CRASH

Guiding the future of patient care

Trauma Panel 2023

Drs. Bethany Benish, Nicole Arboleda & Ryan Laterza

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No financial disclosures

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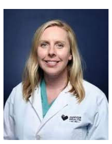
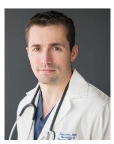
Trauma Anesthesiologist Panel:

Dr. Bethany Benish



Dr. Nicole Arboleda

Dr. Ryan Laterza



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Panel Objectives:

- Best induction strategies for RSI in severe trauma
- Role of calcium supplementation, bicarb administration and the possible role of vasopressors in trauma
- Principles of resuscitation and permissive hypotension in trauma
- Volume optimization and modality for volume assessment in trauma
- Role of whole blood in both adult and pediatric trauma
- Current consensus clinical recommendations for pediatric trauma resuscitation
- Shock Index- Pediatric age-adjusted

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CASE:
30 year old male s/p auto-ped at approximately 45mph

- Vitals on arrival to ED: 93/45, 118, 28, 95% NRB 15L
- In C-collar, mentating but perseverating
- FAST positive in ED
- Massive Transfusion Protocol activated, and decision made to proceed to OR for emergent ex-lap

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Medication choices for Trauma

- Best induction medication?
- Best paralytic?

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What is your induction medication of choice in severe trauma?

- Etomidate
- Propofol
- Ketamine
- Ketofol
- Sux and a smile
- Something else

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Etomidate vs Ketamine

ETOMIDATE

- Rapid onset
- Provides cardiovascular stability
- Used as RSI in Adult Trauma—significant lower cortisol levels at 4-6hrs & decreased response to ACTH stim test

KETAMINE

- Excellent intubating conditions, minimal change to BP
- ?Negative inotropy—maybe negative chronotropic effect
- May increase intraocular pressure
- ?Historic concerns about elevated ICP

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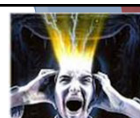
Ketamine and TBI



- Historic concerns about use in TBI were NOT evidence based
- Ketamine actually improves cerebral perfusion by maintaining MAP, and decreases mortality in TBI
- Pediatric TBI studies—ketamine consistently decreased ICP and blunted any increases during stimulation without decreasing BP

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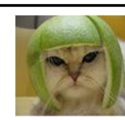
Ketamine -Neuroprotective?



- Ketamine may even be **neuroprotective** & decrease secondary injury
  - Related to NMDA antagonism; Decrease cortical spreading depolarization, less secondary injury

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So…Etomidate or Ketamine?

- Ann Emerg Med 2017:
  - 968 patients (536 Etomidate, 442 Ketamine for RSI in Trauma)—Institutional switch for RSI in trauma:
  - No difference in mortality
- Anesthesia & Analgesia 2018:
  - Ketamine as RSI in trauma vs other induction agents
    - Extremely few studies comparing induction agents in trauma
  - No difference in mortality, LOS, blood transfusion
- J of Trauma Acute Care 2021:
  - No difference in 28d Mortality
  - No difference in blood transfusion

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What about Ketofol?

KEEP PACE 2019 JTACS:

- Ketamine + Propofol (0.5mg/kg each) vs Etomidate (0.15mg/kg) for emergent intubation
  - No difference in MAP change from baseline after induction at 5min, 10min or 15min
  - No difference in new vasoactive drugs
  - No difference in difficult intubation
  - Of those with adrenal testing, etomidate group had more evidence of adrenal suppression (81% vs 38%)

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Conclusions on induction meds:

- No single best induction agent
- Remember to reduce dose in setting of hypovolemia!
  - Induction medication and Opioids
  - Do NOT reduce NMB dose

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What is your paralytic medication of choice in major trauma?

Succinylcholine 1 mg/kg
Succinylcholine 1.5 mg/kg
Rocuronium 0.6 mg/kg
Rocuronium 1.2 mg/kg
Other

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Paralytic of choice??

ROCURONIUM
- Rapid if RSI dose (55-90sec)
- No contraindications
- Prolonged paralysis
  - Difficult airway
  - Neuro checks

SUCCINYLCHOLINE
- Rapid onset (30-45sec)
- Short duration
- Contraindications
  - MH risk
  - Hyperkalemic risk

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ROC vs SUX

Emergency Medicine study at Level1 Trauma Center 2018

- Retrospective
- Assessing peri-intubation factors associated with physician choice of paralytic agent for RSI in the ED

Results:
- Rocuronium was more likely to be chosen:
  - Abnormal Vitals prior to intubation
  - Early ED Mortality
- Rocuronium was associated with:
  - hypoxemia prior to intubation
  - increased use of Video Laryngoscopy

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Paralytic of choice? Roc vs Sux

- **Cochrane Database Review** (RCTs and CCT) showed better intubating conditions with Succinylcholine for RSI
  - BUT--this did include some studies using 0.6mg/kg Roc
  - Subgroup analysis of 1.2mg/kg Roc---no statistical difference in intubating conditions

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Conclusions on Paralytic:

- If 1.2mg/kg Rocuronium is used, either is probably fine
- Availability of Sugammedex has increased the use of Rocuronium for RSI
  - Immediate reversal (16mg/kg) is actually faster than resolution of Succinylcholine
- I generally prefer Succinylcholine, dosed 1mg/kg (TBW)
- Again, do NOT reduce the dose of NMB in hypovolemia!

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Back to the case….

- Successful induction & intubation
- Massive Transfusion ensues
- Surgery begins

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Labs come back…

- ABG: 7.18/38/190/-12
- Na 137, K 4.3, iCa 0.8, Lact 7, Glu 205
- H/H 8.4, 27, Plt 128,000
- TEG pending…

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Let's talk Factor IV….

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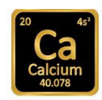

- Calcium is a divalent cation, 45% is biologically active and in ionized state, 55% protein bound (albumin, citrate)
- Key to bone formation, neural transmission, endocrine physiology, **cardiac contractility, vascular constriction, hemostasis and coagulation**

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Hypocalcemia

- ➡ Electrical dysfunction, QT prolongation and increased dysrhythmias
- ➡ Contributes to suppression of myocardial contractility and can contribute to acute CV decompensation
- ➡ less vascular smooth muscle contraction, loss of vasomotor tone

- **Direct association between hypocalcemia and SBP<90 in trauma patients**
- Often **undetected and underestimated**

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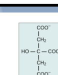
What's the problem?



- Citrate toxicity ➡ hypocalcemia
  - Citrate metabolized quickly by healthy liver
  - MTP overwhelms liver with citrate (transfusing faster than 1 unit/5min quickly overwhelms healthy liver)
  - Even more severe with shock liver or traumatized liver
  - Hepatic clearance of citrate is worsened by hypothermia

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Which blood product contains the most citrate?

- Whole Blood
- RBC
- FFP
- Platelet
- Cryoprecipitate

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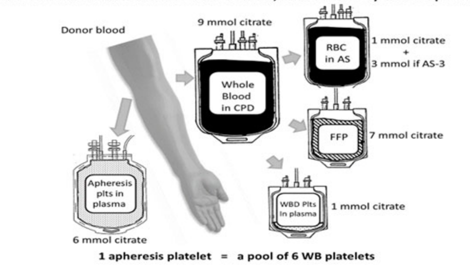
There is 9 mmol citrate in a unit of whole blood, 1 mmol for every 41 mL of plasma



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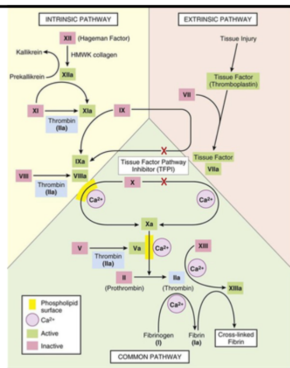
Coagulation Factor IV

- Calcium is critical to coagulation and platelet adhesion
- Essential co-factor Factors II, VII, IX, X, XI
- Required for conversion of fibrinogen to fibrin



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Hypocalcaemia and traumatic coagulopathy: an observational analysis

Mayank Vasudeva, Joseph K. Mathew, Mark C. Fitzgerald, Zoe Cheung & Biswadev Mitra

- Alfred Hospital Trauma Registry (n=15,547Pts)
  - Major trauma patients >18yo with arrival Shock Index >1, no prehospital transfusion
  - 50% of Patients were hypocalcemic (3% severe <0.8)
    - 45% were coagulopathic (vs 13%)
    - 62% required transfusion (vs 37%)
    - 25% mortality (vs 15%)

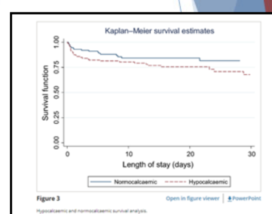

Figure 3

Hypocalcaemic and normocalcaemic survival analysis.

