Physiology
of
Life & Death

Norman McSwain, MD
FACS, NEMT-P
Professor
Tulane University, Surgery
Medical Director
PreHospital Trauma Life Support
Trauma Director
Spirit of Charity Trauma Center
KISS

Keep It Simple Stupid
Life
What is it?
Energy production

What is it?

• Everything that moves or functions requires energy for survival
  – Cars
  – Buildings
  – Computers
  – Lights

• All body functions are energy dependent
  – Heat,
  – Muscle action,
  – Brain function
  – Everything

Car
  • Gasoline provides fuel
  • Moves car
  • Lights show the road
  • Heater warms the inside
  • Power brakes stops movement
  • Power steering aids in control

No energy… the ‘thing’ fails

Death
What is Life?

Adequate energy production to meet the needs for body functions.
Why does energy production fail?

No substrate to make energy

Oxygen delivery system
**Aerobic Metabolism**

38 ATP

**Anaerobic Metabolism**

2 ATP

**ATP = Energy**
Energy production

Ficke Principle

Prevent Anaerobic metabolism

- **On-loading** of $O_2$ onto RBC in lung
- **Transportation** of RBC with $O_2$ to tissue cells
- **Off-loading** of $O_2$ into tissue cells for Krebs cycle

**Requirement**
- Open airway & ventilation
- Adequate Red Cell Mass to carry $O_2$
Triangle of Death

Acidosis

Energy

Coagulopathy

Hypothermia
The *Secret* to the treatment of shock is

Management of anaerobic metabolism
to

Restore energy production

Control the source of the problem

Pump
Fluid
Container
Circulatory System

- Pump (heart)
- Pipes (vessels)
- Fluid (blood)

Failure of any component will reduce effectiveness of the delivery system (flow)
Energy

Delivery Process

Oxygenation
Ficke Principle

Energy production
Krebs cycle
Life

- Air goes in and out
- Blood goes round and round
- Cells make energy
- Energy = Life
- No energy = Death
Think Energy
The End
Thanks for your attention

Questions?
Gross
Early American Surgeon
1854

DEATH
“rude unhinging of the machinery of life”
Preservation of Life
Prevention of Death
Resuscitation
Energy

Delivery Process

Fluid - Blood
Pump – Heart
Pipes – Vessels
Benefits of blood

• **Delivery of oxygen** to tissue cells
• **Stopping leaks** in the vessels
  – clotting factors
  – platelets
• **Maintain fluid** in vascular system
  – Oncotic pressure

Packed RBC’s supply only O₂ delivery
Major components for resuscitation

Trauma

Maintenance of energy production

• Aerobic metabolism
• Stop the hemorrhage
Volume failure
Reduced energy production

- Hemorrhage
  - External
  - Internal

- Dehydration
  - Vomiting, diarrhea
  - Reduced intake
  - Increased evaporation
    - Skin
    - Lungs
Resuscitation

Restore/maintain energy production
Stop hemorrhage
PreHospital Fluid Resuscitation

When ?
What ?
How much ?
ED Crystalloid Resuscitation of 1.5 L or more

Increased Mortality in Elderly and Nonelderly Trauma Patients

Eric J. Ley, MD, Morgan A. Clond, PhD, Marissa K. Sroul, BS, Moshe Barnajian, MD, James Mirocha, MS, Dan R. Margulies, MD, and Ali Salim, MD

*J trauma Feb 2011*

1.5 L crystalloid fluid

- Elderly Odds ratio - **2.89**,
- Nonelderly *Odds ratio - 2.09, (p 0.002).*

3 L, crystalloid fluid

- Elderly *Odds ratio- 8.61, (p 0.014),*
- Nonelderly *Odds Ratio 2.69, (p 0.0006).*
For hypotensive patients with penetrating torso injuries, delay of aggressive fluid resuscitation until operative intervention improves the outcome.

Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries

Bickell WH, Wall MJ, Pepe PE, Martin RR, Ginger VF, Allen MK, Mattox KL
“......prehospital fluid administration was associated with increased survival (hazard ratio, 0.84; 95% confidence interval, 0.72-0.98; p = 0.03). Site differences in ISS and fluid volumes were demonstrated (p < 0.001). CONCLUSION: Prehospital IVF volumes commonly used by PRospective Observational Multicenter Massive Transfusion Study (PROMMTT) investigators do not result in increased systolic blood pressure but are associated with decreased in-hospital mortality in trauma patients compared with patients who did not receive prehospital IVF.”

Prehospital intravenous fluid is associated with increased survival in trauma patients.
Hampton DA, Fabricant LJ, Differding J, Schreiber, MA
J Trauma Acute Care Surg (2013 Jul) 75(1 Suppl 1):S9-15
PreHospital Fluid Resuscitation

When ?
What ?
How much ?
Assessment for Life vs Death (Shock)
Primary Survey

Assessment

• Rapid
  • 15 seconds

• Simultaneously
  • Overview of everything

• Gross/subjective
  • Eyes
  • Fingers
  • Ears
Assessment

Look for signs of decreased perfusion

Distal is the first to go

- Skin perfusion
  - Color
  - Temperature
  - Flow (capillary refilling time)

- Peripheral pulses
  - Character
  - Radial
  - Femoral
  - Carotid
Assessment

Signs of decreased energy production/perfusion (2)

• Mental function
  – Alertness
  – LOC

• Acidosis
  – Increased ventilatory rate
    • CO₂ blow off

• Hypothermia
  – Shivering (35 -> 33)
    • Muscle contractions to produce energy/heat
  – Complains of being cold
  – This is late. Bad sign
Assessment

Skin Perfusion
Capillary refilling time

• Decreased skin perfusion
  – does not define shock
  – nor is it definitive of shock

• Can come from a variety of causes
  – Hypovolemia
  – Hypothermia
  – Vascular obstruction

Very important sign
“...when you.....can express it in numbers, you know something about it;

...when you cannot measure [and]....express it in numbers,

your knowledge is of a meagre and unsatisfactory kind”

PLA, vol. 1, "Electrical Units of Measurement", 1883-05-03
Secondary Survey

- Details of everything
- Objective
- Measurements with numbers
- Think and understand
Vital Functions

**Signs**
- Cardiac rate
- Ventilatory rate
- Temperature
- Mental function – GCS
- Blood pressure
- Urinary output

**Physiology**
- Oxygen debt
- Lactate
- Hemoglobin
- Hematocrit
- pH
- $\text{PaCO}_2$
- $\text{PaO}_2$
Resuscitation

- Do no further harm
  Delay causes harm
- Stop RBC loss
- Restore energy production

Delay
Prehospital
Emergency Department
Operating Room
Critical Elements of Resuscitation

- Maintain movement of $O_2$ to tissues
- Stop leaks in the vascular system
  - Vascular injury
  - Microvascular (crystalloid)
- Preserve oncotic pressure in vessels
  - No crystalloid
  - Plasma

*Time Critical*
Methods of Resuscitation

Restore what is lost or missing

• Cardiac failure => increase cardiac contractility
• Volume failure => restore volume
  – Dehydration => crystalloid
  – Hemorrhage => Red blood cells + Plasma + SMA
• Container failure => restore container/volume mismatch
  – Restore vascular tone
  – Extra volume

Cardio tonic Drugs

NOT Cardio tonic drugs

Is patient happy?
Ideal Trauma Resuscitation

- Reduce blood loss from vascular injury
  - External hemorrhage control
    - Field and ED
  - Internal hemorrhage control
    - Factor 14 (mechanical hemorrhage control)

- Restoration of blood volume
  - achieve adequate tissue oxygenation
  - Replace clotting factors
  - Platelets

