Il*lumen*ating The Future of Trauma Care: Cutting Edge Endovascular Interventions

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Disclosures

- No relevant commercial relationships to disclose

Objectives

- History of the R. Adams Cowley Shock Trauma Center
- The Golden Hour
- Past Advances in Trauma Care
- Surgeon-Led Endovascular Interventions
  - Case #1: TEVAR
  - Case #2: REBOA
  - Case #3: Solid Organ Embolization
  - Case #4: MARS
  - Case #5: ECMO
- Summary/Conclusion

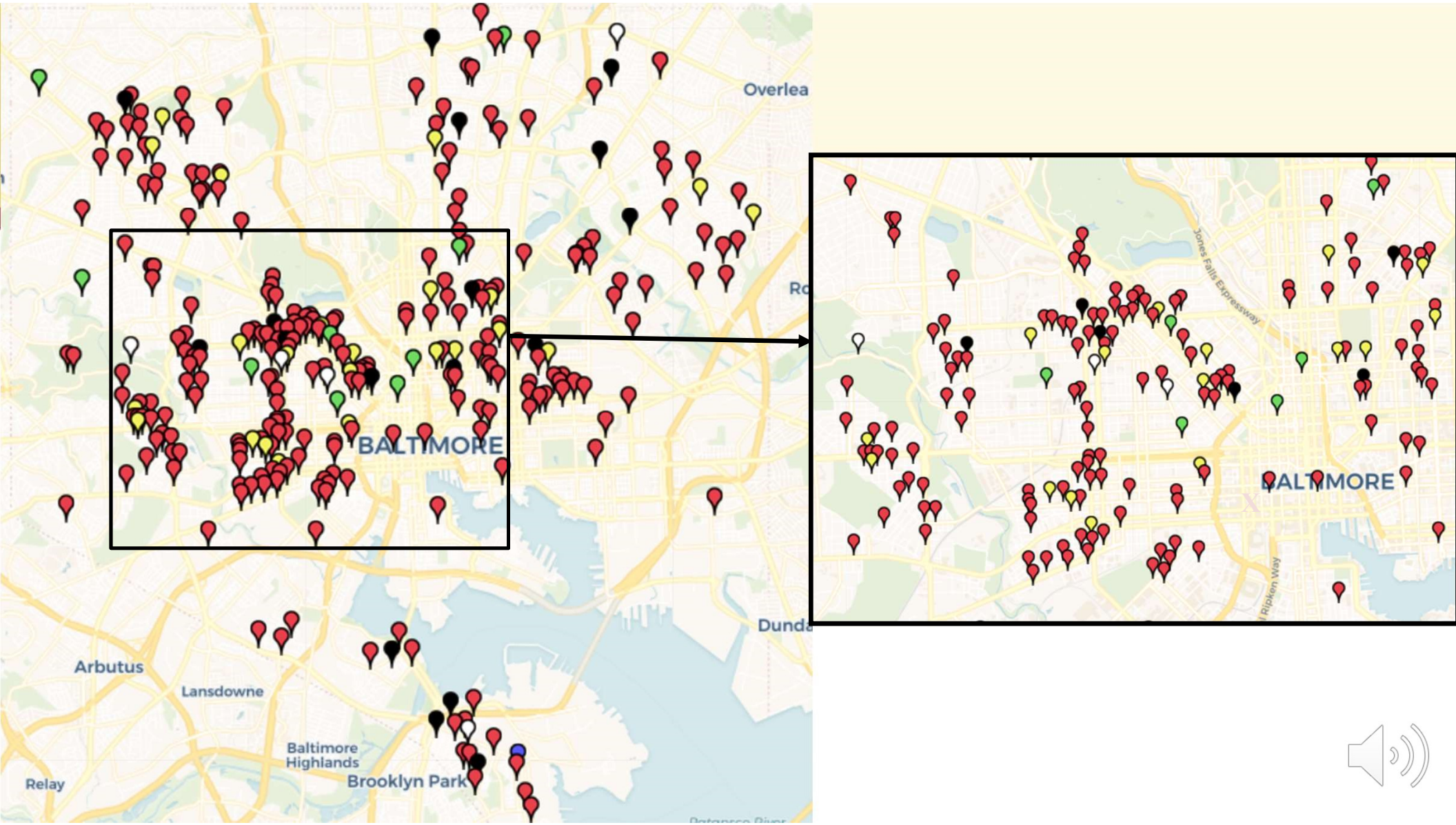
- At the conclusion of this session, participants should be able to:
  - Identify injuries that could be treated with an endovascular intervention
  - Identify common complications of endovascular procedures
  - Identify importance of long-term follow up for patients post-endovascular procedure

Baltimore - Famous

- "Charm City"
- Founded in 1729
- 30th largest city in the country
- Population 615,000
- Notable: Edgar Allen Poe, Babe Ruth, John Waters, The Star-Spangled Banner

Baltimore - Infamous

- 23% live below the poverty line (pre-pandemic)
- 2015 – riots
- 2015 – 2017 – homicide rate ~56/100,000
- 2018 – homicide rate ~ 50/100,000
  681 non-fatal shootings
- Prior to 2015: 600 patients/year for penetrating trauma
- 2015-2016: 800 patients/year
- 2017: over 900 patients/year


Overlea
BALTIMORE
Arbutus
Lansdowne
Baltimore
Highlands
Brooklyn Park
Relay
Jones Falls Expressway
BALTIMORE