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Trauma related hypocalcemia

- Approximately 55% of major trauma patients are hypocalcemic on arrival to ED (even before transfusion) iCa <1.1 mmol/L
- Admission hypocalcemia (less than 1.1) associated with **higher mortality** (almost 2x) and increased need for **transfusion**
  - Useful independent predictor of MTP in trauma patients

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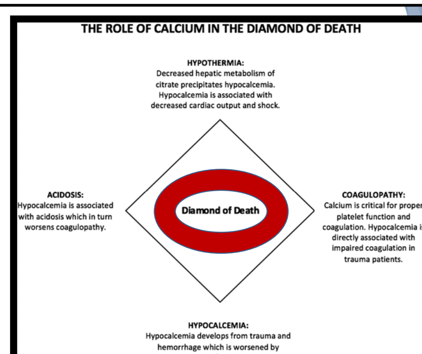

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Hypocalcemia in trauma

- Direct concentration dependent association between severe hypocalcemia and acidosis
- Ischemic reperfusion can cause hypocalcemia and worsen hypocalcemic coagulopathy

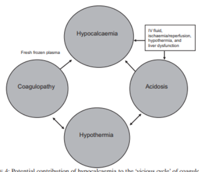

FIGURE 4: Potential contribution of hypocalcaemia to the 'vicious cycle' of coagulopathy, hypothermia and acidosis in patients with critical bleeding requiring massive transfusion.

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Transfusion and hypocalcemia

- 97% of trauma patients requiring MTP experience hypocalcemia
  - 71% were severe (<0.9mmol/L)
    - Lower platelets
    - Received more blood products
    - Higher mortality

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- Blood transfusion and hypovolemic shock exacerbate hypocalcemia
- Current Massive transfusion protocols dictate high ratio early FFP→ independently associated with hypocalcemia
- Most MTPs recommend replacement only when severe hypocalcemia

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How do you replete calcium in during trauma resuscitation?

- 1 Amp per 4 units PRBC or 2 FFP
- 1 Amp per cooler
- Wait for ionized calcium level
- Wait for coagulopathy, acidosis
- None of the above

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How much calcium are we talking?

- Contractility and hemodynamic are affected at ionized Ca++ <0.9
- Protocolized early calcium replacement in major trauma?
  - No well studied published protocols
  - 1-2 grams IV Calcium Chloride per cooler (3-6grams IV calcium gluconate)
  - Use POC monitor for guiding replacement in real time
  - EKG/Tele---very rough guide to calcium
    - Hypocalcemia prolongs ST segment
- Moderate <u>**Hypercalcemia 1.3-3mM**</u> is well tolerated
- Therapeutic target is a high-normal iCa
  - Massively hemorrhaging patient, better to be hypercalcemia than hypo

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What about Bicarb?

- Give it heavy handedly in hemodynamically unstable patients
- Give it when pH<7.2
- Give it when pH<7.1
- Give it only peri-arrest or during CPR
- I never give Bicarb

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Bicarb in trauma

- Lactic acidosis in trauma is often a marker of hypoperfusion
- Acidemia can produce detrimental physiologic consequences

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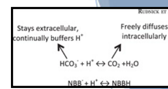
Detrimental effects of Bicarb:



- Worsens **serum hypocalcemia**
- Decrease vasomotor tone and **mean arterial pressure**
- Decrease **coronary perfusion** pressure
- Increases carbon dioxide production→ **decreasing C.O.**
- In setting of cardiac arrest, increased systemic pH but failed to improve intramyocardial pH
- Myocardia contractility decreases (2/2 hypocalcemia & decreased myocardial oxygen extraction)
- Rapid administration of bicarbonate infusions have also been associated with lowering of pH
- Multiple studies in shock (mostly sepsis), show Bicarb failed to improve outcome (ICU LOS, vasopressor requirements, ventilator days, ICU mortality)

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Conclusions on Bicarb

- Sodium bicarbonate administration in the setting of lactic acidosis has consistently failed to significantly improve hemodynamic status in humans
- Effect on intracellular pH depends on ventilation and limitations to CO2 clearance and the presence of intact intracellular buffering systems
- If Bicarb is given,
  - Goal pH >7.2 (no higher)
  - Ensure adequate ventilation!
  - calcium replacement is critical to avoiding negative consequences

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Is there a role for Pressors in trauma?

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- Persistent hypotension and hypoperfusion → progressive coagulopathy and organ dysfunction
- Vasopressor use in severely injured trauma patients is discouraged due to concerns about worsening perfusion resulting in worsening multi-organ dysfunction and increased mortality
- Vasopressor use was reserved for post resuscitative period (SCI/TBI or Sepsis)

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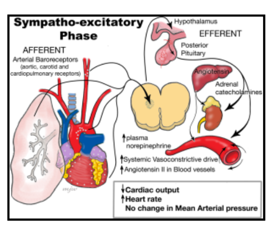
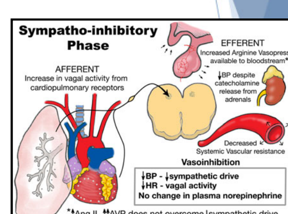
Pathophysiology of trauma shock





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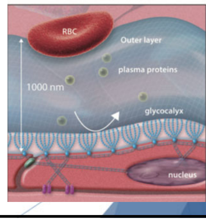
Shock induced endotheliopathy

- Post traumatic endotheliopathy (damage to glycocalyx)→ increased vascular permeability, edema and loss of vascular tone
- Prolonged hypotension/Hypoperfusion→
  - Vascular relaxation via KATP channels
  - NO Synthesis
  - vasopressin deficiency

Normal Microvessel



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Vasopressors in Trauma

- Many older studies (retrospective) showed increased mortality with patients who required vasopressors
- Concerns for increased complications including arrhythmia & anastomotic failure in damage control laparotomy
- BUT: numerous supportive studies in TBI and SCI for improved neurologic function (MAP >85)

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Vasopressor Use during Emergency Trauma Surgery

ROBERT M. VAN HAREN, M.D., M.S.P.H., CHAD M. THORSON, M.D., M.S.P.H., EVAN J. VALLE, M.D., GERARDO A. GUARCH, M.D., JASSIN M. JOURIA, M.D., ALEXANDER M. BUSKO, B.S., NICHOLAS NAMIAS, M.D., M.B.A., ALAN S. LIVINGSTONE, M.D., KENNETH G. PROCTOR, PH.D.

