BioGears Models: Multi-Trauma Physiology

A. Baird[1], J. Carter[1], L. Marin[1], M. McDaniel[1], N. Tatum[1], S. White[1]

1. Applied Research Associates Inc.

Outline

- Multi-trauma Overview
  - BioGears Trauma Models
- Medical Interventions
  - BioGears Treatment Models
  - What Can Go Wrong?
- BioGears Simulation Results
- Conclusions
  - How BioGears Can Impact This Field?

Multi-Trauma Physiology

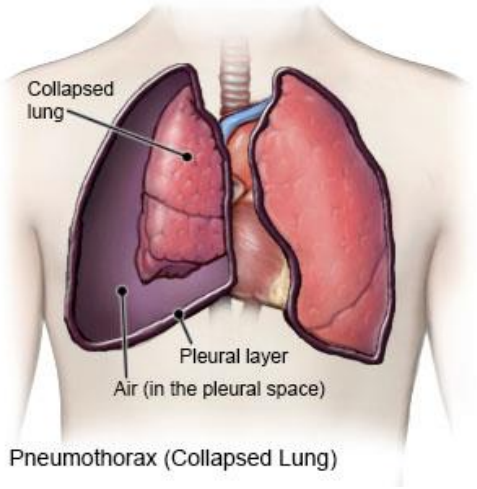
- Multi-Trauma: subjected to multiple traumatic injuries
  - Hemorrhaging across body
  - Tension pneumothorax
  - Burn
  - Musculoskeletal injury
  - Traumatic brain injury
- Physiological changes vary not only based on injury, but on
  - Patient variability
  - Interventions
  - Time to intervention

Multi-Trauma Physiology

- Multi-Trauma in BioGears
  - Hemorrhage
  - Tension pneumothorax
- Tactical Combat Casualty Care (TCCC) emphasizes hemorrhage and airway management[1]
- Goals
  - Medic: Decrease mortality and morbidity of the patient
  - BioGears: Physiological simulation to accurately depict multi-trauma scenarios

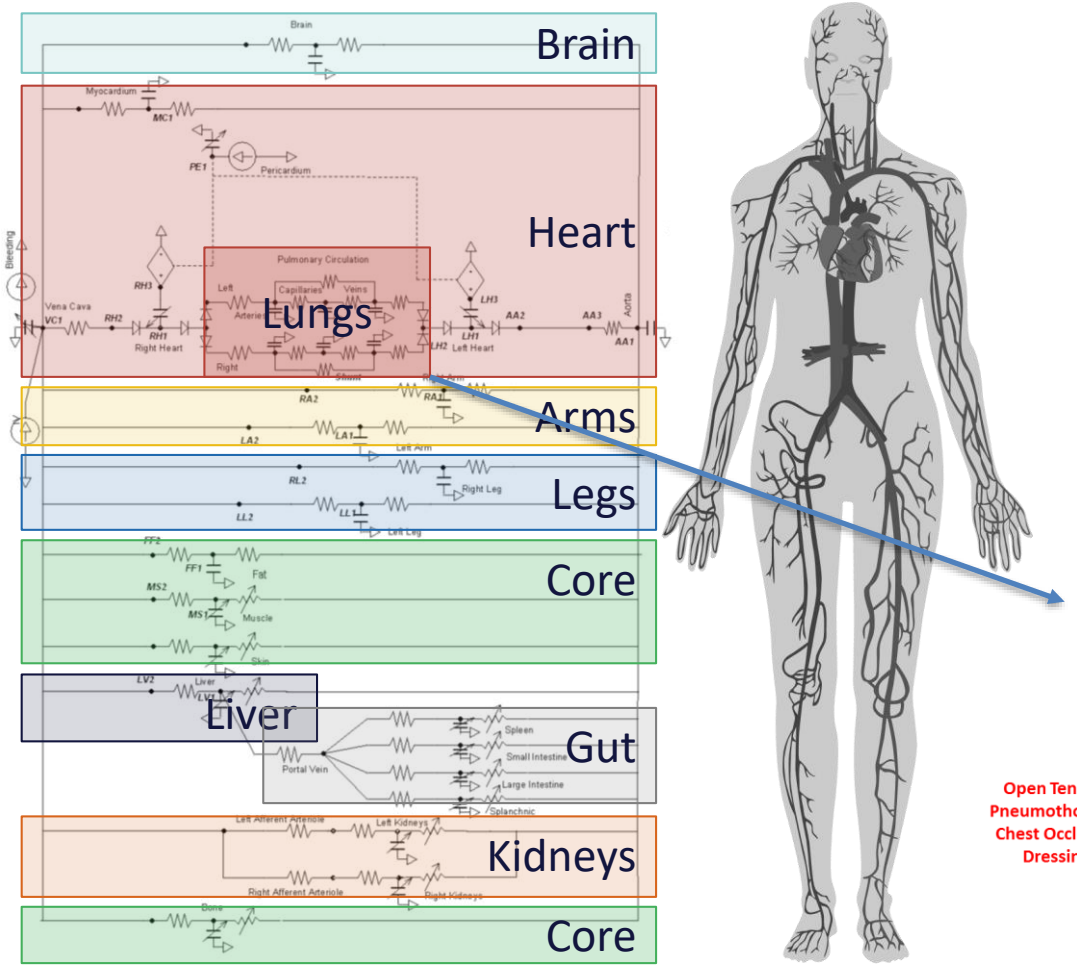
Incidences Background

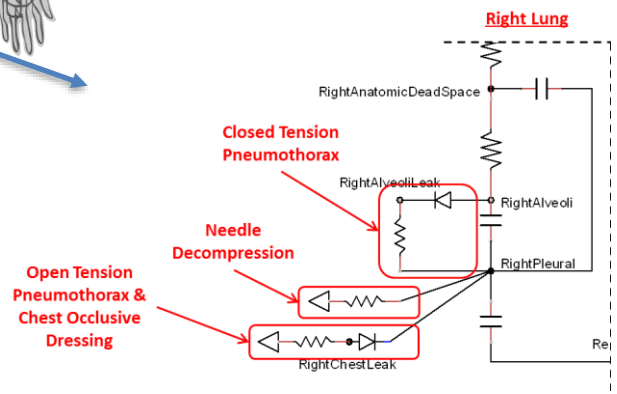
- Hemorrhage: Bleeding, either internally or externally, from a broken blood vessel
  - May lead to inadequate blood gas exchange
  - Largest cause of combat deaths, over 80%[1]
- Pneumothorax: When air gets trapped in the space between the lungs and chest wall (pleural cavity)
  - One way valve effect of respiratory exchange
  - Traumatic vs non traumatic
  - 10-15% of preventable deaths[1]
    - third most potentially survivable cause of death[2]
  - 5% of subjects arrived at a support hospital w/o a definitive airway[1]