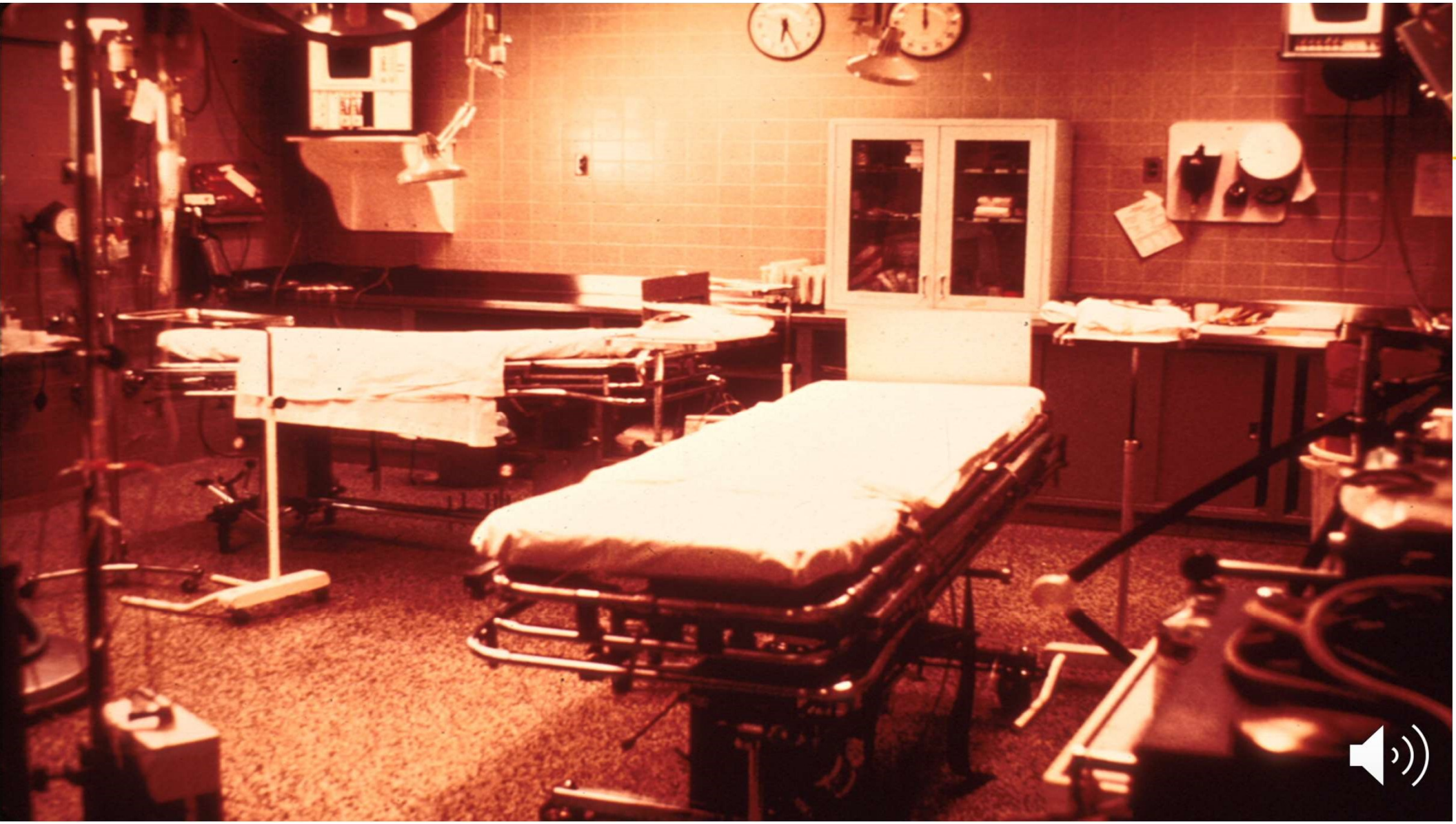
The Golden Hour

"There is a golden hour between life and death. If you are critically injured you have less than 60 minutes to survive. You might not die right then; it may be three days or two weeks later -- but something has happened in your body that is irreparable.“

-- R Adams Cowley

History of the R. Adams Cowley Shock Trauma Center

- Founded by R. Adams Cowley, father of Trauma Care in Maryland
- Received an Army grant to study shock ($100k), started with a 2-bed unit
- 1969 – first MSP medevac transport to the new 32-bed Center for the Study of Trauma
- 1973 – executive order established the Maryland Institute for Emergency Medicine and Division of Emergency Medical Services, led by Dr. Cowley
- 1989 – opening of the R. Adams Cowley Shock Trauma Center
- Largest free-standing trauma center in the country
- Associated with the University of Maryland Medical Center (some shared resources)
- Dr. Cowley then meets with the heads of Hopkins and Baltimore City Hospital (now Hopkins-Bayview) to divide adults, kids, burns



Maryland EMS System

- Headed by the Maryland Institute for Emergency Medical Services Systems, an independent state agency
- Coordinated state-wide network of EMS, communications, transport and receiving hospitals
- Medevac services provided by Maryland State Police, staffed with paramedic-trained sworn officers, funded by vehicle registration fees (no charge to patients)
- Maryland has 9 trauma centers in addition to specialty-designated centers
- Protocol-guided design to get patients to definitive care as quickly as possible

Building on Dr. Cowley's Legacy

- 1997 – Shock Trauma has a new leader, Dr. Thomas Scalea
- Trauma Resuscitation Unit is expanded, and becomes a model for trauma centers around the world
- Partner with US Air Force – Center for Sustainment of Trauma and Readiness Skills (C-STARS)
- New Critical Care Tower houses two unique units: Critical Care Resuscitation Unit and the Lung Rescue Unit
- Development of the Critical Care Network

Anatomy of the Shock Trauma Center

- 8,000 admissions a year, combined primary field admits and inter-facility transfers
- Trauma Resuscitation Unit – 13 bays/26 patients that can also be converted to makeshift OR's if needed
- OR – 11 including a hybrid suite adjacent to the TRU
- PACU – 11 bays
- ICU – 13 neurotrauma beds, 24 multitrauma beds
- IMC – 23 neurotrauma beds, 12 multitrauma beds
- Stepdown – 12 beds
- Capacity – 135+ beds

Trauma Resuscitation Unit (TRU)

Our Resume – Setting the Standard for Trauma Care

- Organized approach to trauma care – now replicated across the world
- Focused Rapid Echocardiographic Evaluation (FREE)
- Continuous Renal Replacement Therapy (CRRT) by intensivists for trauma
- Decompressive laparotomy for intractable intracranial hypertension

J Trauma. 2004 Oct;57(4):687-93; discussion 693-5.

Decompressive laparotomy to treat intractable intracranial hypertension after traumatic brain injury.

Joseph DK[1], Dutton RP, Aarabi B, Scalea TM.

J Trauma. 2011 Jan;70(1):56-62; discussion 62-4. doi: 10.1097/TA.0b013e318207e6ee.

Transthoracic focused rapid echocardiographic examination: real-time evaluation of fluid status in critically ill trauma patients.

Ferrada P[1], Murthi S, Anand RJ, Bochicchio GV, Scalea T.

Intensive Care Med. 1999 Aug;25(8):805-13.

Outcome in post-traumatic acute renal failure when continuous renal replacement therapy is applied early vs. late.

Gettings LG[1], Reynolds HN, Scalea T.

Mil Med. 2015 Mar;180(3 Suppl):74-9. doi: 10.7205/MILMED-D-14-00374.

Focused comprehensive, quantitative, functionally based echocardiographic evaluation in the critical care unit is feasible and impacts care.

Murthi SB[1], Markandaya M[1], Fang R[2], Hong CM[3], Galvagno SM[3], Lissuaer M[1], Stansbury LG[1], Scalea TM[1].

Int J Artif Organs. 2006 Feb;29(2):166-86.

Continuous renal replacement therapy in patients following traumatic injury.

McCunn M[1], Reynolds HN, Reuter J, McQuillan K, McCourt T, Stein D.

Injury Care in the 20th Century

- "Maximally invasive"
- Diagnosis by angiography was the gold standard for vascular injuries, especially blunt aortic injury
- Until recently, emergent open repair of injuries was the only accepted therapy
- Exsanguination from an unknown source below the diaphragm could only be temporized by an "ED" resuscitative thoracotomy and aortic cross-clamp
- "Damage Control" - improved survival
- Operative care remained limited by the lethal triad: hypothermia, coagulopathy and acidosis

- "Minimally invasive"
- Angiography is now part of the therapeutic intervention, with the initial diagnosis now made reliably by high-resolution CT scan
- Transition from Interventional Radiology to Trauma Vascular Surgery

INJURY	OLD WAY	NEW WAY
Blunt Aortic Injury	Open aortic arch repair	TEVAR
Splenic injury	Open splenectomy	Splenic embolization
Hepatic injury	Open packing, resection, etc.	Selective hepatic embolization +/- open intervention
Cardiac arrest /hemorrhagic shock	Open "ED" thoracotomy	REBOA

A Surgical Endovascular Trauma Service Increases Case Volume and Decreases Time to Hemostasis

Jonathan J. Morrison, PhD, FRCS,✉ Marta J. Madurska, MD, Anna Romagnoli, MD, Marcus Ottochian, MD, Sakib Adnan, BS, William Teeter, MD, Tiffany Kuebler, PA-C, Melanie R. Hoehn, MD, Megan L. Brenner, MD, Joseph J. DuBose, MD, and Thomas M. Scalea, MD