From the Dewitt-Daughtry Family Department of Surgery, University of Miami Miller School of Medicine, Ryder Trauma Center, Miami, Florida

2018 BJA: Gause et al---showed no increase in mortality in patients who received Norepi

- vasopressor use is relatively common in the most severely injured patients requiring OR
- EPI is most often used for cardiac arrest, whereas other vasopressors are used for their vasoconstrictive properties
- except for EPI, **vasopressors during OR are not independently associated with mortality**

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Conclusions on pressors in trauma

- Vasopressors have a sound mechanism to improve O_2 delivery by
  - decreasing venous system compliance
  - augmenting the mean systemic filling pressure,
  - increasing the stressed blood volume and cardiac output within the circulation
- Persistent and prolonged shock with severe tissue damage and release of proinflammatory mediators also aggravates vasodilation and necessitates vasopressor administration even after definitive hemorrhage control
- NOREPI or AVP in traumatic shock resuscitation likely augments the body's physiological response and maintain homeostasis

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What about fluids in trauma?

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What are the complications associated with crystalloid administration in the setting of hemorrhagic shock?

- Hypothermia
- Dilutional coagulopathy
- Acidosis
- Higher blood pressure can worsen bleeding
- Increased Mortality
- All of the above

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History

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History: Intravenous Saline

- First reported use of intravenous saline for the treatment of disease:
  - Dr. Latta's letter to the Lancet on the success of saline for a patient with cholera

May 23, 1832

She had apparently reached the last moments of her earthly existence…. ounce after ounce [of saline] was injected….soon the sharpened features, and sunken eye, and fallen jaw, pale and cold, bearing the manifest impress of death's signet, began to glow with returning animation; the pulse, which had long ceased, returned to the wrist.

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History: Intravenous Saline

The quantity to be injected depends on the effect produced, and the repetition on the demands of the system, which generally vary according to the violence of the diarrhoea; the greater the degree of collapse, the greater will be the quantity needed.

The syringe must be quite perfect, so as to avoid the risk of injecting air…

Your most obedient servant,

Thomas Latta, M.D.

Malignant cholera. Documents communicated by the Central Board of Health, London, relative to the treatment of cholera by the copious injection of aqueous and saline fluids into the veins. Lancet 1832;18:274-80.

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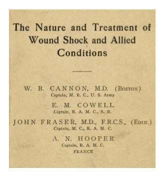
History: Permissive Hypotension in Trauma

- In August, 1917, the Medical Research Committee (Great Britain) appointed a Special Investigation Committee to undertake the coordination of inquiries into surgical shock and allied conditions [during World War I].



The Nature and Treatment of Wound Shock and Allied Conditions

W. B. CANNON, M.D. (Boston)
Captain, M. R. C., U. S. Army
E. M. COWELL
Captain, R. A. M. C., S. R.
JOHN FRASER, M.D., F.R.C.S., (Edin.)
Captain, M. C., R. A. M. C.
A. N. HOOPER
Captain, R. A. M. C.
FRANCE

Injection of a fluid that will increase blood pressure has dangers in itself. Hemorrhage in a case of shock may not have occurred to a marked degree because blood pressure has been too low and the flow too scant to overcome the obstacle offered by a clot. If the pressure is raised [with fluid] blood that is sorely needed may be lost.

Cannon W, et al. The nature and treatment of wound shock and allied conditions. Chicago: American Medical Association; 1918.

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Volume and Complications

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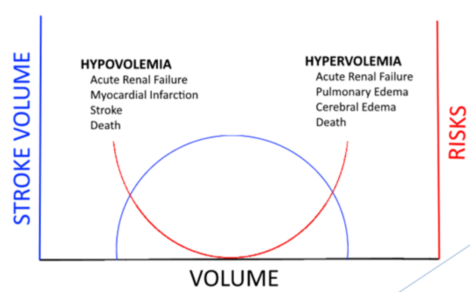
Ideal Volume



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Harm from crystalloid (Trauma)

- **Increase Mortality (HR 2.5) and Coagulopathy (OR 2.2)**
  - Brown J, et al. Inflammation and the Host Response to Injury Investigators. Goal-directed resuscitation in the prehospital setting: a propensity-adjusted analysis. J Trauma Acute Care Surg. 2013 May;74(5):1207-12.
- **Increase Mortality (OR 1.11)**
  - Haut E, et al. Prehospital intravenous fluid administration is associated with higher mortality in trauma patients: A National Trauma Data Bank analysis. *Ann Surg*. 2010 Dec.
- **Increased Mortality (19% vs 7%)**
  - Driessen A, et al. Prehospital volume resuscitation--Did evidence defeat the crystalloid dogma? An analysis of the TraumaRegister DGU® 2002-2012. Scand J Trauma Resusc Emerg Med. 2016 Apr 6;24:42.
- **Increased Mortality (OR 1.11)**
  - Haut E, et al. Prehospital intravenous fluid administration is associated with higher mortality in trauma patients: a National Trauma Data Bank analysis. Ann Surg. 2011 Feb;253(2):371-7.
- **Increased Mortality (OR 1.1)**
  - Joseph B, et al. Improving mortality in trauma laparotomy through the evolution of damage control resuscitation: Analysis of 1,030 consecutive trauma laparotomies. J Trauma Acute Care Surg. 2017 Feb;82(2):328-333.
- **Increased Risk of ARDS (OR 3.4), Multiple Organ Failure (OR 2.9), and Surgical Site Infection (OR 2.8)**
  - Kasotakis G, et al. Inflammation and Host Response to Injury Investigators. Aggressive early crystalloid resuscitation adversely affects outcomes in adult blunt trauma patients: an analysis of the Glue Grant database. J Trauma Acute Care Surg. 2013 May;74(5):1215-21; discussion 1221-2.
- **Increased Risk of Abdominal Compartment Syndrome (9.9 L vs. 2.7 L, p < 0.001)**
  - Madigan M, et al. Secondary abdominal compartment syndrome after severe extremity injury: are early, aggressive fluid resuscitation strategies to blame? J Trauma. 2008 Feb;64(2):280-5.
- **Increase Mortality (HR 1.1) and Coagulopathy (PTT 56 vs 39.1, INR 2.2 vs 1.4)**
  - Morrison C, et al. Hypotensive resuscitation strategy reduces transfusion requirements and severe postoperative coagulopathy in trauma patients with hemorrhagic shock: preliminary results of a randomized controlled trial. J Trauma. 2011 Mar;70(3):652-63.

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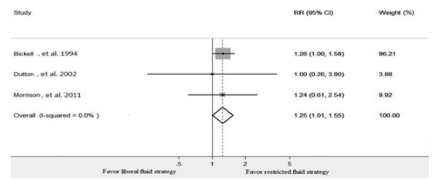
Restrictive vs Liberal Fluid Resuscitation in Trauma Patients

- Meta-analysis of RCT trials



Wang C, et al. Liberal versus restricted fluid resuscitation strategies in trauma patients: a systematic review and meta-analysis of randomized controlled trials and observational studies. Crit Care Med. 2014 Apr;42(4):954-61.

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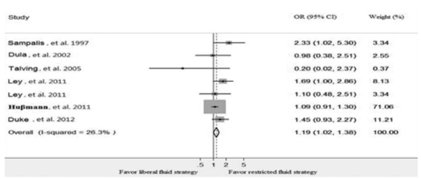
Restrictive vs Liberal Fluid Resuscitation in Trauma Patients

- Meta-analysis of observational trials



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Permissive Hypotension in Trauma

- Permissive hypotension is **permitting** the blood pressure to be low by **deliberately** giving **less crystalloid** in active bleeding trauma patients
- The intervention is restrictive volume resuscitation not deliberate hypotension
- This is analogous to permissive hypercapnia for ARDS whereby the intervention is low tidal volumes and permitting hypercapnia

Disease State	Intervention	Permissive	Goal
Hemorrhagic Shock	Restrictive Fluid Resuscitation	Hypotension	Limit harm due to crystalloids
ARDS	Low Tidal Volume	Hypercapnia	Limit harm due to VILI

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Permissive Hypotension

- Crystalloids cause harm in hemorrhagic shock
  - Hypothermia
  - Dilutional coagulopathy
  - Acidosis (Normal Saline)
  - Higher BP can worsen bleeding
- Recall "Trauma Triad of Death"
  - Hypothermia
  - Coagulopathy
  - Acidosis

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Permissive Hypotension

- European Trauma Guidelines 5th Ed, 2019
  - We recommend permissive hypotension with a target systolic blood pressure of 80-90 mmHg (mean arterial pressure 50-60 mmHg) until major bleeding has been stopped in the initial phase following trauma without brain injury. (Grade 1C)
  - In patients with severe TBI (GCS ≤ 8), we recommend that a mean arterial pressure ≥ 80 mmHg be maintained. (Grade 1C)
    - Note, patients with spinal cord injury should also have higher BP goals (MAP > 85)
- Advanced Trauma Life Support 10th Ed, 2018
  - Does not endorse specific blood pressure goals
  - "Administering excessive crystalloid solution can be harmful"
  - "Early administration of pRBCs, plasma, and platelets in a balanced ratio to minimize excessive crystalloid administration may improve patient survival"
  - "Delaying aggressive fluid resuscitation until definitive control of hemorrhage is achieved may prevent additional bleeding"

Spahn D, et al. The European guideline on management of major bleeding and coagulopathy following trauma: fifth edition. Crit Care. 2019 Mar 27;23(1):98.

