ECMO
Past, Present and Future

Piya Samankatiwat
Division of Thoracic Surgery
Department of Surgery
Ramathibodi Hospital
Mahidol University
Types of mechanical circulatory support

- Impaired cardiac function
  - Ventricular assist device (VAD)
  - Extracorporeal membrane oxygenation (ECMO)
  - Intra-aortic balloon counter pulsation (IABP)
  - Conventional CPB circuit

- Impaired cardiopulmonary function
  - ECMO

- Impaired pulmonary function
  - Veno-venous ECMO
Physiological fundamental of circulatory support

Cardiac function
• Adequate cardiac output
  • Preload
  • Afterload
  • Myocardial contraction
  • Heart rate and rhythm

Pulmonary function
• Lung mechanics
• Gas exchange
ECMO

Extracorporeal membrane oxygenation

- ECMO is temporary support of heart and lung function by partial cardiopulmonary bypass (up to 75% of cardiac output). It is used for patients who have reversible cardiopulmonary failure from pulmonary, cardiac or other diseases.
Cardiopulmonary function
Principle of ECMO

Veno-venous
1. object to pre-oxygenate blood before the lungs
2. no reduction in the pulmonary hypertension
3. provide no circulatory support

Veno-arterial
1. provides total cardiopulmonary support
2. rest the lung
ECMO indications

- After cardiac surgery, unable to wean off CPB
- Acute MI with cardiogenic shock
- Heart failure after transplantation due to graft rejection
- Respiratory distress syndrome
- Persistent pulmonary arterial hypertension of the neonate
- Congenital diaphragmatic hernia
- Sepsis
- Acute respiratory insufficiency
  - in pts. receiving at least 48 hours of optimal conventional ventilatory therapy with no improvement in pulmonary function
  - due to a viral or bacterial pneumonia, aspiration pneumonia, respiratory burns
  - diagnosis must be reversible within 14 days
ECMO indications

- Refractory failing circulation
- Post CPR
- Severe sepsis
- Respiratory failure
- Bridge to transplant
- Bridge to bridge
- Bridge to recovery
ECMO indications

- Oxygenation index (OI): if > 40 predicts 80% mortality without ECMO

\[
\frac{MPaw \cdot FiO2 \cdot 100}{PO2(mmHg)}
\]

- MPaw

\[
\frac{(Paw\cdot Ti) + (PEEP\cdot Te)}{Ti + Te}
\]
Neonatal ECMO
Inclusion criteria

- Gestational age > 35 weeks
- Birth weight > 2000 gm
- No bleeding abnormalities
- No major intracerebral haemorrhage
- No major congenital chromosomal defects
- Mechanical ventilation < 8-10 days
- No irreversible cardiopulmonary disease
- Reversible lung disease
Neonatal ECMO
Inclusion criteria

- Failure of maximal medical therapy
- OI > 40 for 3 hours
- Normal echocardiography
ECMO contra-indications

- Patients with irreversible conditions
- Chronic pulmonary disease
- Bleeding problems
- Documented irreversible brain damage
- Progressively degenerative systemic disease
Decision to Institute ECMO

- Several considerations must be weighed:
  - Likelihood of organ recovery: only appropriate if disease process is reversible with therapy and rest on ECMO
  - Cardiac recovery: to either wait for further cardiac recovery to allow implant of device (LVAD) or to list for transplantation.
  - Disseminated malignancy
  - Advanced age
  - Graft vs. host disease
  - Known severe brain injury
  - Unwitnessed cardiac arrest or cardiac arrest of prolonged duration.
  - Technical contraindications to consider: aortic dissection or aortic incompetence
THE BEGINNING
Evolution

- 1916 Jay McLean discovered heparin
- 1953 John H Gibbons Jr and his first heart-lung machine
- 1954 C Walton Lillihei and controlled-cross circulation – first biological extracorporeal oxygenation
- 1970, Baffes et al reported successful use of ECMO in infants CHD after undergoing cardiac surgery
John H Gibbon
and his heart-lung machine
C Walton Lillehei and controlled cross circulation for open heart surgery
Illustration of controlled cross-circulation as described by Walton Lillehei in 1954.
Cardiopulmonary bypass
CPB and ECMO
## ECMO