- Median time to procedure (hours) was significantly shorter for pelvic angioembolization 3.0 vs 4.3 ($P < 0.001$) and hepatic embolization 2.6 vs 4.3 ($P = 0.03$)
- Statistically significant decrease in LOS, ICU days, and vent days
- Allows for concurrent surgical procedures without having to relocate the patient

Hybrid OR

Case #1

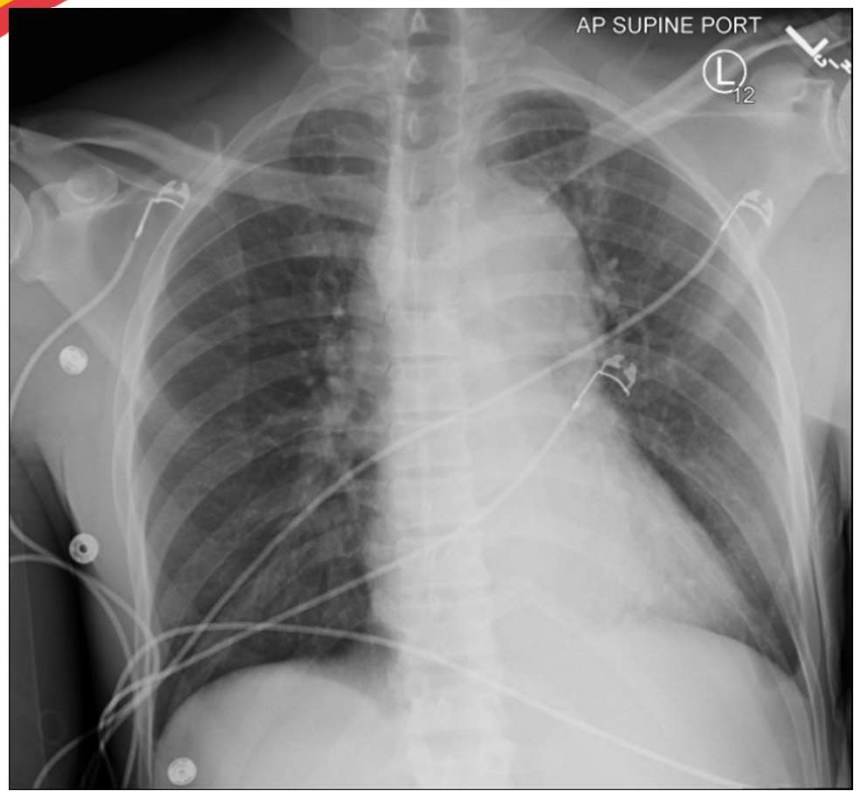
47yo male unknown PMHx transferred from outside hospital s/p motor vehicle collision. Pt was the unrestrained driver vs tree, +LOC, required extrication. On arrival A&O x 2, complaining of chest pain and hip pain. Urine tox positive for cocaine and opioids.

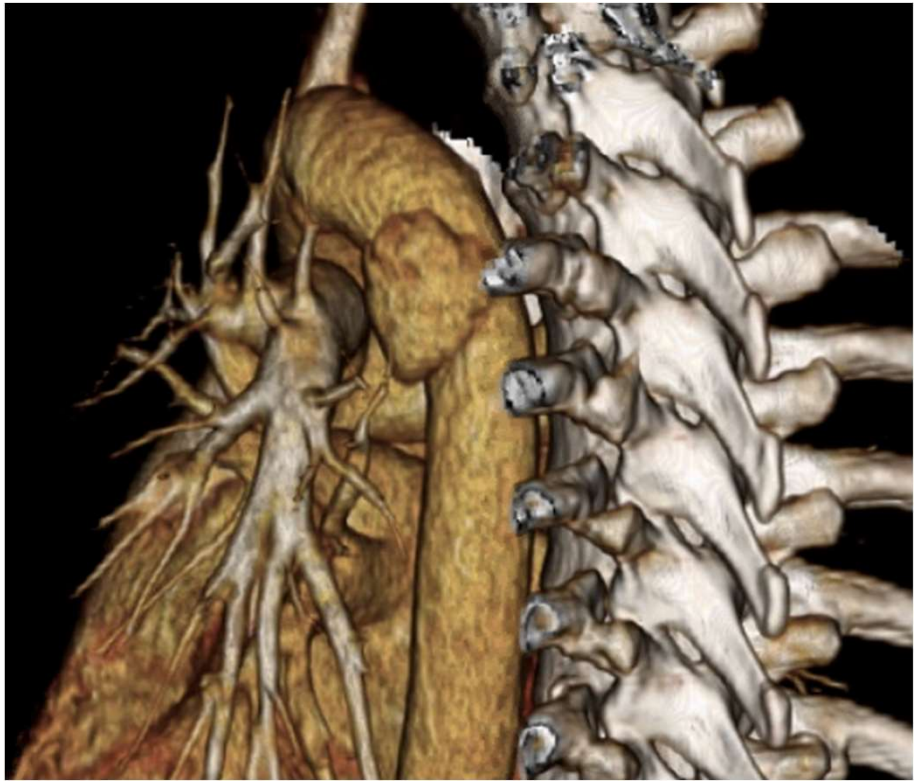
CT scan from outside hospital: descending thoracic aortic dissection, mediastinal hematoma, R acetabular fracture

Interventions PTA: Started on esmolol and nicardipine gtt after consultation with accepting trauma surgeon to treat hypertension.

Vitals on arrival: BP 158/91, P 66, RR 20, O2 100% on RA

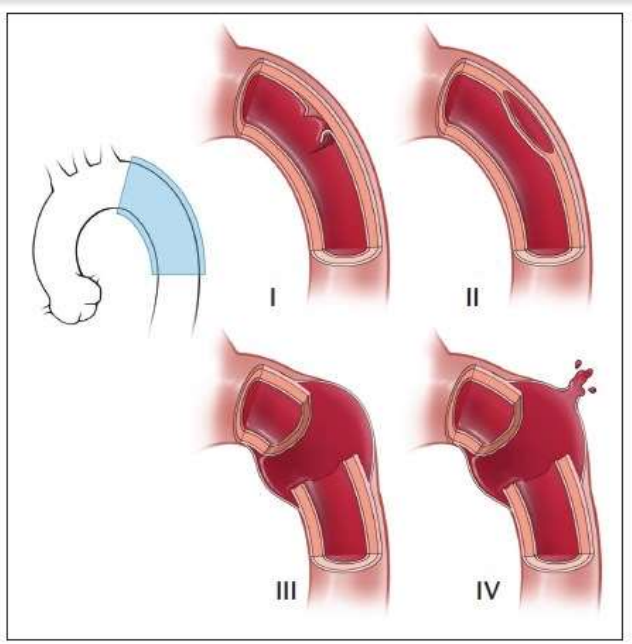
Case #1: Diagnostic Imaging





Blunt Traumatic Aortic Injury

- Usually associated with high-speed horizontal deceleration
- Spectrum of injuries ranging from minor intimal tears to free rupture
- Many patients with BTAI die at the scene



Case #1: Angiography

TEVAR

- Endovascular stentgraft deployment to repair thoracic aortic injuries
- First described for aneurysmal disease in 1994
- FDA approved in 2005
- NEJM – 2008 "*It is our opinion that endovascular repair will soon be the therapy of choice for most patients*" – Shock Trauma/UMMC
- J Trauma – 2017 " *Thoracic endovascular aortic repair, when anatomically suitable, should be the treatment of choice*" – Western Trauma Association
- Lower risk of complication (ischemia and paraplegia)
- Technology advancements have given us more stentgraft options – younger patients were challenging due to few size options and the stiffness of the device meant poor contouring

TEVAR - Outcomes

	ALL	OR	EV	p
Mortality (%)	13	23.5	7.2	.001
Complications (%)	45.1	50	42.4	.311
Paraplegia (%)	1.6	2.9	0.8	.284
Vent days	9.2	10.0	8.8	.893
Blood (units)	10.3	12	9.5	.095

Demetriades et al, 2008

TEVAR - Outcomes

J Am Coll Surg. 2019 Apr;228(4):605-610. doi: 10.1016/j.jamcollsurg.2018.12.022. Epub 2019 Jan 8.