Advanced Trauma Life Support Student Course Manual: tenth edition. Chicago (IL): American College of Surgeons; 2018.

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When poll is active, respond at **pollev.com/bethanybenish100**
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Which is true regarding vasopressors and venous return?

- Vasopressin administration can increase venous return
- Phenylephrine administration does not affect venous return
- Alpha-1 receptor agonists can increase the ratio of stressed to unstressed volume thereby increasing venous return
- The unstressed volume is the primary driver of venous return
- What are stressed and unstressed volumes? I don't know.

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Blood Volume Homeostasis

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Volume: What regulates it?

- Kidneys
  - SLOWEST
  - Governed by RAAS and ADH
- Interstitial space
  - SLOWER
  - Governed by starling forces
    - Can take 1-2 hours to restore intravascular volume during hemorrhage
- Venous system
  - FAST
  - Governed by stress vs unstressed volume
    - Immediate source of intravascular volume during hemorrhage

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Venous Function

- Veins contain 70% of blood volume
- Serve as a reservoir for blood
- 30 times more compliant than arteries
  - $C = \Delta V / \Delta P$
- Veins contain a high population of alpha-1 receptors
- Clinically, this pertains mostly to the splanchnic vasculature (highly compliant vessels) and to a lesser degree the cutaneous vasculature (compliant, but less than splanchnic veins)

Gelman S, et al. Venous Function and Central Venous Pressure: A Physiologic Story. Anesthesiology 2008; 108:735-748

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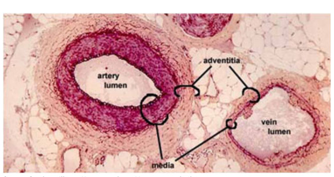
Dualities: Artery vs Vein

- **Arteries** function as **large resistors** and small capacitors
- **Veins** function as **large capacitors** and small resistors



Source: Southern Illinois University (http://www.siumed.edu)

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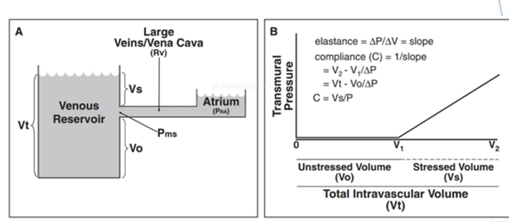
Stress vs. Unstressed Volume



Funk D, et al. The role of venous return in critical illness and shock-part I: physiology. *Crit Care Med*. 2013 Jan;41(1):255-62.

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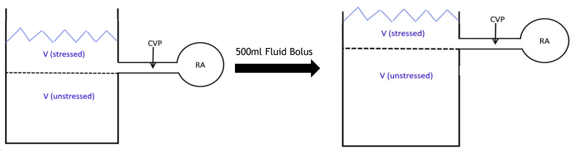
Example: Fluid Bolus

- Healthy patient with high vascular compliance
  - Volume bolus expands unstressed volume
  - Stressed volume stays the same and CVP is **unchanged**



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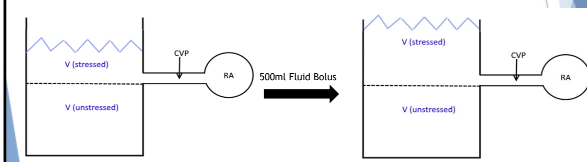
Example: Fluid Bolus

- CHF patient with low vascular compliance (arteriosclerosis)
  - Arteriosclerosis and high catecholamine state decrease vascular compliance
  - Volume bolus expands stressed volume
  - Unstressed volume stays the same and CVP increases



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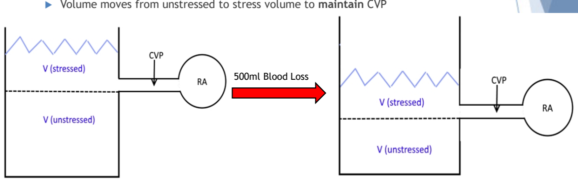
Example: Hemorrhage

- Healthy patient
  - Catecholamines increase causing venoconstriction (decrease venous compliance)
  - Volume moves from unstressed to stress volume to **maintain** CVP



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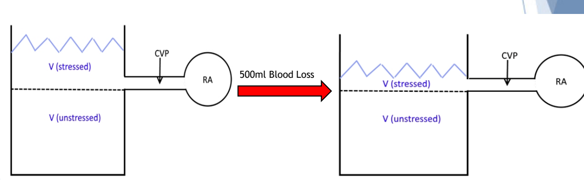
Example: Hemorrhage

- CHF patient with low vascular compliance (arteriosclerosis)
  - Venoconstriction in response to catecholamines is blunted
  - Stress volume decreases and CVP decreases



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Stress vs Unstress Volume Clinical Implications

- Explains why CVP is not an accurate modality to assess volume status
- Explains why young, healthy patients may lose a significant amount of blood with little change in vitals
  - Studies show that maternal vitals signs may initially be normal in PPH despite losing up to 1000 mL of blood†
- Explains how vasopressors may be a useful temporary adjunct to maintain pre-load in a variety of clinical scenarios: spinal anesthesia, neurogenic or septic shock
- Explains why more sophisticated measures to assess volume status should be utilized instead of relying on vitals alone to guide volume resuscitation

† Pacagnella R, et al. A systematic review of the relationship between blood loss and clinical signs. PLoS One. 2013;8(3)

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When poll is active, respond at **pollev.com/bethanybenish100**
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Which of the following is true regarding volume assessment modalities?

- Qualitative arterial line variability is a poor modality to assess volume status
- Qualitative pleth variability is not accurate due to automatic gain adjustment of the waveform to maximize the appearance of the signal
- After adequate volume resuscitation for hemorrhagic shock, the base deficit will completely normalize within minutes
- All patients with a large base deficit need to be volume resuscitated

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Volume Status Assessment Modalities

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Modalities to Assess Volume Status

- Static Modalities
  - Shock Index, Base Deficit, Capillary Refill Time, etc.
- Dynamic Modalities
  - Arterial Line Variability, ΔCO with Fluid Bolus, Pleth Variability Index, etc.

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Shock Index

- $Shock\ Index = \frac{HR}{sBP}$
- SI ≥ 1.0 is highly predictive of massive transfusion (MT) in trauma patients
  - SI ≥ 1.0 RR of 9.67 (95% CI 6.09-15.36) for MT (>10 units in 24 hours)
  - SI also highly predictive of post part partum hemorrhage (SI > 1.4, sensitivity 100%, specificity 70%)
- Heart rate is not predictive of MT in the geriatric (>65 years) trauma patient population.
  - MT and non-MT groups (HR of 92.6 vs 87.4, P > 0.05).
  - SI in this demographic is still predictive of MT (SI 1.3 in MT vs 0.67 in non-MT, P <0.001)

Olaussen A, et al. Review article: shock index for prediction of critical bleeding post-trauma: a systematic review. Emerg Med Australas. 2014;26(3):223-8.