<table>
<thead>
<tr>
<th>CPB</th>
<th>ECMO</th>
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<tbody>
<tr>
<td>1. Membrane oxygenator</td>
<td>1. Silicone membrane</td>
</tr>
<tr>
<td>2. Longer tubing system</td>
<td>2. Smaller tubing system</td>
</tr>
<tr>
<td>3. Ordinary membrane oxygenator up to only 8 hr</td>
<td>3. Longer function oxygenator up to 5-7 days</td>
</tr>
<tr>
<td>4. Hard shell reservoir</td>
<td>4. Small soft bladder reservoir</td>
</tr>
<tr>
<td>5. High-dose heparinisation</td>
<td>5. Lower and titratable heparinisation</td>
</tr>
</tbody>
</table>
First successful ECLS in an adult
ECMO for “Hope” Esperanza

Robert H. Bartlett, M.D.

“...In 1975 we were asked to see a newborn infant with meconium aspiration and persistent fetal circulation in the neonatal ICU. We attached this little girl to our laboratory heart-lung machine. The nurses named this child Esperanza, "hope" in Spanish. After three days on extracorporeal support Esperanza recovered, leading to continued application of this technology to other newborn infants with respiratory and cardiac failure from a variety of problems.”
ECMO for “Hope” Esperanza
ECMO

- Dr Bartlett’s idea
- “We spoke of one week ECMO as if it was like flying to the moon“
- Developed the concept of titrating heparin—which substantionally reduced bleeding complications.
- Refined circuit design with exclusion of stagnant flow areas.
Phil Drinker, PhD
PROLONGED EXTRACORPOREAL PARTIAL BYPASS

Heparin Requirement

2.0 mg/Kg LOADING DOSE

HEPARIN DOSE
mg/Kg/hr

0.8
0.6
0.4
0.2

0
1
2
3
4
5
DAYS

Drinker and Bartlett, 1968
PROLONGED EXTRACORPOREAL PARTIAL BYPASS
Physiologic Effects

- $\text{pO}_2$
- $\text{pCO}_2$
- Platelets
- Plasma HB
- BUN
- Lactate
- Respiration
- B.P. mean
- Flow

Drinker and Bartlett, 1968
Esperanza at 34 years old
THE CURRENT ERA
Current advances

- Expanded indications
- Rationale use
- Advancing perfusion technology
Category I: Cardiac support

- In case of low cardiac output or cardiac dysfunction of any cause and unresponsive to inotropic drugs and intra-aortic balloon pump.
- Post-cardiac surgery
- Post acute myocardial infarction with cardiogenic shock
- Acute fulminating myocarditis
- End-stage CHF
- Post-CPR (extracorporeal CPR, ECPR)
Indication for ECMO in adult cardiac failure is cardiogenic shock:

- Inadequate tissue perfusion manifested as hypotension and low cardiac output despite adequate intravascular volume.
- Shock persists despite volume administration, inotropes and vasoconstrictors, and intraaortic balloon counterpulsation if appropriate.
- Typical causes: Acute myocardial infarction, Myocarditis, Peripartum Cardiomyopathy, Decompensated chronic heart failure, Post cardiotomy shock.
- Septic Shock is an indication in some centres.
Guidelines on relative survival without ECMO:

Options for temporary circulatory support

- Surgical temporary VAD: Abiomed, Levitronix
- Percutaneous VAD: TandemHeart, Impella
- ECMO: Advantages: Biventricular support, bedside immediate application, oxygenation, Biventricular failure, Refractory malignant arrhythmias, Heart failure with severe pulmonary failure
- ECMO is a bridge to...
  - Recovery: Acute MI after revascularisation, Myocarditis, Postcardiotomy
  - Transplant: Unrevascularisable acute MI, Chronic heart failure
  - Implantable circulatory support: VAD, TAH
ECPR group

Indications

- AHA guidelines for CPR recommends consideration of ECMO to aid cardiopulmonary resuscitation in patients who have an easily reversible event, have had excellent CPR.

Contraindications:

- All contraindications to ECMO use (such as Gestational age < 34 weeks) should apply to ECPR patients.

