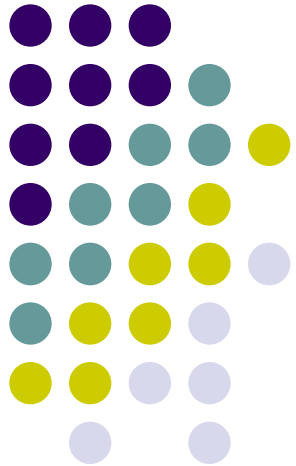
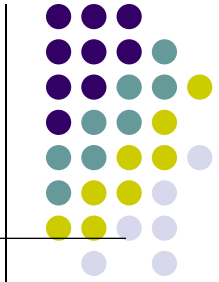
Percutaneous Circulatory Support

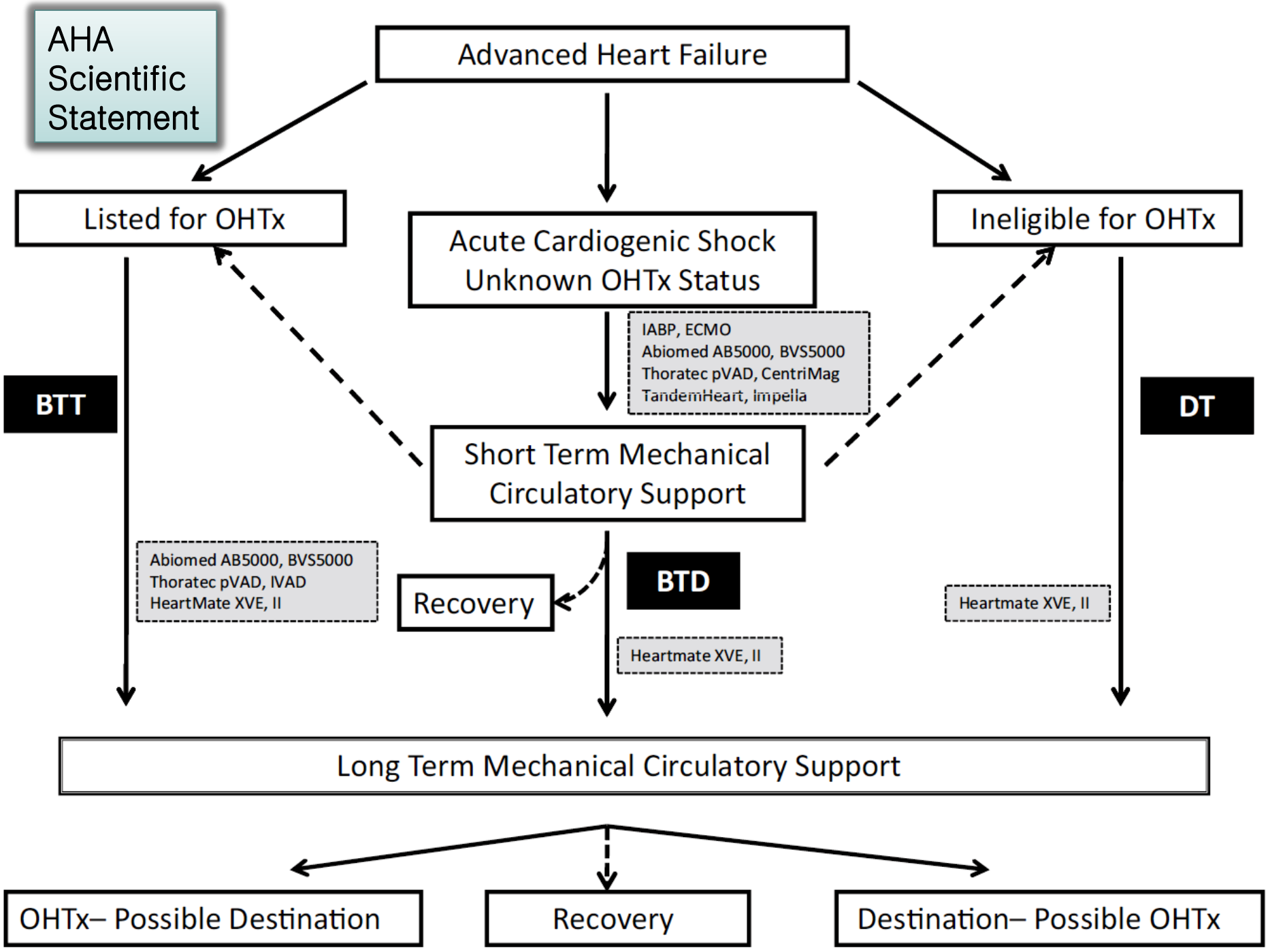
경북대학교병원 순환기내과
양 동 헌



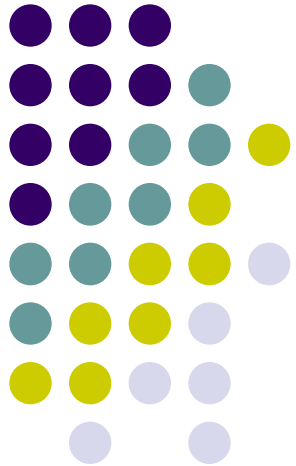
Mechanical cardiac support



- Intra-aortic balloon pump (IABP)
- Extracorporeal membrane oxygenation (ECMO)
- Ventricular assist devices
  - LVAD / RVAD / BiVAD
- Total heart


AHA Scientific Statement
Advanced Heart Failure
Listed for OHTx
Acute Cardiogenic Shock Unknown OHTx Status
Ineligible for OHTx
IABP, ECMO
Abiomed AB5000, BVS5000
Thoratec pVAD, CentriMag
TandemHeart, Impella
BTT
DT
Short Term Mechanical Circulatory Support
Abiomed AB5000, BVS5000
Thoratec pVAD, IVAD
HeartMate XVE, II
Recovery
BTD
Heartmate XVE, II
Heartmate XVE, II
Long Term Mechanical Circulatory Support
OHTx– Possible Destination
Recovery
Destination– Possible OHTx

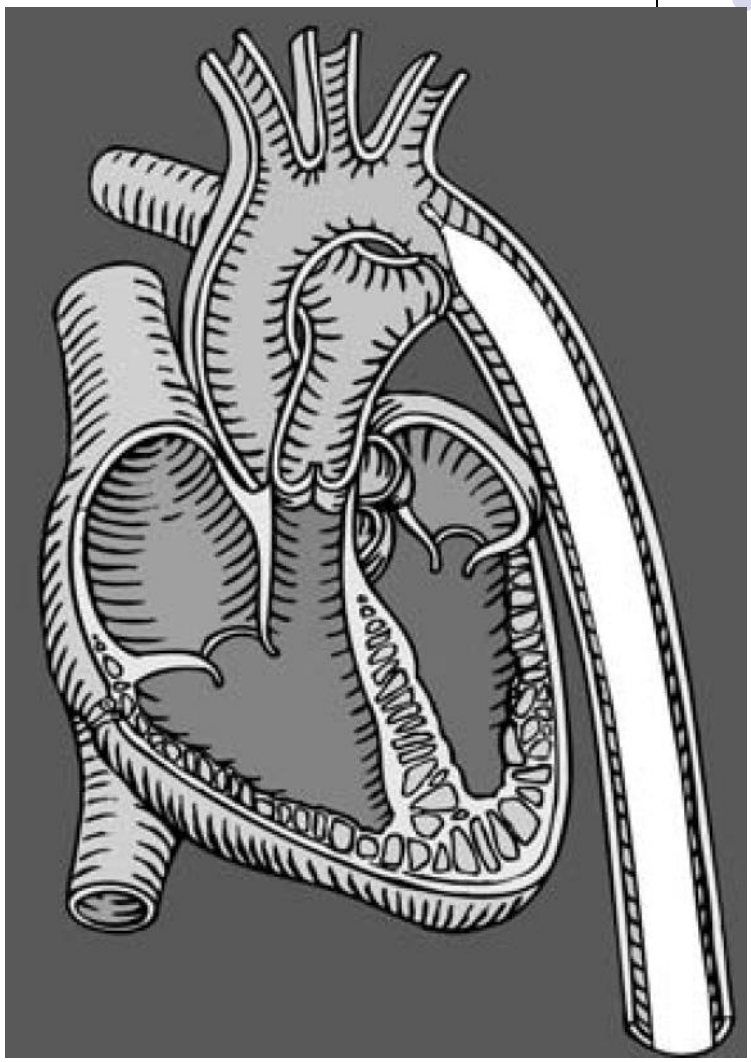
IABP



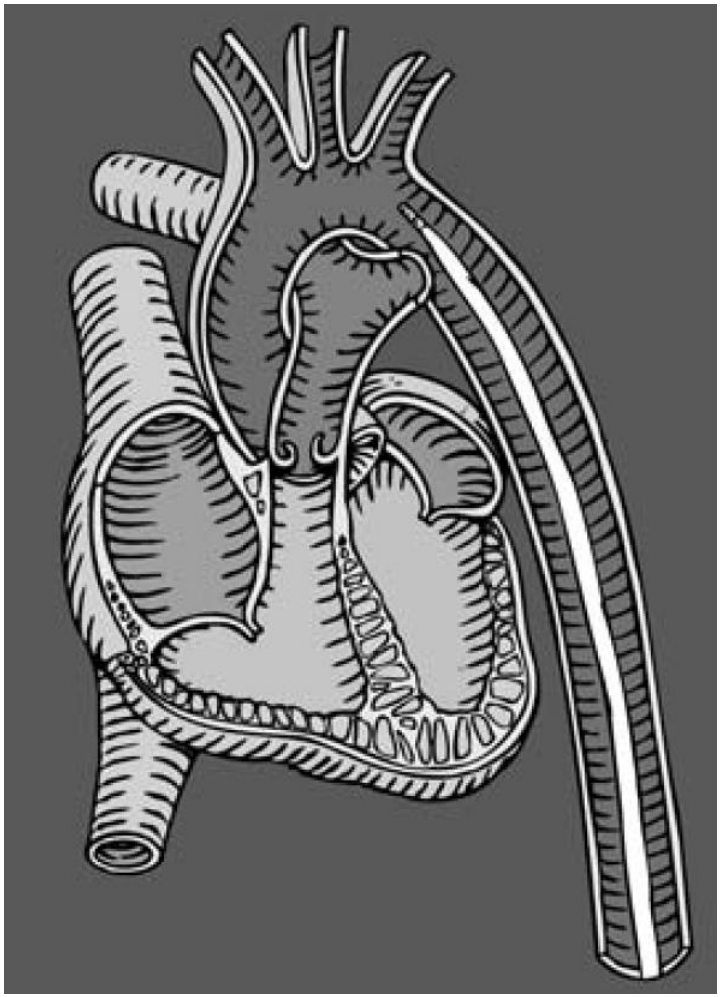
IABP

Diastole

- ↑ diastolic pressure
- ↑ coronary blood flow
- ↑ coronary collateral circulation
- ↑ systemic perfusion
  - Urine output
  - Cerebral perfusion



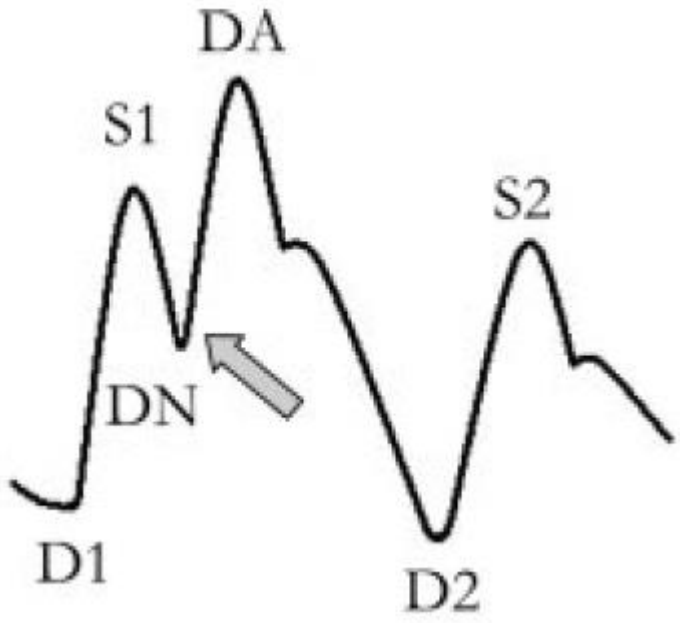
IABP



Systole

- ↓afterload
- ↓ myocardial oxygen demand
- ↑stroke volume
- ↓Lt to Rt shunt

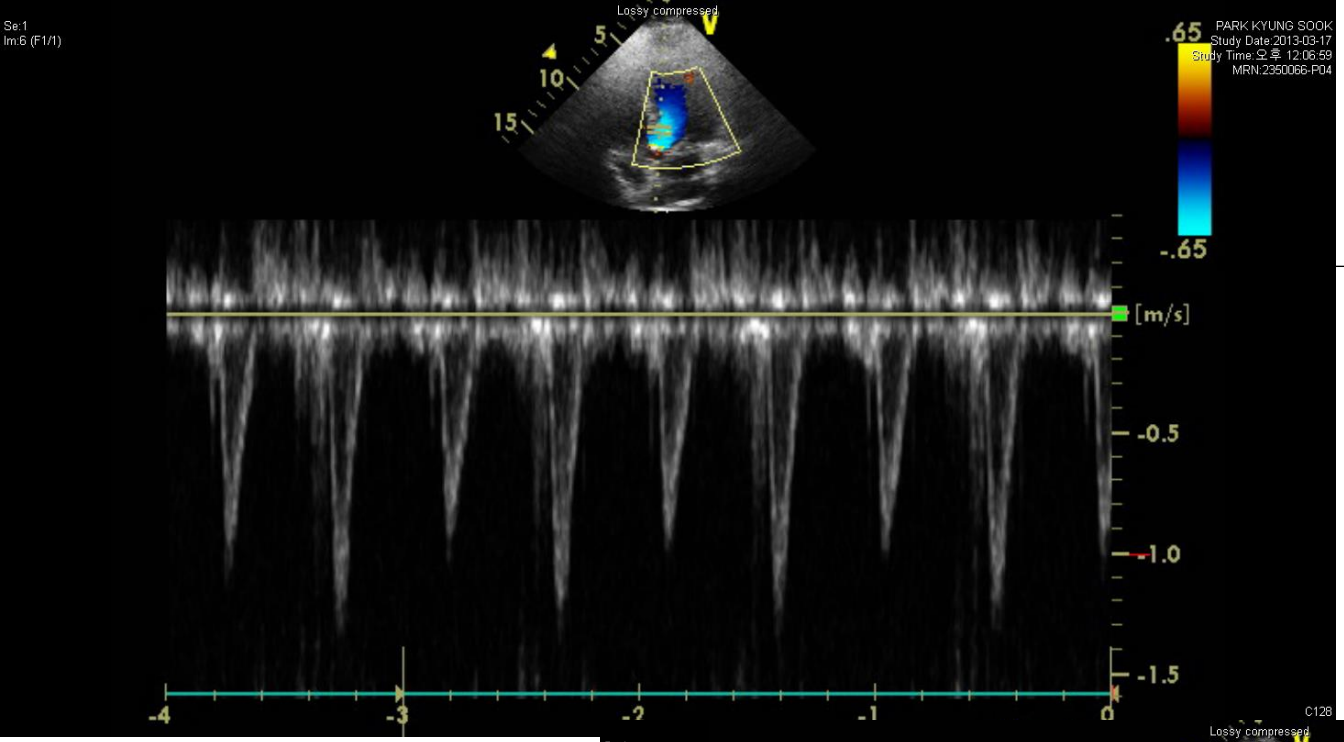
Typical hemodynamic effects

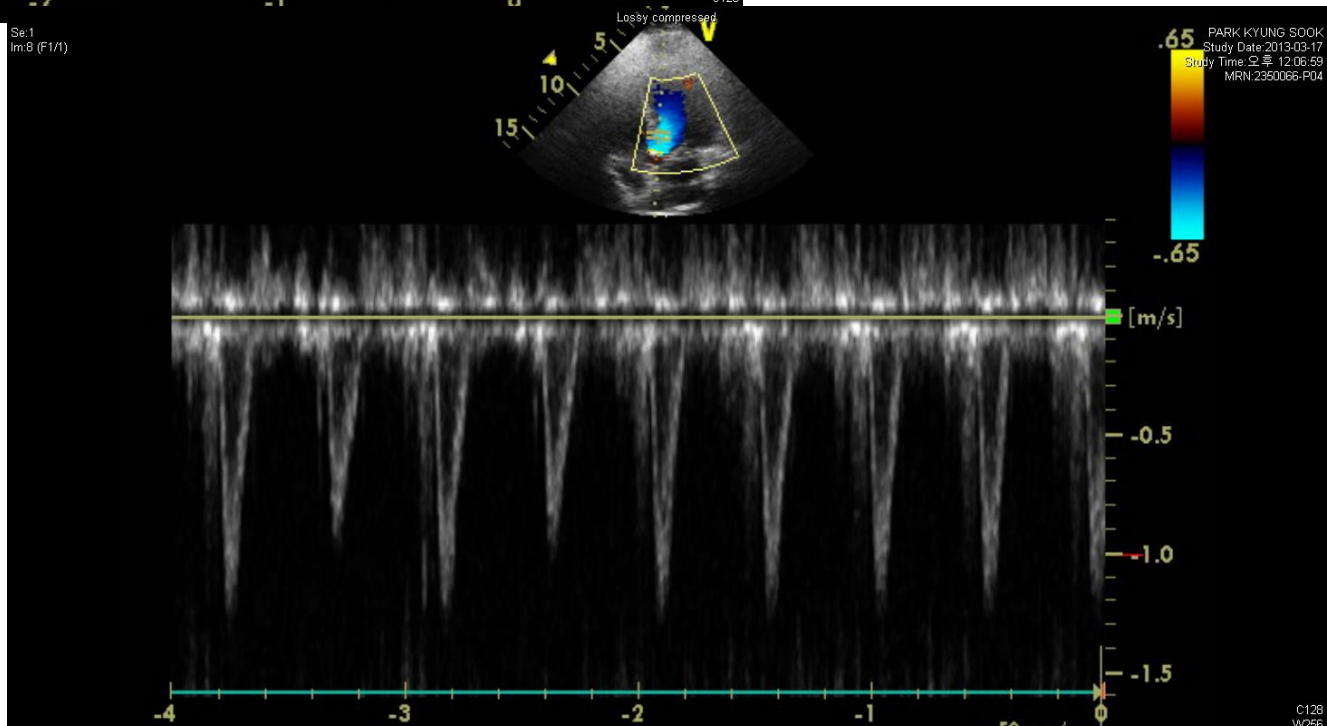


	Unassisted	Assisted
SBP (mmHg)	101	96
DBP (mmHg)	53	45
Diastolic augmentation (mmHg)		114
Mean BP (mmHg)	64	81

