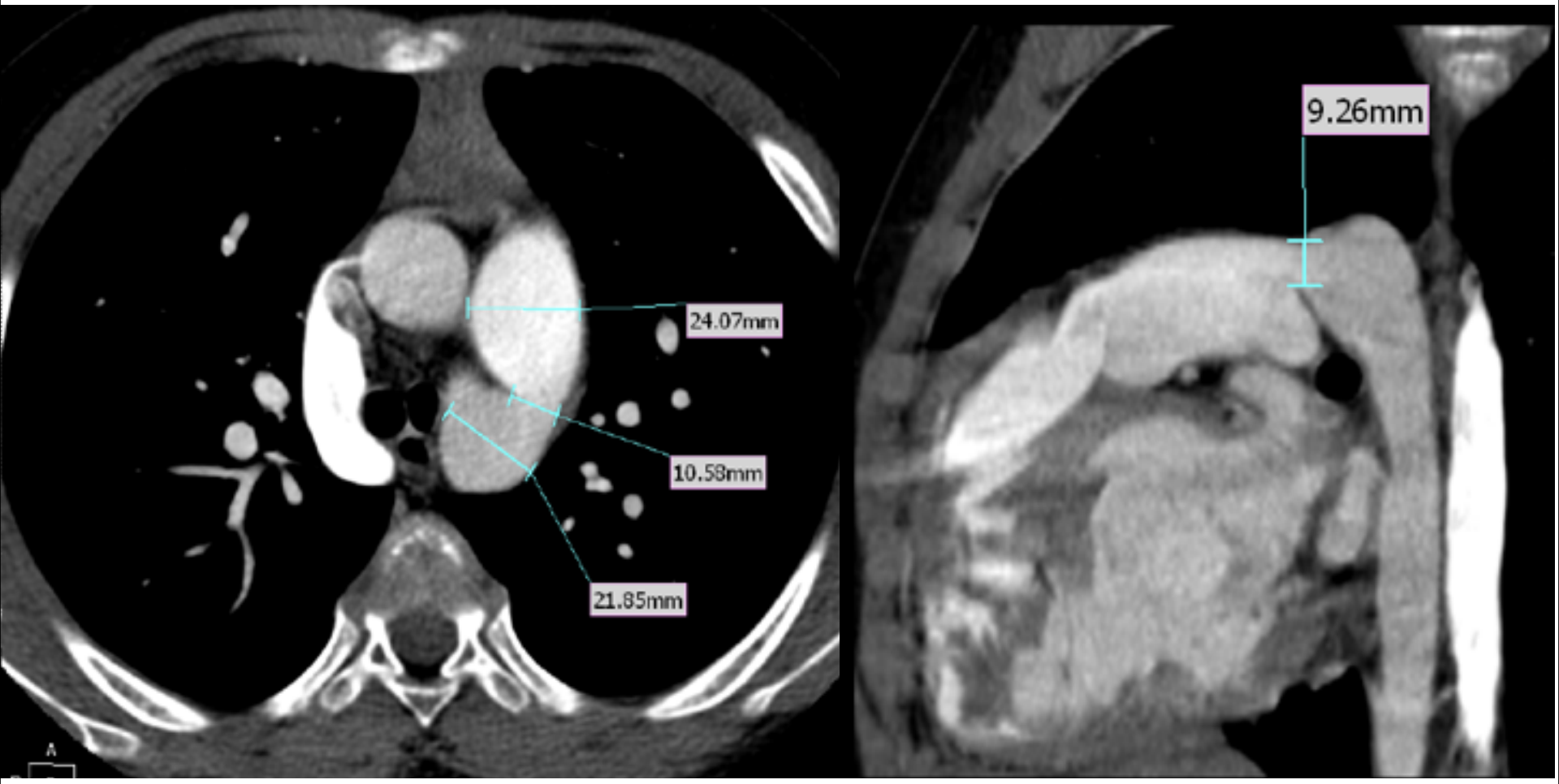
- **PDA PG = 60 mmHg(↑)**
- **Increasing L-to-R shunt**

Change of Chest X-ray

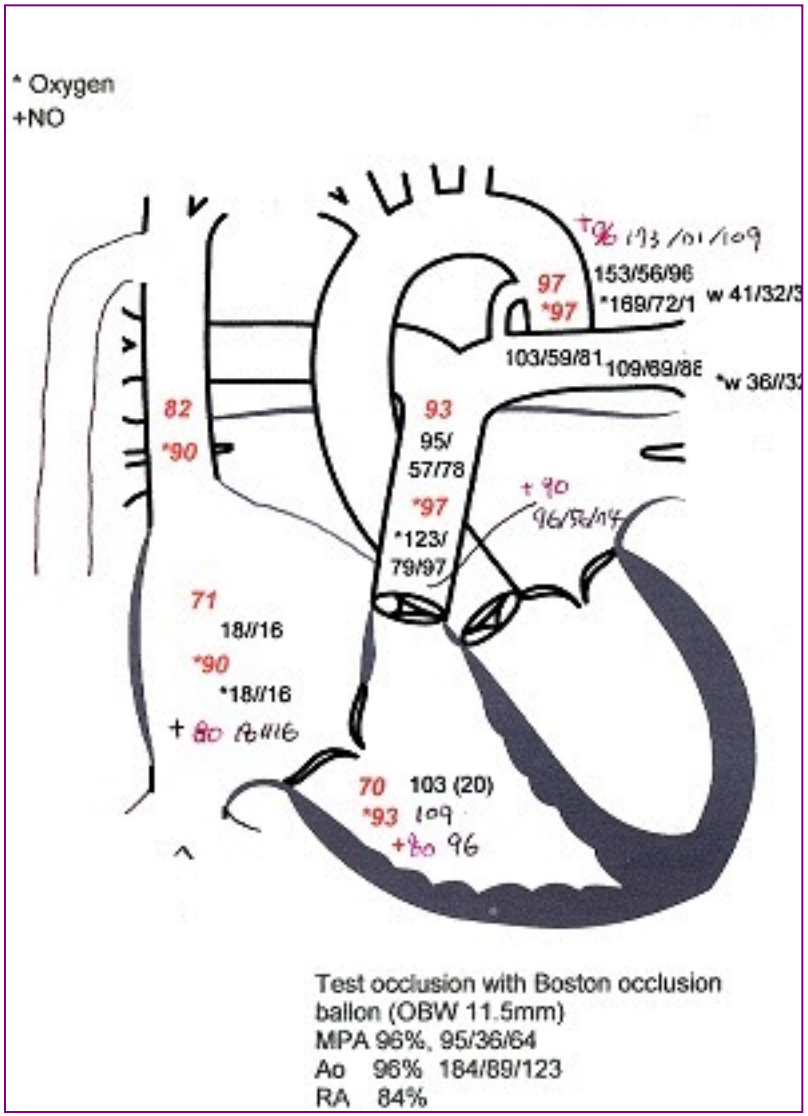
- *2003-1-30, 8y*

- *2007-1-20, 12y*

CT Angio. (2007-1-23)



Cath. (2007-1-22, 11Y)

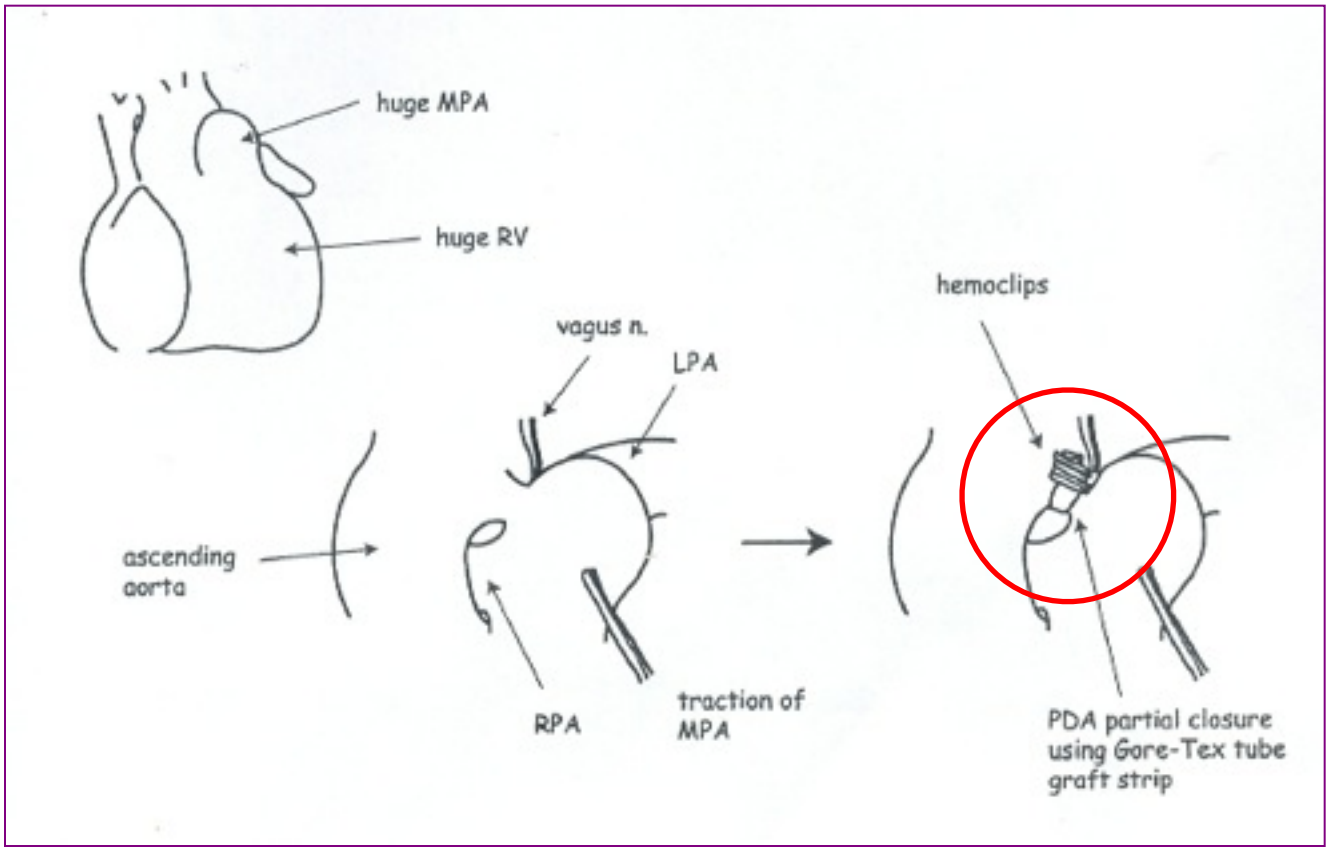


	Baseline	O2	TestOcclusion
Q_P	12.3	24.7	
Q_S	4.9	10.6	
Q_P/Q_S	2.5 ↑	2.3	
R_P	3.3 ↓	2.6	
R_P/R_S	0.21	0.29	
P(PA/Ao)	0.92	0.72	0.51