Pneumothorax (Collapsed Lung)

BioGears Trauma Models

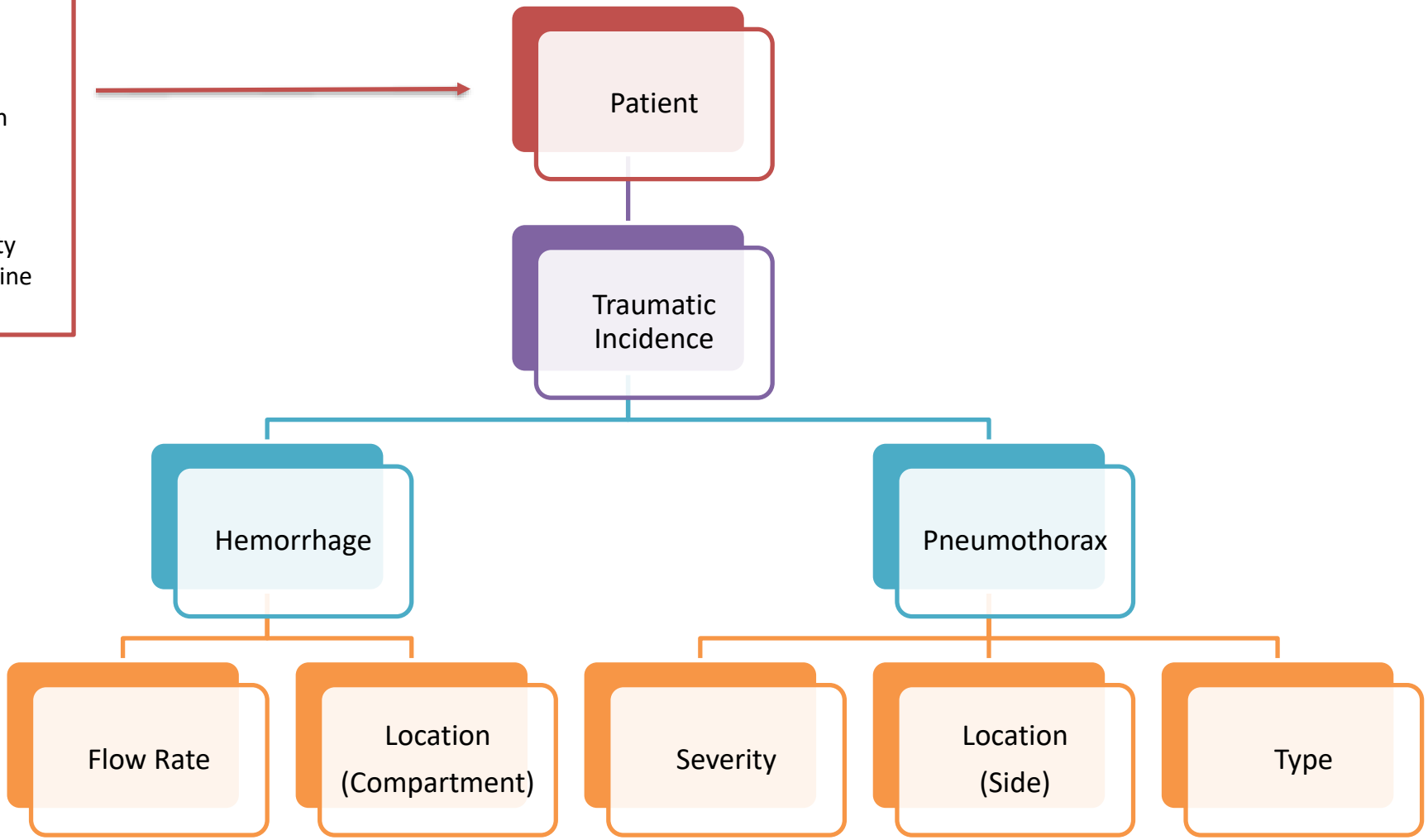




- Hemorrhage
  - Circuit pathway with a switch connected to ground is modified to instantiate bleeding
  - Resistance based on flow rate
- Tension Pneumothorax
  - Closed – traumatic injury causing a “sucking chest wound”
  - Progressive build up of air within pleural space compartment of BioGears circuit structure