1:1:1
Restore Energy Production
Large Volume Resuscitation

- Extensive study by Tom Shires, MD
- Viet Nam war
- 3 liters Crystalloid : 1 Litter blood
- Misinterpreted to huge amounts of crystalloid
- Outcome was fluid overload
  - Michelin Man
  - ARDS – De Nang lung
  - Renal failure
  - Abdominal compartment syndrome
- Dilution of clotting products => blood loss
Hypertonic Resuscitation

- Studied by Holcroft and Jelenko
- Hypertonic fluids
  - 7.5% saline
  - Colloid
- Restoration of blood pressure
- Outcome = intracellular and interstitial dehydration
Volume Resuscitation
popularized by Dr Tom shires

- Pressure \(\downarrow\) 2º to blood loss
- Blood loss \(\downarrow\) from vascular injury
- Crystalloid resuscitation \(\rightarrow\) Hct \(\downarrow\)
- Blood pressure \(\uparrow\)
- Blood loss \(\uparrow\) from injury
- Blood pressure \(\downarrow\)
- Hemorrhage \(\downarrow\)
- Crystalloid resuscitation \(\rightarrow\) Hct \(\downarrow\)
- Blood pressure \(\uparrow\)
- Cycle repeats and RBC mass continues to \(\downarrow\)
Hypertonic Resuscitation
Popularized by Holcroft and Jelenko

- Hemorrhage
- Blood pressure drops
- Hypertonic fluid administration
- Fluid transferred to vascular space from interstitial space – Hct drops
- Fluid transferred from cellular space to interstitial space
- Blood pressure increases
- Hemorrhage increases
- Cycle repeats – Hct drops
- Outcome = dehydrated patient with reduced RBC mass
Volume Restricted Resuscitation
(popularized by Dr Mattox)

• Hemorrhage

• H

• I

• Maintain oxygen perfusion without increasing intra-luminal pressure
  – At reduced rate

• Hemorrhage control in OR

• Full complete resuscitation
Fluid Resuscitation
Replace what is lost with what is lost
Think
Energy production
Resuscitation

- Blood is lost – replace blood
  - Carries oxygen
  - Maintains oncotic pressure
  - Restores lost clotting factors
- Crystalloid is lost – replace crystalloid
- Presser agents are lost – replace pressor agents
Whole blood no longer available in United States

Fractionated by the blood banking industry
Next best option
- Reconstitute blood -

- Packed Red Blood Cells
- Plasma
  - Frozen
  - Liquid
- Platelets
- Cryoprecipitate

Where is this available?
Rapid delivery Patient facility capable providing these elements
EMS Responsibility

• $O_2$ into lung

• Prevent loss of RBC’s

Initiate field hemorrhage control

• Pressure
• Tourniquets

Transport to Factor XIV
Correct Facility

Immediate available

Resuscitation personnel
Open abdomen/Chest
– OR Staff
– Surgeon
– Anesthesia
– Surgeon who cuts quickly
  • Bleeding is inside and not on the skin
– Finds intracavitary hemorrhage
Hemorrhage Control
Bernoulli Equation

\[ Q = \frac{AP + 2V}{E} \]

- **Q** - rate of leakage
- **A** – area of the laceration
- **P** – transmural pressure
  - Intraluminal pressure
  - Extra luminal pressure
- **V** – velocity of the blood flow
- **E** – viscosity of blood
Bernoulli Equation

Blood runs out of a vessel

related to

- size of the hole in the vessel wall
- pressure in the vessel
- pressure surrounding the vessel

= Blood loss
Size of the hole

- Push sides together
- Plug up the hole
  - Outside
    - Finger in hole
    - Gauze in hole
    - Pressure to hold plug in place
  - Inside
    - Blood clots
    - Clotting factors
      - Dilution problem
        » EMS treatable
      - Replacement
Reduction of transmural pressure

\[
\frac{\text{Pressure in the vessel}}{\text{Pressure surrounding the vessel}} = \text{Rate of Blood loss}
\]

Reduce intravascular pressure
Increase extra vascular pressure
Intravascular pressure reduction