Low Rp(3.8), High Qp(12.3)

Op. (2007-4-11, 11Y)

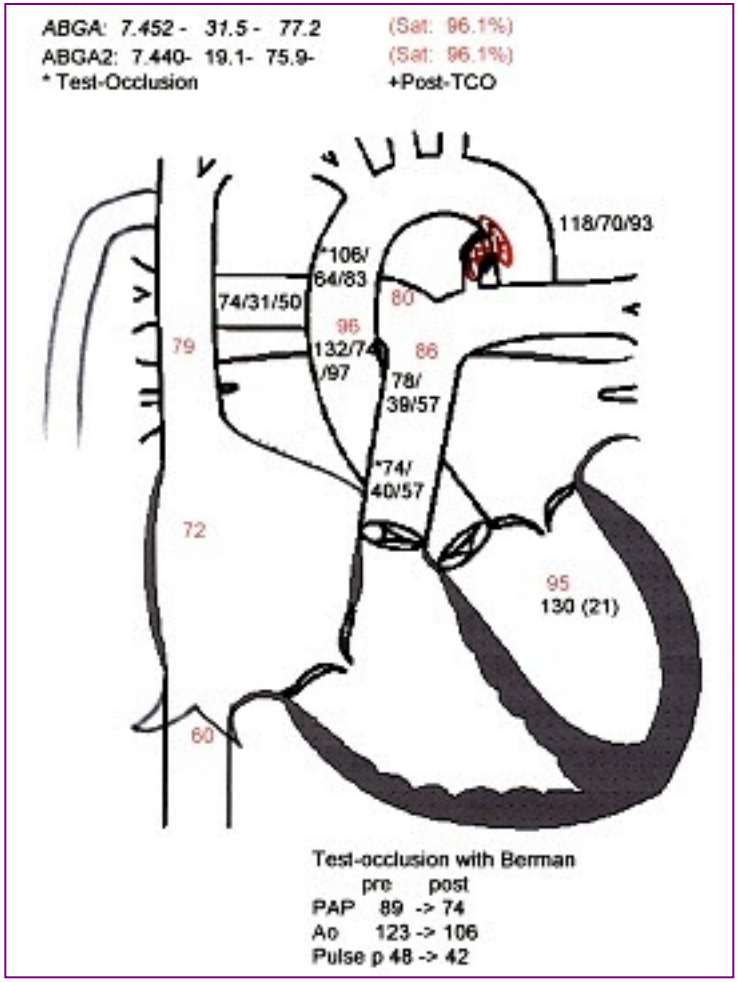
- Partial closure of PDA



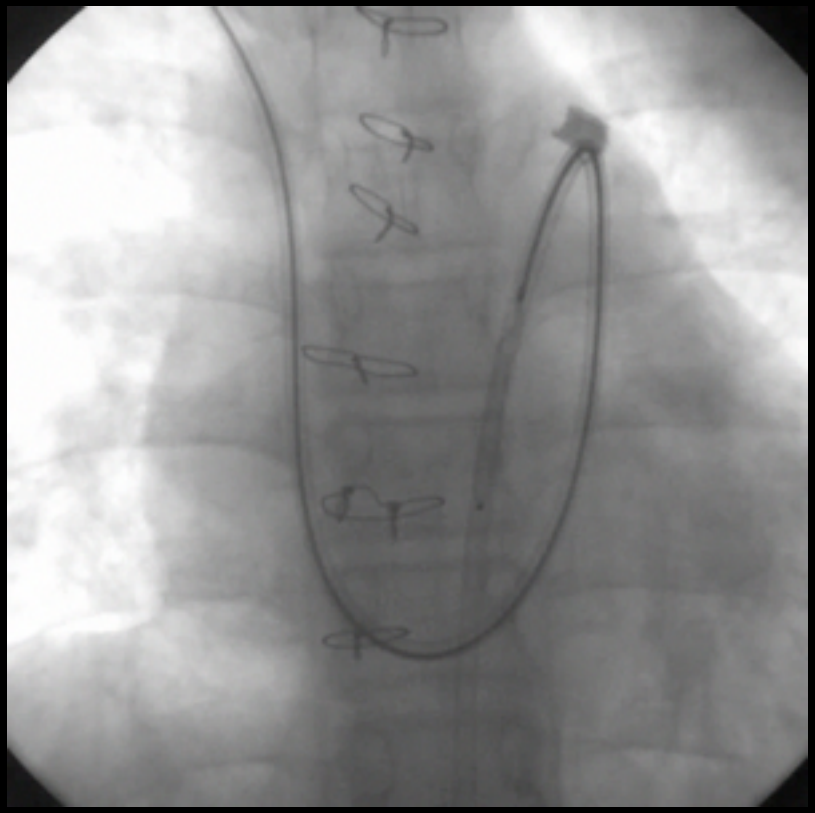
  - after surgery, medication with Tracleer & Beraprost

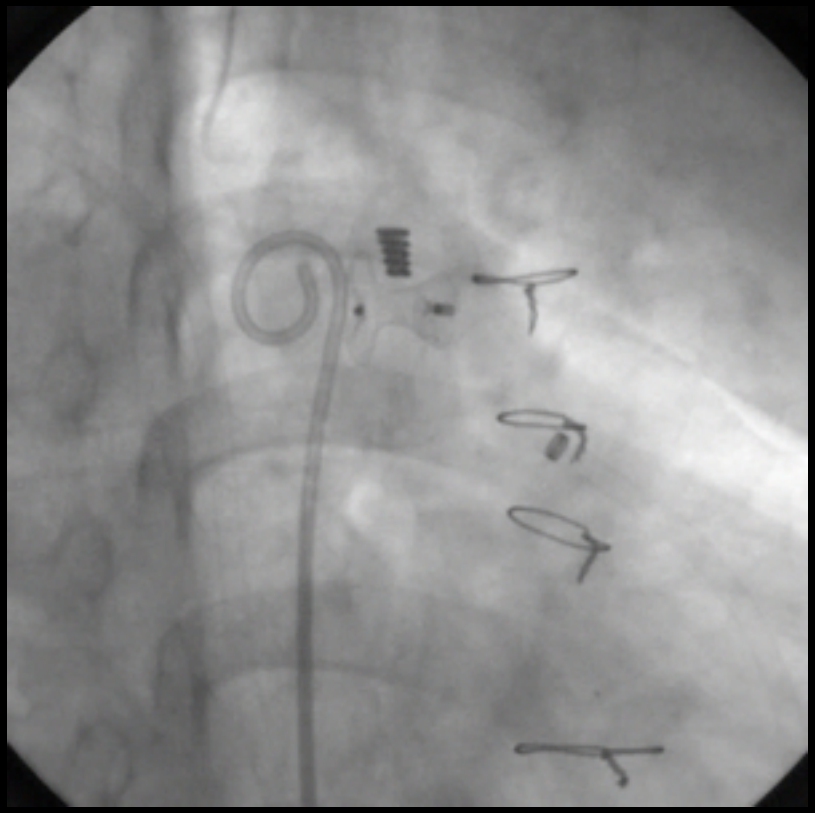
Cath. (2010-1-06, postop. 33mo)

	Baseline
Q_P	5.8
Q_S	3.4
Q_P/Q_S	1.7
R_P	6.2
P(PA/Ao)	0.6 ↓



- After Test Occlusion
- Closure with Amplatzer ductal occluder 10-8mm





Follow - Up

- FC I
- Echo. (2010-1-7)
  - No PDA leak
  - Mild LVE
  - Trivial TR, no RVE
- Medication
  - Bosentan 250mg/day
  - Beraprost 0.04mg/day

Transcatheter closure of patent ductus arteriosus with severe pulmonary arterial hypertension in adults

C Yan, S Zhao, S Jiang, Z Xu, L Huang, H Zheng, J Ling, C Wang, W Wu, H Hu, G Zhang, Z Ye, H Wang

Heart 2007;93:514–518. doi: 10.1136/hrt.2006.091215

Background: Surgical closure of patent ductus arteriosus (PDA) with severe pulmonary arterial hypertension in adults carries higher risk than in children.

Objectives: To investigate the application of self-expandable occluders for transcatheter closure of PDA associated with severe pulmonary arterial hypertension in adults, and the assessment of immediate and short-term results.

Methods: 29 adu…eter closure of PDA at a mean (standard deviati…d a mean (SD) weight of 54.1 (7.1) kg (range …obtained before and after trial occlusion, the … Radiographs of the chest, electrocardiogra…ation of the treatment within 1 day, 1 month …

Results: 20 of th…nts failed (named group 2). In group 1, in whi…pressures decreased markedly after trial occlus…lusion and 41 (13.8) mm Hg (range 23–77 m…was found to be >90% in 19 patients and <9…nd >95% during inhalation of oxygen or after …2, the occlusion was not successful, because in two patients the devic… two patients showed worsening of symptoms. The other five patients showed increased pulmonary arterial pressures after trial closure; their mean (SD) pulmonary arterial pressures increased by 10.3 (6) mm Hg (4–16 mm Hg) after trial occlusion, and systemic arterial oxygen saturation was 85.5% (2.6%) (range 82.6–88%) before inhalation of oxygen and 94.7% (1.7%) (range 90.7–99.1%) during inhalation of oxygen. In group 1, the dimensions of the left atrium, left ventricle and pulmonary artery increased considerably in 3–6-months of follow-up compared with those of preocclusion.