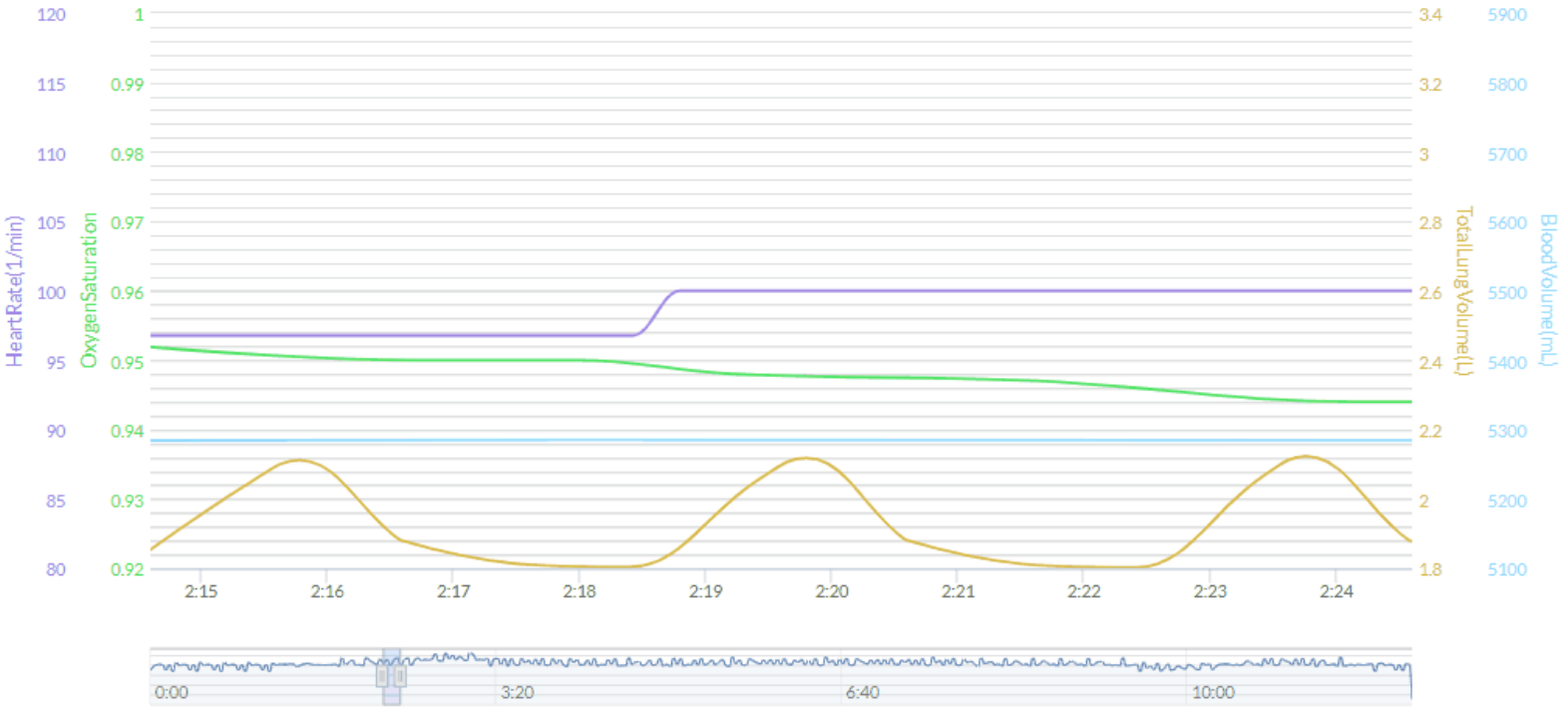
Input Diagram

- Sex
- Age
- Weight
- Height
- Body Fat Fraction
- Blood Volume Baseline
- Max Work Rate
- Pain Susceptibility
- Heart Rate Baseline
- And more



Now What?

- If we can accurately depict a patient state after injury, we can also explore care/treatment scenarios



Background: Medical Intervention

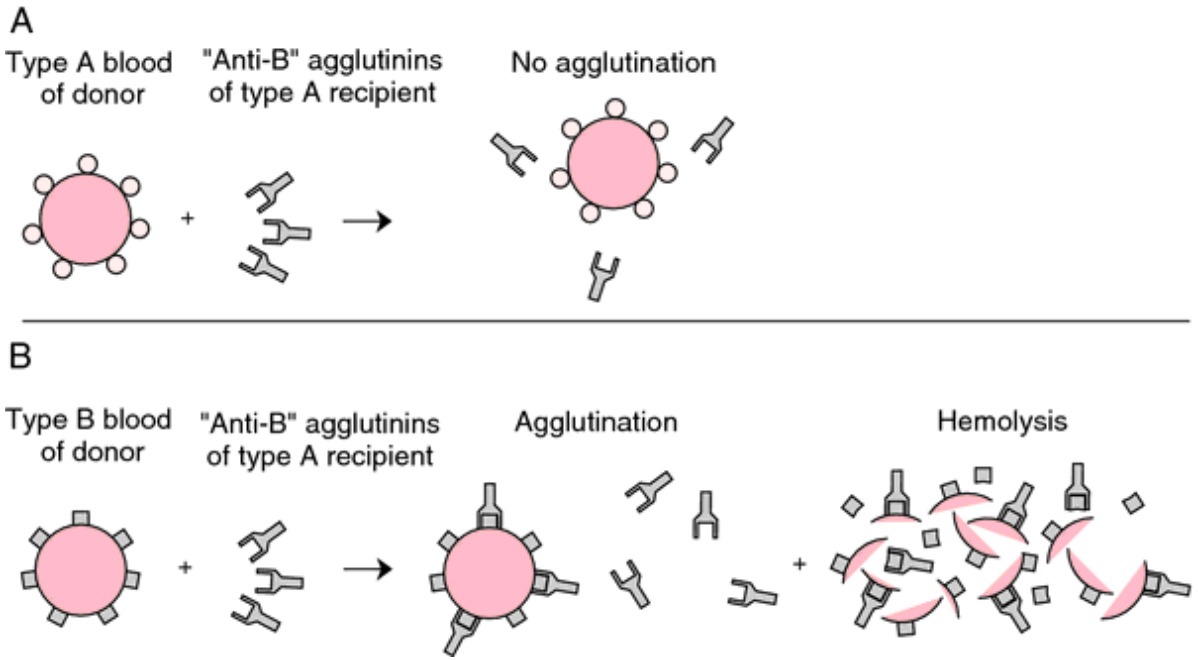
- In prolonged field care, combat medics have limited tools
  - Substances
    - Tranexamic Acid (TXA)
    - Tylenol
    - Whole Blood (more commonly FWB is required)
  - Tools
    - Transfusion bag
    - Tourniquet
    - Decompression needle
- However, specificity and variability can make decision making hard
  - If medics aren't trained on specific physiology, patient response becomes harder to predict
- BioGears set-up reduces computational cost of modeling/simulation

Background

- **Tranexamic Acid (TXA)**
  - Control of bleeding takes precedence over infusing fluids (TCCC) [2]
  - Clinical Practice Guidelines[2]
    - TXA should be given to casualties at risk of hemorrhagic shock as soon as feasible
- **Transfusion**
  - Increase in blood volume increases blood gas transfer and immune health
  - Massively transfused casualties have a high (33%) mortality rate[2]
  - In austere conditions, fresh whole blood is obtainable via a walking blood bank (WBB) program[2]
    - Improperly done can lead to transfusion reaction
- **Needle Decompression**
  - Decompress any suspected tension pneumothorax[1,2]
  - Causalities with multi-trauma showing no pulse or highly decreased respiration should have a bilateral needle decompression performed[1,2]