Ayadi A, et al. Vital Sign Prediction of Adverse Maternal Outcomes in Women with Hypovolemic Shock: The Role of Shock Index. PLoS One. 2016 Feb 22;11(2)

Fligor SC, et al. Vital Signs Strongly Predict Massive Transfusion Need in Geriatric Trauma Patients. Am Surg. 2016 Jul;82(7):632-6.

75

Base Deficit

- Base Deficit (BD) or Base Excess (BE) measures the metabolic component of the acid/base disturbance
- BD is calculated in the following manner:
  - 1) Calculate what the pH would be if the CO2 was 40 mm Hg
  - 2) Calculate the amount of HCO3- (mmol/L) that would then be required to normalize this pH to 7.4
- Formal Definition
  - Base excess is the amount of strong acid (in millimoles per liter) that needs to be added in vitro to 1 liter of fully oxygenated whole blood to return the sample to standard conditions (pH of 7.40, Pco2 of 40 mm Hg, and temperature of 37 C)

Berend K. Diagnostic Use of Base Excess in Acid-Base Disorders. N Engl J Med. 2018 Apr 12;378(15):1419-1428.

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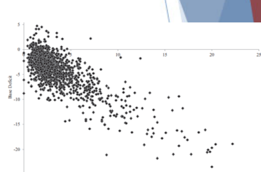
Base Deficit

- BD is not an accurate modality to assess volume status
- BD is highly correlated to lactate levels
  - Lactate kinetics are sluggish
  - Lactate $T_{1/2}$ is 20 minutes assuming normal liver function
- BD may not reflect hypovolemic shock in the following situations
  - Administration of normal saline or HCO3-
  - Renal Failure
  - DKA
  - Prolonged CO2 retention (e.g., COPD)
  - Toxins (methanol, ASA, ethylene glycol)
  - Cardiogenic, Septic, or Neurogenic Shock



Davis JW, Dirks RC, Kaups KL, Tran P. Base deficit is superior to lactate in trauma. Am J Surg. 2018 Apr;215(4):682-685

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Dynamic Modalities

- Dynamic tests
  - Physiological basis, optimize frank-starling curve
- Gold standard
  - $\Delta CO > 10\%$ with 250ml fluid challenge or passive leg raise
    - Other indices such as ΔSV, ΔSVI, ΔCI > 10% may also be used
    - Requires use of PAC, Esophageal Doppler, Pulse Contour Analysis (FloTrac, PiCCO, LiDCO), Echocardiography, or Bioreactance
- Other tests
  - Arterial Line Variability
  - Esophageal Doppler
  - Pulse Contour Analysis
  - Pleth Variability Index

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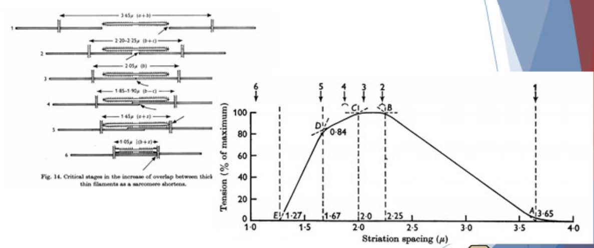
Volume Optimization Goals



Gordon A, et al. The variation in isometric tension with sarcomere length in vertebrate muscle fibres. *J Physiol.* 1966 May; 184(1): 170-192.

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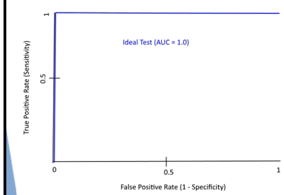
Receiver Operating Curve (Review)



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Arterial Line Variability

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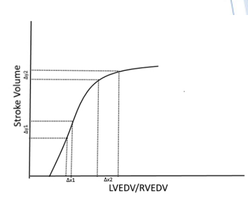
Arterial Line Variability

- ΔSV is a function of Δpreload/afterload
- Positive pressure ventilation
  - Decreases RV preload
  - Increases RV afterload
  - Decreases SV
- Requires
  - **TV > 8ml/kg**
  - **No dysrhythmias**
  - **No spontaneous breathing**



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Arterial Line Variability: Calculation

- Systolic Pressure Variation
  - $SPV = \left(\frac{SBP_{max} - SBP_{min}}{SBP_{mean}}\right) \cdot 100\%$
- Pulse Pressure Variation
  - $PPV = \left(\frac{PP_{max} - PP_{min}}{PP_{mean}}\right) \cdot 100\%$
- Interpretation
  - Volume responsive: SPV or PPV > 12%
  - Indeterminate: SPV or PPV 8-12%
  - Not Volume Responsive: SPV or PPV < 8%

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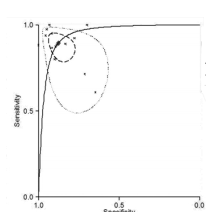
Arterial Line Variability: Evidence

- Meta-analysis of 29 studies
  - 9 MICU
  - 16 Cardiac ICU
  - 4 Intra-operative
- SPV
  - **ROC: 0.86**
- PPV
  - **ROC: 0.94**



Marik P, et al. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature. *Crit Care Med.* 2009 Sep;37(9):2642-7.

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Arterial Line Variability: Eyeball Technique

The Ability of Anesthesia Providers to Visually Estimate Systolic Pressure Variability Using the "Eyeball" Technique

Robert H. Thiele, MD, Douglas A. Colquhoun, MB ChB, MSc, Franziska E. Blum, MD, and Marcel E. Durieux, MD, PhD

- Methods
  - 50 Anesthesia Providers (30 residents and 20 attendings)
  - Asked to give volume or not based on visually observed arterial line variability
- Results
  - 3% elected to treat when (SPV < 8%)
  - 60% elected to treat when (SPV 8 - 12%)
  - 37% elected to treat when (SPV > 12%)

Thiele R, et al. The ability of anesthesia providers to visually estimate systolic pressure variability using the "eyeball" technique. Anesth Analg. 2012 Jul;115(1):176-81.

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Pulse Contour Analysis

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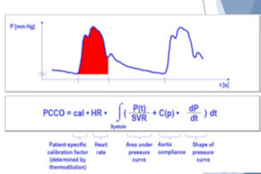
Pulse Contour Analysis

- Analysis of arterial waveform to calculate stroke volume
  - $Pulse\ Pressure \propto Stroke\ Volume$
  - $Pulse\ Pressure \propto \frac{1}{Compliance}$
- Calibrated
  - PiCCO, LiDCO
  - Uses thermodilution to calculate compliance for calibration
- Uncalibrated
  - FloTrac
  - Uses patient demographic data to calculate compliance



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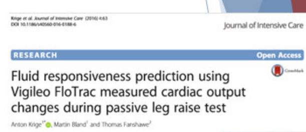
Pulse Contour Analysis: Evidence

- 2nd Generation Flotrac Software
  - Volume Responsive: Δ CO > 15% with 500ml fluid
  - **ROC: 0.92** with **Δ SV > 15% with PLR**†
- 3rd Generation Flotrac Software
  - Volume Responsive: Δ CO > 15% with 250ml fluid
  - **ROC: 0.85** with **Δ CO > 9% with PLR**‡



†Briais M, et al. Changes in stroke volume induced by passive leg raising in spontaneously breathing patients: comparison between echocardiography and Vigileo/FloTrac device. Crit Care. 2009;13(6):R195.

