ECMO as Bridge to Left Ventricular Assist Device and Heart Transplant

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Disclosure

- Unrestricted international training grants
  - Thoratec / St. Jude
  - HeartWare / Medtronic
Case Presentation (1)

• 44 yo M presented with chest pain to referring hospital
  – STEMI
  – IABP intraoperatively
  – CABG x3: LIMA-LAD, SVG- OM, SVG-PDA

• Post-op Day 3
  – On the floor
  – VT arrest, CPR
  – Return to OR
Case Presentation (2)

- 44 yo M presented with chest pain
  - STEMI
  - IABP intraoperatively
  - CABG x3: LIMA-LAD, SVG- OM, SVG-PDA

- Post-op Day 3
  - On the floor
  - VT arrest, CPR
  - Return to OR in cardiogenic shock....
Shock – Classification

• Cardiogenic
  – Primary pump failure
  – Most commonly myocardial dysfunction
    • Loss of myocardium
    • Reduced contractility
  – Ventricular outflow obstruction
  – Ventricular filling anomalies
  – Acute valve failure
  – Cardiac dysrhythmias
  – Ventriculoseptal defects
Etiology of Acute Cardiogenic Shock

- POST-CARDIOTOMY
- Acute MI / Post-infarct VSD
- Blunt cardiac trauma
- Idiopathic
- Valvular
- Infiltrative (amyloid, sarcoid, giant cell)
- Anthracycline or cardiotoxin induced
- Post-partum* / Viral myocarditis*
- Alcoholic* / drug-related (cocaine/methamphetamine)
- Dysrhythmias
- Primary graft dysfunction post transplant

*potentially reversible
Post-Cardiotomy Shock: Etiologies

- Inadequate myocardial protection
- Prolonged cross clamp time
- Left ventricular distention
- Coronary embolization
- Insufficient revascularization
- Surgical technique
- Poor cardiac reserve
- Air embolus
Cardiogenic Shock

- Left ventricular failure
  - Acute loss of > 40% of left ventricular function
  - High associated mortality
  - Physical examination
    - Peripheral vasoconstriction
    - Hypotension
    - Tachycardia
    - Oliguria
    - Pulmonary, peripheral edema

- Right ventricular failure
  - Better prognosis than LV failure
  - Most often from inferior MI
  - Decreased PA pressure, elevated RV diastolic pressure
Shock: Diagnostic Studies

- Laboratory: CBC, CMP, BNP, troponin, lactate, ABG/VBG
- Electrocardiogram
- Echocardiography
- Radiographic studies: CXR, CT
- Cardiac catheterization
  - Left heart: coronary anatomy, valvular and LV function
  - Right heart: hemodynamic measurements
Hemodynamic Assessment

- Right Ventricle
- Left Ventricle
- Pulmonary
- Systemic
- RVSWI
- MPAP
- CVP
- PAOP
- MAP
- LVSWI
Hemodynamic Variables

- Measured
  - HR    CO    SBP    DBP
  - CVP   PAS   PAD   PAOP

- Calculated
  - CI     BSA   MAP   MPAP
  - SVRI   PVRI
  - LVSWI  RVSWI
  - SV     SVI
  - Coronary PP
  - Cerebral PP
Oxygen Transport

Right Ventricle

Systemic

RVSWI

MPAP

Pulmonary

CcO$_2$

PAO$_2$

LVSWI

LVSWI

CaO$_2$

PaO$_2$

SaO$_2$

CvO$_2$

PvO$_2$

SvO$_2$

Ca-vO$_2$

OUC
Oxygenation Variables

• Measured
  – PaO₂  PaCO₂
  – SaO₂  SvO₂  PvO₂
  – Hgb

• Calculated
  – DO₂  VO₂
  – CaO₂  CvO₂
  – Ca-vO₂
  – OUC  RQ  Qsp/Qt
Cardiac Power

• Cardiac power is the strongest hemodynamic predictor of mortality in cardiogenic shock....” Finke, et al. JACC 44:2;2004. p340-8