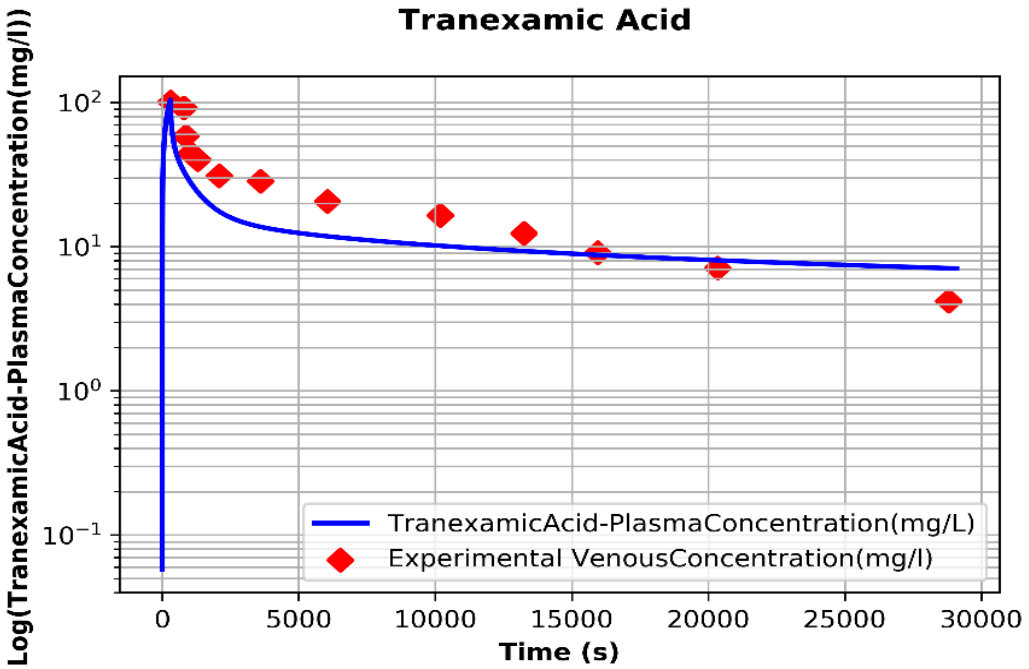
Background: Transfusion Reactions

- Any adverse event associated with blood transfer
  - Hemolytic transfusion reaction (HTR) is most common [3]
- The blood type on identification tags is occasionally incorrect (last correlated data equated to about 4% inaccurate) [4]
- Can cause noticeable metabolic and respiratory distress in patients [3]



Tranexamic Acid: BioGears Validation

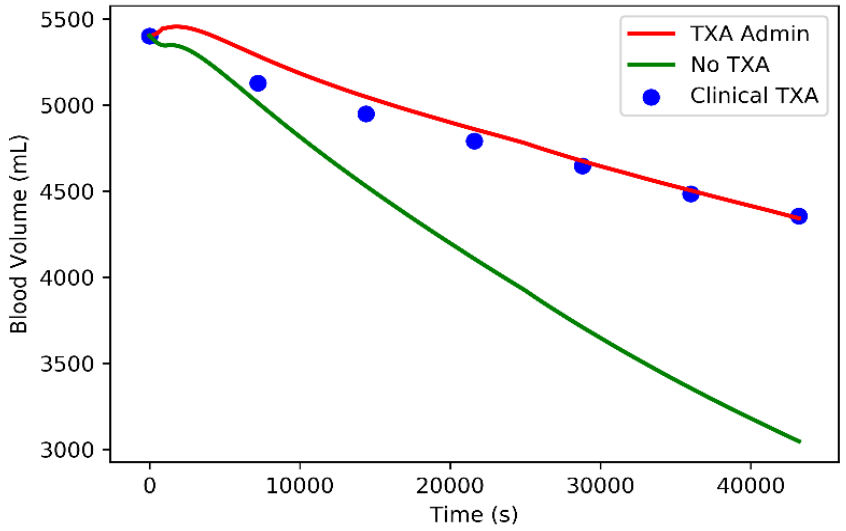
- Pharmacokinetics [5,6]



Tranexamic Acid: BioGears Validation

- Pharmacodynamics
  1. Short Scenario based on calculated blood volume after hemorrhage [7,8]
  2. Long Scenario based on time of survival after dosage [9]

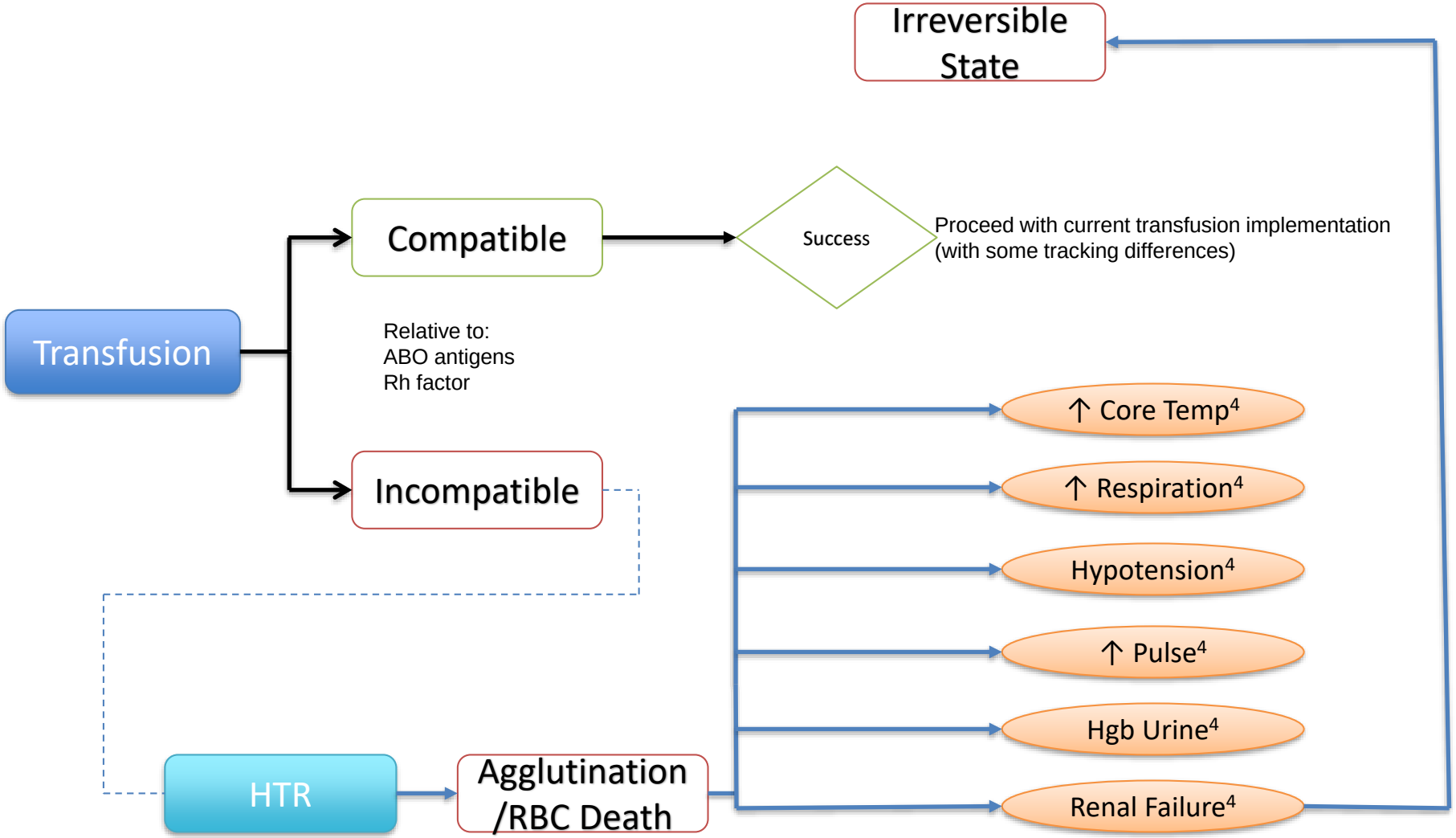
1



2

Hemorrhage Survival Time	Hemorrhage w/ TXA Survival Time	Change	Time To Death
4691.4 s	5341.2 s	+ 13.9 %	Increases