Conclusions: Transcatheter closure is an effective treatment for adults with PDA associated with reversible severe pulmonary arterial hypertension. Further research is needed for the evaluation of long-term results.

29 adult pts with PDA, PHT
"trial occlusion" for 30min
→if 1)not elevated PAP
2) not decreased AOP
3) not worsened Sx
20/29 successful implant

See end of article for authors' affiliations

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Table 1 Clinical and haemodynamic data of successful occlusion in patients (n = 20)

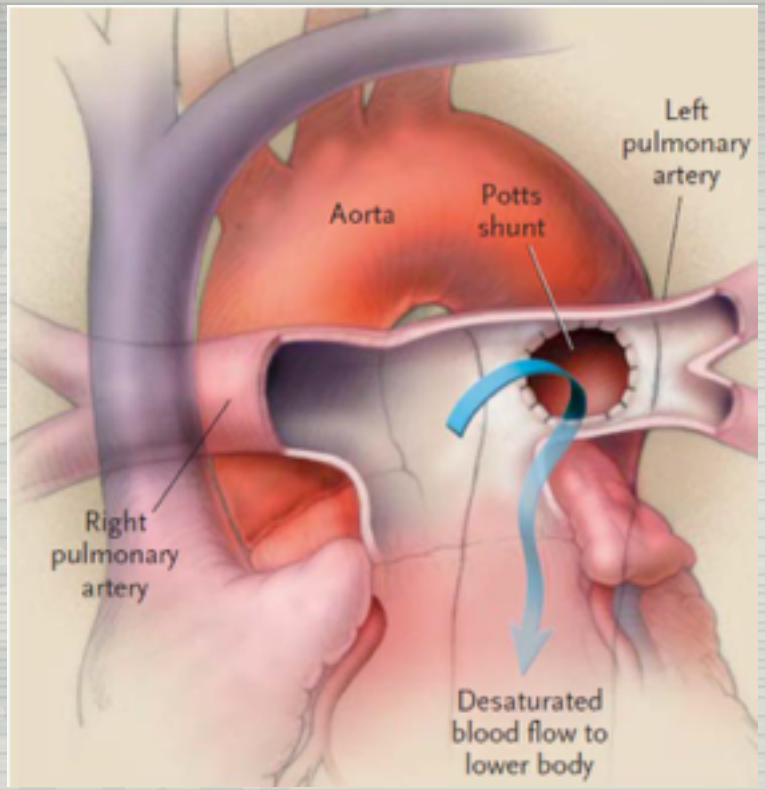
Patient number (n)	Age (years)	Weight (kg)	SAsat (%) Before O_2	During O_2	After closure	Pulmonary arterial pressure (S(M)) mm Hg Before O_2	During O_2	After closure	Aortic pressure [S(M)] mm Hg Before O2	After closure	Qp/Qs	Rp (Wood) Before O2	During O2	Duct diameter (mm)	Occluder diameter (mm)
1	41	58	95.5	99	96.4	75 (55)	74 (53)	40 (30)	170 (100)	190 (120)	2.5	5.24	2.32	7	10
2	20	45	95.7	100	98.2	67 (53)	62 (46)	45 (28)	140 (92)	152 (101)	4.38	1.43	0.93	6	12
3	24	53	96.9	100	98	110 (75)	107 (70)	43 (32)	144 (90)	160 (105)	2.52	2.67	0.86	16	20
4	35	63	95.5	99	97.3	118 (85)	115 (80)	50 (36)	143 (86)	180 (118)	1.7	11.2	8.11	10	16
5	18	53	96.4	100	100	94 (77)	89 (73)	51 (35)	125 (98)	135 (107)	1.23	9.33	0.53	8	14
6	58	57	96.4	100	96	75 (50)	74 (48)	36 (26)	197 (127)	188 (144)	2.97	4.81	2.43	6	10
7	54	60	94.6	98.6	96.2	76 (62)	75 (60)	42 (31)	149 (104)	162 (120)	2.37	8.35	6.3	11	18
8	38	45	92.2	97.8	95	85 (70)	80 (61)	40 (30)	120 (80)	130 (100)	2.25	8.3	7.55	9	14
9	35	66	94.1	99.2	98.8	170 (125)	153 (111)	104 (77)	174 (124)	190 (147)	1.28	17.01	15.31	14	18
10	22	47	93	100	96.5	90 (80)	85 (72)	61 (46)	139 (87)	156 (108)	1.68	6.78	6.16	11	14
11	18	53	92.8	97.4	96.3	128 (103)	110 (91)	49 (36)	135 (110)	160 (112)	1.5	13.07	7.22	13	20
12	25	62	90.2	97	96.2	110 (86)	99 (76)	84 (60)	110 (89)	119 (98)	1.12	14.17	6.57	12	18
13	48	45	93	100	96.7	70 (55)	60 (44)	35 (23)	154 (92)	166 (100)	2	2.59	2.49	11	14
14	39	52	91.8	95.5	94	88 (63)	86 (63)	54 (40)	132 (83)	159 (117)	3.64	5.63	2.95	11	18
15	43	65	91.8	96.3	95	100 (70)	100 (70)	65 (45)	125 (90)	147 (103)	1.5	8.11	7.43	8	12
16	45	71	92.8	97.8	95.3	120 (80)	110 (75)	50 (37)	160 (105)	190 (115)	2.5	5.48	4.29	10	20
17	40	43	92.5	97.6	95.6	130 (81)	69 (49)	57 (45)	125 (95)	123 (96)	1.62	16.1	10.64	14	16
18	25	59	91.6	98	95.2	122 (96)	118 (90)	80 (60)	130 (102)	148 (114)	1.3	10.38	9.78	12	18
19	34	53	94.5	98	97.4	139 (99)	123 (94)	60 (46)	152 (106)	150 (109)	2.44	9.47	6.31	10	16
20▲	22	42	89.4	93.3	95	120 (86)	120 (84)	80 (57)	122 (98)	140 (104)	1.06	22.2	21.03	8	14
Total (n) = 20	34.2 (12.1)	54.6 (8.)4	93.5 (2.1)	98.2 (1.8)	96.5 (1.5)	S104.9 (27.4) M78 (19.3)	S95.5 (24.1) M70.8 (18.2)	S56.3 (18.3) M41 (13.8)	S142.3 (21.2) M97.9 (12.4)	S157.3 (22.1) M111.9 (13.7)	2.1 (0.9)	9.1 (5.3)	6.5 (5.1)	10.4 (2.7)	15.6 (3.2)

SAsat, systemic arterial oxygen saturation; S, systolic arterial pressure; M, mean arterial pressure; Qp/Qs, the ratio of pulmonary blood flow to systemic blood flow; Rp, pulmonary vascular resistance. ▲, associated with mild tricuspid regurgitation. Before O_2, before oxygen inhalation; During O_2, during oxygen inhalation; After occlusion, after trial occlusion; Occluder diameter: the narrowest segment of occluder (the pulmonary segment of ADO and the waist of AMVSDO). Values are given as mean (SD).

Eisenmenger syndrome

V/S

Idiopathic pulmonary HT



Blanc et al., NEJM, 2004

- ASD creation
  - Mortality up to 7% at 1 d,15% at 1 mo
  - Spontaneous closure common

  Keogh et al., JACC, 2009

- Surgical Potts shunt
  - 8 children; 2 deaths (<14 d)
  - Improved functional status, 6MWD, & BNP (median f/u 63 months)

Baruteau et al., Ann Thorac Surg, 2012

Acute vasoreactivity testing

- 100% oxygen inhalation
- NO gas - immediately
- inhaled iloprost (PC) - after 15~30min
- Adenosine, CCB - less sensitive
- PDE inhibitors (ERA, PDE5I) - not recommend
- Temporary balloon test occlusion of shunt

Positive responders in vasoreactivity testing

- **IPAH**
  - reduction of mean PAP of at least 10mmHg to a pressure level of below 40mmHg
  - unchanged or increased CO
- **CHD**
  - operability - PVR less than 8-10WU

Vasoreactivity Test

- **INOP test I** Circulation 2002; 106: I76-81.
- multicenter, retrospective
- N=124

  CHD with PHT(baseline Rp/Rs>0.33)
- Candidates for operability
  - 74/124 Op, 12/74 died
  - broad gray zone 0.16 <Rp/Rs< 0.41

No : 201324963 Name : Age/Sex : 23/ Birth : 19900803

Date : 20131113 Cath No : 2013008104 Angio No : 64074

Physician : / / Fluoro : 16.7 min Dye :

Pt alertness:

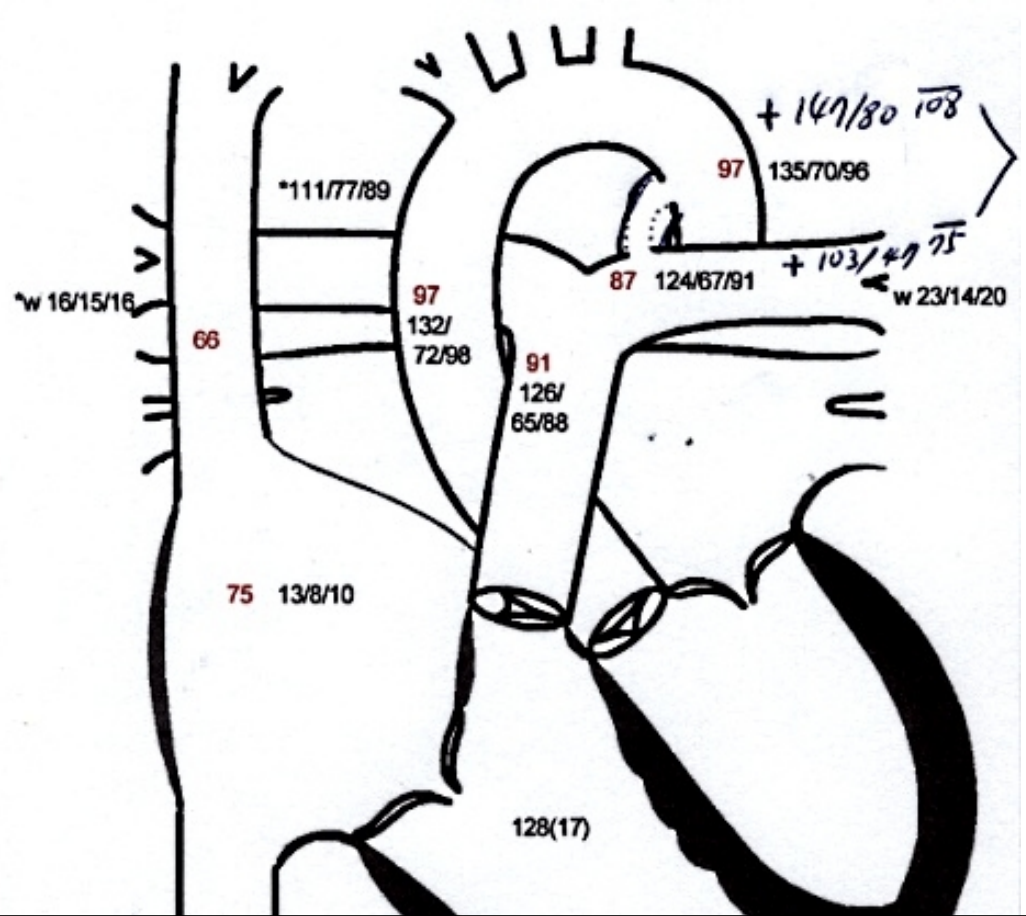
Clinical : Genetic :

Comment : Wt : 48 kg Ht : 161 cm BSA : 1.48

Complication : Hgb : 12.1 HR : VO2 :

ABGA : 7.443-36-97.2- *(Sat : 98.4%)*

*O2 +Test occlusion



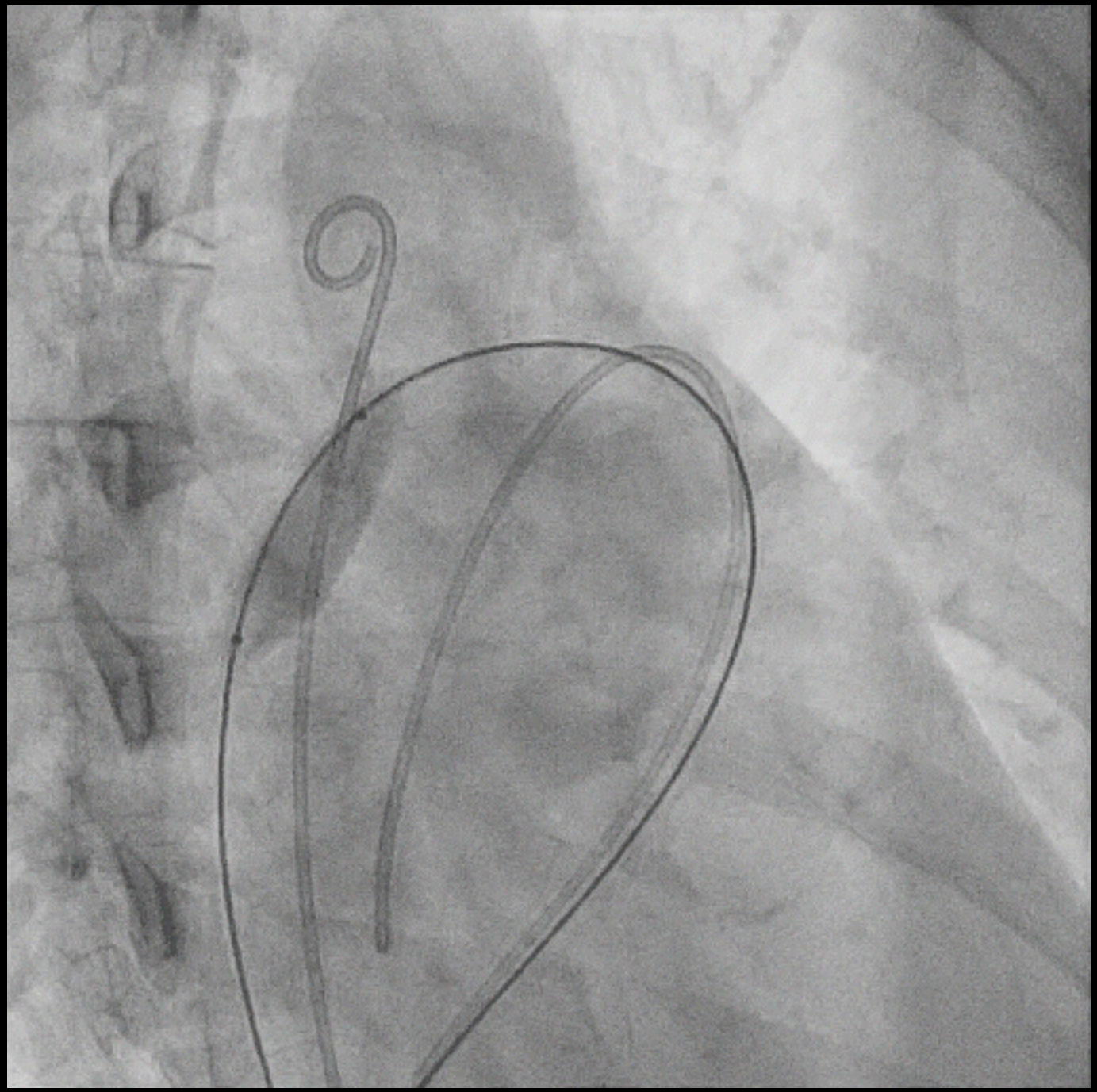
Diagnosis/Intervention

2012-6 PDA op staged? at Mongolia, feel better after op
then viagra for 1Y(10mg tid)
2013-7 cath : systemic PA pressure, L to R only d=12mm tubular by American doctor
2013-9 cath : same by American doctor - not perform device closure,
2013-11-12 CPET : max VO2 21(53%) 10.1METs HR 183 stage 5

PDA
severe PHT with PVOD
balloon sizing 12mm, but 15mm balloon easily pass through

Oxygen 10l/min for 15min
test occlusion with 15mm tyshak balloon from PA side d/t easy slip into MPA from des Ao

Set1 : Baseline
Set2 : O2
Set3 : Test occlusion
Qp/Qs: 2.2 -> 2.3
Qp: 7.3 -> 7.4 Qs: 3.3 -> 3.2
Rp/Rs: 0.4 -> 0.4 TPG : 81 -> 73
Rp : 11.1 -> 9.9
p(RV/Ao): 0.97 -> 0.93 -> 0.7(test occlusion)




SPO2: 99
NIBP: 0/ 0(0)
00:00
FLT V
HR 78
I
II
aVF
BP1
132
67
92
200
150
100
50
0
PA
MA
126
59
83


SPO2: 100
NIBP: 0/ 0(0)
00:00
FLT V
HR 81
I
II
aVF
BP1
141
73
101
200
150
100
50
0
BP2
119
57
87

Date : 20131113 Cath No : 2013008104 Angio No : 64074

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Pt alertness:

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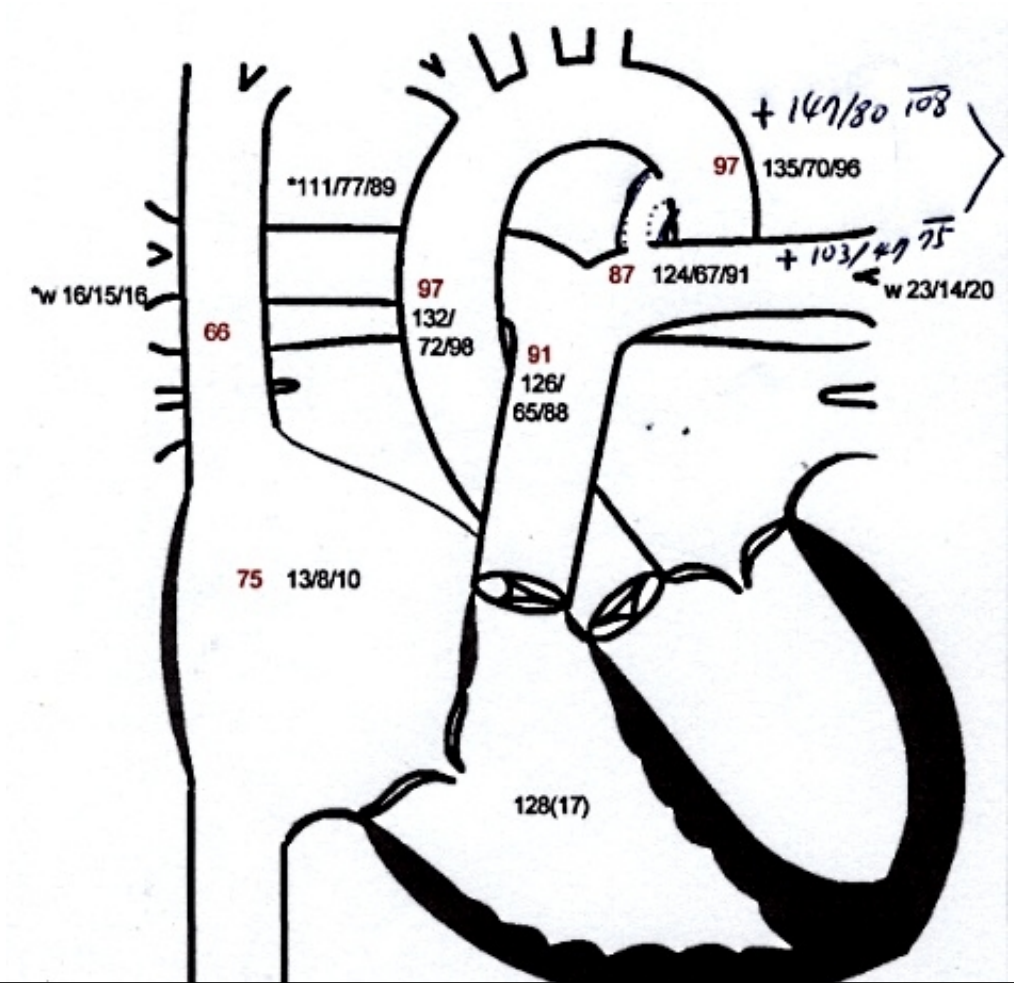