CO ↑ by 30%

Reduced myocardial O2 demand ↓ by 50%


Se:1
Im:6 (F1/1)
Lossy compressed
PARK KYUNG SOOK
Study Date:2013-03-17
Study Time:오후 12:06:59
MRN:2350066-P04
.65
-.65
[m/s]
-0.5
-1.0
-1.5
-4
-3
-2
-1
0
C128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Im:8 (F1/1)
Lossy compressed
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Study Date:2013-03-17
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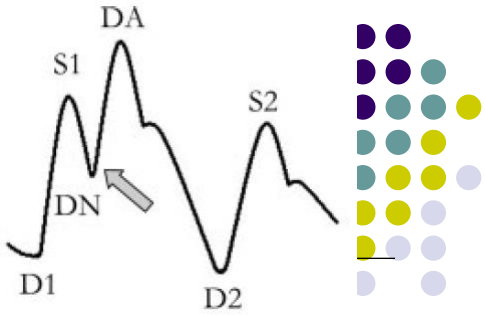
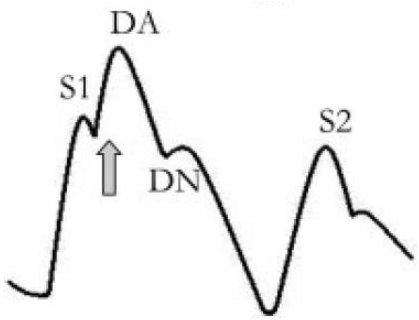
MRN:2350066-P04
.65
-.65
[m/s]
-0.5
-1.0
-1.5
-4
-3
-2
-1
0
C128

Timing of the IABP



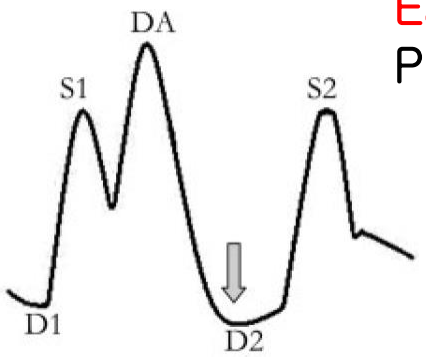


Early inflation

Premature AV closure

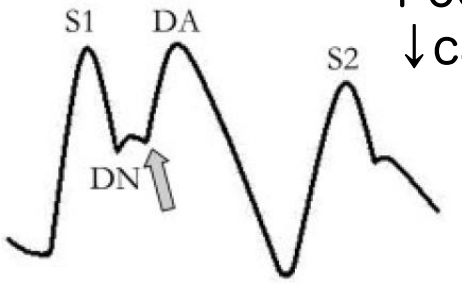
↓cardiac output

↑preload



Early deflation

Poor afterload reduction

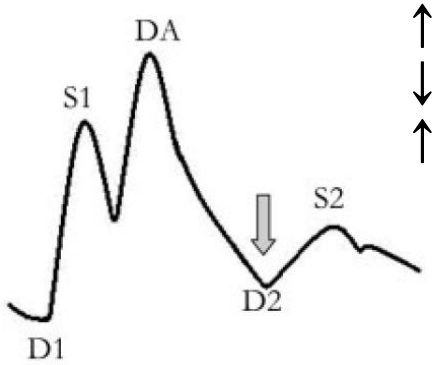


Late inflation

↓diastolic augmentation

Poor afterload reduction

↓cardiac output



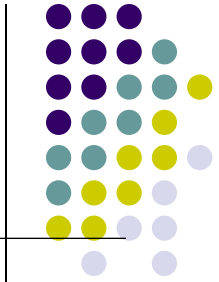
Late deflation

↑afterload

↓cardiac output

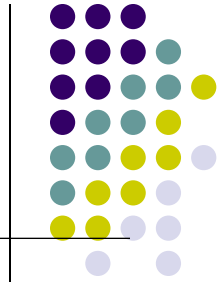
↑oxygen demand

Indications for IABP



- Medical indications
  - Cardiogenic shock that is not quickly reversed with pharmacologic therapy
  - Mechanical Cx. of AMI
    - Acute mitral regurgitation
    - ventricular septal rupture
  - Recurrent ischemic chest discomfort with signs of hemodynamic instability, poor left ventricular function, or a large area of myocardium at risk
  - High risk interventional precedures
  - Bridging device to other mechanical assist (VAD)
- Surgical indications
  - Post-surgical myocardial dysfunction
  - Support for weaning from CPB
  - Pulsatile flow during CPB
  - Maintenance of graft patency after CABG

Contraindications



- Absolute
  - Aortic regurgitation (severe)
  - Dissecting aortic aneurysm
- Relative
  - Severe atherosclerosis
  - Abdominal aortic aneurysm
  - Blood dyscrasia (thrombocytopenia)
  - End-stage cardiomyopathies unless bridging to VAD
  - End-stage terminal disease

Complications

- Aortic wall injury
  - Dissection
  - Repture
  - Local vascular injury
- Emboli
  - Thrombus
  - Plaque
  - Air
- IAB rupture
  - Helium embolism
  - Catheter entrapment
- Infection
- Malposition
  - Obstruction of Lt subclavian, carotid artery
  - Obstruction of renal & mesenteric artery
- Compromised circulation d/t catheter
  - Ischemia
  - Compartment syndrome
- Hematologic
  - Bleeding
  - thrombocytopenia

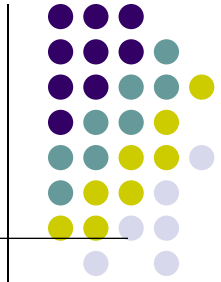
- High risk group
  - PVD
  - Female
  - Diabetes
  - HTN
  - Smoking
  - Obesity
  - Shock

Major complications

- 7~15%
  - Bleeding / Ischemia
- IABP-related mortality : 0.05~0.5%

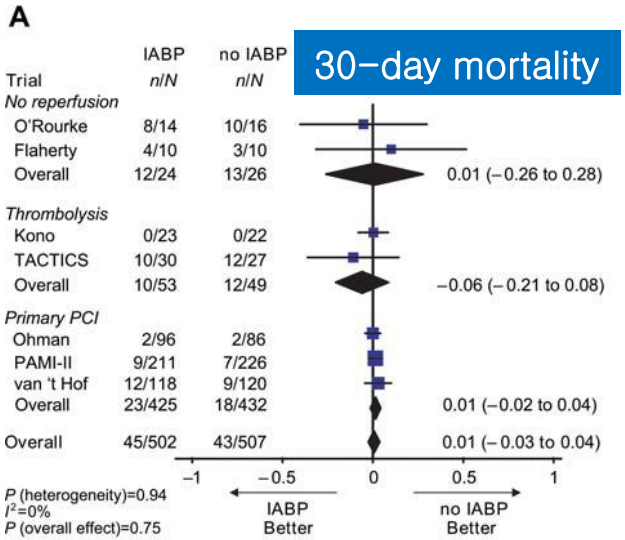
Investigators	Years	*n*	Complications (%)							
			Overall	Any bleeding	Severe bleeding	Any ischemia	Severe ischemia	Infection	IABP death	IABP failure
Arceo et al. [6]	1989–1996	212	10.4	2.4	0.9	5.6	2.8	0.5	0.5	1.4
Cohen et al. [7]	1993–1997	1,119	15	4.6	–	3.3	–	–	0.4	2.8
Cohen et al. [8]	1997–2000	9,332	7.1	3.1	0.9	2.6	0.7	–	0.1	2.0
Ferguson et al. [9]	1996–2000	16,909	7.0	2.4	0.8	2.9	0.9	–	0.05	2.3
Stone et al. [10]	1996–2001	5,495	8.1	4.3	1.4	2.3	0.5	0.1	0.05	2.3
Urban et al. [11]	1997–2002	23,281	7.2	–	0.9	–	0.9	–	<0.1	1.2

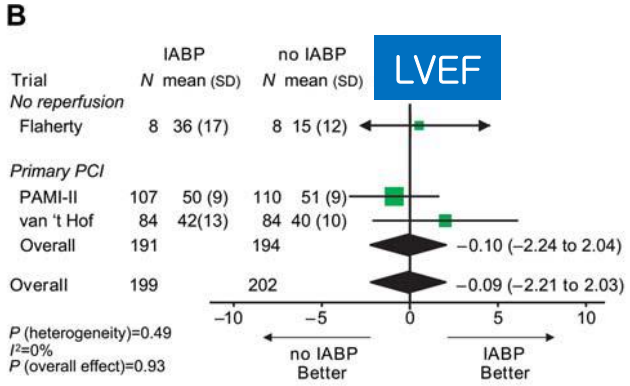
Limitations

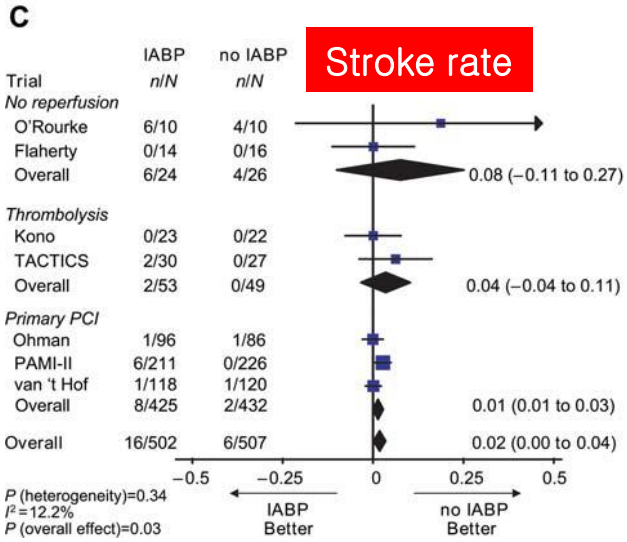


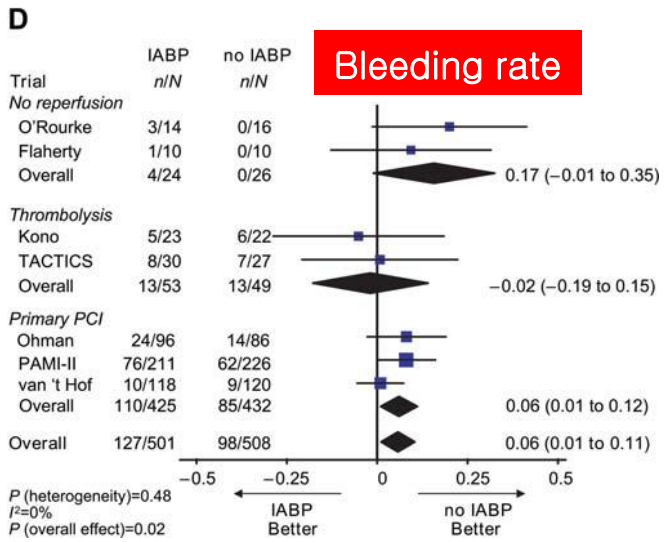
- Atrial fibrillation
- Tachycardia
- Ventricular arrhythmia