‡Krige A, et al. Fluid responsiveness prediction using Vigileo FloTrac measured cardiac output changes during passive leg raise test. J Intensive Care. 2016 Oct 6;4:63

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Esophageal Doppler Monitor

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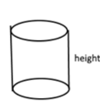
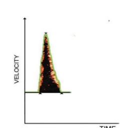
Esophageal Doppler

- Esophageal probe measuring blood velocity in the **descending aorta**
- Aortic area can be approximated by demographics (age, height, weight)
- **Stroke Volume = Aortic Area X VTI**
  - VTI (height) = distance column of blood moved during systole
  - $VTI = \int_{systole\_start}^{systole\_end} Velocity \cdot dt$





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Esophageal Doppler: Evidence

- Stroke Volume Variation (i.e. ΔrespSV)
  - $SVV = \left(\frac{SV_{max} - SV_{min}}{SV_{mean}}\right) \cdot 100\%$
  - **SVV > 14% predictor of fluid responsive**
- FTc – Systolic ejection time corrected for heart rate
- **SVV ROC: 0.91**
- **FTc ROC: 0.49**

Guinot P, et al. Ability of stroke volume variation measured by oesophageal Doppler monitoring to predict fluid responsiveness during surgery. *Br J Anaesth*. 2013 Jan;110(1):28-33.

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Esophageal Doppler: Pitfalls

- Descending aorta receives approximately 70% of total blood flow
  - EDM does 70:30 correction to calculate total CO
  - Shock states divert blood away from mesenteric circulation
  - Lowering percentage of blood flow in the descending aorta
- Velocity Calculation
  - EDM assumes 45 or 60º correction of doppler signal
- Blood flow is laminar and not uniform
- EDM assumes aortic area using patient demographics

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Pleth Variability Index

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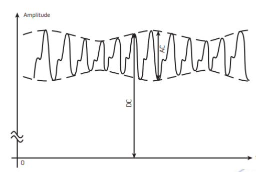
Pleth Variability Index

- Perfusion Index (PI) is calculated as the pulsatile infrared signal (AC) indexed against the non-pulsatile infrared signal (DC). The AC and DC signals reflect the absorption of infrared light.
  - $PI = \frac{AC}{DC} \times 100\%$
- The Pleth Variability Index (PVI)
  - $PVI = \frac{PI_{max} - PI_{min}}{PI_{max}} \times 100\%$
- Requires
  - TV > 8ml/kg
  - No dysrhythmias
  - No spontaneous breathing



Pleth Variability Index: A Dynamic Measurement to Help Assess Physiology and Fluid Responsiveness. Masimo Technical Bulletin. 2013.

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Pleth Variability Index: Evidence

- Advantages
  - Non-invasive
  - Large meta-analysis of 25 studies both in the operating room and the intensive care unit showed a ROC of 0.82[†]
- Disadvantages
  - Proprietary technology from Massimo
  - Qualitative analysis of the waveform is not accurate due to automatic gain adjustment to maximize the appearance of the signal
  - Unclear cut-off value
    - Studies utilize a range of cut-off values from 7-20%
  - PVI is inaccurate in the setting of large volume resuscitation
    - A study in patients undergoing orthotopic liver transplant found a ROC of 0.55[‡]

[†]Liu T, et al. Reliability of pleth variability index in predicting preload responsiveness of mechanically ventilated patients under various conditions: a systematic review and meta-analysis. BMC Anesthesiol. 2019 May 8;19(1):67.

[‡]Konur H, et al. Evaluation of pleth variability index as a predictor of fluid responsiveness during orthotopic liver transplantation. Kaohsiung J Med Sci. 2016 Jul;32(7):373-80.

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Update in Pediatric Trauma

Nicole Arboleda, MD
Associate Professor
University of Colorado School of Medicine
Director of Pediatric Anesthesia
Denver Health Medical Center

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When poll is active, respond at **pollev.com/bethanybenish100**
Text **BETHANYBENISH100** to **22333** once to join

How many of you would consider using whole blood in pediatric blunt or penetrating trauma?

Never, it is not safe

I would consider but my institution does not use it

Yes, we use whole blood for pediatric trauma

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Objectives

- What is LTOWB
- Whole blood in adult civilian trauma
- Upcoming adult studies
- Pediatric trauma resuscitation review
- WB in pediatric trauma
- Safety of WB in pediatric patients
- Consensus clinical recommendations
- Calcium in pediatric trauma
- Shock index, pediatric age-adjusted

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Whole Blood (LTOWB)

- Cold stored 4ºC in refrigerator
- Platelets typically stored at room temperature
- Low titer (low anti-A and anti-B)
- Platelet replete
- Contains RBC, platelets, plasma
- Rh factor less important in acute trauma

Gallaher et al 2020

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Whole Blood in Adult Trauma

ORIGINAL ARTICLE

Large volume transfusion with whole blood is safe compared with component therapy

Jared Robert Gallaher, MD, MPH, Alexandra Dixon, MD, MPH, April Cockcroft, DO, Maverick Grey, BA, Elizabeth Dewey, MS, Andrew Goodman, BS, *and* **Martin Schreiber, MD**, *Portland, Oregon*

Gallaher et al 2020

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LTOWB

- LTOWB as part of MTP safe
- No change in mortality or transfusion reactions
- Can approximate the ideal 1:1:1 ratio than component therapy alone
- Easier, fewer bags to transfuse initially
- Can give at least 4-6 units to adults without evidence of hemolysis
- No difference in mortality at 24 hours or 30 days
- No difference in transfusion reactions in WB group
- Underpowered study to look at massive transfusion with WB transfusion alone

Gallaher et al 2020

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Review

Whole Blood, Fixed Ratio, or Goal-Directed Blood Component Therapy for the Initial Resuscitation of Severely Hemorrhaging Trauma Patients: A Narrative Review

Mark Walsh [1,2], Ernest E. Moore [3,4], Hunter B. Moore [4], Scott Thomas [5], Hau C. Kwaan [6], Jacob Speybroeck [1], Mathew Marsee [1], Connor M. Bunch [1], John Stillson [1], Anthony V. Thomas [1], Annie Grisoli [1], John Aversa [7], Daniel Fulkerson [8], Stefani Vande Lune [9], Lucas Sjeklocha [10] and Quincy K. Tran [10,*]

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Table 2. Advantages and disadvantages of whole blood vs. fixed ratio vs. VET-guided BCT.

	Advantages	Disadvantages
Whole blood	- Simple protocols and uniform dosing - Easy to administer in prehospital and hospital setting - Provides all blood components; avoids hemodilution	- Not physiologically driven - Few RCTs - Unnecessary blood components may be given-Products currently not universally available; shorter shelf life - Requires AABB variances and additional cost
Fixed ratio	- Simple protocols and uniform dosing - Easy to administer in prehospital and hospital setting - More RCTs, but questionable validity regarding 1:1:1 vs. 1:1:2 - Blood components readily available	- Not physiologically driven - Unnecessary blood components may be given - Does not replenish fibrinogen effectively in early stages
VET-guided BCT	- Provides early physiologically driven resuscitation - Limits blood product waste - Blood components readily available	- Protocols not straight forward; accuracy operator dependent; steep learning curve - Cannot be used in prehospital setting - Few RCTs

Abbreviations: AABB, American Association of Blood Banks; BCT, blood component therapy; RCT, randomized control trial; VET, viscoelastic test [1–11,14,40,42,46,47,52,54,59,61,69,78,85–87,89,94,95,98–100,109,115,126].