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Rp : 11.1 -> 9.9
p(RV/Ao): 0.97 -> 0.93 -> 0.7(test occlusion)

No : 201327708 Name : _ _ _ Age/Sex : 42/ Birth : 19710214

Date : 20131227 Cath No : 2013009336 Angio No : 64693

Physician : / Fluoro : 23.1 min Dye : 160 cc

Pt alertness: alert

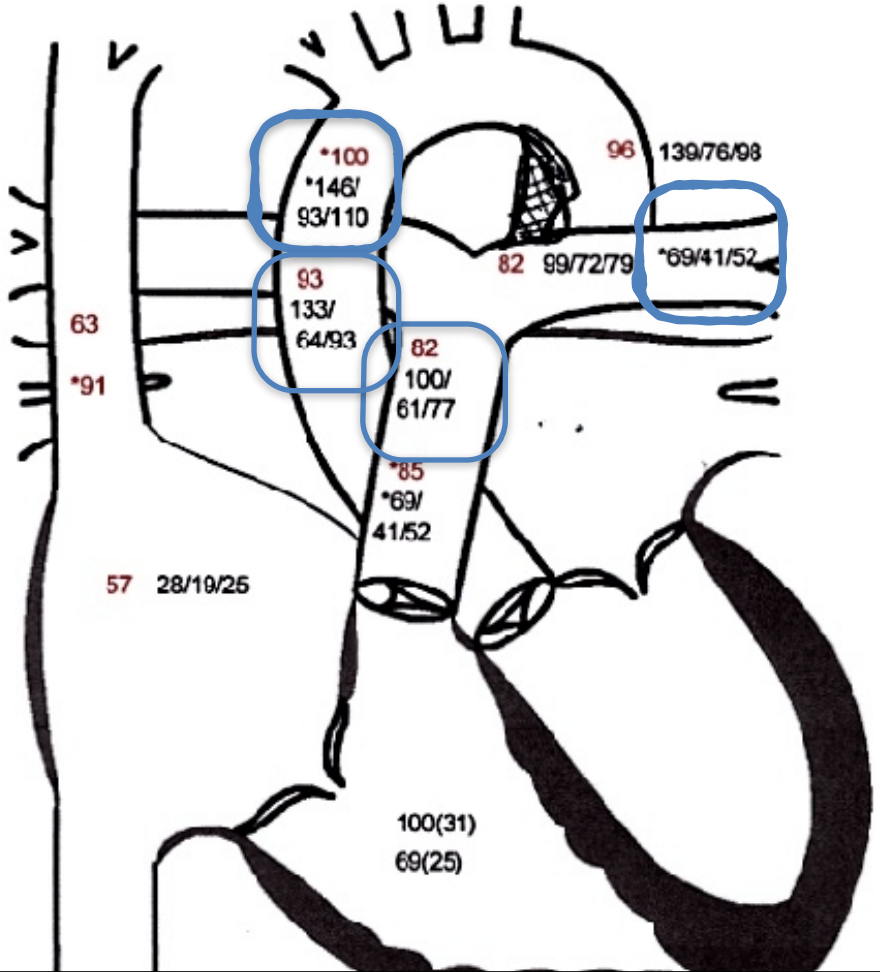
Clinical : heart failure Genetic :

Comment : Wt : 78.3 kg Ht : 162 cm BSA : 1.83

Complication : Hgb : 14.6 HR : VO2 : 150 ml/min/

ABGA : 7.418-46.4-82.2- *(Sat : 96.1%)*

*test occlusion & O2 for 10min +after TCO



Diagnosis/Intervention

2004 general edema , DOE till 2 ys old, re- DOE since 1997(26ys) recommend heart Tx since 2012 at

2013-12 echo :PDA(7.3 mm) TR G2 PG 8 0

A.fib with RVR

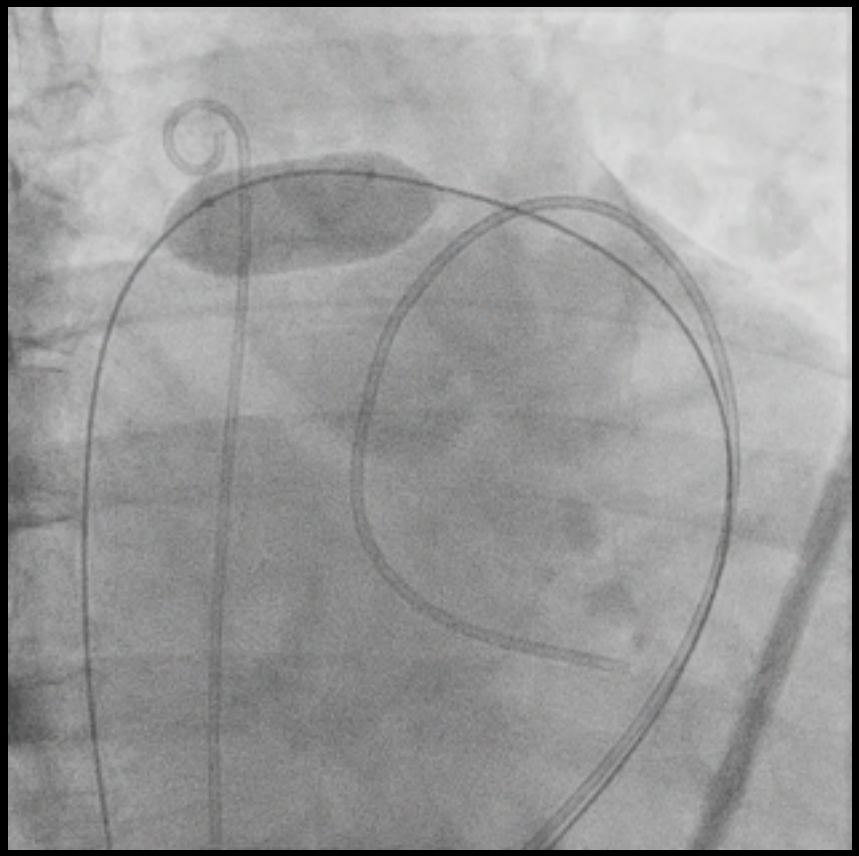
Dilated LV 71/60, LA 68, EF 30-35%, MR II, AR I,

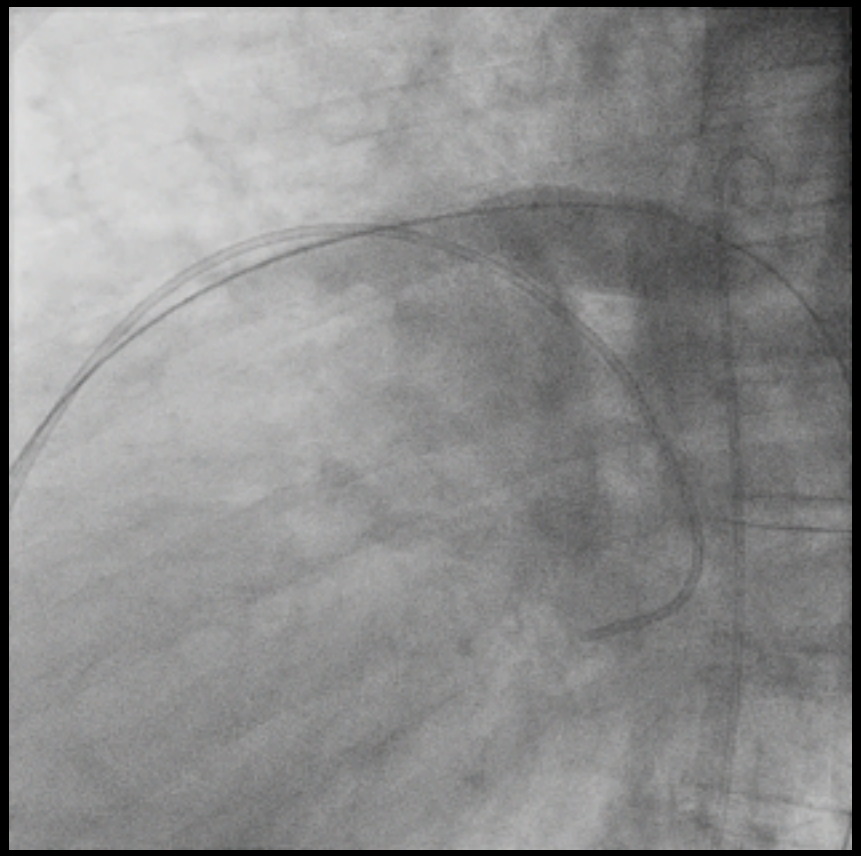
Global hypokinesia and slightly D-shaped LV