• SHOCK Trial Registry (n = 541)

• Cardiac Power Output = MAP x CO / 451

• Cardiac Power Output Index = MAP x CI / 451

• CPO of 0.53 watts most accurately predicted mortality
  – ≤ 0.53W = 58% mortality
  – > 0.53W = 71% survival
Therapeutic Options

- ECMO
- CentriMag
- TandemHeart
- Impella
- IABP
- Drugs

Invasiveness

Improvement in cardiac performance
Case Presentation (3)

• Intraop Exploration
  – Placed back on CPB
  – Flow measured in 3 grafts

• Decision
  – Consulted with regional ECMO center surgeon
  – VA ECMO instituted
  – Stabilized for 24 hours
  – Transfer to regional ECMO center
Indications for VA-ECMO

- Cardiogenic shock with inability to oxygenate 2° to cardiovascular insults
  - Acute MI and complications
  - Decompensated heart failure
  - Post-partum cardiomyopathy
  - Bridge to durable VAD support
  - Bridge to heart transplant....

- Post-cardiotomy shock

- Absence of non-reversible organ failure
  - Neurologic
  - Underlying end-stage malignancies
Central VA ECMO Cannulation
Technical Considerations for VA-ECMO

• Anticoagulation / Bleeding
  – Initial anticoagulation to go on ECMO support: ACT 180-200
  – Correct all coagulopathy and thrombocytopenia
  – Do not start anticoagulation until bleeding is controlled
  – With good flow in circuit, safe to be off anticoagulation or 24-48 hours
  – Heparin, bivalirudin, etc... (PTT 40-60 sec)

• Hemodynamic monitoring
  – PA catheter not necessary until weaning
  – R/L radial arterial line for peripheral femoral cannulation
  – Patient is the reservoir in ECMO: may need more volume

• Avoiding low flow and stasis in the LV
  – LV vent
  – Inotropic support while on ECMO
Too much of a good thing....
Guide to Success

• **Partnership / Collaboration**
  – External partnership:
    • Establish channels of communication
    • Education – indications for ECMO
    • Education – cannulation techniques / circuit setup
    • Education – patient stabilization / management

• Internal Multi-disciplinary team
Case Presentation (4)

• POD 4 ECMO 2
  – Transferred to IU Health Methodist Hospital
  – Lifeline and ECMO specialists on transfer

• ECMO Day 9
  – Extubated
  – Central ECMO cannulation
  – Flows 4L/min
Case Presentation (5)

- Next Steps?
  - Talk to the patient and family
  - Define goals of therapy
  - How to achieve the goals
Exit Strategy

- Bridge to Recovery
- Bridge to Transplant
- Bridge to a Durable VAD
  - LVAD
  - RVAD
  - BiVADs
  - Total artificial heart
- Bridge-to-Bridge
A Treatment Algorithm...

INTERMACS I Cardiogenic Shock

- **LEFT VENTRICULAR FAILURE**
  - TandemHeart
  - Impella 2.5, 5.0
  - Recovery
  - Transplant
  - Long Term LVAD

- **RIGHT VENTRICULAR FAILURE**
  - TandemHeart RVAD
  - CentriMag RVAD
  - Recovery
  - Transplant
  - Thoratec PVAD

- **BI-VENTRICULAR FAILURE**
  - Bio-Medicus/CentriMag
  - Central ECMO
  - Recovery
  - Transplant
  - Thoratec BiVAD
  - Syncardia TAH
Factors Affecting Choice of Exit Strategy

- Likelihood of reversible process (duration of support)
- Potential transplant candidate?
- Right, left or biventricular involvement
- Neurologic status
- End-organ dysfunction
- Prior co-morbidities
  - Diabetes
  - Tobacco / non-compliance
- Psychiatric / Social support issues / consentability
- Coagulopathy / GI bleed
- Peripheral vascular disease / anatomic issues
Case Presentation (6)