A systematic review and meta-analysis of IABP therapy in STEMI

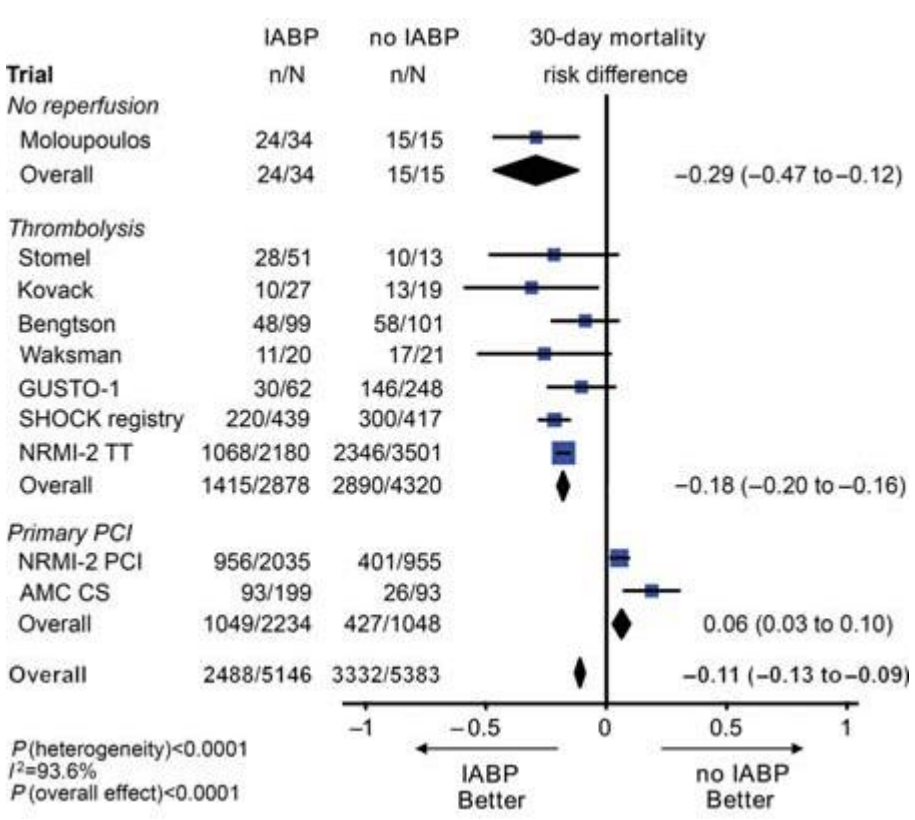


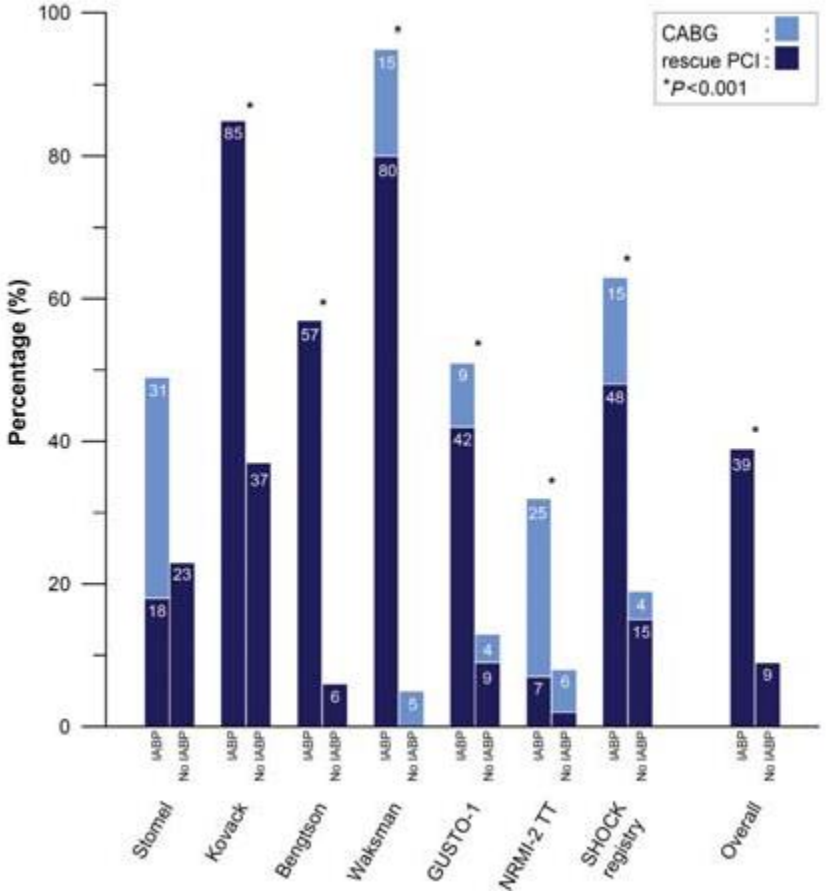




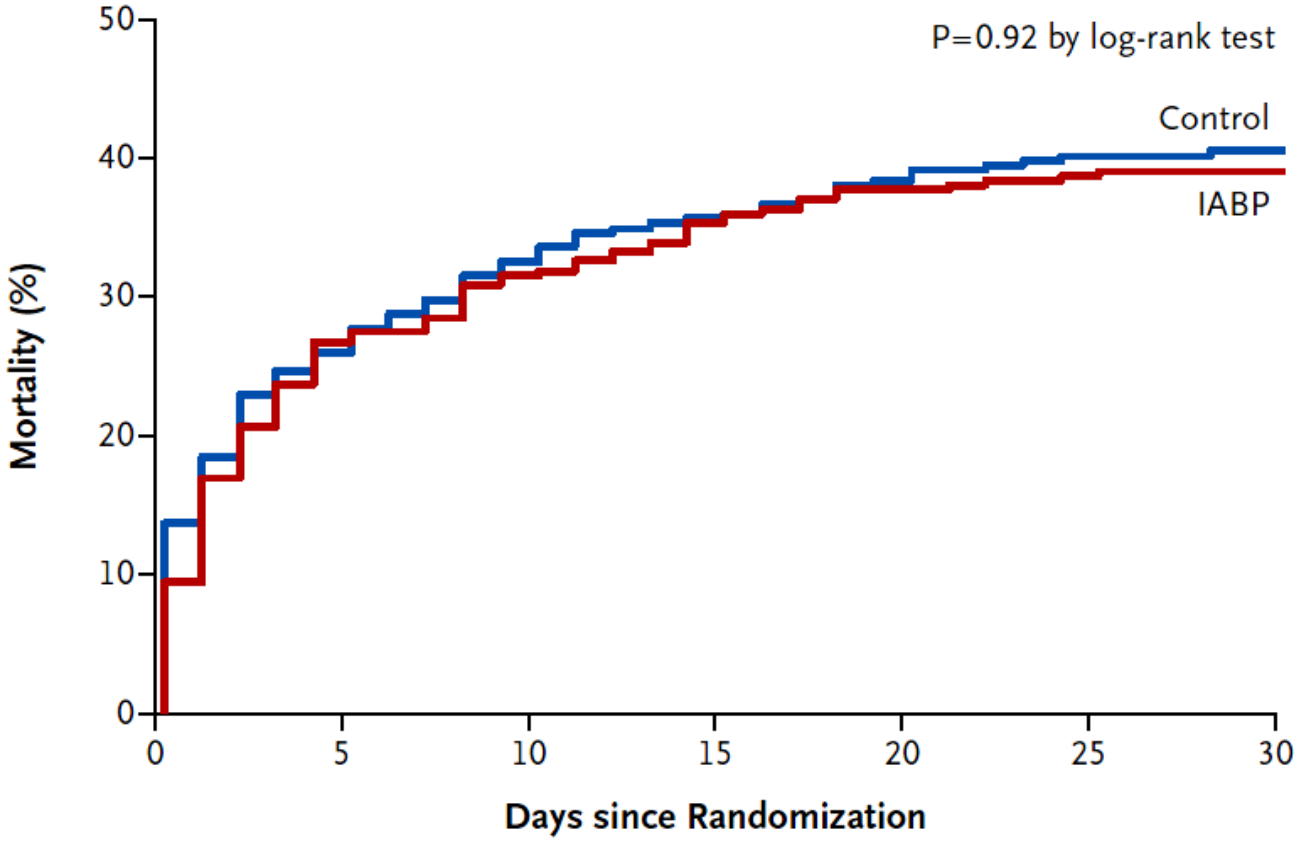


A systematic review and meta-analysis of IABP therapy in STEMI with cardiogenic shock

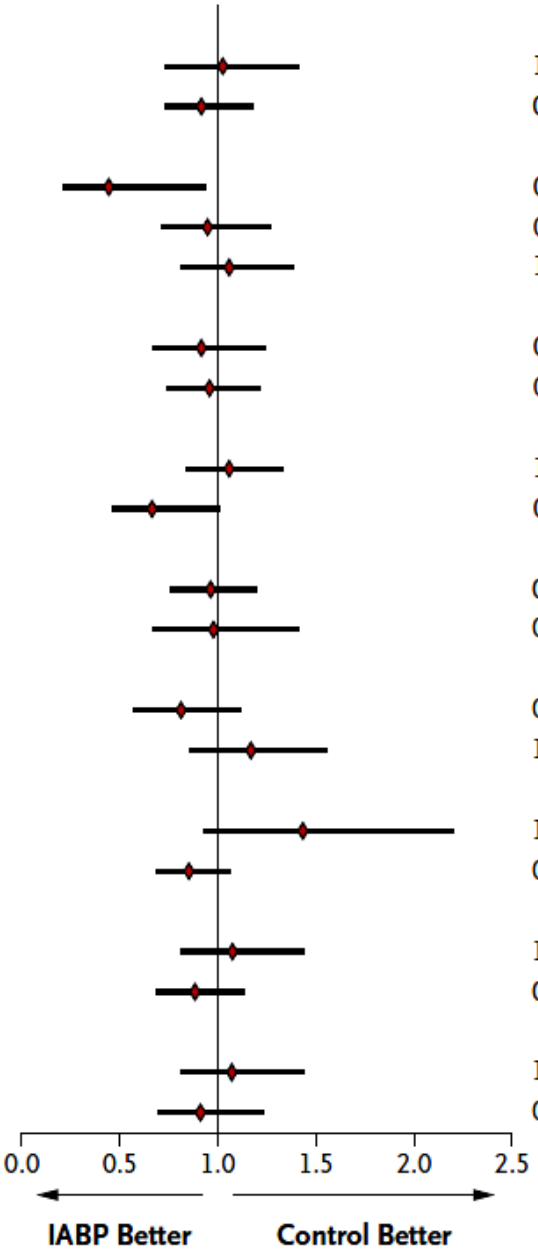




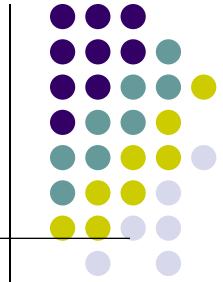
IABP-SHOCK II Trial



Baseline Variable	No. of Patients	IABP	Control	Relative Risk (95% CI)	P Value for Interaction
		30-day mortality (%)			
Sex					0.61
Female	187	44.4	43.2	1.03 (0.74–1.43)	
Male	411	37.3	40.5	0.92 (0.72–1.18)	
Age					0.09
<50 yr	70	19.4	44.1	0.44 (0.21–0.95)	
50–75 yr	334	34.6	36.5	0.95 (0.71–1.27)	
>75 yr	194	53.7	50.0	1.07 (0.81–1.41)	
Diabetes					0.82
Yes	195	42.9	46.7	0.92 (0.67–1.26)	
No	399	37.2	38.9	0.96 (0.74–1.23)	
Hypertension					0.05
Yes	410	42.9	40.4	1.06 (0.84–1.34)	
No	183	28.9	43.0	0.67 (0.45–1.01)	
Type of MI					0.76
STEMI/LBBB	412	41.0	42.9	0.96 (0.77–1.21)	
Non-STEMI	177	37.5	38.3	0.98 (0.67–1.43)	
STEMI type					0.14
Anterior	216	35.4	43.7	0.81 (0.58–1.13)	
Nonanterior	196	48.3	42.2	1.16 (0.85–1.57)	
Previous infarction					0.04
Yes	131	47.9	33.3	1.44 (0.93–2.21)	
No	466	37.3	43.3	0.86 (0.69–1.07)	
Hypothermia					0.31
Yes	226	48.1	44.2	1.09 (0.82–1.44)	
No	372	35.1	39.3	0.89 (0.68–1.16)	
Blood pressure					0.76
<80 mm Hg	161	50.7	46.4	1.09 (0.79–1.50)	
≥80 mm Hg	432	35.9	39.2	0.92 (0.72–1.17)	



Criticism



- Open-label
- Crossover
  - 30 case, 5 centers
- VAD
- Slightly lower mortality
  - 40% vs 42-48%
  - Use of catecholamines : 89.8%

Benefits of IABP

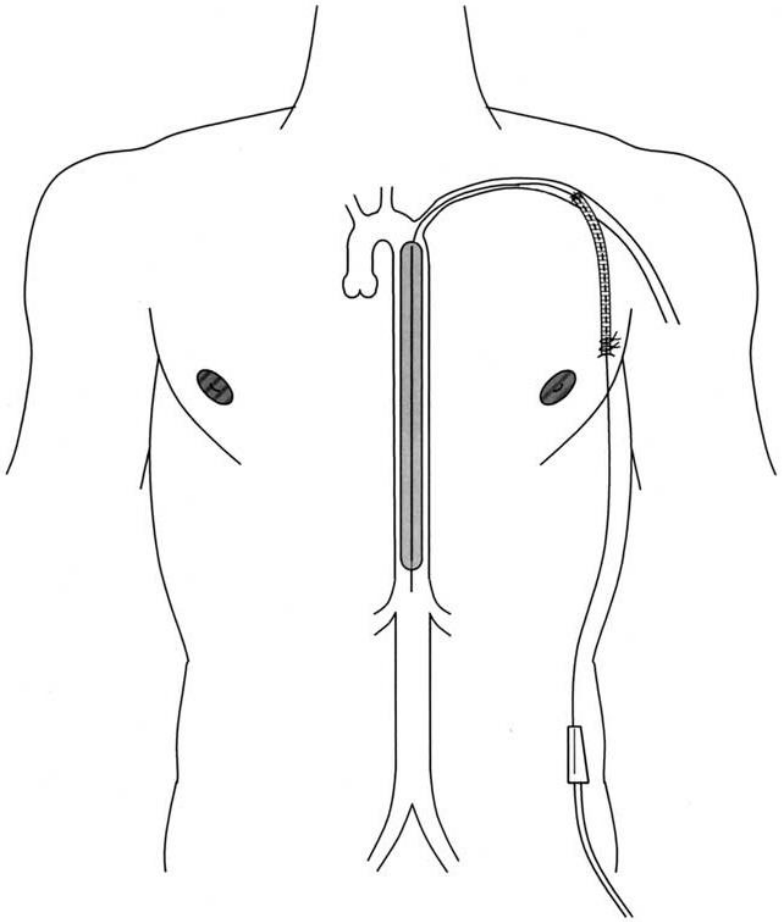
- Relatively low cost
- Easy and immediate application
- Beneficial hemodynamics
- Low complication rate

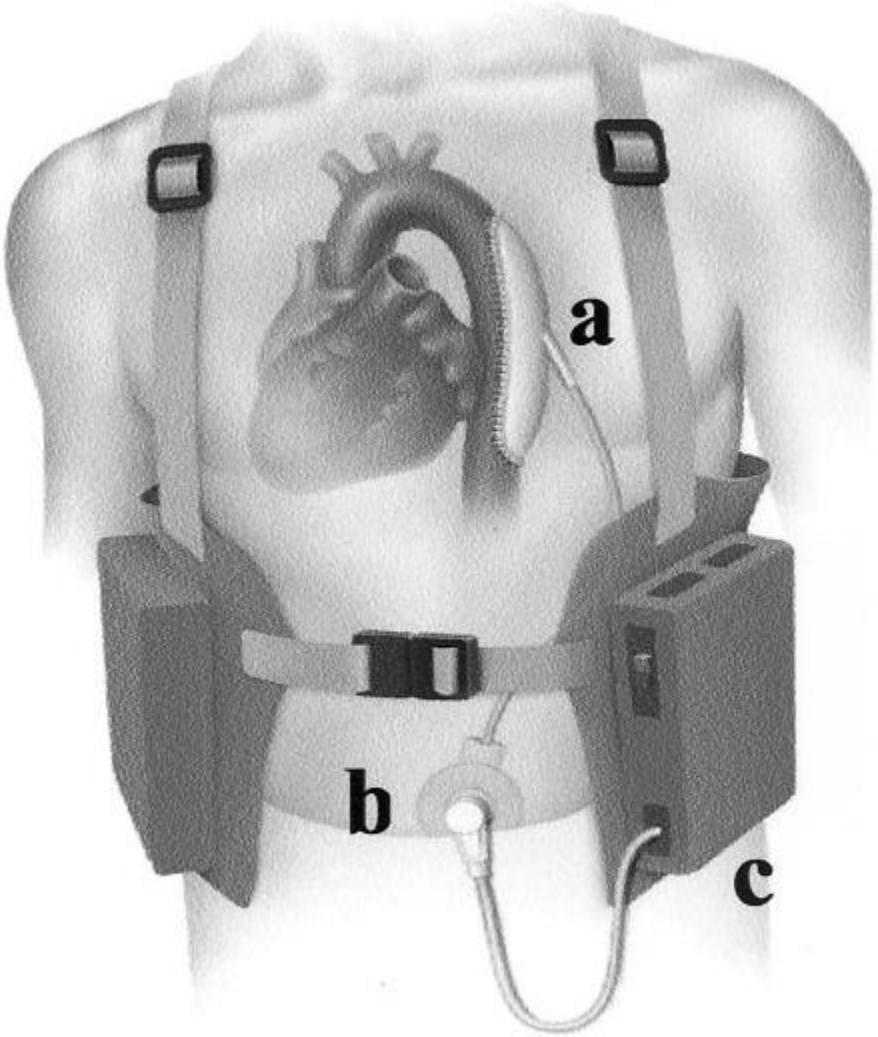
Table 2. Comparison of Ambulatory Intraaortic Balloon Pump Cost to "Standard" Ventricular Assist Device Costs

Variables	Patient 1	Patient 2	Patient 3	Patient 4
Number of days on device	46	70	12	19
Number of AIABP replacements	0	4	0	1
Trial IABP cost	$960	$960	$960	$960
AIABP initial cost	$960	$960	$960	$960
AIABP replacement cost	$0	$3,840	$0	$960
Total AIABP cost	**$1,920**	**$5,760**	**$1,920**	**$2,880**
Heartmate cost	$70,150	$70,150	$70,150	$70,150
Heartmate console rental ($284/day)	$13,064	$19,880	$3,408	$5,396
Total Heartmate cost	**$83,214**	**$90,030**	**$73,558**	**$75,546**
Heartmate VE cost	$95,100	$95,100	$95,100	$95,100
Heartmate VE rental (none)	$0	$0	$0	$0
Total Heartmate VE cost	**$95,100**	**$95,100**	**$95,100**	**$95,100**
Abiomed cost	$13,100	$13,100	$13,100	$13,100
Abiomed console rental ($900/day)	$41,400	$63,000	$10,800	$17,100
Total Abiomed cost	**$54,500**	**$76,100**	**$23,900**	**$30,200**
Thoratec cost	$80,500	$80,500	$80,500	$80,500
Thoratec console rental ($284/day)	$13,064	$19,880	$3,408	$5,396
Total Thoratec cost	**$93,564**	**$100,380**	**$83,908**	**$85,396**

AIABP = ambulatory intraaortic balloon pump; IABP = intraaortic balloon pump.