Futility: Unsuccessful CPR (no return of spontaneous circulation) for 5-30 minutes.

ECPR may be indicated on prolonged CPR if good perfusion and metabolic support is documented.
Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis

Yih-Shiang Chen\textsuperscript{a}, Jou-Wei Lin\textsuperscript{a}, Hsi-Yu Yu, Wen-Je Ko, Jin-Shin Jeng, Wei-Tien Cheng, Wen-Jue Chen, Shu-Chien Huang, Nai-Hsin Chi, Chih-Hsin Wang, Li-Chin Chen, Pi-Ru Tsai, Shien-Shen Wang, Juey-Jen Hwang, Fang-Yue Lin

Summary

Background Extracorporeal life-support as an adjunct to cardiac resuscitation has shown encouraging outcomes in patients with cardiac arrest. However, there is little evidence about the benefit of the procedure compared to conventional cardiopulmonary resuscitation (CPR), especially when continued for more than 30 min. We assessed whether extracorporeal CPR was better than conventional CPR for patients with in-hospital cardiac origin.

Cardiology in the Young (2011), 21(Suppl. 2), 109–117
doi:10.1017/S1047951111003168

Original Article

Extracorporeal cardiopulmonary resuscitation for post-operative cardiac arrest: evaluation of techniques, controversies, and early results

Paul J. Chai,\textsuperscript{1} Jeffrey P. Jacobs,\textsuperscript{1} Heidi J. Dalton,\textsuperscript{2} John M. Costello,\textsuperscript{2} David S. Cooper,\textsuperscript{3} Roxanne Kirsch,\textsuperscript{4} Tami Rosenthal,\textsuperscript{5} Joseph N. Graziano,\textsuperscript{6} James A. Quintessenza\textsuperscript{1}

\textsuperscript{1}The Congenital Heart Institute of Florida, All Children’s Hospital, Saint Petersburg, Florida; \textsuperscript{2}Division Chief and Professor of Child Health, Phoenix Children’s Hospital and University of Arizona College of Medicine, Phoenix; \textsuperscript{3}Children’s Memorial Hospital, Feinberg School of Medicine, Northwestern University, Chicago, Illinois; \textsuperscript{4}Children’s Hospital of Philadelphia, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, United States of America

Benefit of ECPR over conventional CPR in in-hospital witness arrest

A 5-year experience with cardiopulmonary resuscitation using extracorporeal life support in non-postcardiomyotomy patients with cardiac arrest

Assad Hany\textsuperscript{a,b}, Alois Philipp\textsuperscript{a}, Claudius Dietz\textsuperscript{a}, Simon Schopka\textsuperscript{a}, Thomas Bein\textsuperscript{a}, Markus Zimmermann\textsuperscript{a}, Matthias Lubnow\textsuperscript{a}, Andreas Luchner\textsuperscript{a}, Ayman Agha\textsuperscript{a}, Michael Hilker\textsuperscript{a}, Stephan Hirt\textsuperscript{a}, Christoph Schmidt\textsuperscript{a}, Thomas Müller\textsuperscript{a}

\textsuperscript{a}Dept. of Cardiac Surgery, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93042 Regensburg, Germany
\textsuperscript{b}Dept. of Cardiology, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93042 Regensburg, Germany
\textsuperscript{c}Dept. of Intensive Medicine I, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93042 Regensburg, Germany
\textsuperscript{d}Dept. of Surgery, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93042 Regensburg, Germany

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\textsuperscript{d}Dept. of Surgery, University Medical Center Regensburg, Franz-Josef-Strauss-Allee 11, D-93042 Regensburg, Germany
Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis

- Of the 975 patients with in-hospital cardiac arrest events who underwent CPR for longer than 10 min, 113 were enrolled in the conventional CPR group and 59 were enrolled in the extracorporeal CPR group. Unmatched patients who underwent extracorporeal CPR had a higher survival rate to discharge (log-rank p<0.0001) and a better 1-year survival than those who received conventional CPR (log rank p=0.007). Between the propensity-score matched groups, there was still a significant difference in survival to discharge (hazard ratio [HR] 0.51, 95% CI 0.35–0.74, p<0.0001), 30-day survival (HR 0.47, 95% CI 0.28–0.77, p=0.003), and 1-year survival (HR 0.53, 95% CI 0.33–0.83, p=0.006) favouring extracorporeal CPR over conventional CPR.