- Attempt to wean off ECMO
  - ECMO day 11 patient sitting on edge of bed
  - Not an immediate candidate for transplant due to active smoking history
  - Identify social support structure
  - Patient uncertain of long-term LVAD
  - Echo EF 15%
• Attempt to wean off ECMO
  – ECMO day 13 circuit change due to clot burden
  – Patient sitting in chair
  – Further family conference to discuss care
  – Patient willing to accept long term LVAD therapy
  – Daily attempt to continue ECMO wean

• ECMO day 14
  – End organ functions normalized
  – ECMO support down to 2.5L/min
  – Walked 200 yards
Ambulatory ECMO

• Plan for it – optimize patient for definitive therapy
  – Cannulation strategy
  – Organized team
  – Exit strategy

• Careful patient selection/action
  – Acute patients
  – Acute on chronic patients
  – End organ function
  – Nutritional status
Ambulatory ECMO
Guide to Success

• Partnership / Collaboration
  – External partnership:
    • Establish channels of communication
    • Education – indications for ECMO
    • Education – cannulation techniques / circuit setup
    • Education – patient stabilization / management

• Internal Multi-disciplinary team

  CT surgery
  Perfusion staff
  Critical Care
  Respiratory Care
  Speech Therapy
  Physical Therapy
  Social Work
  Ethics representative

  CHF/Cardiology/Transplant
  ECMO/VAD Coordinators
  ICU Nursing staff/tech
  Nutrition
  Occupational Therapy
  Pastoral Care
  Consulting services (ID, renal...)
Case Presentation (8)

• Attempt to wean off ECMO
  – ECMO day 15 attempt wean with echo: no recovery
  – ECMO day 16 attempt wean with echo: no recovery
  – Daily ambulation
  – Decision to proceed with LVAD implantation
Case Presentation (9)

• LVAD implantation
  – ECMO day 17: OR
    • Use existing cannula for establishing CPB
    • HeartMate-II implanted
    • Chest packed
  – POD 1: return to OR for washout
  – POD 3: return to OR for delayed sternal closure
  – POD 5: extubated
  – POD 6: echo EF 25% on LVAD support
Case Presentation (10)

• Post-LVAD course
  – POD 7: transfer to step-down unit
  – POD 20: transfer to local rehabilitation facility
    • RPM 9800
  – POD 27: discharged to home; NYHA class II
  – POD 48: NYHA class I
    • LVAD 9400 rpm
    • EF 45%
Next Steps?

- Plan for heart transplant
- Complete evaluation
- Continue ambulation, increase exercise tolerance
Heart transplant in ECMO patients

- Impact of heart transplantation on survival in patients on VA ECMO at listing in France
  - Transplantation 2016(9);100:1979-87
  - French allocation system: priority for VA ECMO and inotrope-dependent patients
  - Retrospective analysis of CRISTAL registry from 1/2010-12/2011
  
- Patients on
  - Inotropes 35%
  - VAD 13%
  - VA ECMO 15%
Heart transplant in ECMO patients

Total N=866

Comparison group N=786

Without MCS N=703

Long-term MCS N=60
+/- ECMO (N=9) or +/- Balloon (n=2)

VAD N=51
+/- ECMO (N=7) or +/- Balloon (n=2)

Temporary MCS other than ECMO N=23

Total artificial heart N=9
+/- ECMO (N=2)

Intra-aortic balloon pump N=23

Study group N=80

ECMO N=80
+/- balloon (n=12)

Transplant 2016(9);100:1979
Heart transplant in ECMO patients

- ECMO at listing: N=80
- ECMO at transplantation (1):
  - N=46
- Long-term MCS at transplantation:
  - N=9
- Not transplanted (2):
  - N=25

Transplant 2016(9):100:1979
Heart transplant in ECMO patients

• Impact of heart transplantation on survival in patients on VA ECMO at listing in France
  – Transplantation 2016(9);100:1979-87
  – Outcomes measured
    • Primary: survival after listing
    • Secondary:
      – Survival after transplantation
      – Competing outcomes on the waiting list (transplant, death, delisting, and waiting for transplant )and inotrope-dependent patients
Heart transplant in ECMO patients