Blunt Thoracic Aortic Injury: Endovascular Repair Is Now the Standard.

Scalea TM[1], Feliciano DV[1], DuBose JJ[1], Ottochian M[1], O'Connor JV[1], Morrison JJ[2].

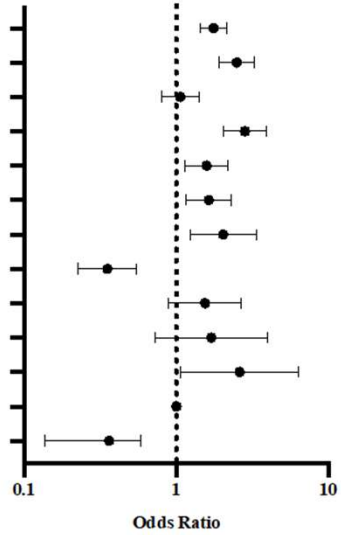
- Decrease in morbidity 29.4% vs 49.1%
- Decrease in median ICU LOS 9 vs 12 days (p=.04)
- Decrease in mortality 9.3% vs 16.6% (p=0.015)

TEVAR Outcomes - Update

Retrospective cohort analysis of ACS-TQIP registry 2007-2017. 2990 patients, 2867 survived to discharge (mortality 4.1%).

Complication	N (%)
AKI/ARF	140 (4.7)
Stroke	83 (2.8)
SCI	58 (1.9)
SSI	56 (1.8)
Unplanned Return to OR	47 (1.6)
Bleeding	44 (1.5)
Extremity Compartment Syndrome	21 (0.7)
Open Aortic Repair	21 (0.7)
MI	16 (0.5)
Paraplegia	7 (0.2)
Coma	7 (0.2)
Extremity Ischemia	2 (0.1)
Wound Disruption	2 (0.1)

Complication	Odds Ratio (95% CI)
AKI/ARF	1.758 (1.449-2.134)
Stroke	2.489 (1.917-3.232)
SCI	1.061 (0.799-1.409)
SSI	2.821 (2.042-3.898)
Unplanned Return to OR	1.578 (1.139-2.186)
Bleeding	1.634 (1.165-2.291)
Extremity Compartment Syndrome	2.026 (1.228-3.342)
Open Aortic Repair	0.352 (0.226-0.549)
MI	1.541 (0.885-2.683)
Paraplegia	1.698 (0.728-3.961)
Coma	2.605 (1.061-6.395)
Extremity Ischemia	1.001 (1.000-1.002)
Wound Disruption	0.587 (0.137-2.519)



Kundi et al. 2021

TEVAR: Follow Up

- Other Potential Complications:
  - Vascular injury (pseudoaneurysm or AVF) at femoral insertion site
  - Endoleak (can be seen on CTA chest)

- Important Notes:
  - Patients may have a lower blood pressure in left arm compared to right arm as often the left subclavian artery is covered by the stent – this is normal and OK
  - Patients do not need long term blood pressure management or antiplatelet therapy unless otherwise indicated (presence of stent is not an indication)

- Recommendation:
  - Patients who have undergone aortic stentgrafting should have annual follow up with their vascular surgeon for at least the first five years after intervention

Case #2

41yo off-duty police officer is brought to STC s/p multiple GSW to the torso and LUE at close range while sitting in his vehicle. Presents distressed with four abdominal ballistic wounds and one flank ballistic wound identified, as well as multiple to the LUE, with no palpable radial pulse.

Notable vitals: pulse 132

Notable labs: Lactate 9

Pt is emergently intubated while a R femoral arterial line and R subclavian cordis is placed. Transfused PRBC x 3 and FFP x 1 and taken emergently to the OR . He is hypotensive; the arterial line is exchanged for REBOA catheter and the balloon inflated to in zone 1. SBP increases to > 90.

Case #2

Initial operative Intervention:

Insertion of REBOA, exploratory laparotomy, right hemicolectomy, small bowel repair x3, small bowel resection x3(left in discontinuity), ligation of pancreatic bleeders, packing and temporary vacuum closure.

Repair of axillary artery, ligation of multiple veins, and forearm fasciotomy, catheter directed thrombectomy, intraoperative angiogram.

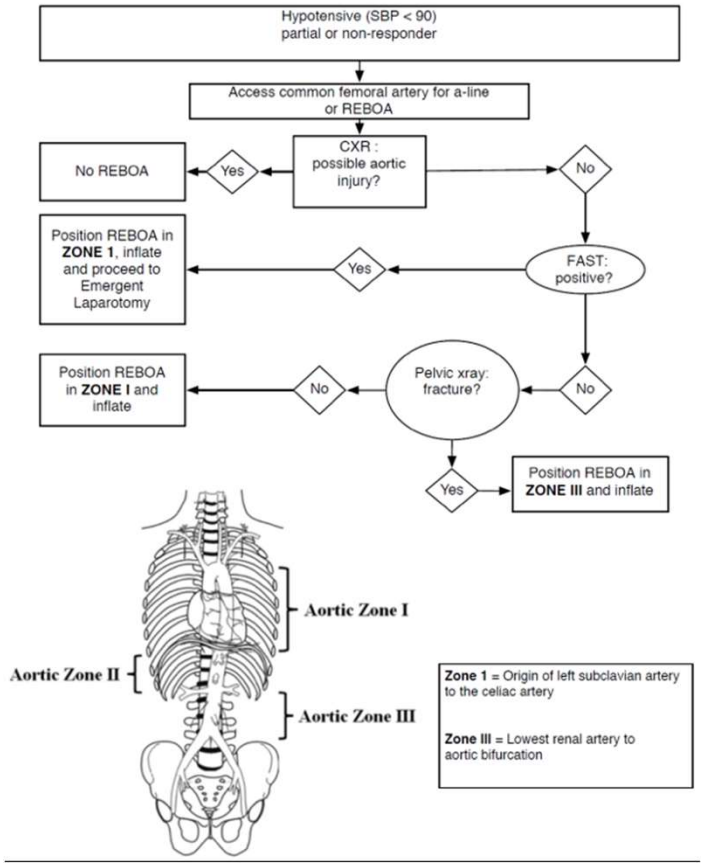
Vein patch angioplasty of the left femoral artery (common and SFA) and thrombectomy.

He undergoes close to 30 additional surgeries before he is discharged to rehab.