Walsh et al 2021

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Upcoming studies

- PPOWER from Pittsburgh
  - Prospective RCT
  - WB in prehospital setting
  - Endpoint is mortality
- STORHM from France
  - Study comparing WB to 1:1:1 fixed BCT
  - Endpoint is mortality, lactate clearance, TEG parameters
- SWAT from a consortium of trauma centers
  - Prospective observational cohort study
  - Compare WB to standard BCT
  - Severe hemorrhagic shock +/- TBI

Walsh et al 2021

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Pediatric Trauma Review

Contents lists available at ScienceDirect
Journal of Pediatric Surgery
journal homepage: www.elsevier.com/locate/jpedsurg

Massive transfusion in pediatric trauma: An ATOMAC perspective

Daniel K. Noland [a], Nadja Apelt [a], Cynthia Greenwell [a,*], Jefferson Tweed [a], David M. Notrica [b], Nilda M. Garcia [c], R. Todd Maxson [d], James W. Eubanks III [e], Adam C. Alder [a]

[a] Children's Medical Center, the flagship of Children's Health℠, 1935 Medical District Dr, Dallas, TX, USA 75235
[b] Phoenix Children's Hospital, 1919 E Thomas Rd, Phoenix, AZ, USA 85016
[c] Dell Children's Medical Center, 4900 Mueller Blvd, Austin, TX, USA 78723
[d] Arkansas Children's Hospital, 1 Children's Way, Little Rock, AR, USA 72202
[e] Le Bonheur Children's Hospital, 50 N Dunlap St, Memphis, TN, USA 38103

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ASA Paper

Whole Blood is Superior to Component Transfusion for Injured Children

A Propensity Matched Analysis

Christine M. Leeper, MD, MS, Mark H. Yazer, MD, Darrell J. Triulzi, MD, Matthew D. Neal, MD, and Barbara A. Gaines, MD

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- Whole blood group:
  - Faster resolution of base deficit
  - Lower post-transfusion INR
  - Lower RBC, plasma, platelet volumes administered
  - No difference in mortality, hospital LOS
- Mortality data in children compared to adults is difficult due to less data, lower pediatric mortality overall, and few centers using LTOWB

Leeper at al 2020

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Received: 22 October 2020 | Revised: 8 December 2020 | Accepted: 10 December 2020
DOI: 10.1111/trf.16436

SUPPLEMENT ARTICLE

TRANSFUSION

Safety profile of low-titer group O whole blood in pediatric patients with massive hemorrhage

Katrina M. Morgan[1] | Mark H. Yazer[2] | Darrell J. Triulzi[2] | Stephen Strotmeyer[3] | Barbara A. Gaines[3] | Christine M. Leeper[1]

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Safety of LTOWB in Pediatric Patients

- 2021 University of Pittsburgh
- 47 patients transfused for hemorrhagic shock due to trauma
- LTOWB advantages compared to BCT: faster resolution of shock, reduced transfusion requirements following initial resuscitation
- Primary outcome laboratory evidence of hemolysis or report of transfusion reaction
- 2021 Conclusion: up to 40 ml/kg LTOWB serologically safe
- 2016 criteria for administering LTOWB initially age ≥ 3 yrs and weight ≥ 15 kg
- 2019 revised to age ≥ 1 yr

Morgan at al 2021

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REVIEW ARTICLE

Resuscitative practices and the use of low-titer group O whole blood in pediatric trauma

Katrina M. Morgan, MD, Christine M. Leeper, MD, MS, Mark H. Yazer, MD, Philip C. Spinella, MD, *and* **Barbara A. Gaines, MD**, *Pittsburgh, Pennsylvania*

ABSTRACT: Increasing rates of penetrating trauma in the United States makes rapid identification of hemorrhagic shock, coagulopathy, and early initiation of balanced resuscitation in injured children of critical importance. Hemorrhagic shock begins early after injury and can be challenging to identify in children, as hypotension is a late sign that a child is on the verge of circulatory collapse and should be aggressively resuscitated. Recent data support shifting away from crystalloid and toward early resuscitation with blood products because of worse coagulopathy and clinical outcomes in injured patients resuscitated with crystalloid. Multicenter studies have found improved survival in injured children who receive balanced resuscitation with higher fresh frozen plasma: red blood cell ratios. Whole blood is an efficient way to achieve balanced resuscitation in critically injured children with limited intravenous access and decreased exposure to multiple donors. Administration of cold-stored, low-titer O-negative whole blood (LTOWB) appears to be safe in adults and children and may be associated with improved survival in children with life-threatening hemorrhage. Many pediatric centers use RhD-negative LTOWB for all female children because of the risk of hemolytic disease of the fetus and newborn (0–6%); however, there is a scarcity of LTOWB compared with the demand. Low risks of hemolytic disease of the fetus and newborn affecting a future pregnancy must be weighed against high mortality rates in delayed blood product administration in children in hemorrhagic shock. Survey studies involving key stakeholder's opinions on pediatric blood transfusion practices are underway. Existing pediatric-specific literature on trauma resuscitation is often limited and underpowered; multicenter prospective studies are urgently needed to define optimal resuscitation products and practices in injured children in an era of increasing penetrating trauma. (*J Trauma Acute Care Surg.* 2023;94: S29–S35. Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Pediatric trauma; whole blood; balanced resuscitation.

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TABLE 2. Literature Supporting Whole Blood Resuscitation in Pediatric Trauma

Article	Population	Study Type	Results
Manno et al. 1991[62]	• Single center • Children requiring cardiac surgery	RCT comparing room temperature fresh WB, cold-stored WB, and CT	• Significantly less postoperative bleeding and improved platelet aggregometry in WB vs. CT groups
Leeper et al. 2018[57]	• Single center • Severely injured children 3 y or older	Retrospective review comparing WB recipients to historical cohort that received CT	• No transfusion reactions • Shortened time to administration of RBCs, plasma, and platelets compared with CT
Leeper et al. 2019[63]	• Single center • Severely injured children 2 y or older	Retrospective review comparing children who received WB but no component platelets vs. historical cohort that received component RBCs and platelets	• No difference in platelet count and function between cold-stored WB and room temperature component platelets
Leeper et al. 2020[59]	• Single center • Severely injured children 1 y or older	Retrospective review with propensity-matched cohort who received ≥1 U RBC	• Faster resolution of base deficit, decreased posttransfusion INR vs. CT group • Less plasma and platelet volumes transfused vs. CT group
Anand et al. 2021[60]	• TQIP • 1–17 years who received blood transfusion within 4 hrs	Retrospective review with propensity matching between WB and CT recipients	• Decreased total blood products transfused at 4- and 24-h postadmission in WB group • Fewer ventilator days in WB group
Lauby et al. 2021[61]	• DOD • Combat injured children in Iraq and Afghanistan transfused ≥ 1 blood product	Retrospective review comparing CT vs. any amount of warm fresh WB	• Improved survival in children without severe TBI who received warm fresh WB
Morgan et al. 2021[64]	• Single center • All children who received WB	Retrospective review comparing group O vs. non-group O blood types	• No differences in hemolysis, mortality, disability, ventilator, or hospital length of stay between group O and non-group O blood types
Leeper et al. 2021[65]	• Single center • All children who received ≥ 1 WB or RBC within 24 h	Retrospective review with propensity matching between WB and CT recipients	• No differences in transfusion reactions or organ dysfunction vs. CT • Significantly shorter ICU stay vs. CT
Gaines et al. 2021[58]	• Single center • 1–17 y who received >40 mL/kg blood product in 24 h	Prospective observational study comparing WB and only CT recipients	• Improved survival at 72 h and 28 d in WB recipients adjusting for age, total product transfused in 24 h, admission base deficit, INR, and ISS

CT, component therapy; DOD, Department of Defense trauma registry; ICU, intensive care unit; INR, international normalized ratio; ISS, Injury Severity Score; TBI, traumatic brain injury; RBC, red blood cell; TQIP, Trauma Quality Improvement Program database; WB, whole blood.