Ambulatory IABP

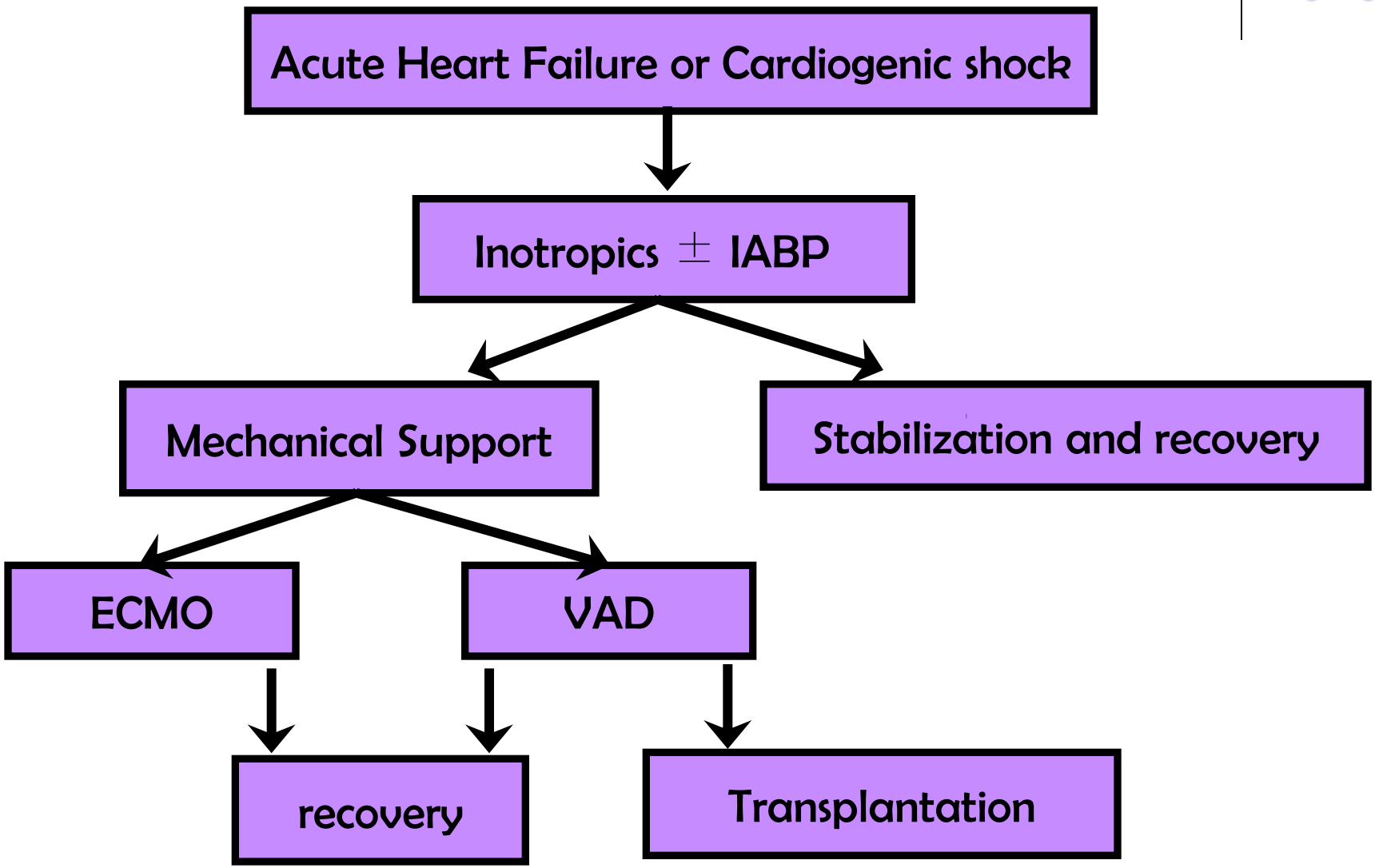




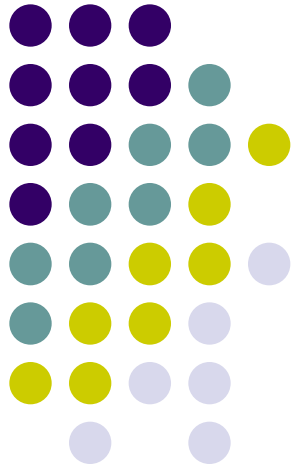
ACC/AHA IABP practice guideline

Clinical situation	ACC/AHA recommendation	Level of evidence
Cardiogenic shock (when cardiogenic shock is not quickly reversed with pharmacological therapy)	Class I → IIa	B
Recurrent ischemia/infarction (in the setting of hemodynamic instability, poor LV function, or a large area of myocardium at risk)	Class I	C
Unstable angina (severe ischemia that is continuing or recurs frequently despite intensive medical therapy or for Hemodynamic instability in patients before and after coronary angiography)	Class IIa	C
CHF (it may be reasonable for the management of patients with refractory pulmonary congestion)	Class IIb	C
Polymorphic ventricular tachycardia (refractory to medical management)	Class IIa	B

Mechanical circulating support decision tree

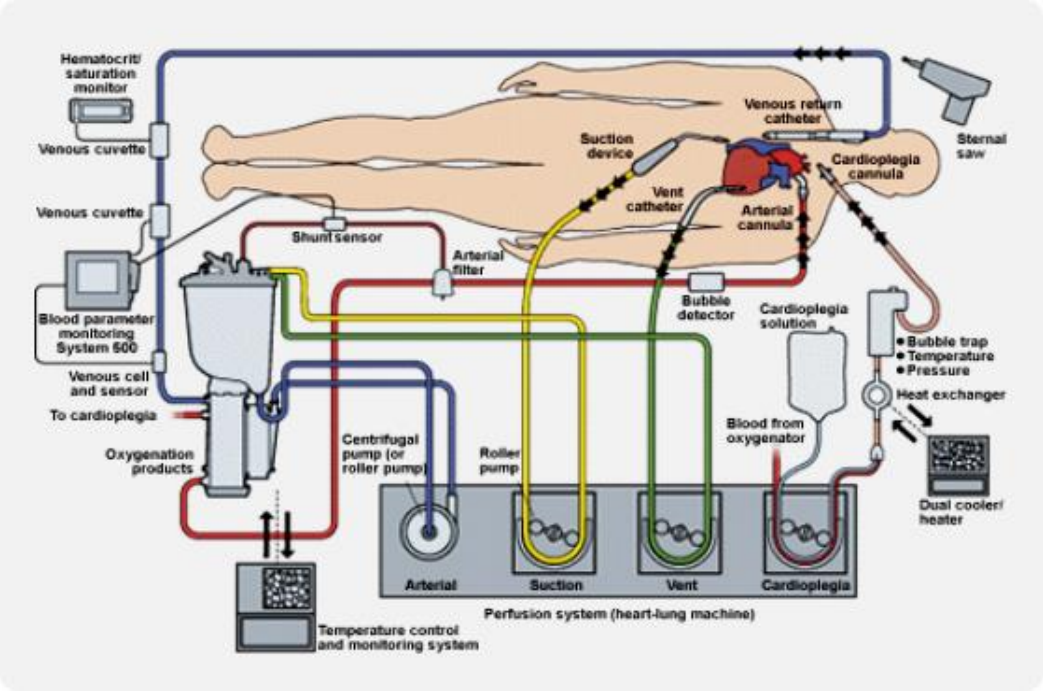


ECMO

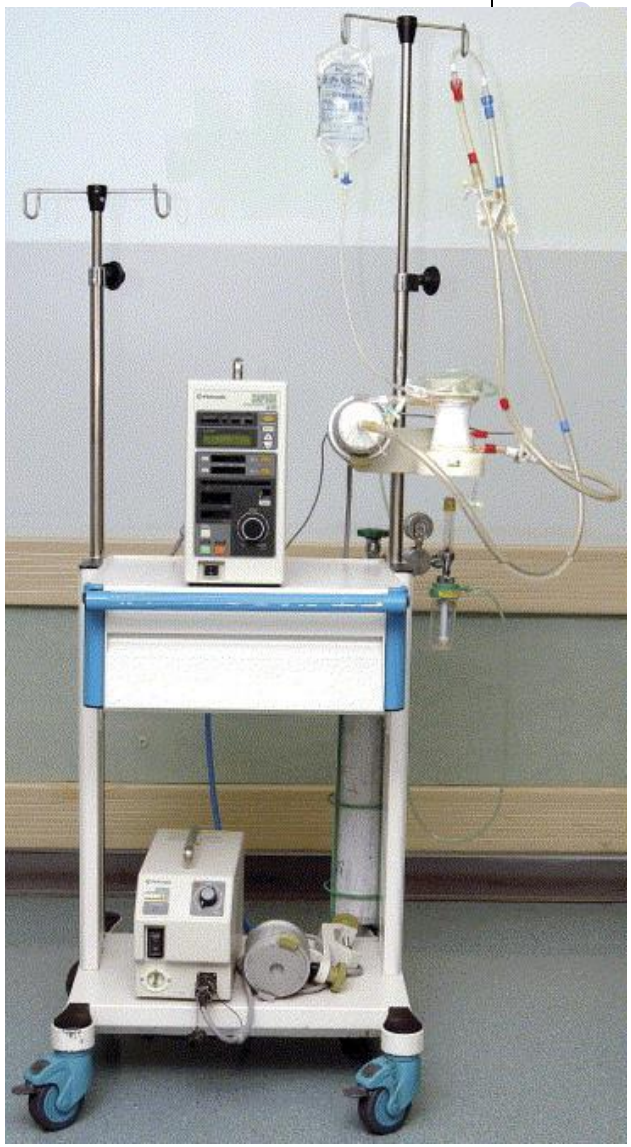


CP bypass

EBS

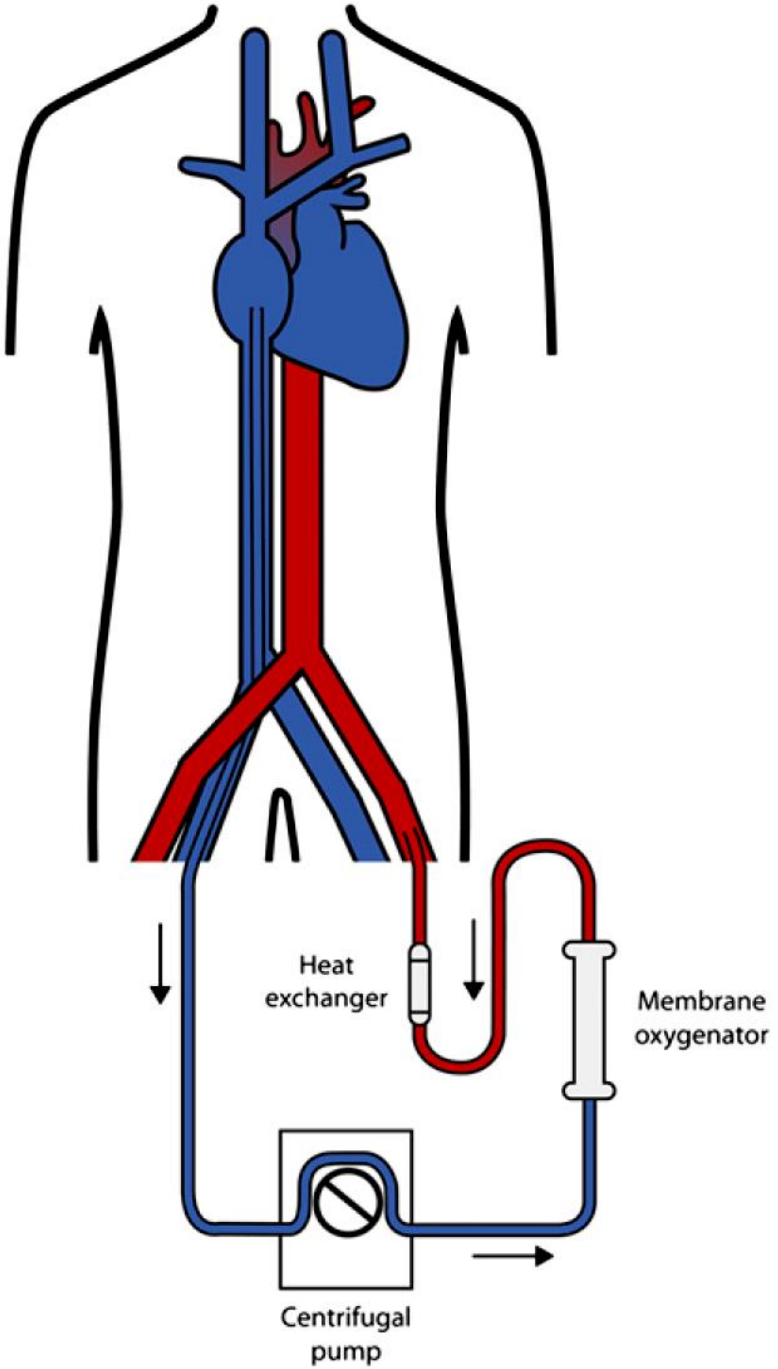


Quick, Compact,
Simple, Safe

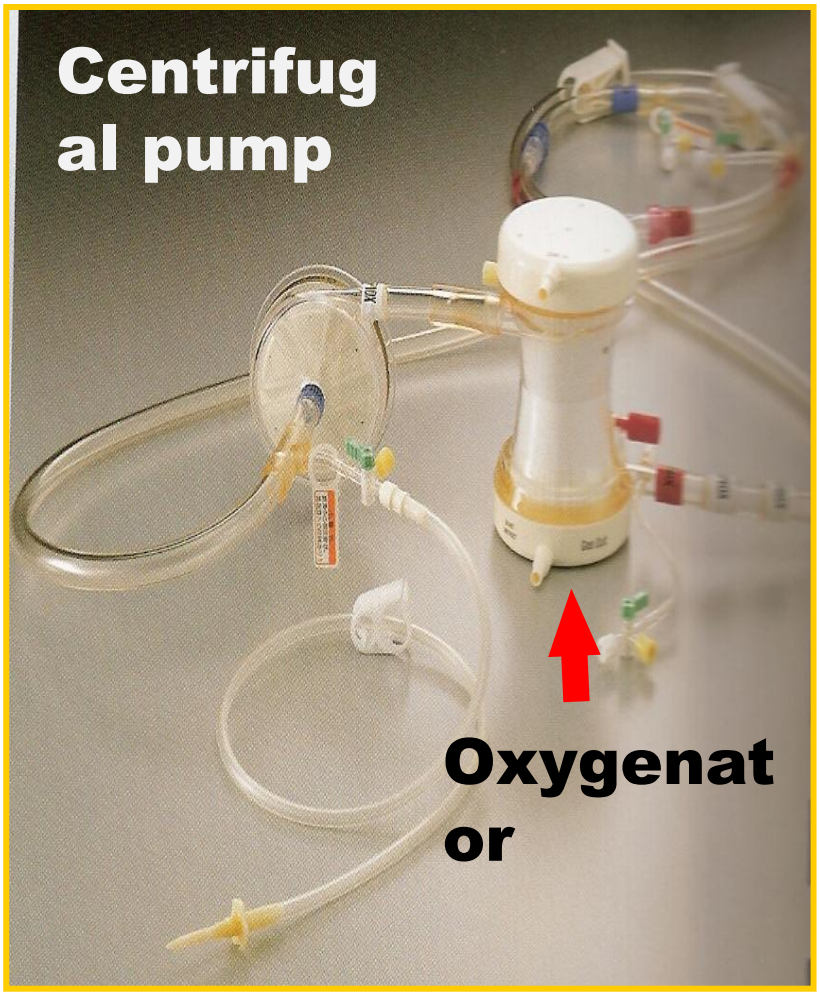


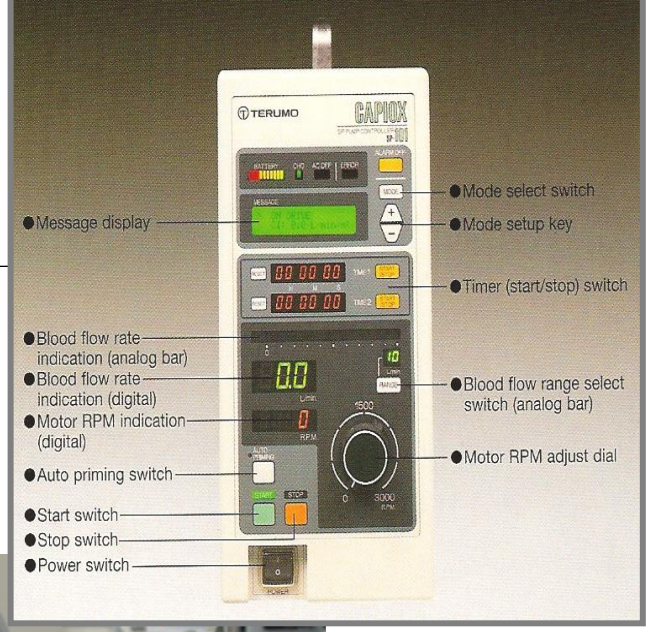
ECMO

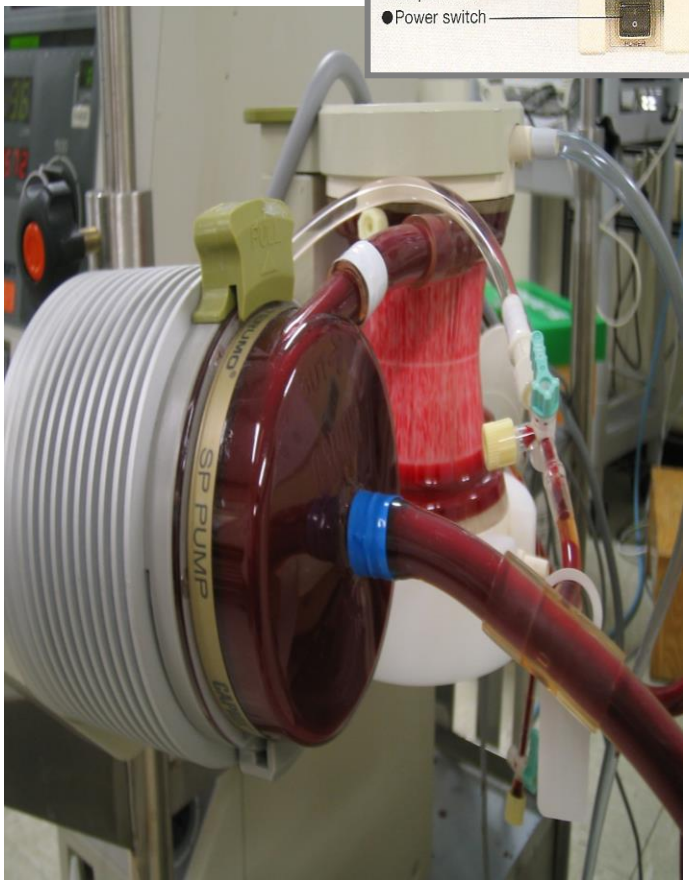
- Removed from the venous system
  - either peripherally via cannulation of a femoral vein or centrally via cannulation of the right atrium
- Oxygenated, and CO_2 Extraction
- Returned back to the body
  - either peripherally via a femoral artery or centrally via the ascending aorta at physiologic perfusion pressures