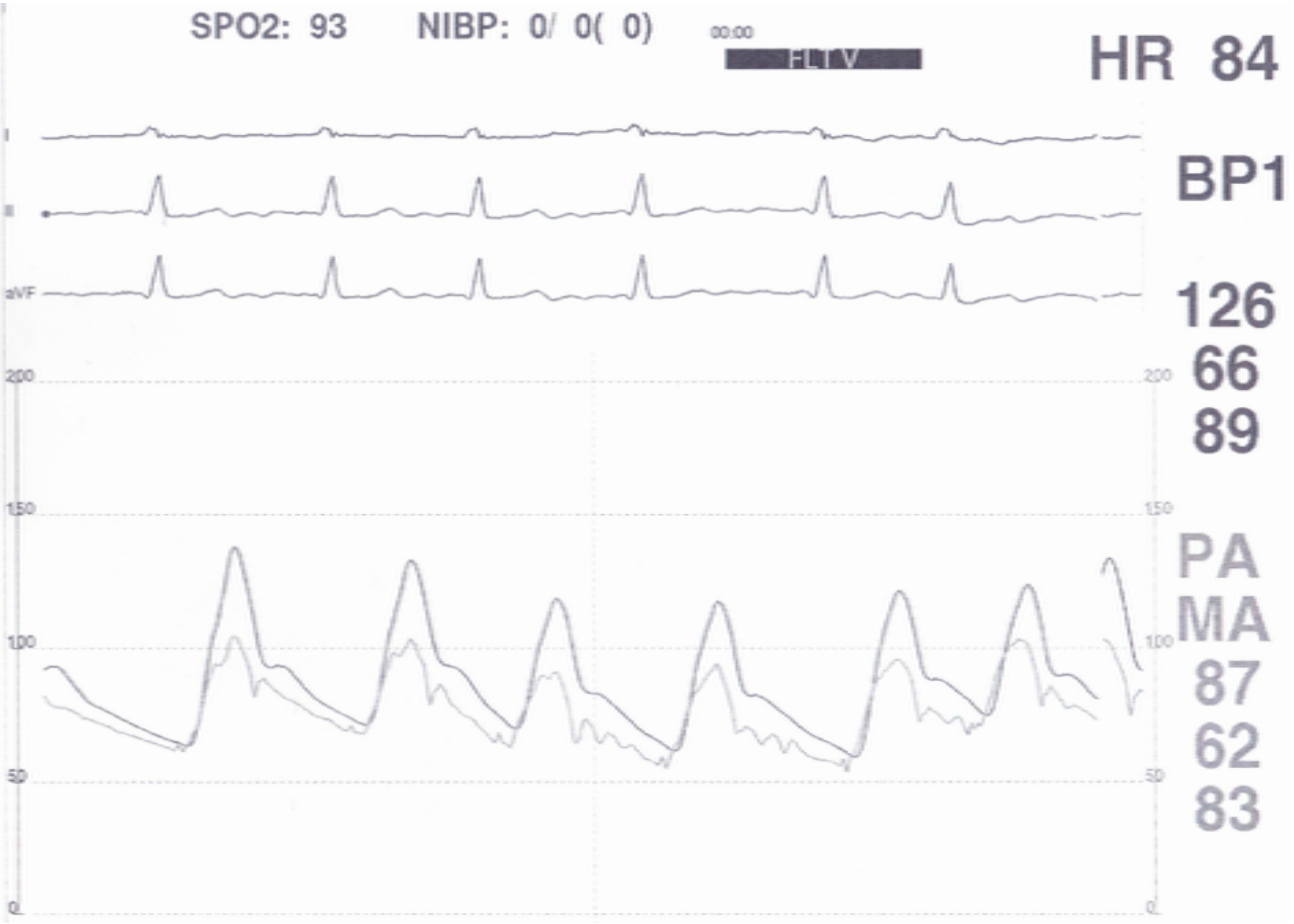
findings>
Short conical large PDA d=10mm severe PHT
Af, poorly contractile dilated LV
high CVP, EDP

Set1 : Baseline
Set2 : test occlusion & O2 for 10min with Tyshak 16mm
Set3 : after TCO
Qp/Qs: 2.8 -> 0.7 -> 1
Qp : 5.4 -> 4 -> 3.5
Qs : 2 -> 5.7 -> 3.5
Rp/Rs: 0.3 -> 0.6 -> 0.4
TPG : 54 -> 42 -> 42
Rp : 10 -> 10.5 -> 12
p(RV/Ao): 0.75 -> 0.47 -> 0.53

TCO with ,Amplatzer16*14
Trivial leak






SPO2: 93
NIBP: 0/ 0(0)
00:00
HR 84
I
II
aVF
BP1
126
66
89
200
150
100
50
0
PA
MA
87
62
83


SPO2: 99
NIBP: 0/ 0(0)
00:00
HR 81
I
II
aVF
AO
147
85
106
200
150
100
50
0
PA
LT
69
42
51

No : 201327708 Name : _ _ _ Age/Sex : 42/ Birth : 19710214

Date : 20131227 Cath No : 2013009336 Angio No : 64693

Physician : / Fluoro : 23.1 min Dye : 160 cc

Pt alertness: alert

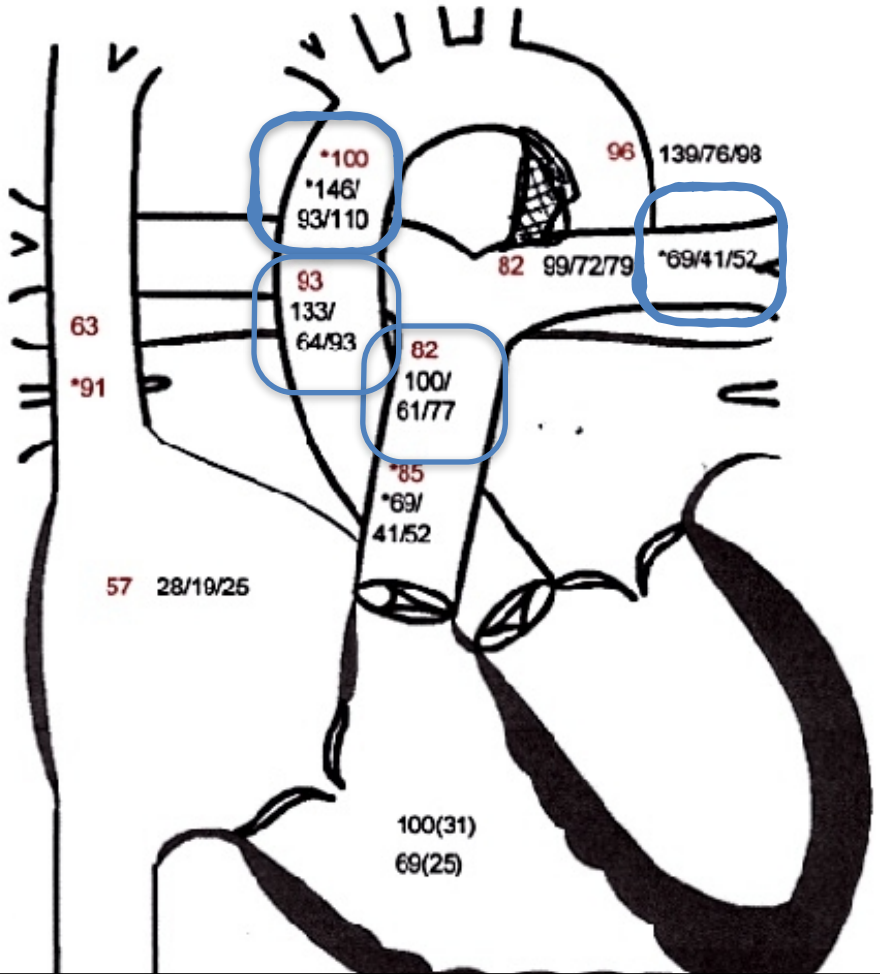
Clinical : heart failure Genetic :

Comment : Wt : 78.3 kg Ht : 162 cm BSA : 1.83

Complication : Hgb : 14.6 HR : VO2 : 150 ml/min/

ABGA : 7.418-46.4-82.2- *(Sat : 96.1%)*

*test occlusion & O2 for 10min +after TCO



Diagnosis/Intervention

2004 general edema , DOE till 2 ys old, re- DOE since 1997(26ys) recommend heart Tx since 2012 at

2013-12 echo :PDA(7.3 mm) TR G2 PG 8 0

A.fib with RVR

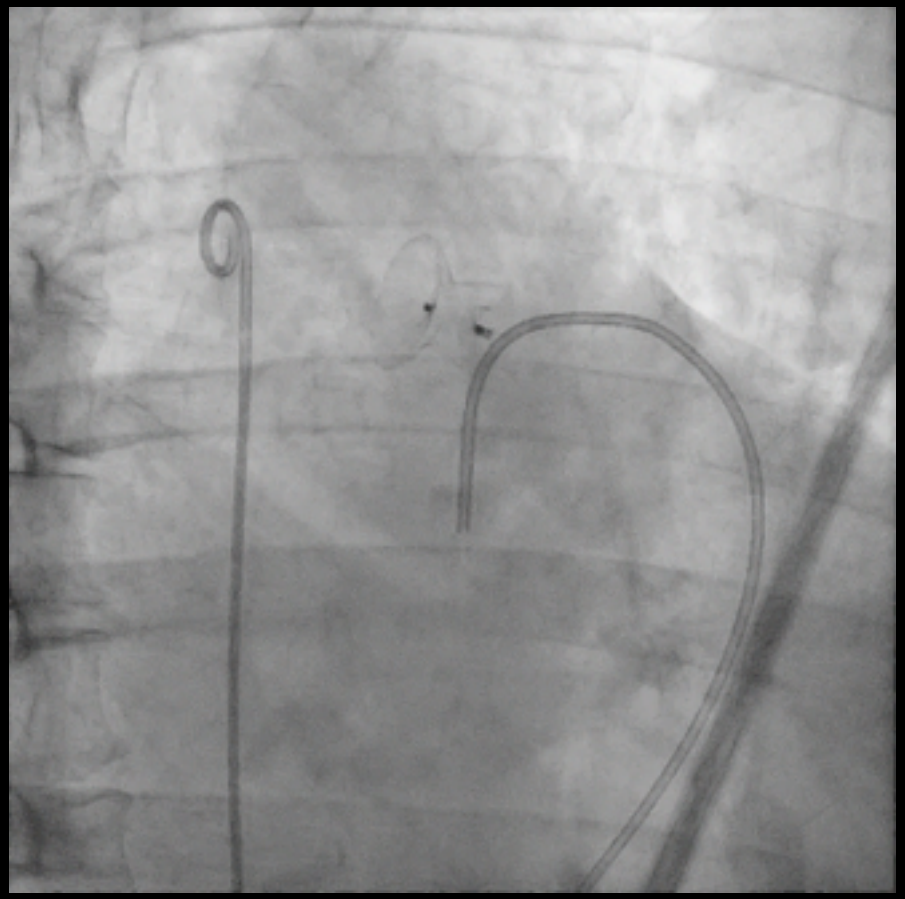
Dilated LV 71/60, LA 68, EF 30-35%, MR II, AR I,