Morgan et al 2023

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- Addresses potential concerns for hemolysis and RhD sensitization
- Need for future studies in use of WB for pediatric trauma, multicenter trials, and prehospital administration WB
- Unclear which subset of pediatric patients will benefit most

Morgan et al 2023

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CONSENSUS STATEMENT

Pediatric traumatic hemorrhagic shock consensus conference recommendations

Robert T. Russell, MD, MPH, Joseph R. Esparaz, MD, MPH, Michael A. Beckwith, MD, Peter J. Abraham, MD, Melania M. Bembea, MD, PhD, MPH, Matthew A. Borgman, MD, Randall S. Burd, MD, PhD, Barbara A. Gaines, MD, Mubeen Jafri, MD, Cassandra D. Josephson, MD, Christine Leeper, MD, Julie C. Leonard, MD, MPH, Jennifer A. Muszynski, MD, MPH, Kathleen K. Nicol, MD, Daniel K. Nishijima, MD, MAS, Paul A. Stricker, MD, Adam M. Vogel, MD, Trisha E. Wong, MD, MS, *and* **Philip C. Spinella, MD**, *Birmingham, Alabama*

ABSTRACT: Hemorrhagic shock in pediatric trauma patients remains a challenging yet preventable cause of death. There is little high-quality evidence available to guide specific aspects of hemorrhage control and specific resuscitation practices in this population. We sought to generate clinical recommendations, expert consensus, and good practice statements to aid providers in care for these difficult patients. The Pediatric Traumatic Hemorrhagic Shock Consensus Conference process included systematic reviews related to six subtopics and one consensus meeting. A panel of 16 consensus multidisciplinary committee members evaluated the literature related to 6 specific topics: (1) blood products and fluid resuscitation for hemostatic resuscitation, (2) utilization of prehospital blood products, (3) use of hemostatic adjuncts, (4) tourniquet use, (5) prehospital airway and blood pressure management, and (6) conventional coagulation tests or thromboelastography-guided resuscitation. A total of 21 recommendations are detailed in this article: 2 clinical recommendations, 14 expert consensus statements, and 5 good practice statements. The statement, the panel's voting outcome, and the rationale for each statement intend to give pediatric trauma providers the latest evidence and guidance to care for pediatric trauma patients experiencing hemorrhagic shock. With a broad multidisciplinary representation, the Pediatric Traumatic Hemorrhagic Shock Consensus Conference systematically evaluated the literature and developed clinical recommendations, expert consensus, and good practice statements concerning topics in traumatically injured pediatric patients with hemorrhagic shock. (*J Trauma Acute Care Surg.* 2023;94: S2–S10.Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Trauma; pediatrics; hemorrhage; consensus.

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- Panel of 16 consensus multidisciplinary committee members
- 21 recommendations:
  - 2 Clinical recommendations
  - 14 expert consensus statements
  - 5 good practice statements
- Evaluated literature on 6 topics:
  - Blood products and fluid resuscitation
  - Utilization of prehospital blood products
  - Use of hemostatic agents
  - Tourniquet use
  - Prehospital airway and BP management
  - CCT or TEG based resuscitation

Russell at al 2023

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Clinical Recommendations

- In traumatically injured children in hemorrhagic shock:
- Prioritize the use of blood products over crystalloids
- Use of LTOWB can be considered for resuscitation
- If BCT, target high plasma:RBC ratios
- Target high platelet:RBC weight-based ratios
- Consider prehospital transfusion by EMS based on product availability and clinical judgement
- Empiric use of TXA within 3 hrs of injury might be considered

Russell at al 2023

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Clinical Recommendations

- Use commercially available tourniquets by individuals with training for exsanguinating extremity hemorrhage
- Prehospital BP management- suggest against permissive hypotension, instead optimize end organ perfusion and adequate oxygen delivery
- Initial empiric resuscitation approach using MTPs and balanced product administration
- Use of TEG or viscoelastic assays recommended for goal directed resuscitation if available to optimize hemostasis and correction of coagulopathy

Russell at al 2023

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Text **BETHANYBENISH100** to **22333** once to join

There is an unrestrained 3 yo male s/p ejection from a motor vehicle. He presents to the ED by ambulance. You are the anesthesiologist on call. His ionized calcium on arrival is 0.98 mmol/L. What do you do with this number?

Nothing, only interested in H/H, coags, blood gas

I would treat the calcium but it is just a random lab result

I would treat the hypocalcemia and know that it indicates more about transfusion requirements for this child

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Calcium in Pediatric Trauma

- After first few months of life (>6 months old) calcium metabolism and physiology similar to adults
- Role of calcium in normal physiologic function:
  - Effective coagulation
  - Cardiac contractility
  - Muscle function
  - Component of bone mineral matrix
- Pediatric hearts are more vulnerable to myocardial dysfunction in presence of hypocalcemia (↓ SR)
- Age and weight adjustments for treatment of hypocalcemia
- IV access more challenging in children
- Extravasation of CaCl can lead to tissue necrosis

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Hypocalcemia

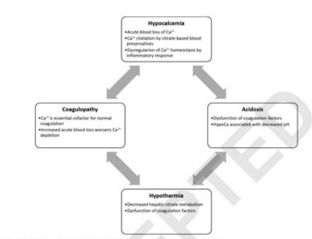

Figure 1. Lethal Diamond diagram. Adapted from Ditzel et al. Ca^{2+}: ionized calcium; HypoCa: hypocalcemia

Ciaraglia at al 2023

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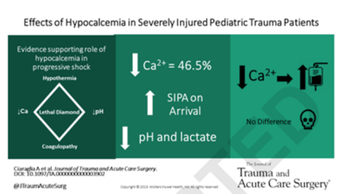
Hypocalcemia in Pediatric Trauma



Ciaraglia et al 2023

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Calcium Repletion

- Calcium gluconate vs calcium chloride
  - Calcium chloride 10% has 3 times more elemental calcium than calcium gluconate for the same volume administered
  - Calcium chloride has a higher risk of tissue necrosis with extravasation compared to calcium gluconate when administered through a peripheral IV
- Calcium gluconate 60 mg/kg over 10 minutes
- Calcium chloride 20 mg/kg over 10 minutes

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Pediatrics
Presented at the Academic Surgical Congress 2020

The shock index, pediatric age-adjusted (SIPA) enhanced: Prehospital and emergency department SIPA values forecast transfusion needs for blunt solid organ injured children

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Calculate SIPA

- The shock index, pediatric age-adjusted (SIPA), defined as the maximum normal heart rate divided by the minimum normal systolic blood pressure by age

TABLE 1 | Vital signs by age with the calculated SIPA cutoff value.

Age	HR	SBP	SIPA cutoff value
1–3 years	70–110	90–110	1.2
4–6 years	65–110	90–110	1.2
7–12 years	60–100	100–120	1.0
>12 years	55–90	100–135	0.9

SIPA, shock index, pediatric age-adjusted; HR, heart rate; SBP, systolic blood pressure.

Huang et al 2021

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SIPA in Blunt Solid Organ Injury

Table I
Normal vital signs by age with calculated SIPA cutoff values

Age (y)	Heart rate	Systolic blood pressure	SIPA
1–3	70–110	90–110	1.2
4–6	65–110	90–110	1.2
7–12	60–100	100–120	1.0
>12	55–90	100–135	0.9

Table IV
Comparison of elevated and normal SIPA values in the prehospital and the ED in those who required blood transfusion compared those who did not

Prehospital SIPA	ED SIPA	Blood transfused (n = 95)*	No blood transfused (n = 382)
Elevated	Elevated	52 (55%)	64 (17%)
Elevated	Normal	22 (23%)	108 (28%)
Normal	Elevated	10 (10%)	20 (4%)
Normal	Normal	11 (11%)	190 (51%)

Categorical variables presented as n (%)
* There is a **significant difference** between the groups; the groups with an elevated prehospital or ED SIPA compared with those with a normal SIPA were more likely to receive a blood transfusion ($P < .001$).

Phillips et al 2020

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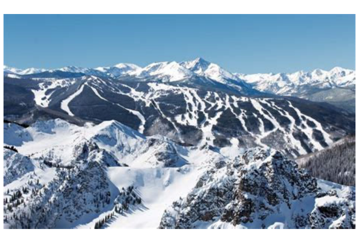
The End….any questions?



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