Configurations

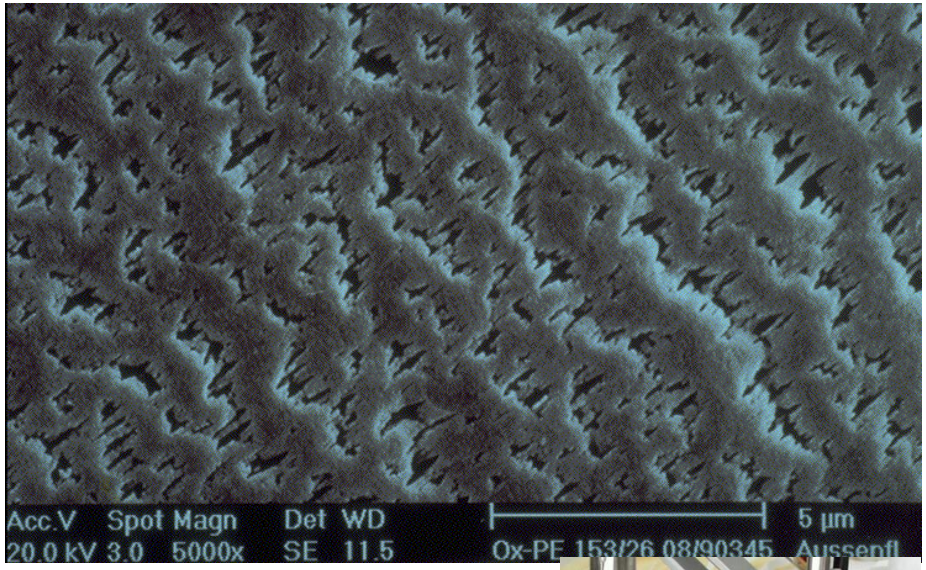




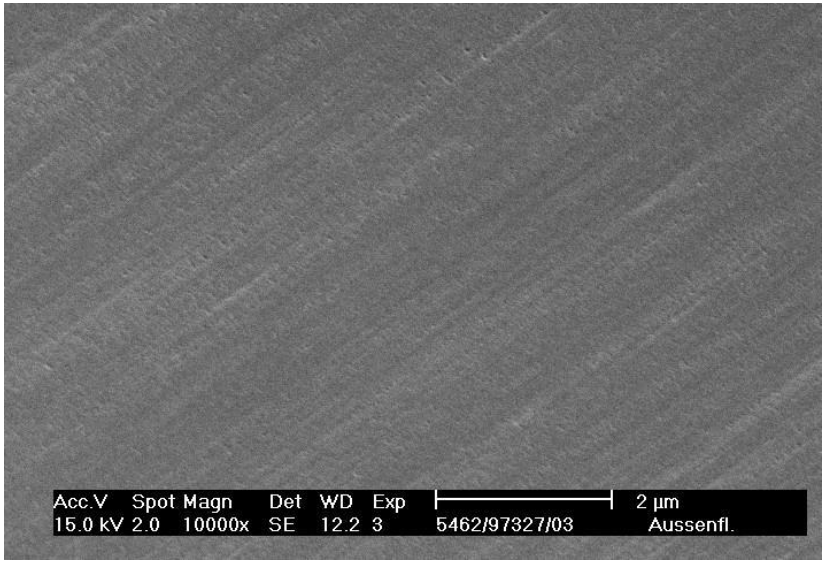


Oxygenator membrane

Microporous membrane surface

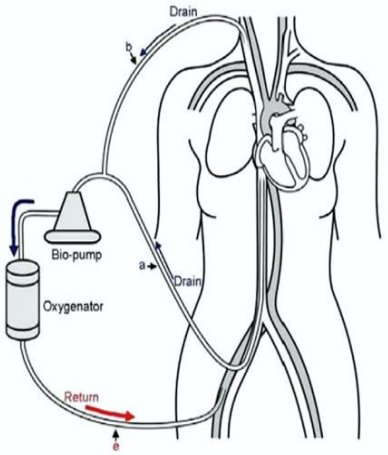


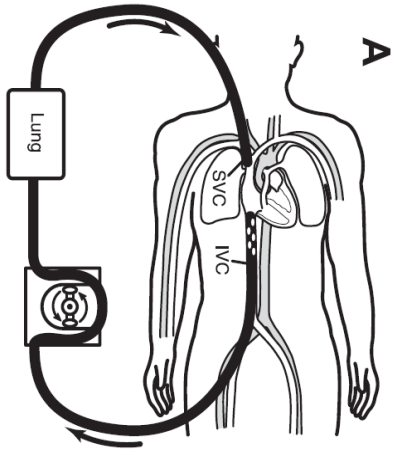
Diffusion membrane surface



Type

- VA (Veno-arterial) ECMO for cardiac failure
  - Inflow; RA, SVC, IVC
  - Outflow; aorta, femoral a., carotid a.
- VV (Veno-venous) ECMO for respiratory failure
  - Inflow; IVC
  - Outflow; SVC or RA

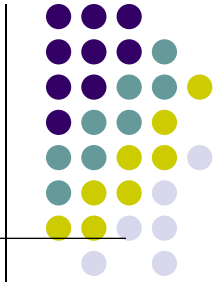




Effects of ECMO

- ECMO for heart
  - Support :
    - Improve systemic perfusion
  - Rest :
    - Decrease preload requirement
    - Decrease catecholamine
    - Decrease myocardial work
- ECMO for lung
  - Support :
    - O2 supply & CO2 removal
  - Rest :
    - Reduce ventilator induced lung injury

Indications



- Acute severe cardiac or pulmonary failure
  - potentially reversible and
  - unresponsive to conventional management

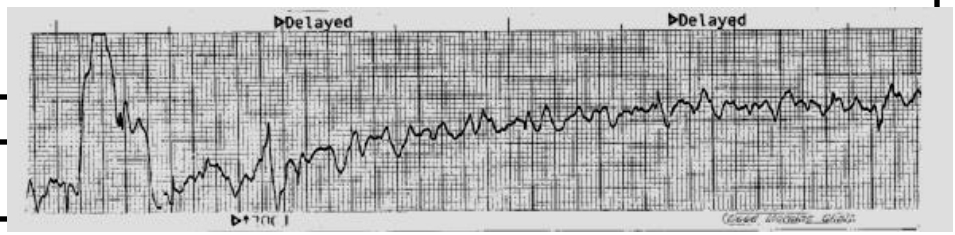
- Criteria for introducing PCPS
  - Difficulty in weaning from CPB during open heart surgery
  - Inadequate cardiopulmonary support even after IABP
  - Low blood pressure below 80 mmHg under full support by catecholamines
  - Oliguria/anuria (<1ml/kg/h)
  - Low cardiac output (<1.8 l/min/m2)
  - Low PaO2 (<60mmHg)
  - Uncontrollable VF/VT
  - Uncontrollable metabolic acidosis

Indications

- Cardiac failure
  - Severe cardiac failure due to
    - Cardiomyopathy
    - Myocarditis
    - ACS
  - Cardiopulmonary resuscitation
  - Post-cardiotomy
  - Post-heart transplant
- Pulmonary failure
  - ARDS
  - Pneumonia
  - Trauma
  - Primary graft failure following lung transplantation

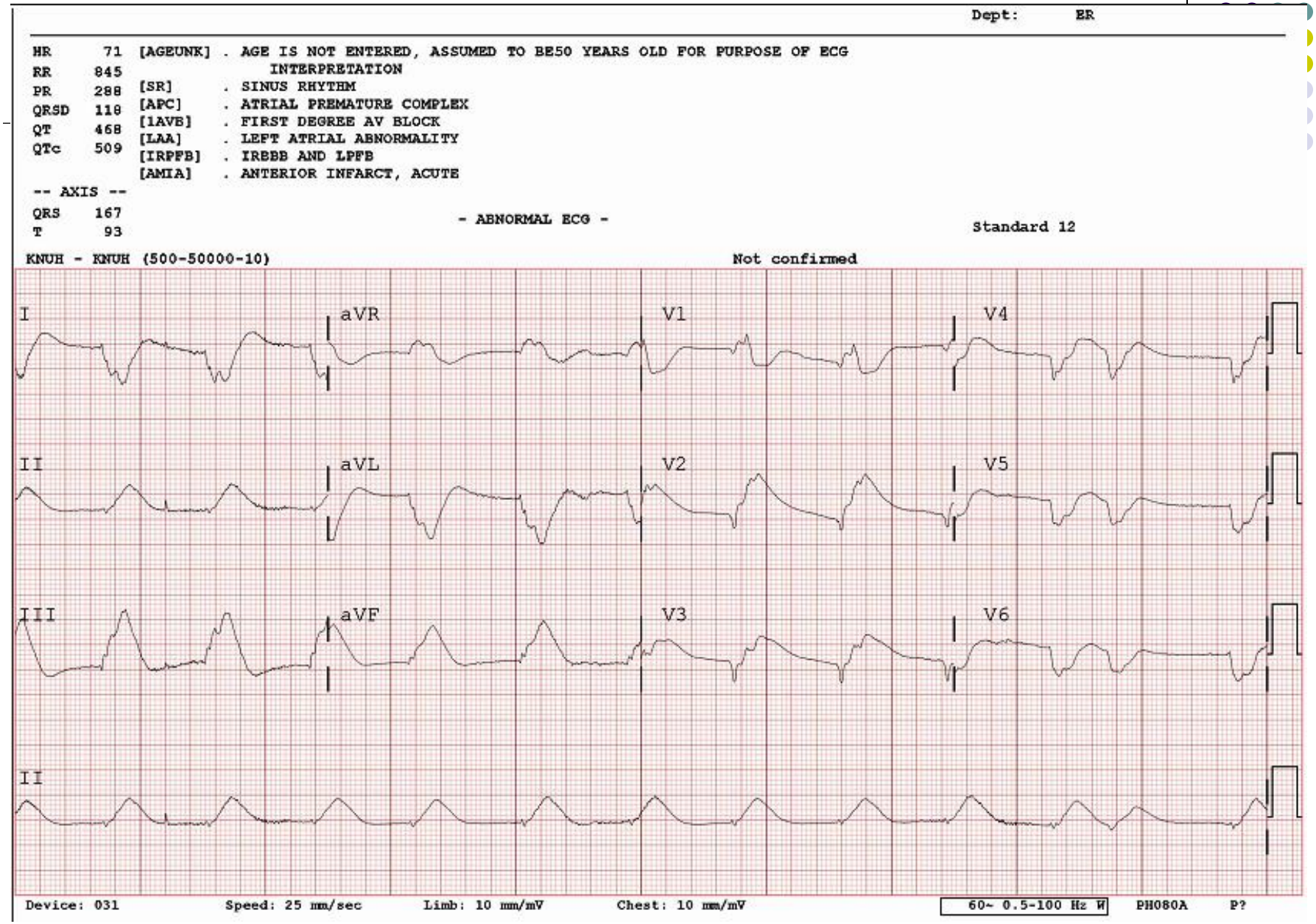
CASE

- 2011.05.25
- 46yrs, Male
- HTN/DM/dyslipidemia (-/-/+)



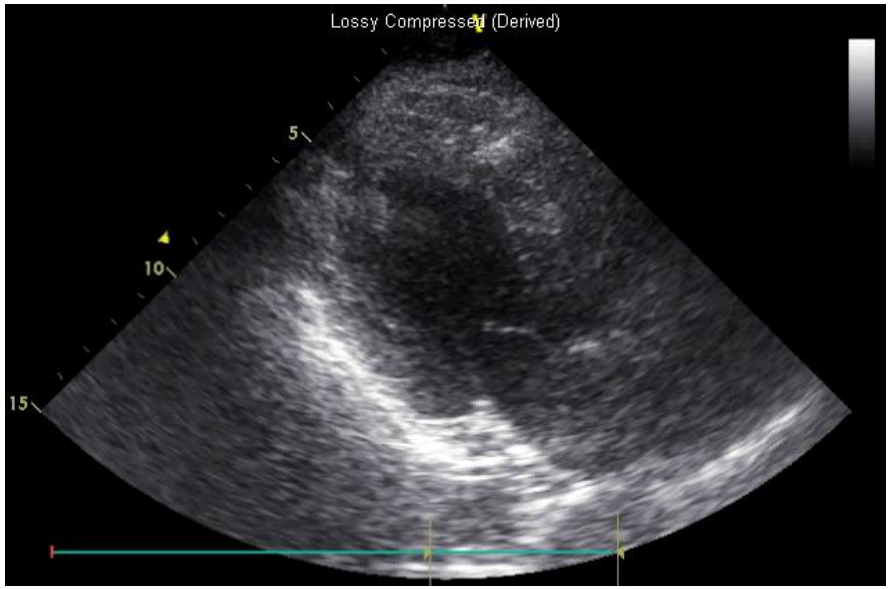
- 동성로 노래방에서 술을 마시던 중...

22:50	Chest discomfort, drowsy mentality보이다 의식 잃고 쓰러짐.
22:53	119 신고됨.
22:56	119 도착, 당시 pulse(+)/self respiration(-)/pupil full dilatation -> AED #1 시행, rhythm 회복되지 않아 CPR start
23:04	본원 ER 도착, 당시 comatous mentality, ECG상 VF(+) -> Defibrillation #3 시행, IV amiodarone injection -> VF 반복되어 CPR 지속함.
23:40	Pulse 회복되어 ECG check.


Dept: ER
HR 71
RR 845
PR 288
QRSD 118
QT 468
QTc 509
-- AXIS --
QRS 167
T 93
[AGEUNK] . AGE IS NOT ENTERED, ASSUMED TO BE50 YEARS OLD FOR PURPOSE OF ECG INTERPRETATION
[SR] . SINUS RHYTHM
[APC] . ATRIAL PREMATURE COMPLEX
[1AVB] . FIRST DEGREE AV BLOCK
[LAA] . LEFT ATRIAL ABNORMALITY
[IRPFB] . IRBBB AND LPFB
[AMIA] . ANTERIOR INFARCT, ACUTE
- ABNORMAL ECG -
Standard 12
KNUH - KNUH (500-50000-10)
Not confirmed
I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6
II
Device: 031
Speed: 25 mm/sec
Limb: 10 mm/mV
Chest: 10 mm/mV
60~ 0.5-100 Hz W
PH080A
P?