BioGears Transfusion Model

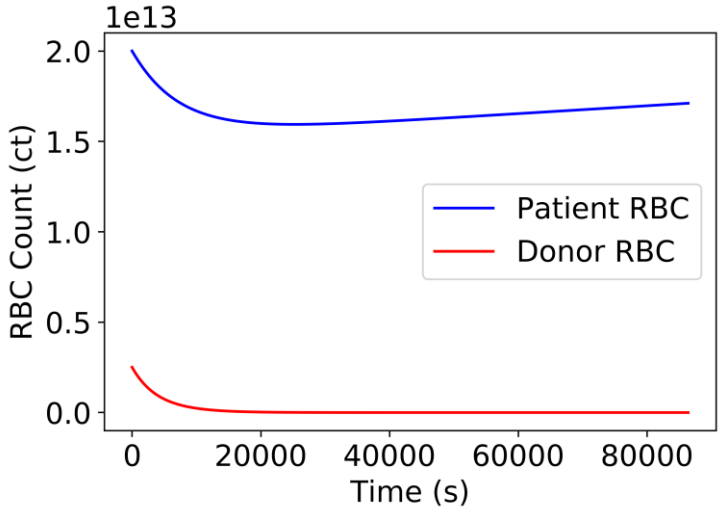


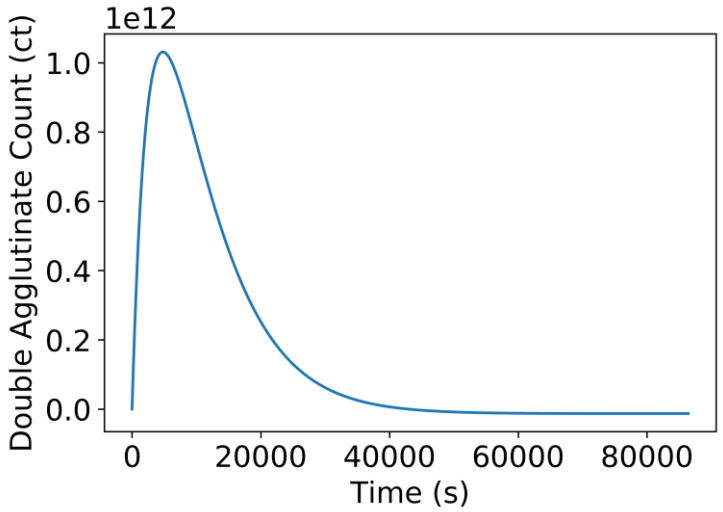
Model: Transfusion Reaction

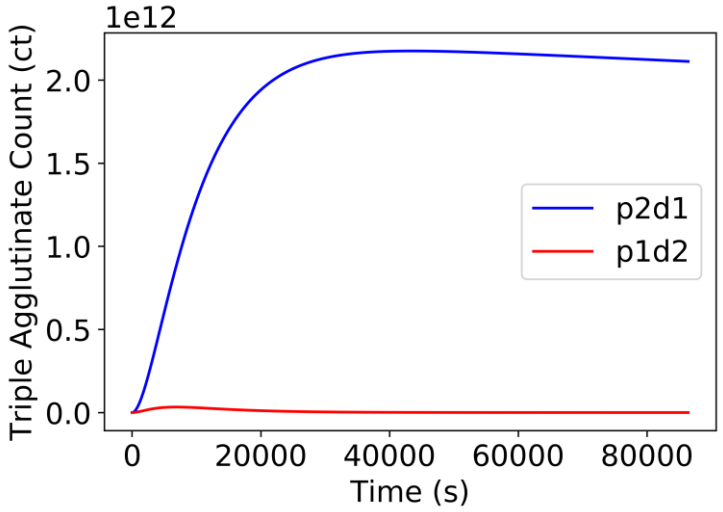
- Predator-Prey Relationship of Agglutination[10]
- Assume:
  - Surface area estimated as cylinders
  - Four cells is “stable” and remove those cells/attachments
  - Only unlike cells can agglutinate

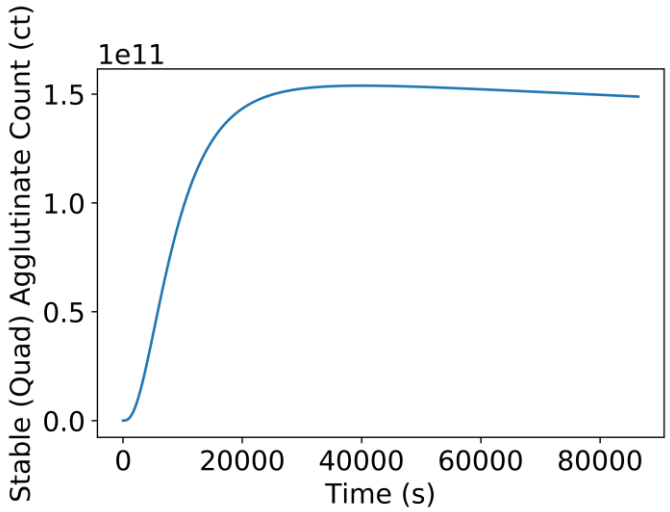
	Expected	Timing	Value	% Change	Result	Notes	Source
Core Temperature	Increase(>1 degC)	after	37.1	0.27027027		one degree change reached at 1820 secs	Davenport2005Pathophysiology/Anaesth2014Adverse
Respiration Rate	Increase		20.55	30.14566181			Davenport2005Pathophysiology
Blood Pressure	Change(Systolic, +/- ~20% @ severe)	during/shortly after	117	2.631578947		Can show increase OR decrease, key is change, severe not defined	Davenport2005Pathophysiology/Anaesth2014Adverse
Pulse	Increase(Tachycardia)	Immediately after	93.75	28.12628126		Tachycardia reached about 2.5 mins after end of transfusion	Davenport2005Pathophysiology/Anaesth2014Adverse

Agglutination Results (4 hrs)