The Lancet, 372(9638), p554–561
ECMO and acute myocarditis

Pathogenesis

Direct myocyte injury

Acute Myocarditis
- Viral infection
- Myocyte necrosis
- Macrophage activation
  - Cytokine expression
    - Interleukin-1
    - Interleukin-2
    - Tumor necrosis factor
    - Interferon-γ

Subacute Myocarditis
- Infiltrating mononuclear cells
  - Natural killer cells
  - Perforin
  - Nitric oxide
- Cytotoxic T lymphocytes
- B lymphocytes
- Neutralizing antibodies

Chronic Myocarditis
- Fibrosis
- Cardiac dilatation
- Heart failure

Immunological activation

Autoimmune mediated

(Magnani JW, Dec GW. “Myocarditis: current trends in diagnosis and treatment.” Circulation. 2006 Feb 14;113(6):876-90.)
MCS Devices to support Myocarditis

Acute Myocarditis

Fulminant Myocarditis
Lung Injury
CPR

ECMO

Heart Failure / DCM
Slow Deterioration
Increasing Support

Short Term VAD
Durable VAD

Type of MCS in Myocarditis

Ghelani S. Circ Cardiovascul Qual Outcomes 2012

Limited data:
No recovery of ejection by 72 hours
Inability to wean by day ~ 7 of support
Rationale behind ECMO support for myocarditis

- Timely ECMO deployment
- Early LV decompression
  - Promotes Myocardial Recovery
  - Decreased lung Injury due to decreased LAP
- Timely transition to VAD & Heart Transplantation evaluation
Category II

Respiratory support

- Adult respiratory failure
- Neonatal respiratory failure
- Paediatric respiratory failure
**Category II: adult**

**Indications**

- In hypoxic respiratory failure due to any cause (primary or secondary) ECLS should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of mortality is 80% or greater.
  - 50% mortality risk is associated with a PaO$_2$/FiO$_2$ < 150 on FiO$_2$ > 90% and/or Murray score 2-3.
  - 80% mortality risk is associated with a PaO$_2$/FiO$_2$ < 100 on FiO$_2$ > 90% and/or Murray score 3-4 despite optimal care for 6 hours or more.
- CO$_2$ retention on mechanical ventilation despite high Pplat (>30 cm H$_2$O)
- Severe air leak syndromes
- Need for intubation in a patient on lung transplant list
- Immediate cardiac or respiratory collapse (PE, blocked airway, unresponsive to optimal care)
CESAR: conventional ventilatory support vs extracorporeal membrane oxygenation for severe adult respiratory failure

Giles J Peek*,1, Felicity Clemens2, Diana Elbourne2, Richard Firmin1, Pollyanna Hardy2,3, Clare Hibbert5, Hilliary Killer1, Miranda Mugford4, Mariamma Thalanany4, Ravin Tiruvoipati1, Ann Truesdale2 and Andrew Wilson6

Address: 1Department of Cardiothoracic Surgery, Glenfield Hospital, Groby Road, Leicester, LE3 9QP, UK, 2Medical Statistics Unit, London School of Hygiene and Tropical Medicine, Keppel St, London WC1E 7HT, UK, 3Clinical Epidemiology and Biostatistics Unit, Royal Children’s Hospital, Melbourne, Australia, 4School of Medicine Health Policy and Practice, University of East Anglia, Norwich, NR4 7TJ, UK, 5School of Health and Related Research, University of Sheffield and RTI Health Solutions, Williams House Manchester Science Park, Manchester ME15 6SE, UK and 6Department of Health Sciences, University of Leicester, Leicester General Hospital, Leicester, LE5 4PW, UK