ECMO (n=80)  
Comparison (n=786)
Post-transplant survival in ECMO patients

### Table: Survival Rates

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>1-month Survival</th>
<th>3-month Survival</th>
<th>1-year Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison group</td>
<td>617</td>
<td>88,3% [85,5% - 90,6%]</td>
<td>84,3% [81,2% - 87,0%]</td>
<td>80,7% [77,3% - 83,6%]</td>
</tr>
<tr>
<td>Number of patients at risk*</td>
<td>535</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study group</td>
<td>55</td>
<td>79,7% [66,3% - 88,2%]</td>
<td>77,8% [64,3% - 86,8%]</td>
<td>70,4% [56,3% - 80,7%]</td>
</tr>
<tr>
<td>Number of patients at risk*</td>
<td>43</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Comparison group:*

- N: 617
- 1-month Survival: 88,3% [85,5% - 90,6%]
- 3-month Survival: 84,3% [81,2% - 87,0%]
- 1-year Survival: 80,7% [77,3% - 83,6%]

*Study group:*

- N: 55
- 1-month Survival: 79,7% [66,3% - 88,2%]
- 3-month Survival: 77,8% [64,3% - 86,8%]
- 1-year Survival: 70,4% [56,3% - 80,7%]

*Comparison group:*

- N: 617
- 1-month Survival: 88,3% [85,5% - 90,6%]
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*Study group:*

- N: 55
- 1-month Survival: 79,7% [66,3% - 88,2%]
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- 1-year Survival: 70,4% [56,3% - 80,7%]
Conditional survival in ECMO patients

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<th>Group</th>
<th>N</th>
<th>1-month Survival</th>
<th>3-month Survival</th>
<th>1-year Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison group</strong></td>
<td>537</td>
<td>97.6% [95.9% - 98.6%]</td>
<td>94.4% [92.1% - 96.1%]</td>
<td>91.6% [88.9% - 93.7%]</td>
</tr>
<tr>
<td>Number of patients at risk*</td>
<td>523</td>
<td>506</td>
<td>473</td>
<td></td>
</tr>
<tr>
<td><strong>Study group</strong></td>
<td>43</td>
<td>97.7% [84.6% - 99.7%]</td>
<td>97.7% [84.6% - 99.7%]</td>
<td>88.3% [74.2% - 95.0%]</td>
</tr>
<tr>
<td>Number of patients at risk*</td>
<td>42</td>
<td>42</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
Temporary Support before LVAD Implant

- Clinical outcomes of advanced heart failure patients with cardiogenic shock treated with temporary circulatory support before durable LVAD implant
  - ASAIO J 2016;62:20-7
    - INTERMACS 1 patients
    - ECMO vs TandemHeart vs direct LVAD implant
# INTERMACS Profile