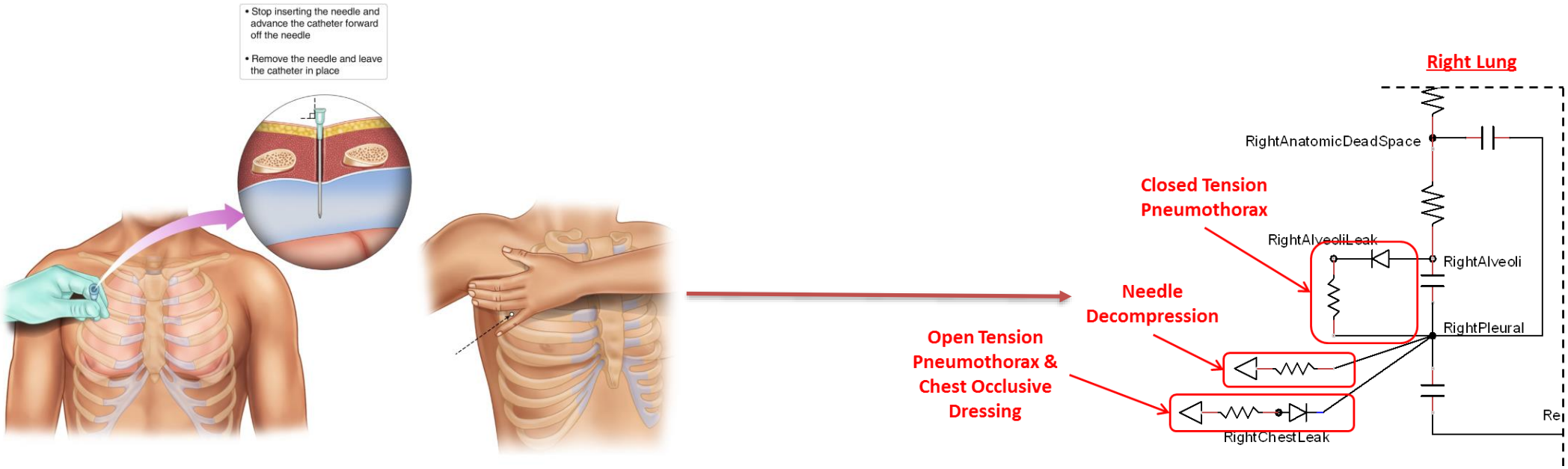






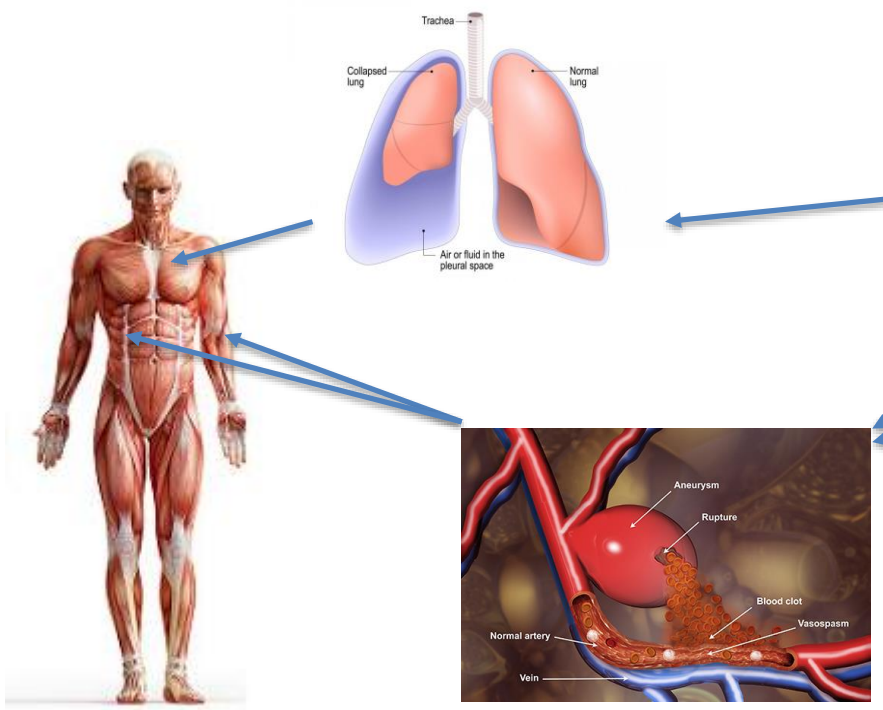


Model: Needle Decompression



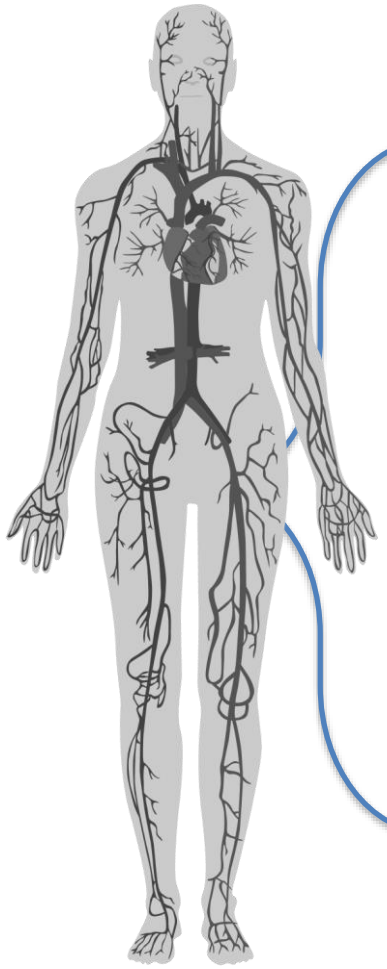
- BioGears incorporates a circuit component to permit airflow based on pressure differentials between pleural space and environment
  - Modified Resistance based on scaling factor
  - Appropriately tunes the circuit to vary breathing/air flow over time

Actions and Scenario Exploring



- Standard male patient
- Incidence
  - Closed left tension pneumothorax - moderate
  - Liver hemorrhage – Class III
  - Left arm hemorrhage – Class II
- Possible Interventions
  1. Do nothing
  2. Follow CPG
  3. Improper Care

Scenario Timelines



Standard Male Patient

Start 1

Initiate Actions:
- Tension Pneumothorax
- Hemorrhage (0 mL/min) of Spleen
- Hemorrhage (0 mL/min) of Left Arm

Patient Death

Scenario 1:
No Response

Start 2

Initiate Actions:
- Tension Pneumothorax
- Hemorrhage (0 mL/min) of Spleen
- Hemorrhage (0 mL/min) of Left Arm