Email: Giles J Peek* - giles.peek@uhl-tr.nhs.uk; Felicity Clemens - Felicity.clemens@lshtm.ac.uk; Diana Elbourne - diana.elbourne@lshtm.ac.uk; Richard Firmin - richard.firmin@uhl-tr.nhs.uk; Pollyanna Hardy - polly.hardy@mcri.edu.au; Clare Hibbert - chibbert@rti.org; Hilliary Killer - hilliary.killer@uhl-tr.nhs.uk; Miranda Mugford - m.mugford@uea.ac.uk; Mariamma Thalanany - M.Thalanany@uea.ac.uk; Ravin Tiruvoipati - rt67@leicester.ac.uk; Ann Truesdale - ann.truesdale@lshtm.ac.uk; Andrew Wilson - aw7@le.ac.uk
* Corresponding author

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Paediatric respiratory failure

**Indications:** consideration for ECMO is best within the first 7 days of mechanical ventilation at high levels of support

**Contraindications**

- Recent neurosurgical procedures or intracranial bleeding (within 10 days). Grade II or III intracranial haemorrhage is a general contraindication.
- Recent surgery or trauma: increased risk of bleeding. Care to maintain adequate coagulation factors, platelet counts and use of low ACT’s (160-180) may be helpful.
- Age and size: No weight limit although obese patients (especially >100kgs) may require special beds, have high risk of decubiti. May also be more difficult to cannulate.
- Patients with severe neurologic compromise, genetic abnormalities (not including Trisomy 21).
- Relative: end-stage hepatic failure, renal failure, primary pulmonary hypertension.
ECMO indications

- Oxygenation index (OI): if > 40 predicts 80% mortality without ECMO

\[
\frac{MPaw \cdot FiO2 \cdot 100}{PO2(mmHg)}
\]

- MPaw

\[
\frac{(Paw \cdot Ti) + (PEEP \cdot Te)}{Ti + Te}
\]
Neonatal respiratory failure

Contraindications:
- Lethal chromosomal disorder (includes trisomy 13, 18 but not 21) or other lethal anomaly
- Irreversible brain damage
- Uncontrolled bleeding
- Grade III or greater intraventricular haemorrhage.

Relative contraindications include
- Irreversible organ damage (unless considered for organ transplant)
- <2 Kg
- <34 weeks GA because of the increased incidence of increased intracranial haemorrhage.
- Mechanical ventilation greater than 10-14 days.
- Patients with disease states with a high probability of a poor prognosis.
Extracorporeal membrane oxygenation (ECMO)

Queen Elizabeth II visited one of ECMO patients at GOSH on its 150th anniversary on 14 February 2002.
Extracorporeal membrane oxygenation (ECMO)

- Principle of cardiopulmonary bypass
- VA ECMO
- VV ECMO
## Difference between VA and VV ECMO

<table>
<thead>
<tr>
<th>Hemodynamics</th>
<th>V-A</th>
<th>V-V</th>
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<tbody>
<tr>
<td>Systemic perfusion</td>
<td>Circuit flow and cardiac output</td>
<td>Cardiac output</td>
</tr>
<tr>
<td>Art. BP</td>
<td>Pulse is damped</td>
<td>Pulse is full</td>
</tr>
<tr>
<td>CVP</td>
<td>Accurate guide to volume status</td>
<td>Not helpful</td>
</tr>
<tr>
<td>PA Pressure</td>
<td>Decrease in proportion to ECC flow</td>
<td>Not affected by flow</td>
</tr>
</tbody>
</table>
### Difference between VA and VV

<table>
<thead>
<tr>
<th>Gas exchange</th>
<th>V-A</th>
<th>V-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial oxygenation</td>
<td>Sat controlled by ECC flow</td>
<td>80-95% sat common for maximum flow</td>
</tr>
<tr>
<td>CO2 removal</td>
<td>Depends of gas sweep and surface area of membrane</td>
<td>Same as VA</td>
</tr>
<tr>
<td>Decrease ventilator setting</td>
<td>Rapidly</td>
<td>Slowly</td>
</tr>
</tbody>
</table>
Equipments for ECMO

- Pump: roller or centrifugal
- Membrane oxygenator
- Bladder reservoir
- Tubing
- Cannula
- Air bubble detector
- Heat exchanger
- Additional equipment: haemofiltration
The Heart

- Roller pump
- Centrifugal pump
- Non pulsatile
- Pulsatile is more physiological
ECMO

- Membrane oxygenator
- Avoid direct contact between oxygen and red blood cell
- Less thrombogenic effect
- Suitable for prolonged use