<table>
<thead>
<tr>
<th>Profile</th>
<th>Description</th>
<th>Time Frame for Definitive Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Patient with life-threatening hypotension despite rapidly escalating inotropic support, critical organ hypoperfusion with increasing lactate levels and/or systemic acidosis. “Crash and burn”</td>
<td>Needed within hours</td>
</tr>
<tr>
<td>2</td>
<td>Patient with declining function despite intravenous inotropic support, may be manifest by worsening renal function, nutritional depletion, inability to restore volume balance. “Sliding on inotropes”</td>
<td>Needed within few days</td>
</tr>
<tr>
<td>3</td>
<td>Patient with stable blood pressure, organ function, nutrition, and symptoms on continuous intravenous inotropic support, but demonstrating repeated failure to wean owing to recurrent symptomatic hypotension or renal dysfunction. “Dependent stability”</td>
<td>Elective over a few weeks</td>
</tr>
<tr>
<td>4</td>
<td>Patient can be stabilized close to normal volume status but experiences frequent relapses into fluid retention, generally with high diuretic doses. Symptoms are recurrent rather than refractory. More intensive management strategies should be considered, which in some cases reveal poor compliance. “Frequent flyer”</td>
<td>Elective over weeks to months as long as treatment of episodes restores stable baseline, including nutrition</td>
</tr>
<tr>
<td>5</td>
<td>Patient is living predominantly within the house, performing activities of daily living and walking from room to room with some difficulty. Patient is comfortable at rest without congestive symptoms, but may have underlying refractory elevated volume status, often with renal dysfunction. “Housebound”</td>
<td>Variable, depends upon nutrition, organ function, and activity</td>
</tr>
<tr>
<td>6</td>
<td>Patient without evidence of fluid overload is comfortable at rest and with activities of daily living and minor activities outside the home, but fatigues after the first minutes of any meaningful activity. “Walking wounded”</td>
<td>Variable, depends upon nutrition, organ function, and activity</td>
</tr>
<tr>
<td>7</td>
<td>A placeholder for future specification, patients without recent unstable fluid balance, living comfortably with meaningful activity limited to mild exertion.</td>
<td>Transplantation or circulatory support not currently indicated</td>
</tr>
</tbody>
</table>

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Temporary Support before LVAD Implant

Patient Population

Primary dVAD Implants (n=427)
163 Inova, Univ of Mich 264

Comparator Group #1
- INTERMACS Profile 2-3 without TCS (n=269)

Excluded (n=85)
- INTERMACS Profile 4-7 (n=43)
- INTERMACS Profile 2-3, Limited Data (n=27)
- Unclassified INTERMACS, no TCS (n=15)

INTERMACS 1 (n=73)

Clinical Allocation

Excluded (n=4)
- Alternate TCS Device (Centrimag = 1, Impella = 3)

Follow-Up

ECMO (n=14)
Operative Mortality (n=6, 43%)
Died within 1-year (n=6, 43%)
Transplanted (n=4, 29%)
Ongoing Support (n=4, 29%)

TandemHeart (n=26)
Operative Mortality (n=3, 12%)
Died within 1-year (n=7, 27%)
Transplanted (n=12, 46%)
Ongoing Support (n=7, 27%)

Direct to dVAD (n=29)
Operative Mortality (n=5, 18%)
Died within 1-year (n=6, 21%)
Transplanted (n=12, 40%)
Ongoing Support (n=6, 21%)
## Temporary Support before LVAD Implant