Medic Response:
Hemostatic Dressing/TXA injection

Medic Response: Needle Decompression

Medic Response: Blood Transfusion

Patient Lives

Scenario 2:
Do this

Start 3

Initiate Actions:
- Tension Pneumothorax
- Hemorrhage (0 mL/min) of Spleen
- Hemorrhage (0 mL/min) of Left Arm

Medic Response:
Needle Decompression

Medic Response:
TXA Low Dose

Medic Response: Blood Transfusion

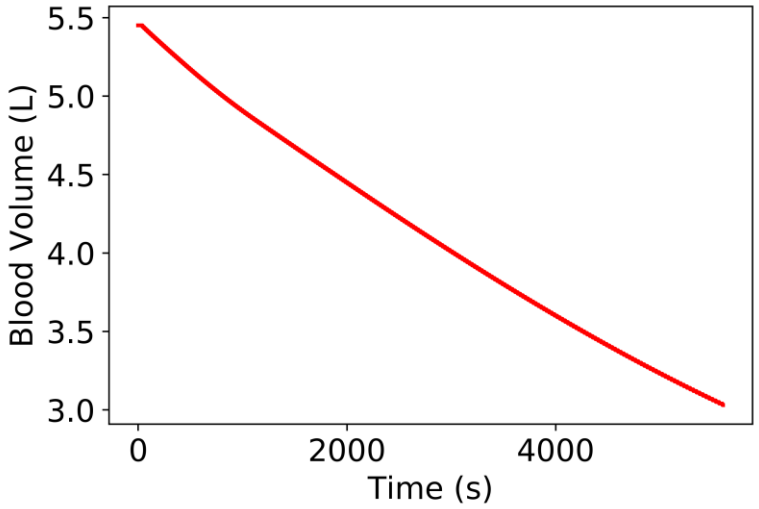
Transfusion Reaction: Stop transfusion

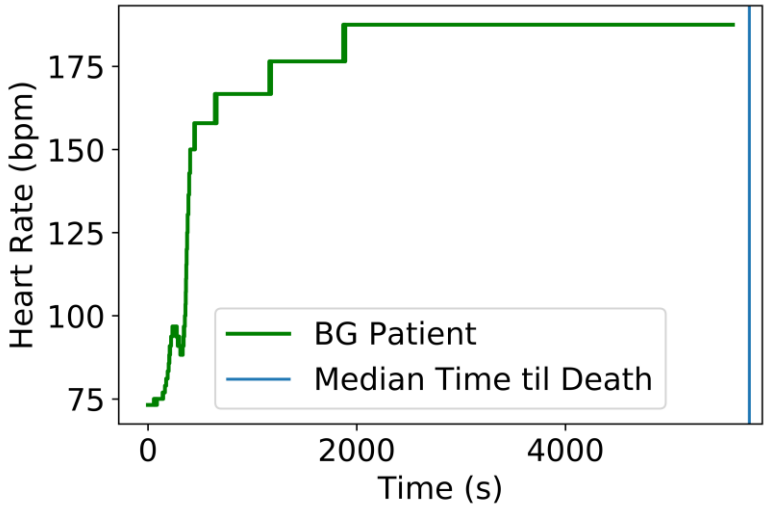
Patient Lives

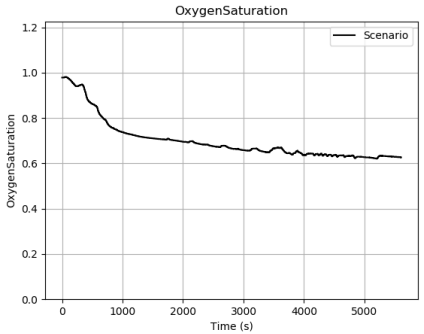
Scenario 3:
Don't do that

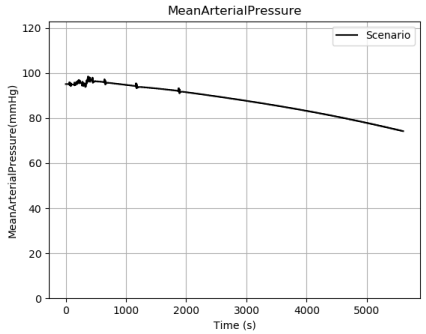
Scenario 1: Do Nothing

- Exsanguination median time to death is 1.6 hours (5760 s) [12]