23:50

순환기내과 당직 전임의 call, portable 2D-Echo 시행



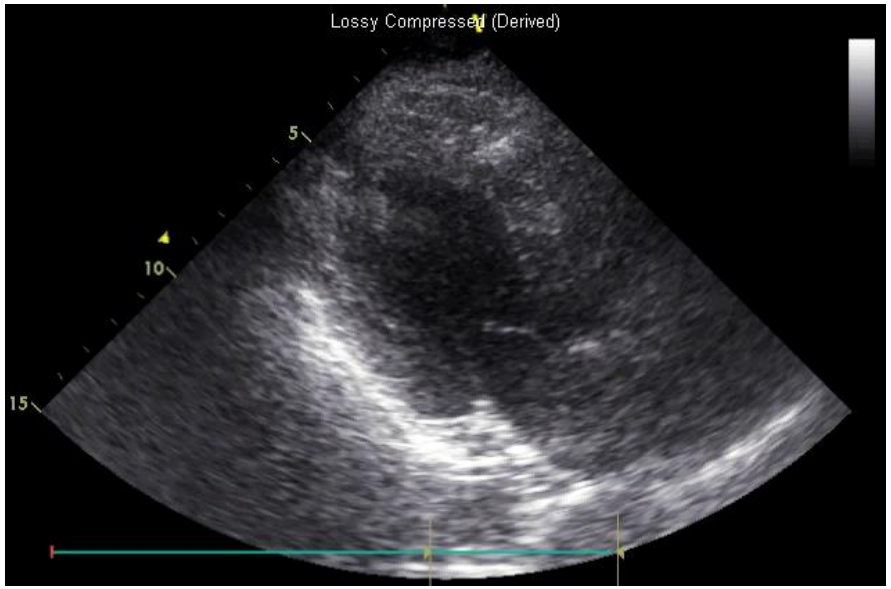
After Cardiac arrest,
what else can we do next?

Comatous mentality
Wide QRS
Very weak LV contractility

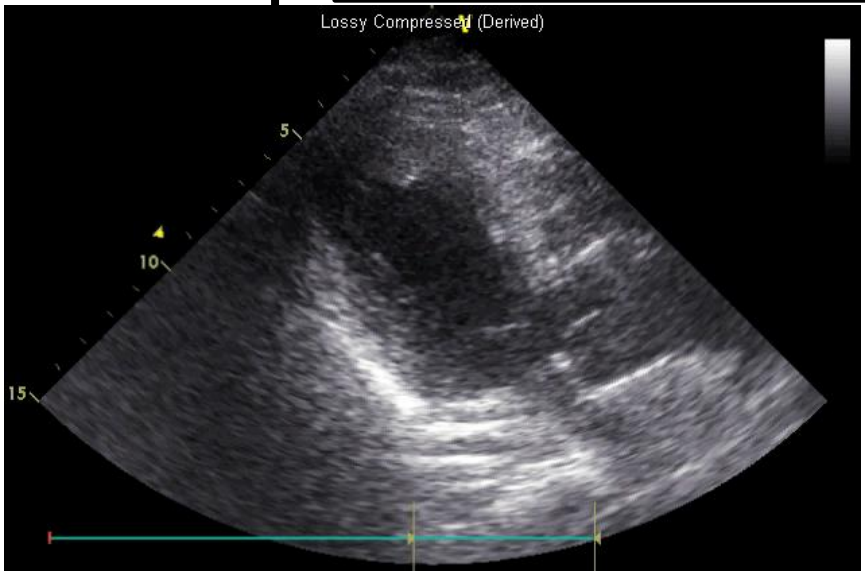
- 보호자에게 심장이 더 이상 뛰지 않음을 설명하고 돌아선다.
- 응급실에서 더 열심히 CPR을 계속 한다.
- CAG를 하기 위해 cath room으로 바로 이동한다.
- What else???

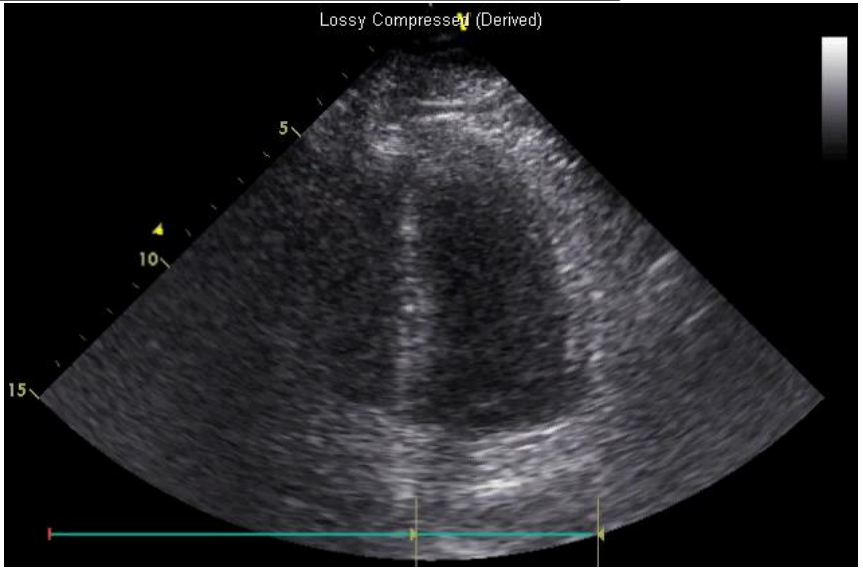
23:50

순환기내과 당직 전임의 call, portable 2D-Echo 시행



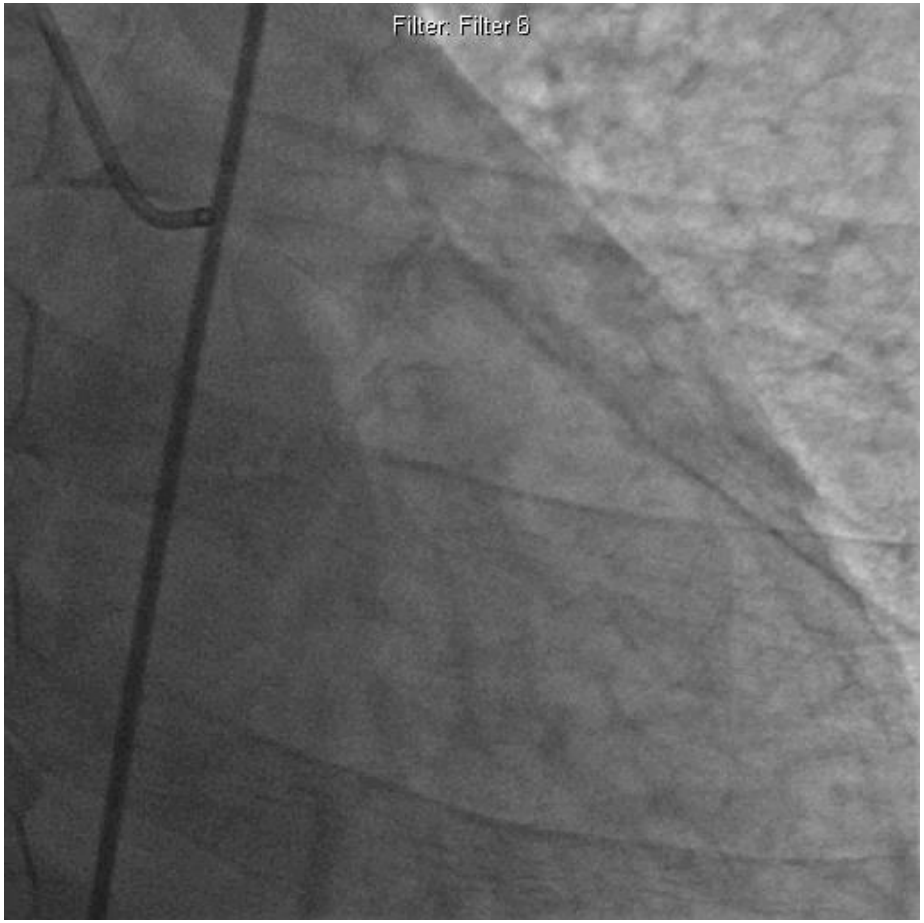
Primary PCI 결정, 준비하던 중 cardiac arrest
-> CPR 시행, 응급실에서 EBS 시행함.

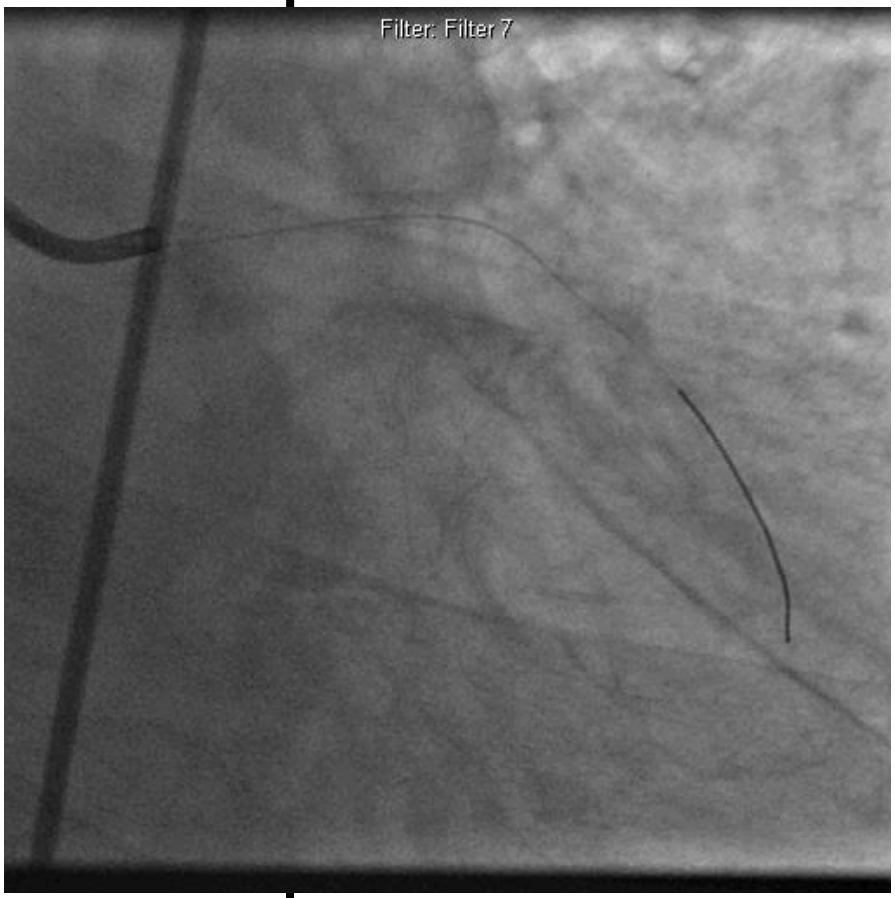


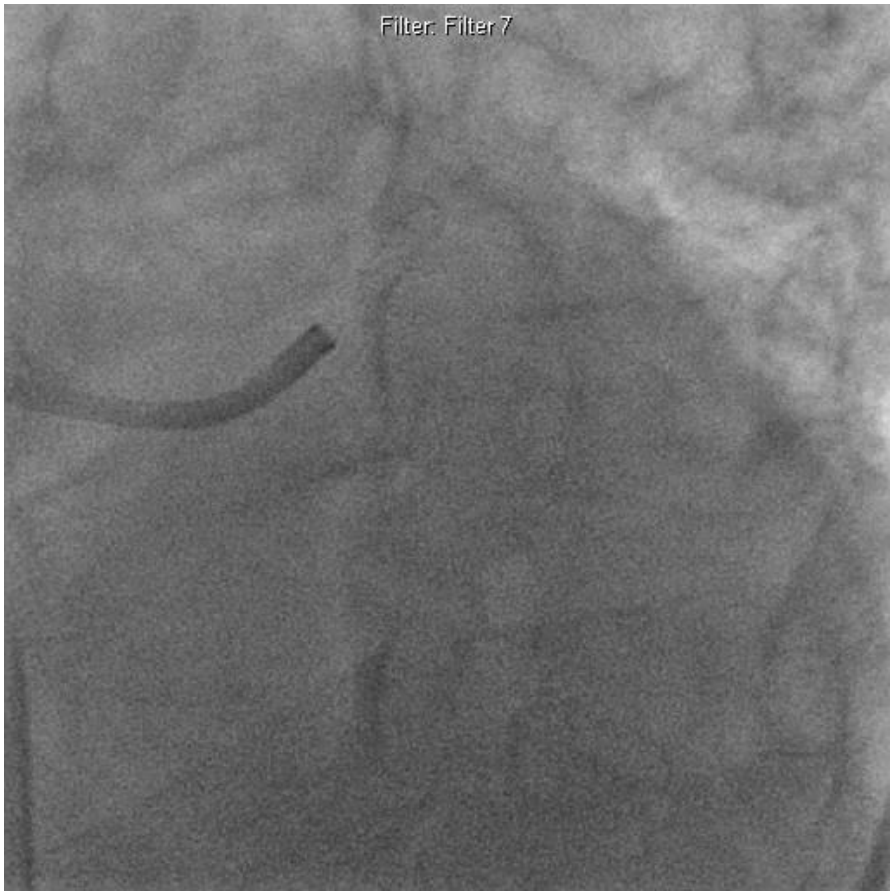


01:15 Cath. room 입실.

01:35 CAG 시행





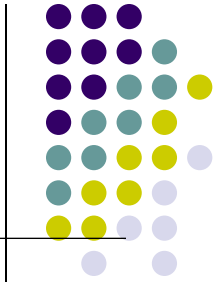


CCU 입실, MV, EBS, IABP, Inotropics keep

Maintenance

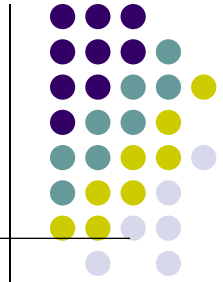
- Respiratory point
  - Increasing the flow rate and FiO2 of the ECMO circuit, not by altering the FiO2 and PEEP on the ventilator
- Cardiac point
  - Minimize the use of inotropes
- Neurologic
  - Hypothermia

Management



- Ventilator : rest setting
  - 4-10회/분, FiO2 <0.5, PIP <35cmH2O,
  - PEEP 10-15cmH2O
- Prone positioning ?
- Early tracheostomy
- Daily neurologic assessment
  - NSE 1, 3 day / EEG
- Enteral feeding is prefer
  - TPN order

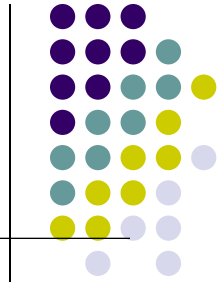
Maintenance



- MAP : 70-80mm Hg
- CVP : 6~8 mmHg, PCWP; 10~12mmHg
- Cardiac index : > 2.4 L/min/m2
  - Flow rate > 4 L/min, Pump RPM < 2500

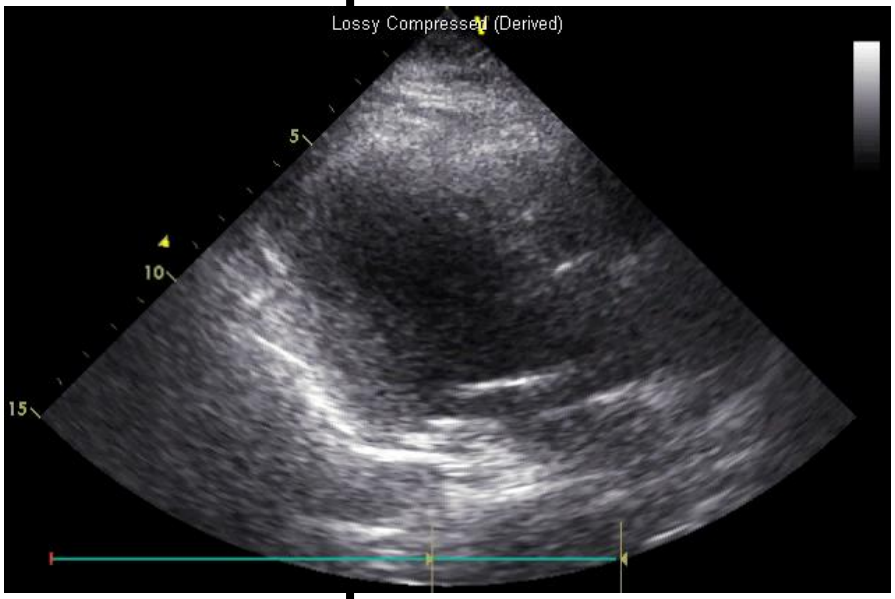
- ACT : 160~200 s (bleeding 150 s)
- Hct > 35% (14<Hb<16, 40%<Hct<50%), platelet > 100,000
- PaO2 >100 mmHg, SaO2 > 90%
- V-line saturation 75-80% (SVO2 >60%)
- A-line saturation 100%