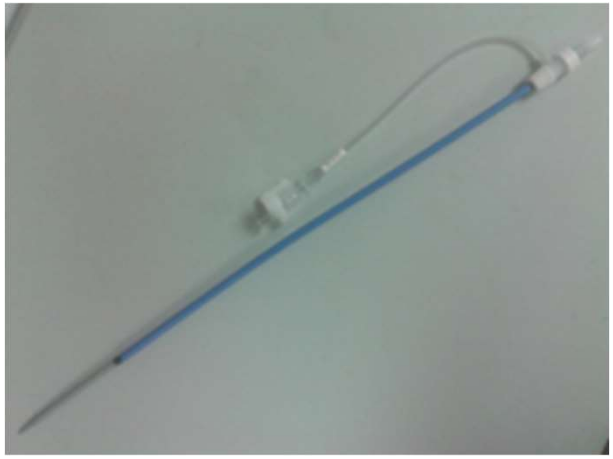
REBOA

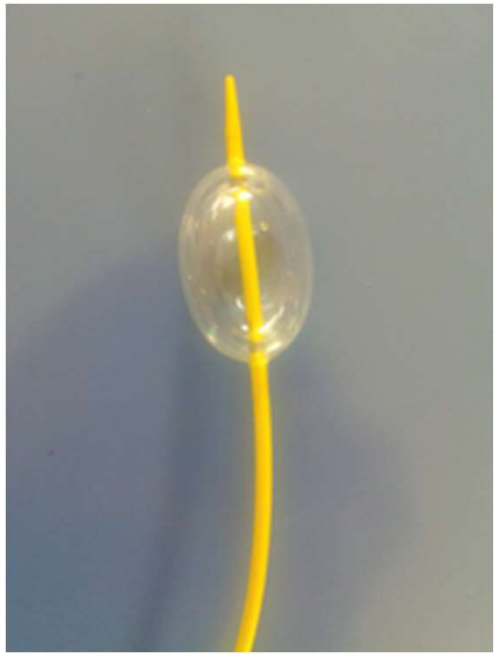
- Indication: non-compressible torso hemorrhage below the diaphragm
- Less-invasive alternative to open resuscitative thoracotomy with aortic cross clamp
- Starts with placement of a femoral arterial line
- Catheter is removed over a guide wire, then sheath is inserted, followed by balloon
- Balloon is inflated and position confirmed by XR, US, FL

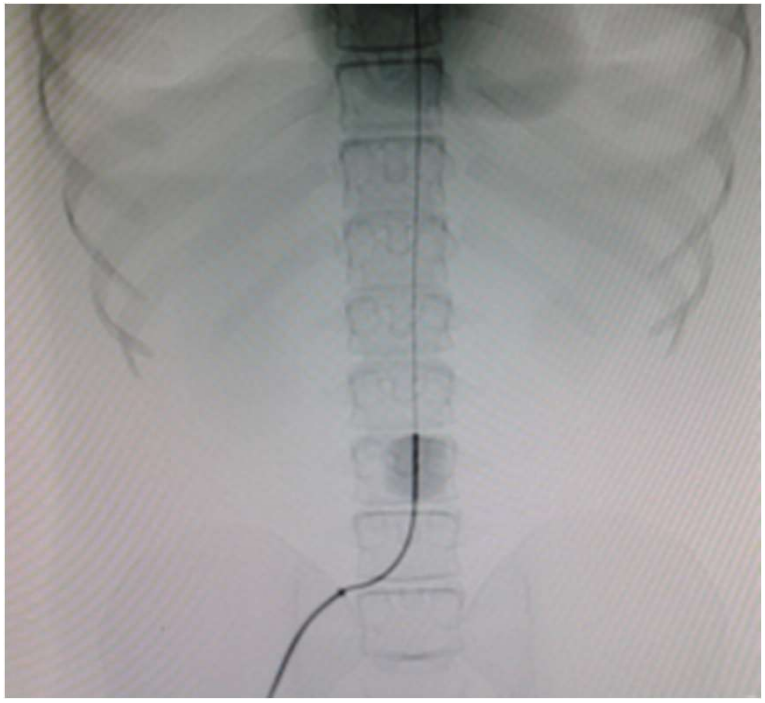
REBOA


Hypotensive (SBP < 90)
partial or non-responder
Access common femoral artery for a-line
or REBOA
CXR :
possible aortic
injury?
Yes
No REBOA
No
FAST:
positive?
Yes
Position REBOA in
ZONE 1, inflate
and proceed to
Emergent
Laparotomy
No
Pelvic xray:
fracture?
No
Position REBOA
in ZONE I and
inflate
Yes
Position REBOA in
ZONE III and inflate
Aortic Zone I
Aortic Zone II
Aortic Zone III
Zone 1 = Origin of left subclavian artery to the celiac artery
Zone III = Lowest renal artery to aortic bifurcation

REBOA







REBOA: Outcomes

J Am Coll Surg. 2018 May;226(5):730-740. doi: 10.1016/j.jamcollsurg.2018.01.044. Epub 2018 Feb 6.

Resuscitative Endovascular Balloon Occlusion of the Aorta and Resuscitative Thoracotomy in Select Patients with Hemorrhagic Shock: Early Results from the American Association for the Surgery of Trauma's Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery Registry.

Brenner M[1], Inaba K[2], Aiolfi A[2], DuBose J[3], Fabian T[4], Bee T[4], Holcomb JB[5], Moore L[5], Skarupa D[6], Scalea TM[3]; AAST AORTA Study Group.

	RT	REBOA	P
Survival beyond ED	44%	63%	0.004
Survival to discharge	2.5%	9.6%	0.023
Survival beyond ED without CPR	48%	93%	<0.001
Survival to discharge without CPR	3.4%	22.2%	0.048
Survival to discharge - presented with SBP< 90	0	44%	0.008

REBOA: Outcomes

- High quality chest compressions plus aortic occlusion may generate perfusion pressures that increase the rate of ROSC in traumatic cardiac arrest (Eur J Trauma 2018)
- Duration of interruptions of cardiac compressions shorter for REBOA than resuscitative thoracotomy (Ann Emerg Med 2018)
- Use is expanding to community trauma centers and for placement by IDMTs downrange
- Caveats:
  - Not for patients with concomitant thoracic vascular injury
  - Requires training
  - Not risk free -- Complications related to catheter placement and balloon inflation time

REBOA: Outcomes

- Potential complications:
  - Vascular injury (pseudoaneurysm or AVF) at femoral insertion site on both the REBOA site *and the opposite side (secondary to failed attempts)*
  - Distal embolization
  - Lower extremity ischemia
  - Compartment syndrome secondary to ischemia

- Recommendations for maximum balloon inflation time to minimize risk of ischemic complications:
  - Zone 1: 30 minutes
  - Zone 3: 60 minutes