- Restricted prehospital fluid resuscitation
  - **Systemic**
    - Maintain systolic pressure $< 90$ mmHg
    - No crystalloid
    - Colloid (hetastarch only)

- No blood flow to damaged extremities
  - **Local**
    - Tourniquet
Phases of Trauma Related Hemorrhage

- **Dilutional**
  - Loss of RBC
  - Loss of Plasma
  - Loss of platelets

- **Trauma induced hemorrhage**
  - Protein C

- **Fibrinolysis**
  - inappropriate breakdown of clots

- **Intravascular thrombosis**
  - DVT
  - PE
Summary
Shock management

Stop deterioration

- Restore/maintain energy production
  - Damage control resuscitation
    - Restore O2 delivery to tissues
    - Restore clotting
    - Maintain oncotic pressure
Shock management

Stop deterioration

• Hemorrhage control
  – External
    • Pressure on injury
    • Vascular isolation
  – Internal
    • In proving clotting
    • Hypotensive reduction of blood loss
    • Rapid assess to Factor XIV
    • Damage control surgery
Hypothermia is a symptom, not a disease
The disease is anaerobic metabolism

Acidosis is a symptom
The disease is anaerobic metabolism
Resuscitation

Think

Energy production

☐ Stop anaerobic metabolism

☐ Control hemorrhage
Critical Elements of Resuscitation

- Maintain movement of $O_2$ to tissues
- Stop leaks in the vascular system
- Preserve oncotic pressure in vessels

Time Critical
Extending the Hand of Education to those who care for the trauma patient

67 countries
1,000,000 providers
Norman McSwain, MD
FACS, NEMT-P
Professor
Tulane University, Surgery
Medical Director
PreHospital Trauma Life Support
Trauma Director
Spirit of Charity Trauma Center

? Questions?
? Comments?
? Paranoid outbreaks?
Dilutional

- Loss of RBC
- Loss of Plasma
- Loss of platelets
- Replacement with crystalloid

Immediate loss of clotting ability
Damage Control Resuscitation
Prehospital

Indicators - Pulse character & mentation
(Holcomb)

Hypotensive care

• Restricted Fluid Resuscitation
• Short transports - Minimal Crystalloid
• Long transports – colloid
Damage Control Resuscitation
In-hospital

Goal

• Reduced blood loss
• Aerobic metabolism

Measurement

• Continued mentation
• Systolic blood pressure 80-90 mmHg
• External hemorrhage controlled
• Warm patient (continued energy production)
Prevention of RBC loss

• **External hemorrhage**
  - Visible
  - Treatable
    • Compression
    • Vascular isolation of injury

• **Internal hemorrhage**
  - Invisible
  - Treatable – Factor XIV
Hemorrhage Control
External

• Pressure on external hemorrhage
• Tourniquets for extremities
• Clotting agents for torso
External pressure boost

• Direct pressure at injury site
  – Point pressure
  – Finger pressure
  – Packing gauze directly into the wound

• Generalized pressure on wound
  – Circumferential pressure
  – Elastic bandage
  – Pneumatic Splint
  – Blood pressure cuff
  – PASG
Factor XIV

• Available in the hospital only
• Especially helpful for internal hemorrhage
  – Abdomen
  – Thorax
  – Pelvis
• Rapid transport to trauma center

Operating room
  • Ligature
  • Hemostats
Invasive Radiology
  • embolization
McSwain Rules for Hemorrhage control

- Low *transmural* pressure
- Adequate *clotting* plugs for injured vessels
- Rapid *transportation* to open abdomen/chest
Delay = Continued Hemorrhage

• In Field
• In ED
• In OR
Damage Control Surgery
Field Hemorrhage Control

Non-combat patient care

Direct hand pressure

Pressure Bandage

Hospital

Hemorrhage continues

Torso

Hemostatic Agent

Hospital

Extremity

Tourniquet

Hospital
Tourniquets

Cravat/Windlass
Combat Applied Tactical Tourniquet

CATT
Tourniquets

• Application **before** onset of shock – 87% survival
• Application **after** onset of shock – 4% survival
Albert Sidney Johnston
General, Confederate Army