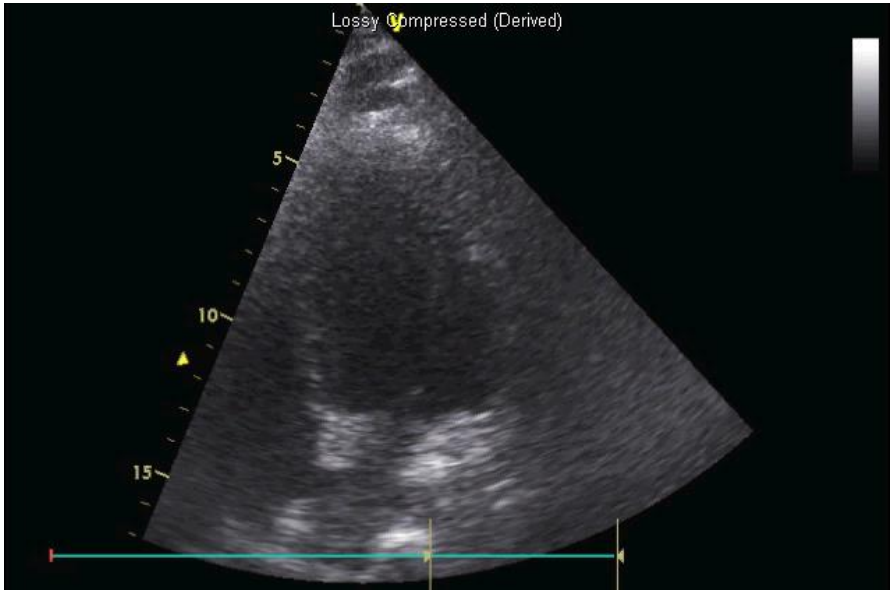
Monitoring



- Continuously
  - MAP, Pulsation, CVP, mPAP, pulse oxymetry, bypass flow, SaO_2, SvO_2 , body Temp
- Every 4-6 hrs
  - ABGA (pt, arterial catheter), VBGA
  - ACT, capillary refilling, (glucose)
- Every 12 hrs
  - Clot formation, cannular kinking & position
  - Calibration of monitoring devices, oxygenator
  - Distal perfusion
- On demand
  - TEE: ↑CVP, PAP, no pulsation, unexplained bypass flow 감소

2011.05.30 F/U 2D-Echo





2011.05.30 EBS weaning

2011.06.04 IABP remove

2011.06.17 Mechanical ventilator weaning

Weaning

The following conditions are satisfied at flow rate of 1.0 L/min

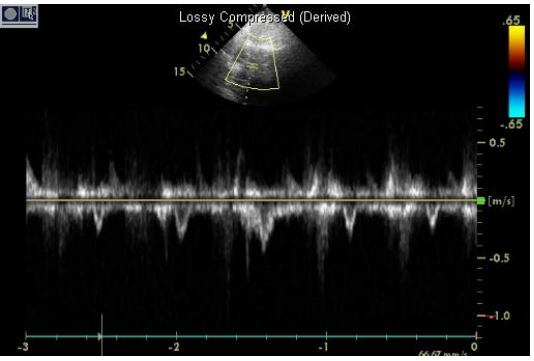
Markers of circulatory failure

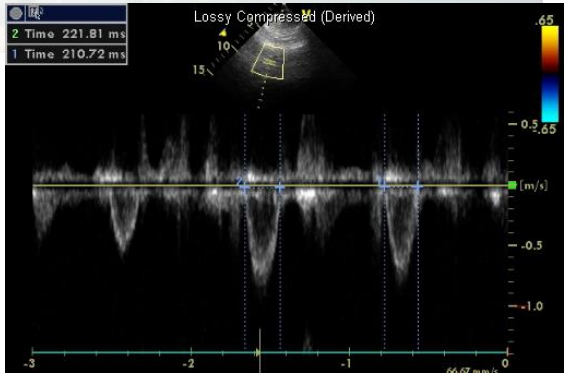
(1) No metabolic acidosis
(2) SVO2 >60%
(3) LA: normal
(4) TB (without hemolysis) <3.0 mg/dl (or AKBR: normal)
(5) Blood biochemistry: recovery from organic failure

Markers of cardiac function

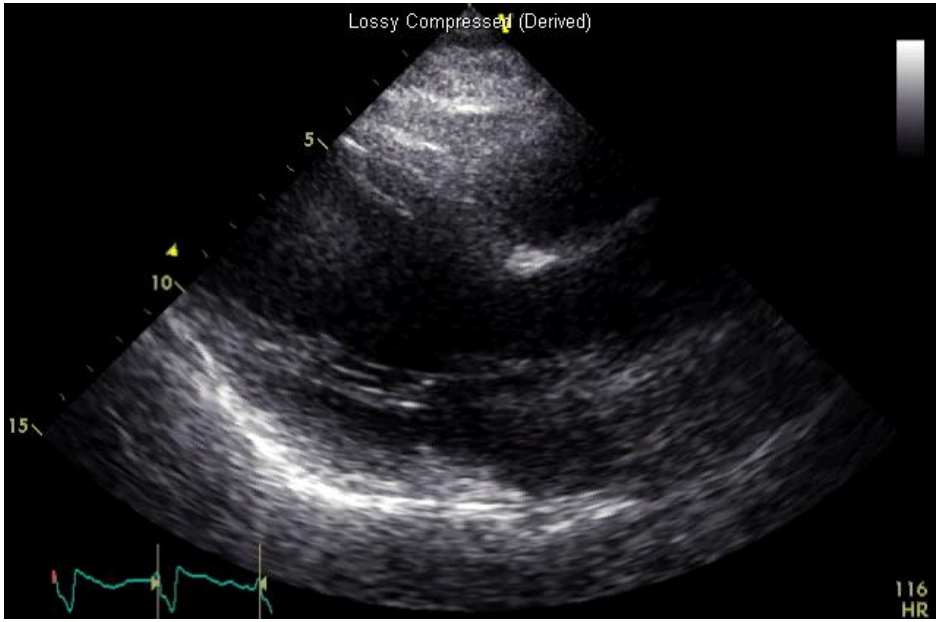
(1) Wall motion improvement
(2) EF, %FS: improvement
(3) Ejection time >200 ms
(4) ETCO2= PaCO2
(5) CI >2.0L/min^{-1}/m^{-2}
(6) Pulse pressure