- No specific long term follow up needed

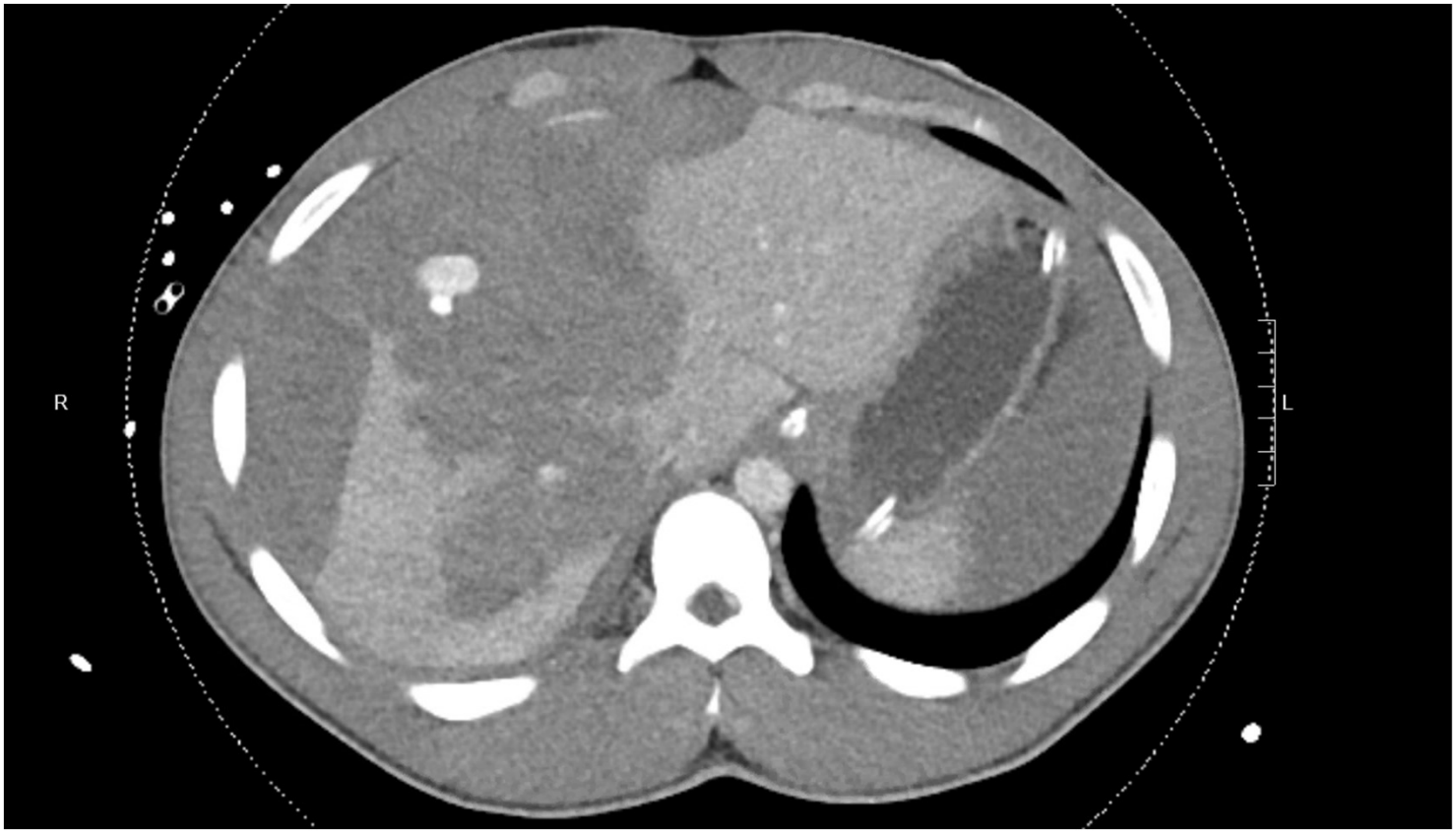
Case #3

18yo male transferred from outside hospital s/p blunt trauma to RUQ during football practice 12 hours PTA. -LOC. Diagnosed with hepatic subcapsular hematoma by CT scan. Not transfused PTA. Physical exam notable only for abdominal pain.

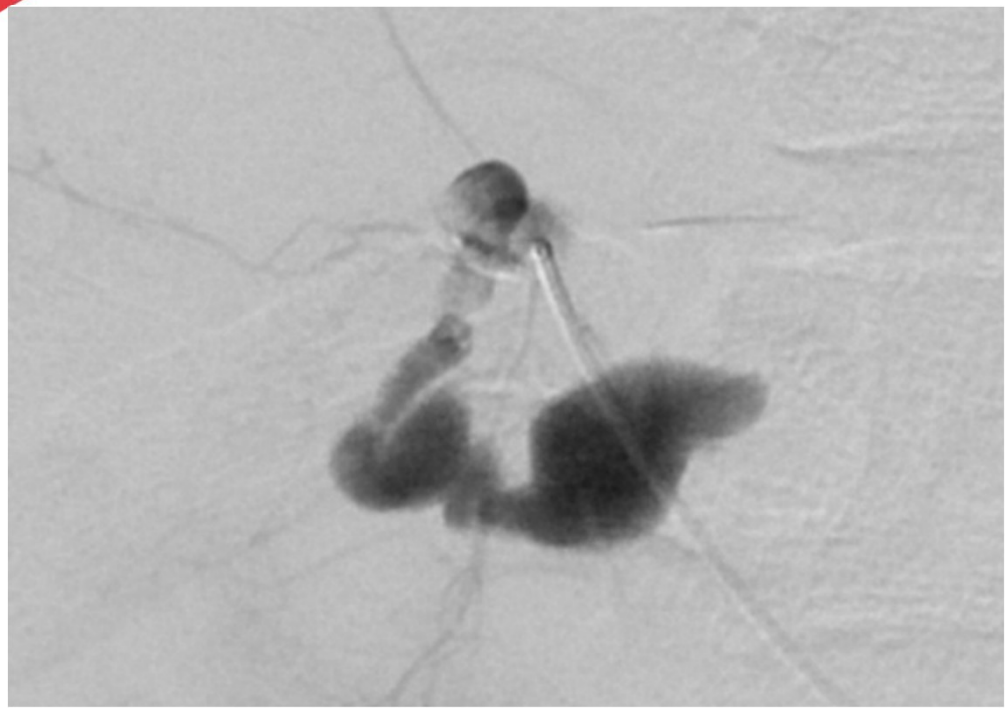
Notable vitals: BP 94/53, P 112

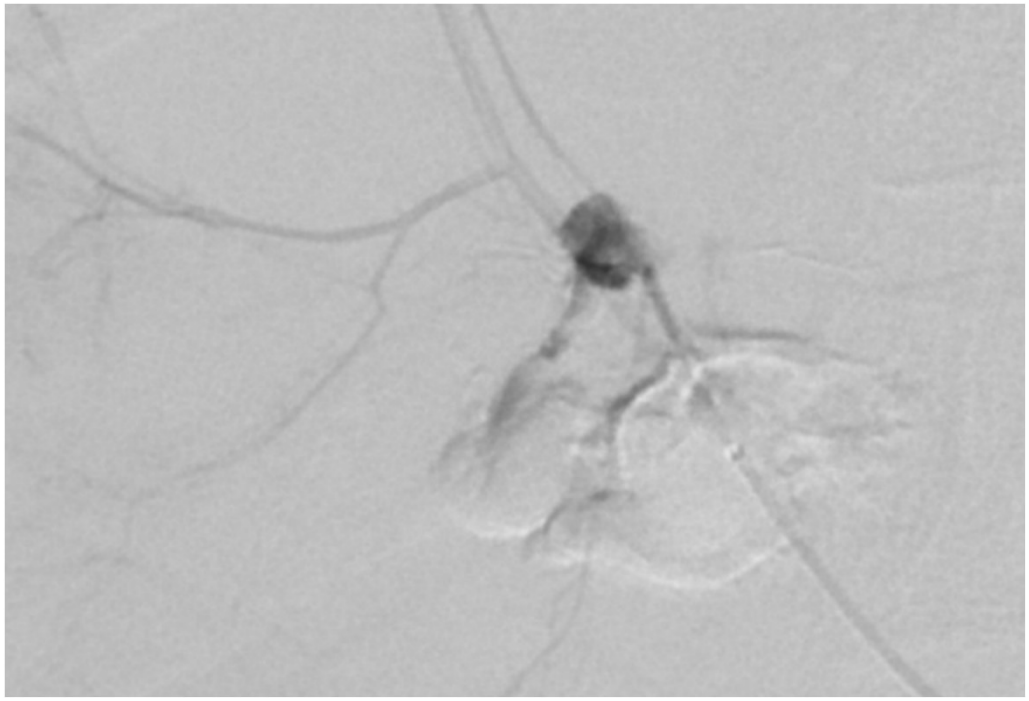
Notable labs: Lactate 8.9, H/H 10/32 (Hgb 14.5 prior to transfer)