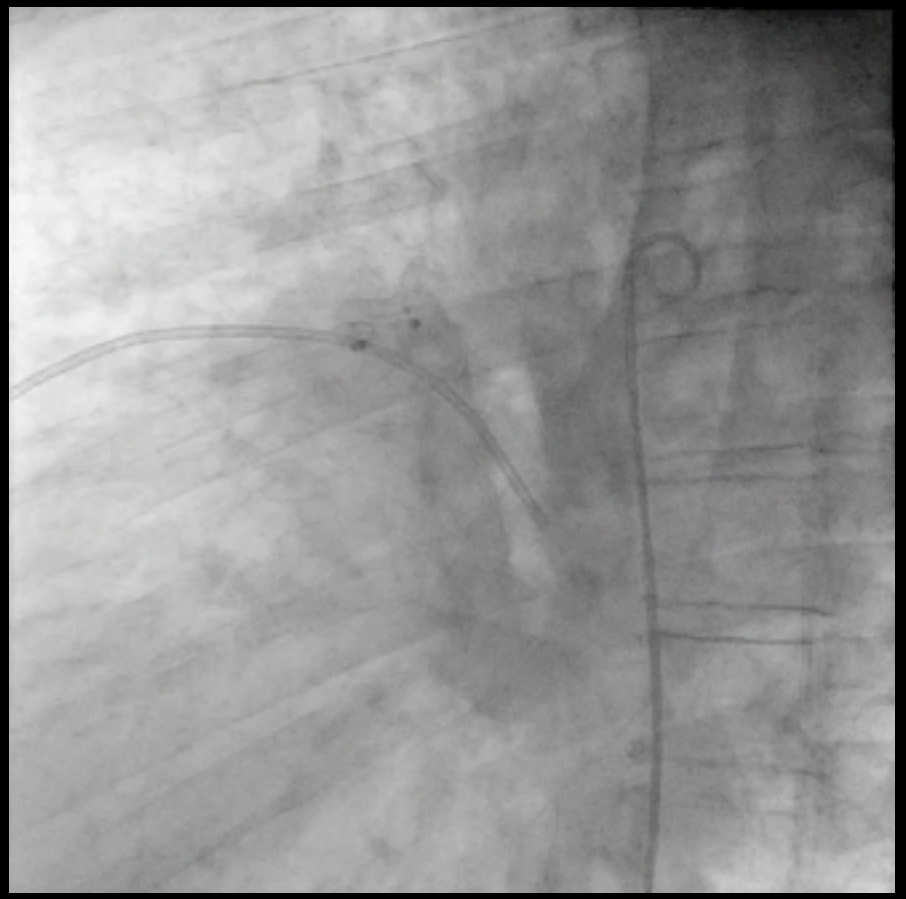
Global hypokinesia and slightly D-shaped LV

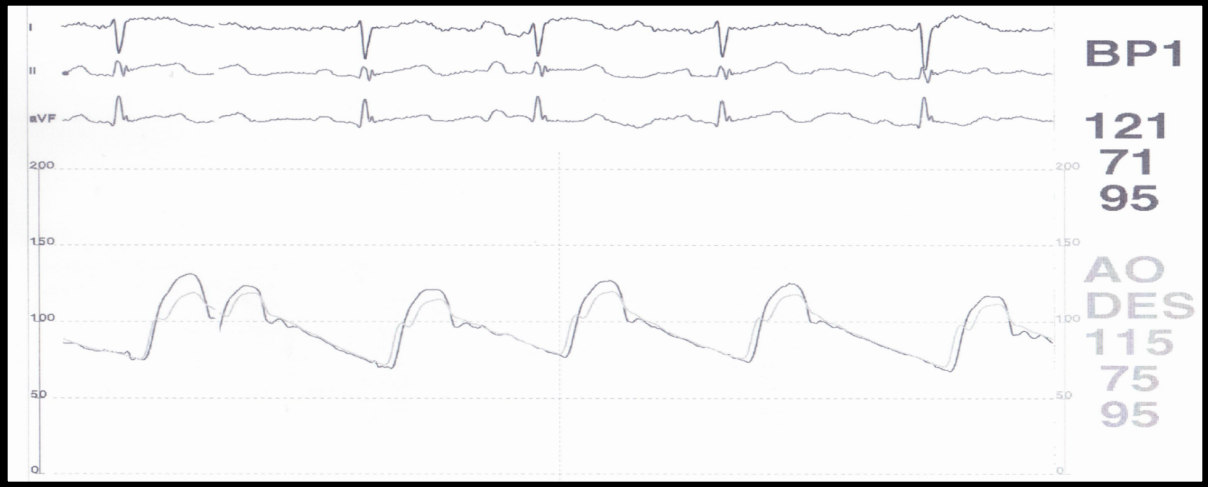
findings>
Short conical large PDA d=10mm severe PHT
Af, poorly contractile dilated LV
high CVP, EDP

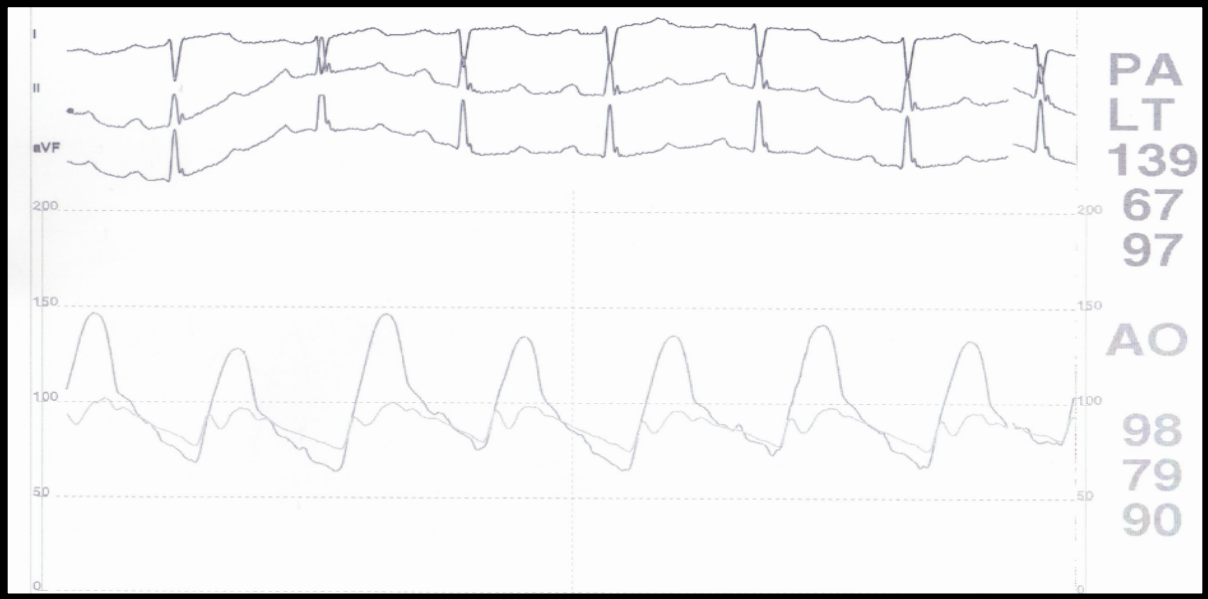
Set1 : Baseline
Set2 : test occlusion & O2 for 10min with Tyshak 16mm
Set3 : after TCO
Qp/Qs: 2.8 -> 0.7 -> 1
Qp : 5.4 -> 4 -> 3.5
Qs : 2 -> 5.7 -> 3.5
Rp/Rs: 0.3 -> 0.6 -> 0.4
TPG : 54 -> 42 -> 42
Rp : 10 -> 10.5 -> 12
p(RV/Ao): 0.75 -> 0.47 -> 0.53

TCO with ,Amplatzer16*14
Trivial leak






I
II
aVF
200
150
100
50
0
BP1
121
71
95
AO
DES
115
75
95


I
II
aVF
200
150
100
50
0
PA
LT
139
67
97
AO
98
79
90

Cardiac Catheterization Report

No : 201404556 Name : Age/Sex : 17y7m/ Birth : 19960731

Date : 20140303 Cath No : 2014001735 Angio No : 65646

Physician : / Fluoro : 11 min Dye :