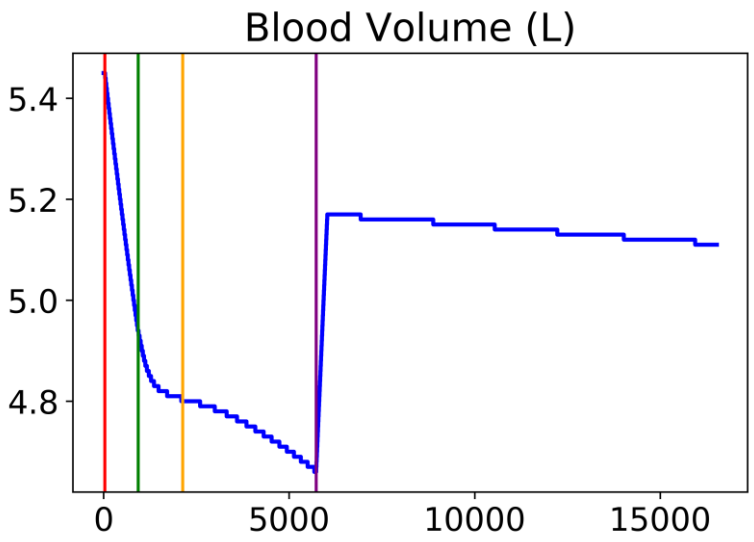


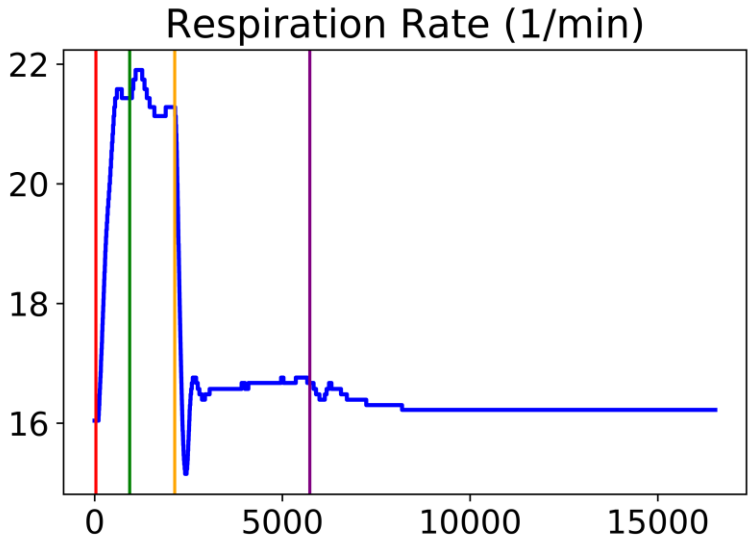


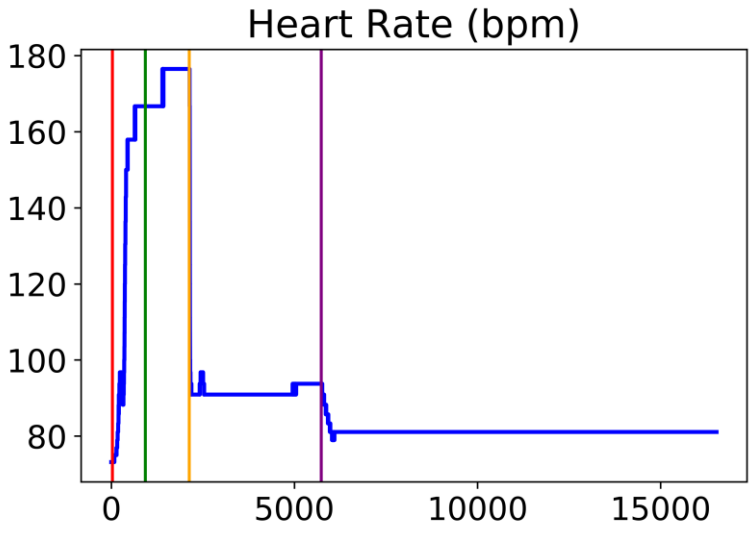




Scenario 2: Clinical Practice Guidelines

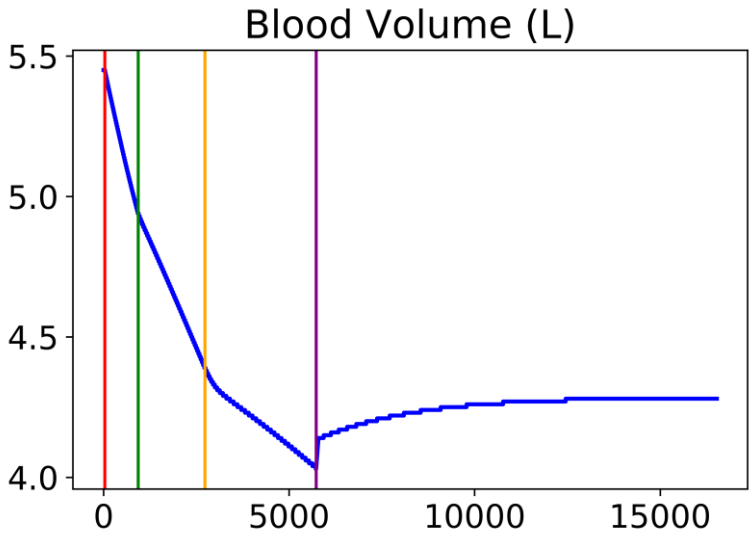


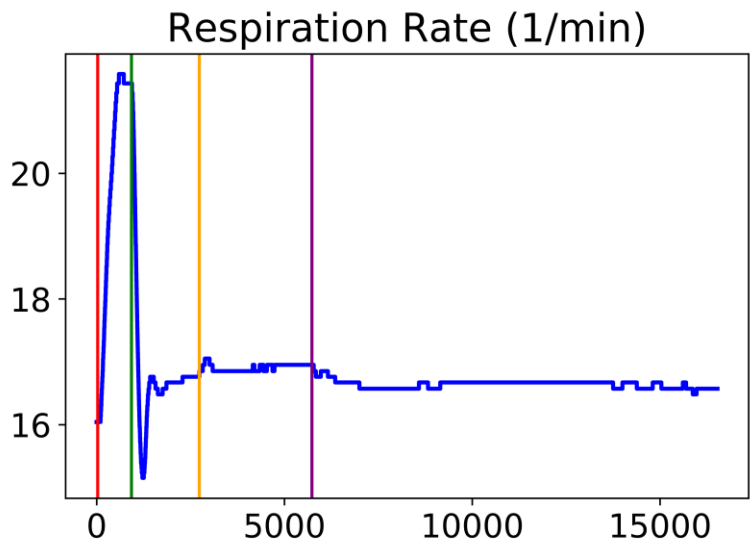


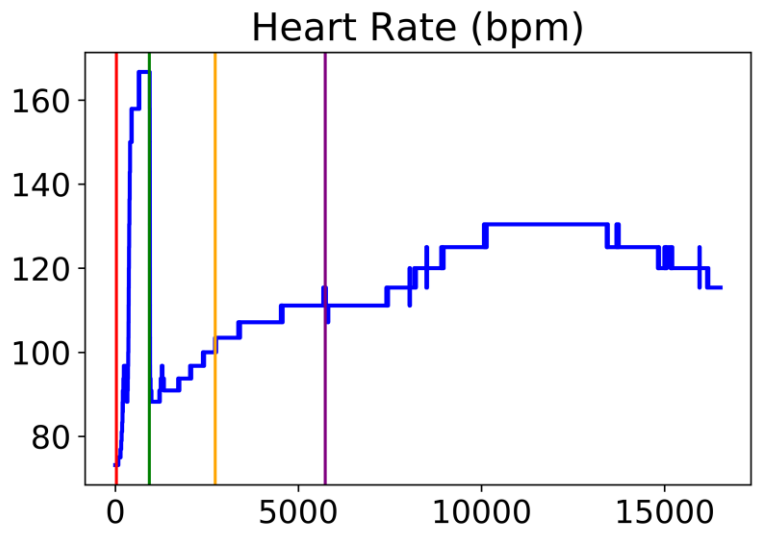


- — is traumatic incident: initiate multi-trauma
- — is hemostatic dressing and TXA injection: slowed blood loss
- — is needle decompression: restore breathing
- — is Blood transfusion to restore blood levels and relieve cardiovascular distress

Scenario 3: Medical Errors







- — is traumatic incident: initiate multi-trauma
- — is needle decompression: restore breathing
- — is TXA injection: low dose but still slowed blood loss
- — is Blood transfusion, stopped early due to HTR

Conclusions

- BioGears can accurately depict physiological responses to multi-trauma events and a variety of interventions
- Numerous applications
  - Training: Help less experienced personnel understand the dynamics of human physiology
    - Response to proper and improper care
  - Decision making: Using faster than real time simulations can help determine if an approach is more or less likely to help a patient

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