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ECMO (n = 14)</th>
<th>TandemHeart (n = 26)</th>
<th>Profile 1 (n = 29)</th>
<th>Profile 2–3 (n = 269)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr), median (IQR)</td>
<td>57 (36–63)</td>
<td>54 (48–61)</td>
<td>56 (49–61)</td>
<td>58 (47–64)</td>
<td>0.32</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>13 (93)</td>
<td>18 (69)</td>
<td>19 (68)</td>
<td>212 (80)</td>
<td>0.15</td>
</tr>
<tr>
<td>Caucasian</td>
<td>8 (57)</td>
<td>20 (77)</td>
<td>18 (64)</td>
<td>180 (68)</td>
<td>0.60</td>
</tr>
<tr>
<td>Bridge-to-transplant status</td>
<td>11 (79)</td>
<td>21 (81)</td>
<td>27 (96)</td>
<td>193 (73)</td>
<td>0.043</td>
</tr>
<tr>
<td>Ischemic cardiomyopathy</td>
<td>6 (43)</td>
<td>10 (39)</td>
<td>11 (39)</td>
<td>119 (45)</td>
<td>0.88</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>27.9 (23.4–29.6)</td>
<td>26.6 (23.5–31.2)</td>
<td>26.1 (21.0–29.9)</td>
<td>27.2 (23.0–32.0)</td>
<td>0.53</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>3 (21)</td>
<td>7 (27)</td>
<td>6 (21)</td>
<td>93 (35)</td>
<td>0.32</td>
</tr>
<tr>
<td>Hypertension</td>
<td>7 (50)</td>
<td>6 (23)</td>
<td>12 (43)</td>
<td>139 (53)</td>
<td>0.034</td>
</tr>
<tr>
<td>Stroke/TIA</td>
<td>1 (7)</td>
<td>3 (12)</td>
<td>6 (21)</td>
<td>33 (13)</td>
<td>0.51</td>
</tr>
<tr>
<td>Prior sternotomy</td>
<td>4 (29)</td>
<td>3 (15)</td>
<td>4 (14)</td>
<td>68 (26)</td>
<td>0.38</td>
</tr>
<tr>
<td>Implantable defibrillator</td>
<td>9 (64)</td>
<td>15 (58)</td>
<td>16 (57)</td>
<td>205 (77)</td>
<td>0.02</td>
</tr>
<tr>
<td>ECHO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>10 (10–15)</td>
<td>10 (10–15)</td>
<td>10 (10–20)</td>
<td>15 (10–20)</td>
<td>0.11</td>
</tr>
<tr>
<td>LVEDD (mm), mean ± SE</td>
<td>65 ± 4.2</td>
<td>69 ± 2.5</td>
<td>68 ± 2.7</td>
<td>71 ± 0.8</td>
<td>0.34</td>
</tr>
<tr>
<td>Moderate to severe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR</td>
<td>8 (57)</td>
<td>5 (19)</td>
<td>14 (50)</td>
<td>121 (46)</td>
<td>0.02</td>
</tr>
<tr>
<td>TR</td>
<td>8 (57)</td>
<td>7 (27)</td>
<td>9 (32)</td>
<td>62 (24)</td>
<td>0.34</td>
</tr>
</tbody>
</table>

ECHO, echocardiogram; IQR, interquartile range; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; MR, mitral regurgitation; SE, standard error; TIA, transient ischemic attack; TR, tricuspid regurgitation.
Temporary Support before LVAD Implant

![Graph showing survival rates for different support methods]

Profile 2-3 vs Profile 1 or TandemHeart or ECMO, p < 0.01
ECMO vs TandemHeart vs Profile 1, p = NS

<table>
<thead>
<tr>
<th>Group</th>
<th>Patients at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operative 30-Day</td>
</tr>
<tr>
<td>ECMO</td>
<td>14</td>
</tr>
<tr>
<td>TH</td>
<td>26</td>
</tr>
<tr>
<td>Profile 1</td>
<td>29</td>
</tr>
<tr>
<td>Profile 2-3</td>
<td>269</td>
</tr>
</tbody>
</table>
Case Presentation (12)

• Next Steps

• Post-LVAD 8 months
  – EF 55%
  – Gym membership

• Post-LVAD 10 months
  – LVAD turn down to 8600 rpm
Case Presentation (13)

- Post-LVAD 12 months
  - Cardiac PET: normal myocardial perfusion
  - Transplantation vs Explantation

- Post-LVAD 13 months
  - EF 70%
  - LVAD RPM 8400 then 8000
  - Ramp study
    - RPM 8000  CI 2.1  MAP 87
    - 7000 2.2 83
    - 6000 2.2 81
Case Presentation (14)

- Post-LVAD 14 months
  - Coronary angio: SVG-PDA graft occluded
  - Drug eluting stent to native RCA
- Post-LVAD 17 months
  - LVAD explant via subxyphoid incision
  - POD 1 extubated
  - POD 2 transfer to step down
  - POD 6 discharge home
Guide to Success

• Multi-disciplinary Team
• Timing is everything
• Univentricular vs. biventricular support
• Reversible process
• Successful operation
Conclusions

- Cardiogenic shock is highly varied, complex, and lethal
- Rapid identification and correction of underlying condition is key to improving patient outcome
- VA ECMO circulatory assistance provide successful bridge to decision and recovery
- Survival of heart transplant and LVAD patients following VA ECMO support remains less than patients not requiring VA ECMO support
- VA ECMO remains a viable support for cardiogenic support to provide long term survival
- Multi-disciplinary team is key to successful patient outcome