Pt alertness: alert

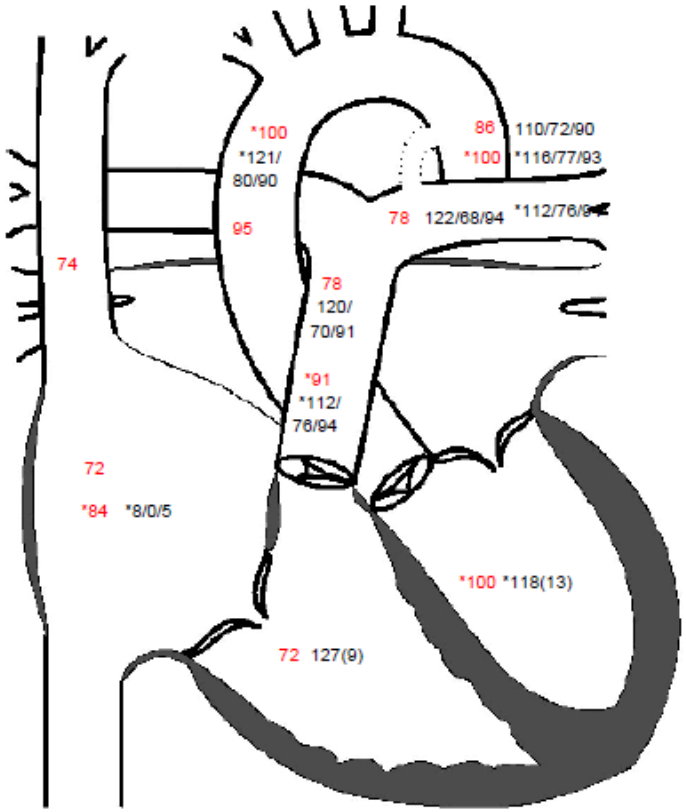
Clinical : moderate cyanosis Genetic :

Comment : Wt : 46.5 kg Ht : 150 cm BSA : 1.39

Complication : Hgb : 20.5 HR : VO2 : 140 ml/min/

ABGA : 7.397-43.6-59.3- *(Sat : 90%)*

*Oxygen +Ventavix



<Test occlusion>
LPA : 135,67,97
DA : 97,78,87

Diagnosis/Intervention

2013 - primary PHT
1 dyspnea

PDA d=10mm
severe PHT PVOD
increased PA pressure after test occlusion

Set2 : Oxygen
Set3 : Ventavix
Qp/Qs: 1.4 -> 1.7 -> 0.9
Qp : 3 -> 5.4 -> 3.9
Qs : 2.2 -> 3.1 -> 4.5
Rp/Rs: 0.7 -> 0.6 -> 1.1
TPG : 81 -> 81 -> 79
Rp : 27 -> 15 -> 20.3
p(RV/Ao): 1.09 -> 0.97 -> 0.92->1.39(TO)

Conclusions

- Sources of error should be excluded in measuring hemodynamic data
- Preoperative assessment of pts with CHD and PAH provides important information about the operability.
- Vascular reactivity to inhaled NO or iloprost correlates with survival and response to long term treatment of vasodilators in pts with PAH.
- Test occlusion of shunt may be beneficial for deciding operability


Thank You!

Staged repair : SMC experience

- F/38
- NYHA Fc III
- Spo2 90% (rest), 87% (exercise), 96%(with O_2)
- EchoCG
  1) Huge PMC-SA VSD (size 32mm) with bidirectional shunt
  2) Gr I MR, Gr I TR, Gr I-II PR
  3) Markedly dilated PA (size 60mm), LA & LV (LVDd=77.3mm)

Staged repair : SMC experience

- Cath

	Baseline	O2	NO
PAP	***117/46(96)***	***101/33(65)***	***112/39(68)***
A Ao	***118/92(88)***	***117/68(88)***	***118/84(86)***
Rp	***6.8***	***2.3***	***4.0***
Qp/Qs	***2.5***	***5.7***	***3.1***
Rp/Rs	***0.31***	***0.11***	***0.22***
PaO2	***61***	***280***	***65mHg***

- PAB
  - SpO2 92% at FiO2 0.23
  - Systemic BP 110mmHg, PAP 62mmHg
  - Intraoperative TEE

    PA banding state: diameter 25mm

    Bidirectional shunt (mainly L->R) through large VSD

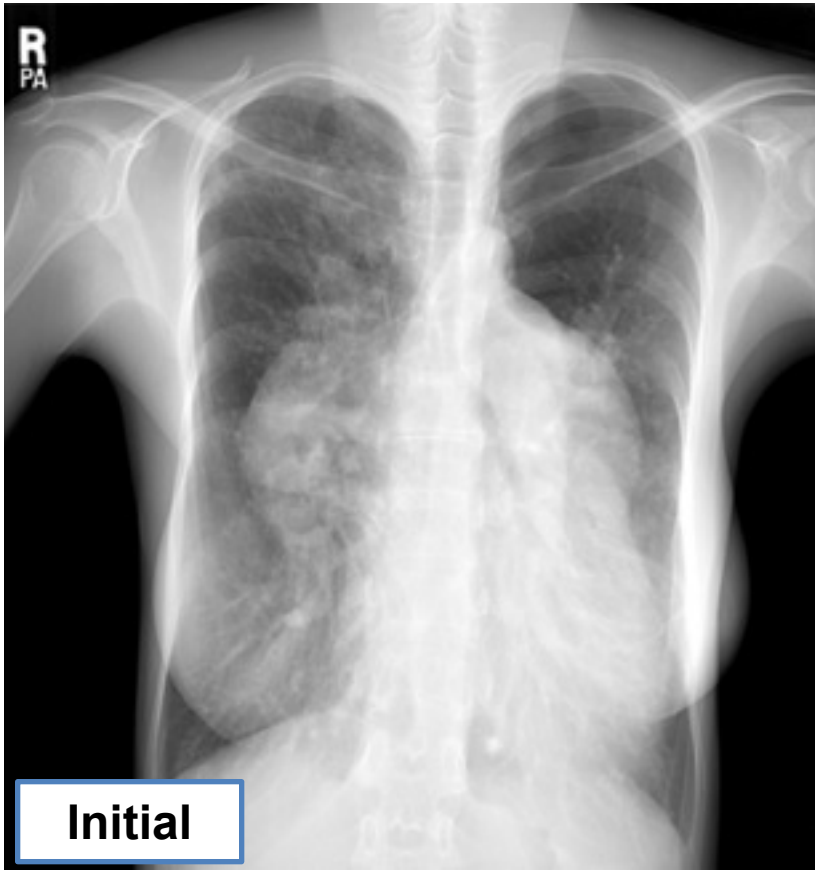
Staged repair : SMC experience

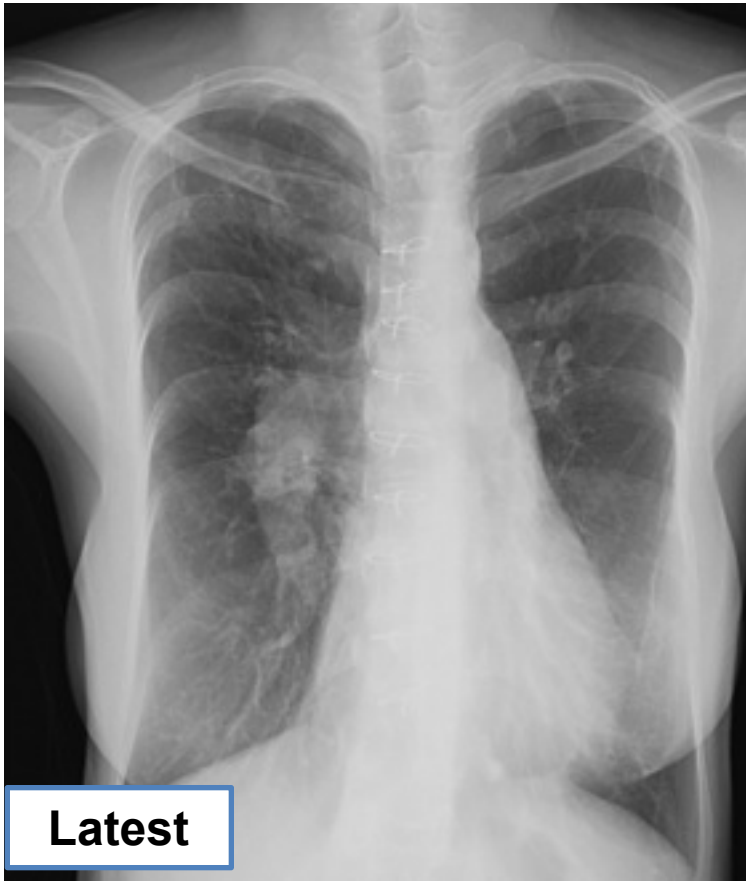
- Cath (8Mo after PAB)

	Baseline	O2	NO
PAP	***98/31(57)***	***83/24(48)***	***84/21(49)***
A Ao	***96/58(75)***	***93/57(73)***	***102/60(78)***
Rp	***7.33***	***2.2***	***5.9***
Qp/Qs	***2.6***	***5.4***	***2.23***
Rp/Rs	***0.25***	***0.10***	***0.24***
PaO2	***64***	***225***	***67mmHg***

Staged repair : SMC experience

- Op.
  - VSD closure, ASD creation (6mm)
  - PA debanding, TR repair
- Immediate postop. data
  - Spo2 94~100%
  - BP: 105/43mmHg, sPAP 33mmHg
- 4 yrs after op.
  - NYHA Fc II, SpO2 94%
  - Medication : Enalapril, diuretics, Aspirin
  - EchoCG
    1) Small residual VSD (size 3mm) (L->R, PGmax 86mmHg)
    2) Neo-ASD (size 5~6mm) (bidirectional shunt)
    3) G1 TR (PG 20mmHg), G1 MR
    4) hyperkinetic IAS motion: rather paradoxical, RL during systole





Cath data	Pre-PAB	After PAB	After VSD closure
Pr Ao/PA	*117/118 → 117/101*	*96/98 → 93/83*	*138/44*
mean PAP	96 → 65 mmHg	57 → 48 mmHg	44 mmHg
Rp	*6.8 → 2.3*	*7.33 → 2.2*	*5.49*
Qp/Qs	2.5 → 5.7	2.6 → 5.4	1.75
Rp/Rs	*0.31 → 0.11*	*0.25 → 0.10*	*0.15*

Cardiac output

- **direct Fick technique**
  - not available MRM II for measuring VO2
- **indirect Fick technique**
  - VO2 obtained from tables, unreliable
- **thermodilution**
  - method of choice, but unreliable in shunt lesion