Case #3: Diagnostic Imaging



Case #3: Angiography





Case #3

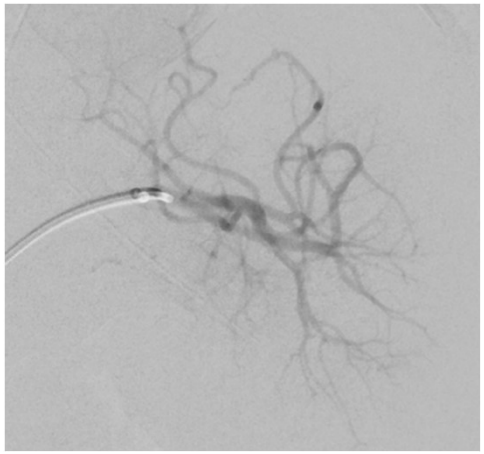
At the completion of the hepatic angiography, the surgical team then immediately begins exploratory laparotomy. Upon entry into the abdomen, huge volume hemoperitoneum is identified and evacuated. On exploration of the liver, the subcapsular hematoma is overlying the dome of both lobes and a tear is visible. The tear is opened to allow for complete evacuation of the hematoma which allows for visualization of a laceration that extends toward the vena cava with oozing. This was controlled with argon beam combined with packing made from vicryl mesh and fibrin sealant. He was left open with a vac.

On POD#1 the patient returns to the OR for unpacking. There was no sign of active bleeding. He undergoes cholecystectomy secondary to concerns for devascularization. He is closed over drains.

Pt is discharged to home on hospital day #7.

Splenic Artery Embolization

- Algorithms based on AAST grading scale
- Grade 3, 4 and 5, hemodynamically stable get an angiogram +/- embolization
- Proximal, non-selective embolization
- Followed by a repeat CT 48-72 hours later to eval for persistent pseudoaneurysm
- Higher risk of failure with higher grade
- Subcapsular hematomas are often poor candidates



Hepatic/Splenic Embolization: Outcomes

- Patients who have undergone splenic artery embolization may receive vaccinations: pneumococcal, meningococcal and h.flu
- While there is no compelling evidence in support, it was generally thought that patients are functionally asplenic for some time and reward > risk, however many are now trending away from this practice
- Potential complications of solid organ embolization:
  - Vascular injury (pseudoaneurysm, AV fistula) at femoral insertion site
  - Delayed splenic or hepatic infarct
  - Persistent pseudoaneurysm may be seen on CT scan

Case #4

32yo previously healthy male found unresponsive in the middle of a triathlon was transferred from outside hospital for presumed heat stroke. Initial GCS 5, 3 on presentation to Shock Trauma. Rectal temperature 108. Cooled passively prior to transfer. Exam notable for a tight right thigh and only DP signals by doppler.

Notable labs: Glucose 40, Troponin 8, K 7, Creatinine 2.6, CK 25,000, Lactate 6.6

CT scan: mild cerebral edema

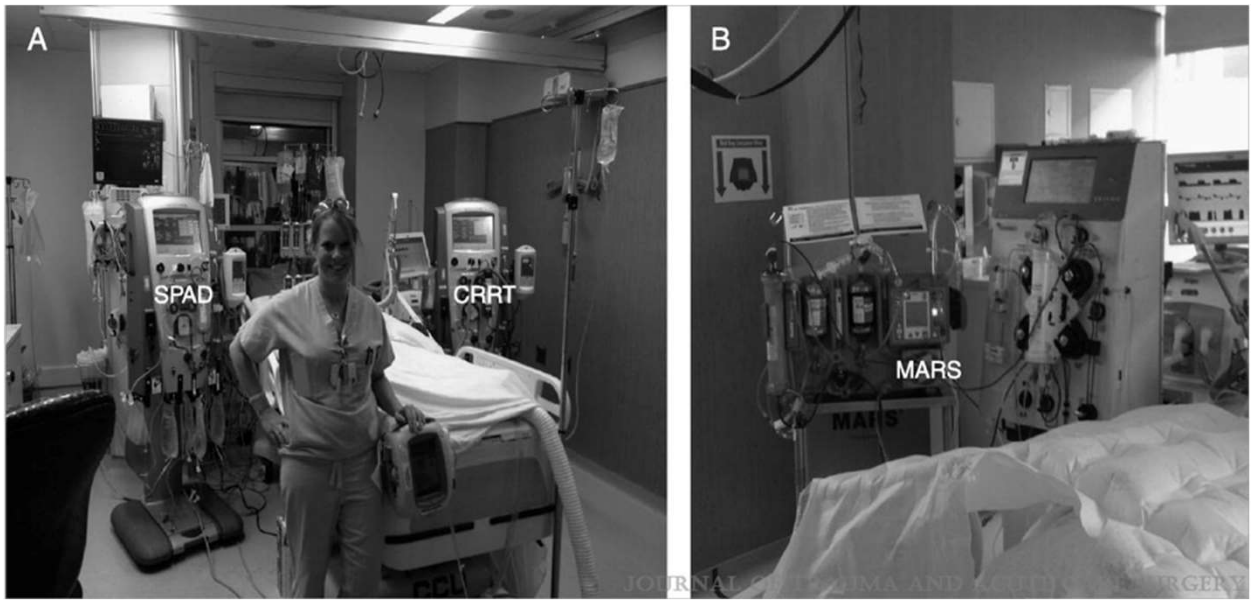
Diagnosis: fulminant hepatic failure secondary to heat stroke, right thigh compartment syndrome

He is taken to the OR for fasciotomy. Transplant evaluates him and lists him code 1.

ICU care includes CRRT and vasopressors. MARS is used to bridge to transplant.

MARS

- Molecular Adsorbent Recirculating System
- Short term extracorporeal liver support – aka Liver Dialysis
- Used as a bridge to transplant
- Selective removal of albumin-bound toxins



MARS: Outcomes

Ann Surg. 2017 Oct;266(4):677-684. doi: 10.1097/SLA.0000000000002361.

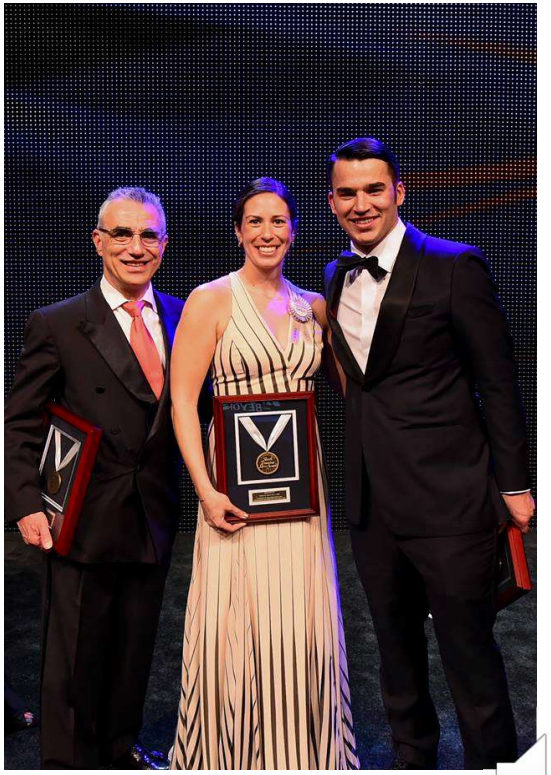
Molecular Adsorbent Recirculating System Effectively Replaces Hepatic Function in Severe Acute Liver Failure.