- Gun shot would to thigh
- Blood ran down into boot
- Directed medic to another soldier
- Exsanguinated
- Tourniquet would have saved his life
- Reportedly in his pocket.
Tourniquets – Kragh et al
Annals of Surgery 2009

• Ibn Sina Hospital, Baghdad, 2006
• Tourniquets are saving lives on the battlefield
• 31 lives saved in this study by applying tourniquets prehospital rather than in the ED
• Author estimates 2000 lives saved with tourniquets in this conflict (Extrapolation provided to MRMC)
Hemostatic Agents

- QuikClot
- Hemcon
- Wound Stat
- Combat Gauze
- Plain gauze

Outcome is equal
Critical factor is pressure
Packing of gauze into wound is important
Almost 3/4 million EMT’s, Physicians & Nurses trained in 52 countries Translated into 12 languages

Extending the hand of education to those who care for trauma patients.
Problems of Volume Resuscitation

Dilution

- $O_2$ carrying capacity $\Rightarrow$ anaerobic metabolism
- Clotting factors $\Rightarrow$ free hemorrhage

Increased intravascular pressure

- Increased transmural pressure $\Rightarrow$ hemorrhage
- ‘Pop the clot’ $\Rightarrow$ hemorrhage

Triangle of Death

Acidosis, Hypothermia, Coagulation
Volume Resuscitation
popularized by Dr Tom Shires

- Pressure ↓ 2º to blood loss
- Blood loss ↓ from vascular injury
- Crystalloid resuscitation ➔ Hct ↓
- Blood pressure ↓
- Blood loss ↑ from injury
- Blood pressure ↓
- Hemorrhage ↓
- Crystalloid resuscitation ➔ Hct ↓
- Blood pressure ↑
- Cycle repeats and RBC mass continues to ↓
Hemorrhage Control

Maintain reduced transmural pressure

- **Low intravascular pressure**
  - Hypotensive (restricted fluid) resuscitation
    - No overhydration
    - No “normal” blood pressure
  - Colloid fluid replacement prehospital
  - Tourniquet

- **High extravascular pressure**
  - Direct pressure on injured vessels
  - Circumferential pressure
Hemorrhage control

Maintain clotting plugs

• Minimal dilutional fluid
  – No crystalloid
  – Colloid only

• Replaced lost clotting factors
  – Fresh Frozen Plasma (FFP)
  – Liquid plasma
  – Platelets
  – Cryoparticipate
  – Specific factor replacement
Hemorrhage control

Factor XIV

- Rapid transportation to Trauma Center
- Experienced and available trauma personnel
- Quickly available OR
- Quickly available Invasive radiology
- Blood, plasma and factors
Conclusion

• Return energy (ATP) production to normal
  – Temperature >35° C
  – Pulse < 100
  – Systolic pressure > 100 mmHg
    • With controlled hemorrhage
  – Lactate better than (-) 6
  – Intra- abdominal pressure < 20 mmHg
  – U/O > 50 cc/hr
  – Stable peak inspiratory pressure
Combat Gauze

- Studied extensively by US Army Surgical Research Institute (USASRI)
- Compared to other types of hemostatic agents
- Approved by Committee on Tactical Combat Casualty Care (CoTCCC)
- Approved by DOD Defense Medical Board, Subcommittee on Trauma and Injuries
- Approved by Dept of Defense
- Only current agent with such approval
Damage Control
Surgery
Resuscitation

Norman McSwain, MD
FACS, NEMT-P
Professor
Tulane University, Surgery
Medical Director
PreHospitial Trauma Life Support
Trauma Director
Spirit of Charity Trauma Center
Understanding Resuscitation
August 2011

Norman McSwain, Jr  MD
Professor of Surgery, Tulane University
Trauma director, Spirit of Charity Trauma Center, ILH
Medical director, PreHospital Trauma Life Support