2 major types
- Hollow fiber
- Silicone membrane
Membrane oxygenator

MEMBRANE OXYGENATOR

SWEEP GAS FLOW

PO2  100 kPa

SILICON MEMBRANE

PCO2  6.5 kPa

BLOOD FLOW

PO2  100 kPa

PvO2  4.5 kPa
Silicone membrane
• Silicone membrane
• Rolled silicone sheet
• Plasma leak
Hollow fiber
Current oxygenator

- Hallow fiber
- Polymethylpentene
- Heparin-coated
- Effective in
  - Blood oxygenation
  - CO$_2$ elimination
  - Low pressure drop
- Last 15-21 days
ECMO cannulae
ECMO cannulae

Bio-Medicus Venous Cannulae

Bio-Medicus Venous Cannulae Tip
Multiple Wholes
Bladder reservoir

- Soft silicone bag
- Observe amount of blood coming in and out the reservoir
Heat exchanger
Pressure monitor and flow detector

- Pre-membrane and post-membrane pressure monitor
- Flow detector
ECMO techniques and cannulation

- Common sites
  1. Venous
     a. right atrium
     b. femoral vein
     c. jugular vein
  2. Arterial
     a. aortic
     b. carotid artery
     c. femoral artery
     d. axillary artery
ECMO cannulation
ECMO circuits
Initiation and maintenance of ECMO

- Circuit setup
- Heparinisation
- Cannulation
- Flow:
  - Paediatric 100-150 ml/kg/min
  - Adult 80 – 100% cardiac output
- Monitoring
Haemodynamic support

- Inotropic drugs: Dopamine, Dobutamine, etc.
- In some cases: Noradrenaline may be needed because of low SVR. Blood pressure generated by ECMO depends upon ECMO flow and SVR.

\[ MABP = \text{Flow} \times SVR \]

- Fluid replacement
- Blood component
Ventilatory management

• “Rest setting”
• Rate 10 bpm
• FiO$_2$ 0.21
• PEEP 10
• PIP 20
• Increased ventilation setting may be used for VV ECMO or cardiac ECMO
Monitoring

- pO2 60-80 mmHg
- pCO2 40-45 mmHg
- pH 7.40
- ACT 180-250 sec. (vary from institution to institution), present 160-180 sec.
- Fluid intake and output should be balanced
- Respiratory tidal volume of 10ml/kg
Haematocrit

For VV ECMO:
Keep 40-45 %

For VA ECMO
Keep > 40%
Anticoagulation management

- **Loading of heparin**: 100 units/kg/dose (70 units/kg/dose before cannulation)
- **Maintenance**: 30 – 60 units/kg/hour
  - Add heparin 25 units/kg in 1ml of 0.9%NaCl or 5% D/W 50 ml
  - Start infusion when ACT < 350 sec.
Anticoagulation monitoring

- Activated clotting time (ACT)
- Use diatomaceous earth as the activator
- Required level 180-250 sec. (GOSH 170-200 sec.)
- Maintained by continuous heparin infusion
Anticoagulation monitoring
Cerebral monitoring

• Electroencephalography: periodically done in case of monitoring CNS function
Applications of ECMO

- Cardiopulmonary support
- Bridge to recovery
- Bridge to destination
- Bridge to bridge
- Bridge to transplantation
ECMO as a bridge to bridge

- “...Strategy of ECLS to implantable LVAD bridge to heart transplant in adult patients who are in need of circulatory support and who are not initially candidates for other forms of mechanical support. The favorable results of this strategy support utilization of ECLS even in situations where myocardial recovery is thought to be unlikely.”

Francis D. Pagani, MD, PhD, Keith D. Aaronson, MD, Fresca Swaniker, MD, and Robert H. Bartlett, MD Ann Thorac Surg 2001;71:S77–81
Possible complications

- Pump Failure
- Decannulation
- Circuit Rupture
- Air Embolism
- Cardiac Arrest
- Oxygenator Failure
ECMO experience
Experience at Ramathibodi
Recent case
Example
Pre-hospital ECMO cannulation
Future>>>
THANK YOU FOR YOUR ATTENTION