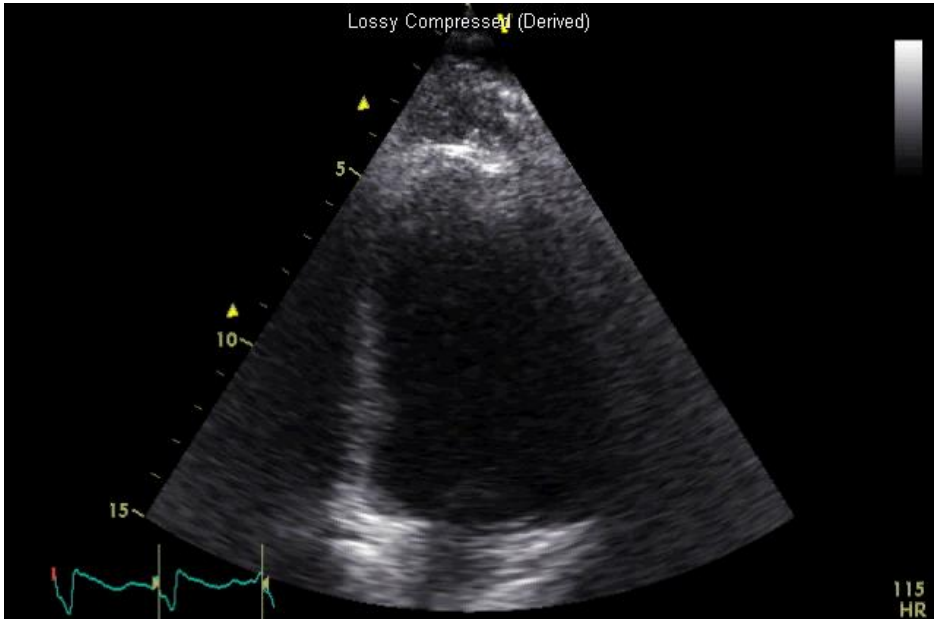
Pulse pressure / cET

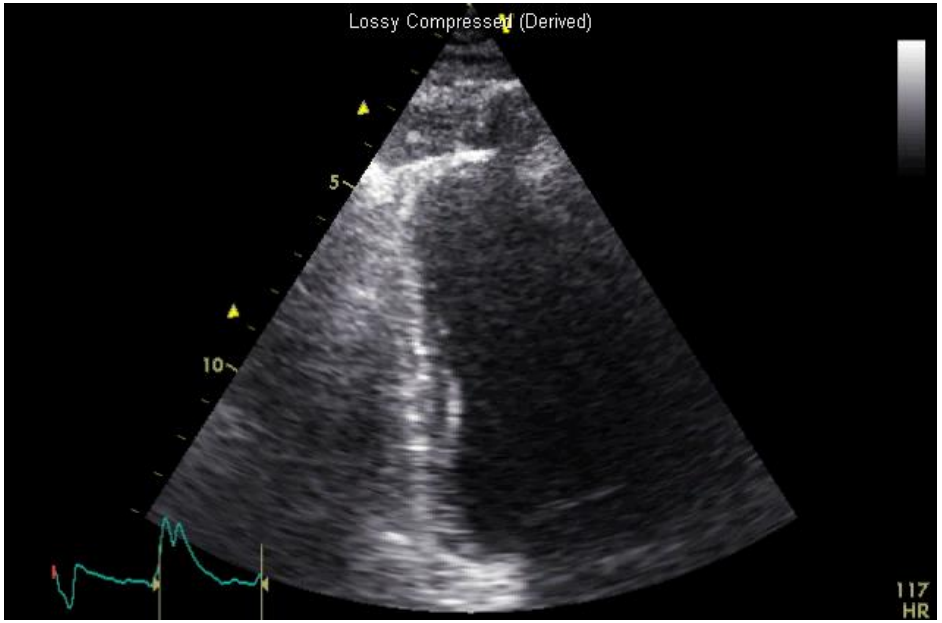


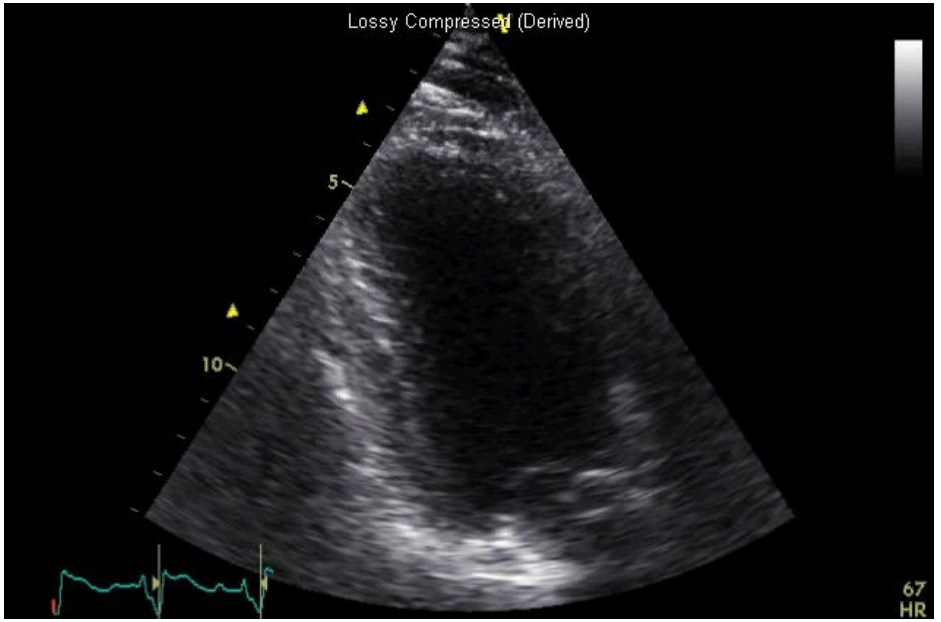


2011.06.10 퇴원 전 시행한 TTE

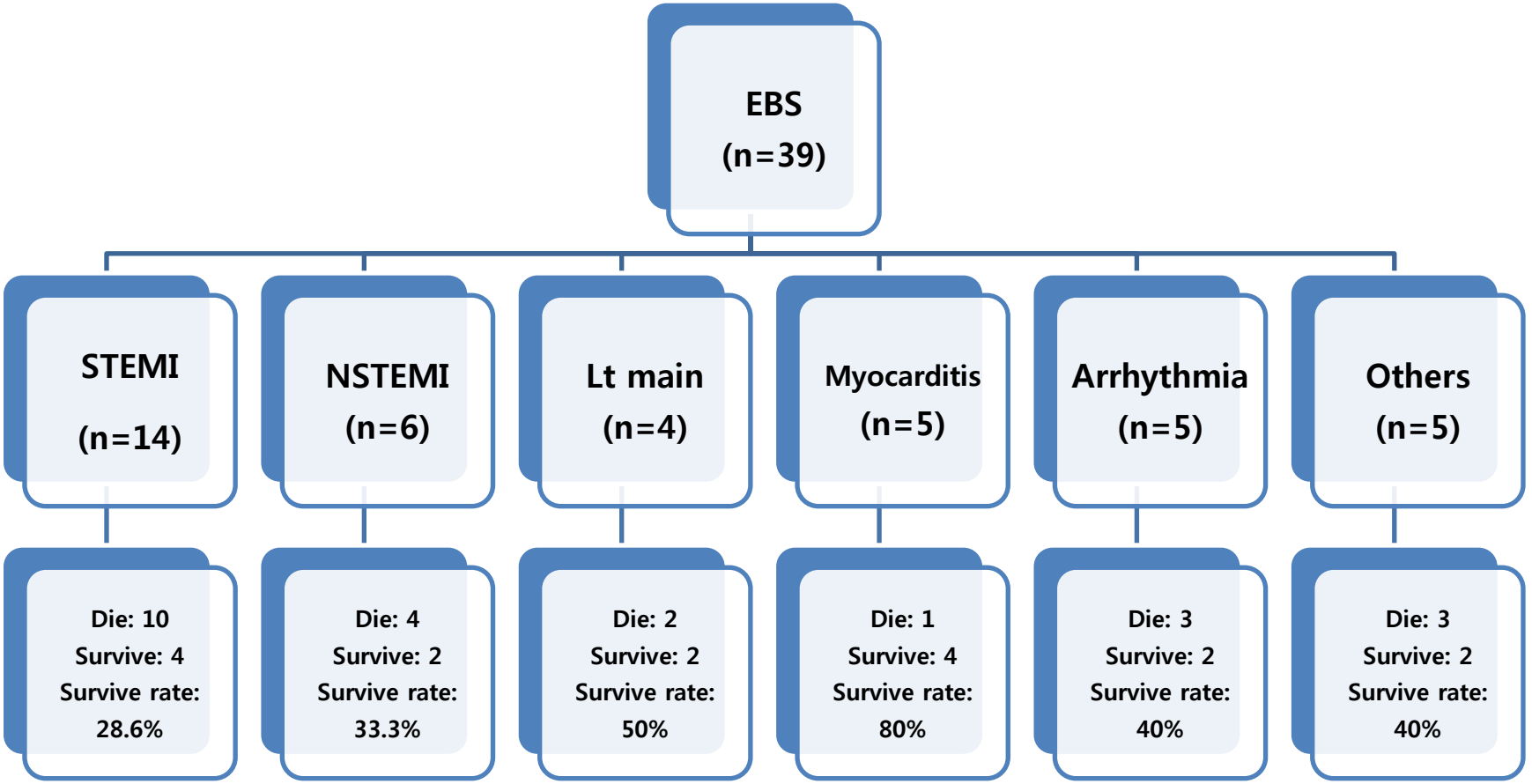






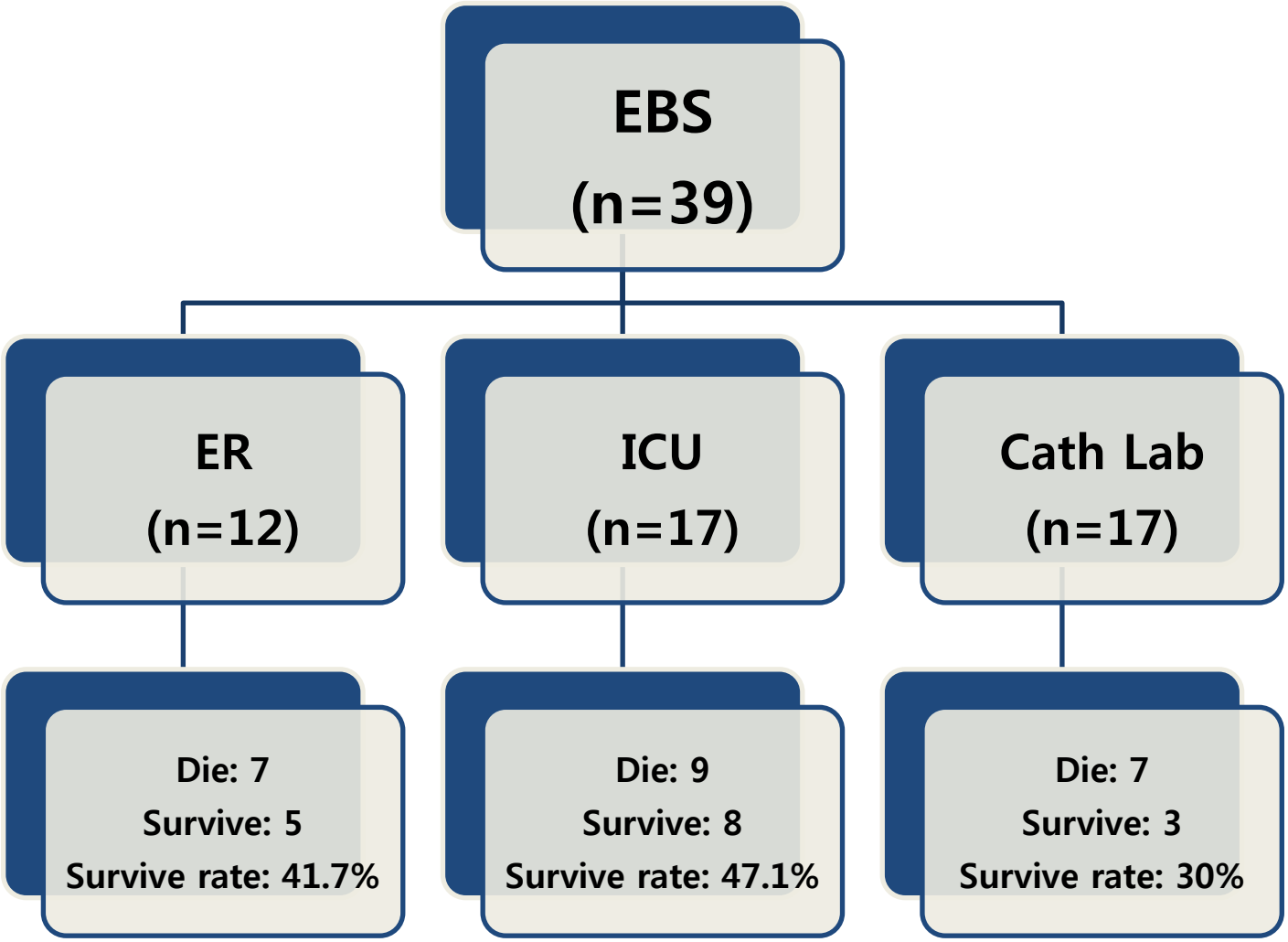


Cause of cardiac arrest (KNUH EBS)



Other cause : no reflow during PCI, idiopathic pulmonary HTN, adriamycin induced CMP

EBS start site (KNUH EBS)



CPR time before PCPS

Author	CPR <30 min	CPR >30 min
Hill	14/54 (25.9%)	8/56 (14.3%)
Wittenmyer	16/63 (25.4%)	1/13 (7.7%)
Willms	15/29 (51.7%	1/20 (5.0%)
Hartz	1/19 (5.3%)	0/10 (0%)
Cochran	N/A	2/3 (67%)

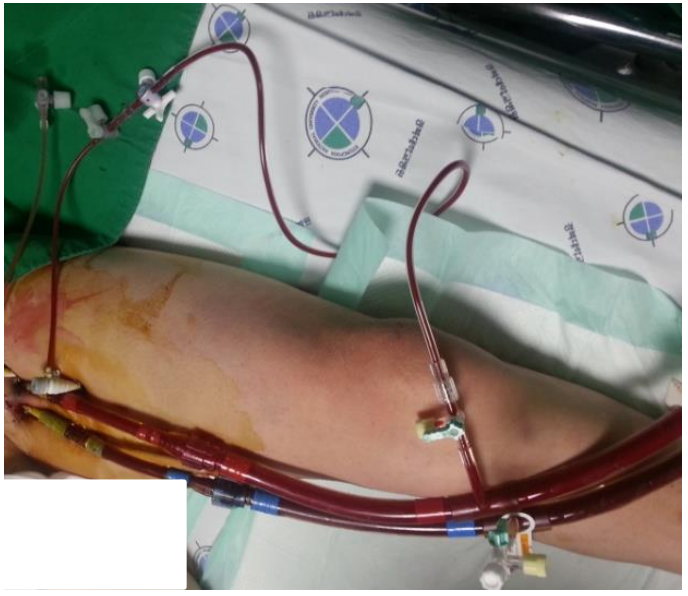
Contraindication of ECMO

✓ "Impossibility" of organ recovery

- Disseminated malignancy
- Advanced age
- Graft vursus host disease (GVHD)
- Known severe brain injury
- Unwitnessed cardiac arrest or cardiac arrest of prolonged duration
- Aortic dissection or aortic regurgitation
- Bleeding

Complications

- **Bleeding**
  - Systemic heparinization is still advisable because of the risk of end organ damage from microthrombus and fibrin deposition
- **Coagulopathy** (consumption and dilution of factors)
- **Non-pulsatile perfusion**
  - kidneys, splanchnic circulation -> renal failure, GI bleeding
- **Leg ischemia**
- **Air embolism, thromboembolism**
- **LV ballooning**



Survival >30 days

Authors [ref. no.]	CA	CS	P	T	H	Misc	Total
Hill *et al.*[30]	125/17	44/17	9/3		7/3	2/0	187/40
Wittenmyer *et al.*[36]	76/17	27/14	1/1				104/32
Willms *et al.*[31]	68/17	13/3					81/20
Reichman *et al.*[49]	36/6						36/6
Hartz *et al.*[40]	27/1	3/3			2/0		32/4
Phillips *et al.*[50]	18/5				2/1	1/0	21/6
Mooney *et al.*[51]	11/9						11/9
Overlie[42]	35/8						35/8
Cochran *et al.*[32]	3/2						3/2
Kawahito *et al.*[22]	4/2	3/2					7/4
Ohteki *et al.*[38]	2/2	1/1					3/3
Hsieh *et al.*[39]	1/1						1/1
Wanner *et al.*[47]	1/1						1/1
Sasako *et al.*[52]		40/7					40/7
Hata *et al.*[29]		30/13					30/13
Aiba *et al.*[53]		26/5					26/5
Yamashita *et al.*[43]		24/4			1/0		25/4
Jacobs *et al.*[18]		23/11					23/11
Orime *et al.*[54]		19/6					19/6
Matsuwaka *et al.*[55]		16/6					16/6
Orime *et al.*[56]		12/5					12/5
von Segesser[13]		11/9					11/9
Sone *et al.*[46]		10/7					10/7
Kato *et al.*[44]		9/7					9/7
Shawl *et al.*[57]		8/7					8/7
Mitsui *et al.*[58]		8/2					8/2
Yamashita *et al.*[59]		3/3					3/3
Aliabadi *et al.*[60]		2/2					2/2
Yasu *et al.*[61]		2/2					2/2
Ihno *et al.*[62]		1/1					1/1
Perchinsky *et al.*[33]				6/3			6/3
Hirose *et al.*[34]				1/1			1/1
Sudo *et al.*[35]			1/1				1/1
Klofas[37]			1/0				1/0
Waters *et al.*[41]					1/1		1/1
Totals	407/88 (21.6%)	335/137 (40.1%)	12/5 (41.7%)	9/5 (55.6%)	13/5 (38.5%)	3/0 (0%)	777/239 (30.8%)

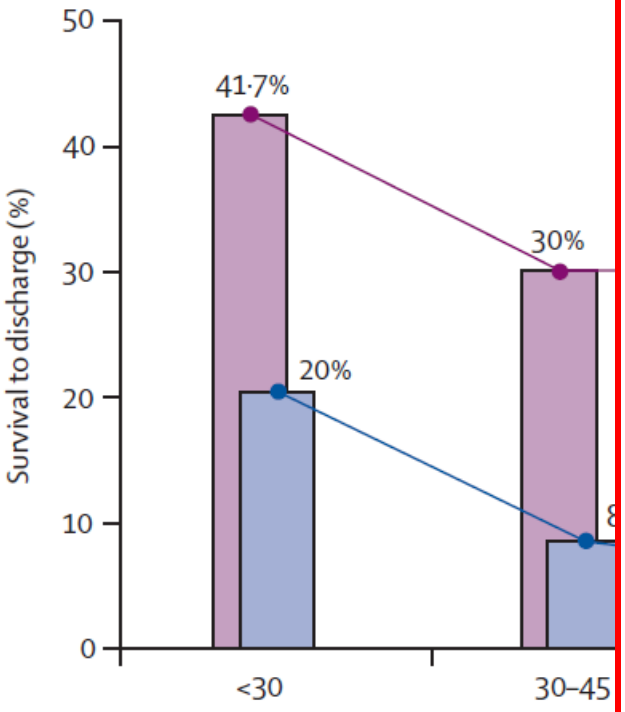
21.6%

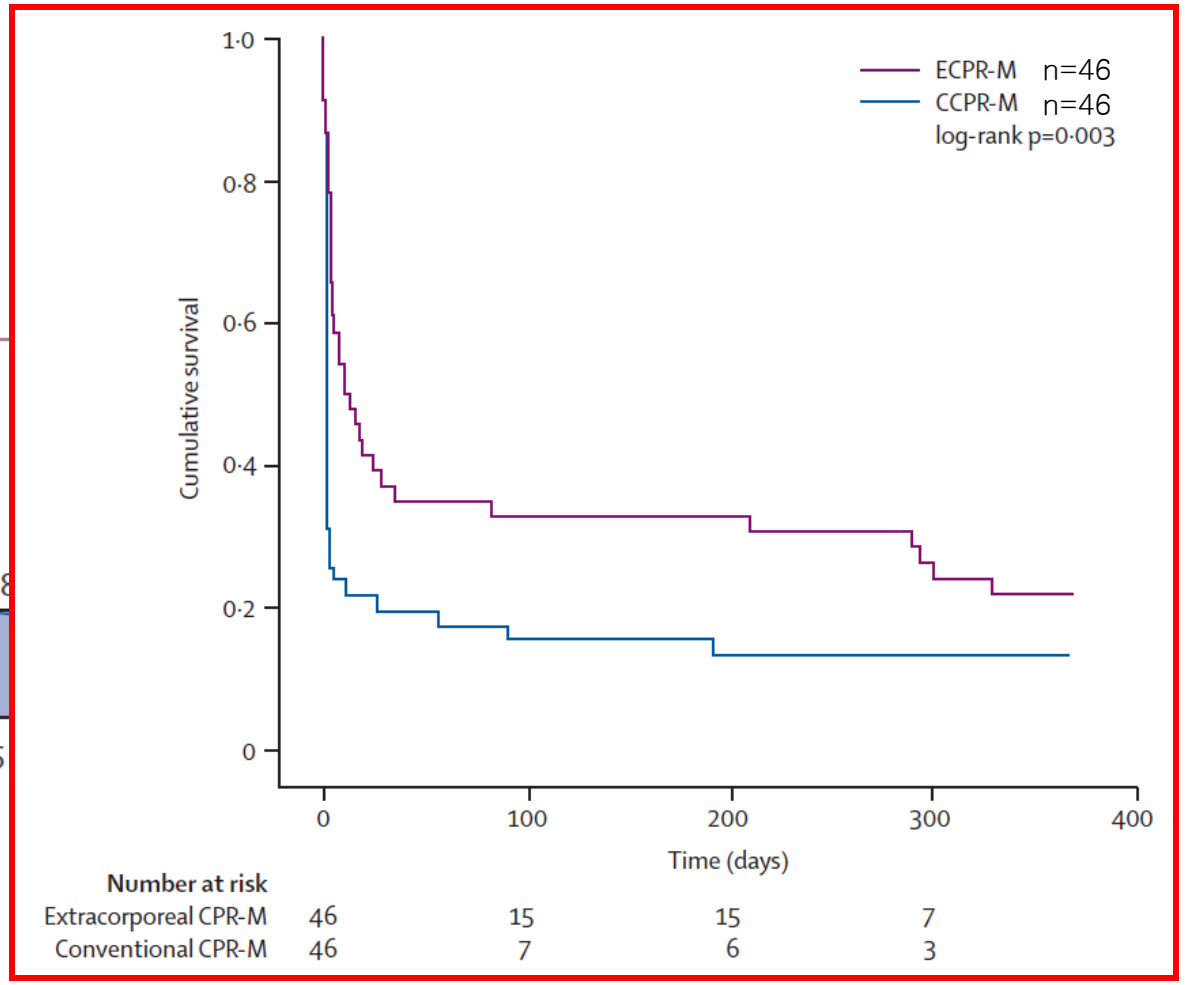
40.1%

38.5%

Extracorporeal CPR vs Conventional CPR

10분이상 CPR : ECPR 59 vs CCPR 113





Chen YS, et al. Lancet 2008; 372:554.

ECPR (85) vs CCPR (321)

Samsung Medical Center
Crit Care Med 2011;39:1–7

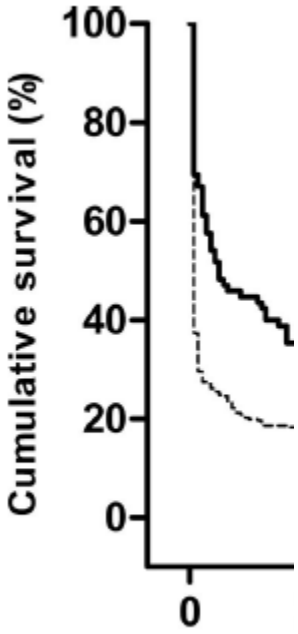
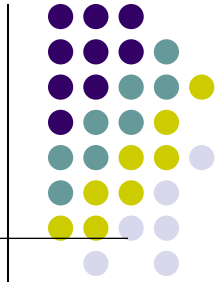


Table 3. Multivariate analysis of predictors of survival with minimal neurologic impairment

Variable	Inhospital Survival With Minimal Neurologic Impairment[a]		Six-Month Survival With Minimal Neurologic Impairment[b]	
	Odds Ratio[c]	95% CI	Hazard Ratio[c]	95% CI
Overall matched group				
Adjusted with all covariates[d]				
E-CPR	0.06	0.008–0.54	0.38	0.19–0.77
Adjusted with the propensity score				
E-CPR	0.17	0.04–0.71	0.50	0.30–0.84
Propensity score	0.06	0.004–0.92	0.06	0.00–764.78
Cardiogenic subgroup				
Adjusted with all covariates[d]				
E-CPR	0.03	0.001–0.75	0.41	0.15–1.07
Adjusted with the propensity score				
E-CPR	0.19	0.04–0.88	0.60	0.34–1.05
Propensity score	0.02	0.001–0.48	0.02	0.00–335.53

Factors of Poor Outcome



- Bleeding; mediastinal or peripheral
- Infection/sepsis on ECMO
- Multiple system organ failure; renal or liver
- Leg ishemia
- Duration of ECMO exceeding 8-10 days

IABP on ECMO

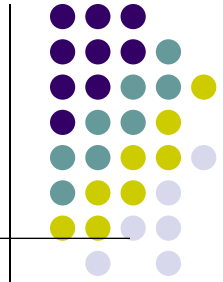
- Pulsatile IABP + Non-pulsatile ECMO

-> Increased coronary flow, decrease LV afterload

-> The pulsatility created by using an IABP in combination with a non-pulsatile pump, is supposed to be more effective at organ perfusion and at restoring

Madershahian N, et al. J Card Surg. 2009;24:265-8

Summary



- IABP
  - Relatively low cost
  - Easy and immediate application
  - Beneficial hemodynamics
- Extracorporeal CPR may be effective for cardiac resuscitation in patients with cardiac arrest or cardiogenic shock who would otherwise not survive.
- Proper timing for proper patients

경청해 주셔서 감사합니다.