Hanish SI[1], Stein DM, Scalea JR, Essien EO, Thurman P, Hutson WR, Bartlett ST, Barth RN, Scalea TM.

- Largest series of MARS therapy in the US as temporary hepatic replacement for acute liver failure
- 27 patients:
  - 5 had recovery of liver function and 60% survival
  - 13 were a bridge to transplant; 9 transplanted and 78% 1-year survival
  - 9 treated for toxin ingestion had recovery of liver function and 67% survival
- Conclusion: MARS therapy successfully replaces hepatic function in ALF allowing time for spontaneous recovery or transplantation.

Case #4: Outcome

- Patient goes on to transplantation. He is able to be weaned from CRRT with full renal recovery.
- He returns to physical activity including biking, running.
- In 2017, he is honored at the Shock Trauma Gala.



Case #5

43yo male is transferred from the field s/p MCC where he clipped a vehicle and then was ejected from his bike. +Helmet. +LOC but GCS 15. He has an obvious LLE deformity and no palpable DP pulse. Also c/o L hand pain, chest pain, and shortness of breath. He appears distressed with decreased breath sounds on the left. FAST negative for lung sliding on the left. CXR confirms L HPTX. A chest tube is placed and pt is intubated. DP pulse is reestablished with manual traction of the LLE. Pt is then taken to CT scan. In scanner he becomes unstable but responds to blood products. Chest tube output 1100mL then another 700mL. Pt is taken to the OR for a thoracotomy.

Notable labs: Troponin 36.2, H/H 9.2/27.9

CT scan: Extensive L pulmonary contusions with multiple displaced rib fractures, persistent HPTX

Case #5

OR: Ligation of bleeding intercostal arteries, excision of devascularized floating rib segment, placement of two new chest tubes, I&D and ex-fix of L tibia

ICU post-op: Ongoing resuscitation. Evidence of cardiac dysfunction secondary to blunt cardiac injury requiring inotrope support. Placed on APRV and right-side-down positioning secondary to extensive L pulmonary contusions.

Hospital day #1: Episode of desaturation with evidence of derecruitment and decreased aeration on CXR. Vent adjusted. However shortly after he has worsening hemodynamics requiring further vasopressor support. Bedside TTE compromised by artifact. Increased subcutaneous emphysema on repeat CXR -> new chest tube. Bronch attempted but aborted due to desaturation. Pt is proned, but there is minimal improvement in oxygen saturation. Pt is cannulated for ECMO and transferred to the Lung Rescue Unit.

Lung Rescue Unit

- Dedicated unit for patients that need V-V ECMO for respiratory failure of varying etiologies including:
  - Trauma
  - Pneumonia
  - ARDS
  - Influenza
  - Pre-transplant (pulmonary fibrosis, cystic fibrosis, etc)
- Increased survival to discharge - 78%

World J Surg. 2018 Aug;42(8):2398-2403. doi: 10.1007/s00268-018-4480-6.

Veno-Venous Extracorporeal Membrane Oxygenation (VV ECMO) for Acute Respiratory Failure Following Injury: Outcomes in a High-Volume Adult Trauma Center with a Dedicated Unit for VV ECMO.

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ECMO

- Extra Corporeal Membrane Oxygenation
- V-V is used for isolated respiratory failure, cardiac function is maintained to bypass the body's inability to oxygenate
- Conversely, V-A is used for primarily cardiac dysfunction when the hearts pumping mechanism needs to be bypassed
- Requires an inflow and outflow cannula
- Usually also requires at least a low dose anticoagulant to prevent clot in the circuit

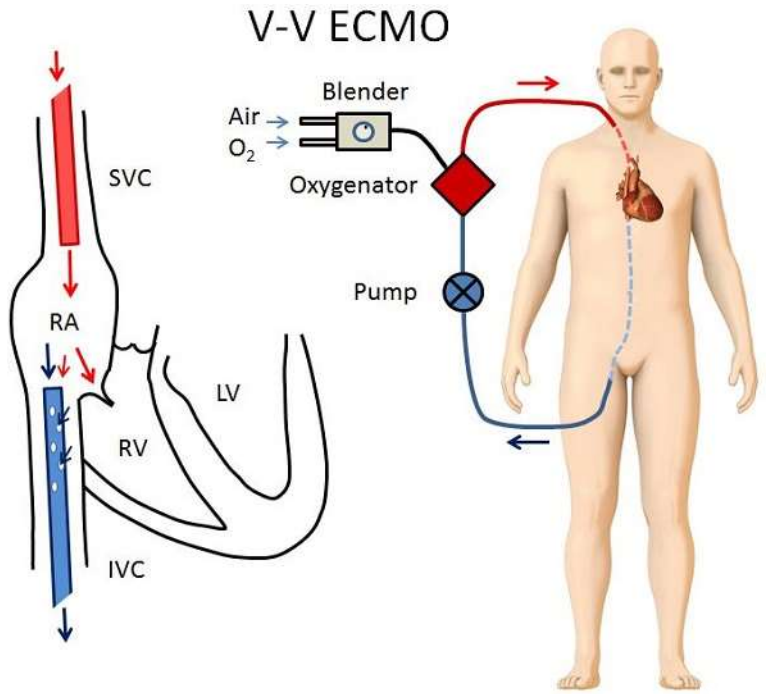

Image source: icuecmo.ca

ECMO: Outcomes

- Our LRU has a 78% survival rate; survival rates are higher in tertiary care centers that specialize in ECMO.
- Complications:
  - Bleeding, due to need for anticoagulating the circuit
  - 85% were found to have catheter-associated DVT
- Outpatient/Long term considerations
  - Patients should undergo PFT's or walking test to assess lung function after discharge
  - Pulmonary rehab is beneficial
  - Anticoagulation for DVT
  - Psychological support (high rates of PTSD regardless of indication for ECMO)

Case #5: Outcome

Patient remains on ECMO for 19 days then is decannulated. During that time he is on high dose pressors. He develops vascular complications including mesenteric ischemia and distal limb ischemia/necrosis. He undergoes somewhere around 30 surgeries including exploratory laparotomy with numerous small bowel resections/repairs, tracheostomy, R mid-foot amputation, L below knee amputation, R forearm amputation, multiple L digit amputations. After 4.5 months in the hospital, he is discharged to rehab on TPN. He returns approximately 6 months later for enterocutaneous fistula takedown. He undergoes another 6 months of inpatient rehab before finally being discharged to home, ambulating using a LLE prosthesis.

Take Home Points

- Endovascular interventions are now the gold standard of treatment for several traumatic injuries
- Having these interventions performed by surgical teams has led to decreased time to treatment, decreased ICU days, vent days and LOS
- Endovascular procedures are not risk-free and patients are still at risk for complications
- Identification of injuries amenable to endovascular interventions and transferring patients for this specialized definitive care improves outcomes
- Providers in community settings such as primary care and ED may encounter patients who are post-endovascular procedure and should be aware of what sequelae to screen for or how to identify them
- Consulting the treating trauma center and surgical team is preferred when there are questions about the patient's care. We love phone calls!

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Questions?

THANK YOU!

Please feel free to email questions to
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