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RDCR – SHOCK PHYSIOLOGY





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Shock is bad for you





Level of shock is correlated with outcome

Manikis, Panagiotis, et al. "Correlation of serial blood lactate levels to organ failure and mortality after trauma." *The American journal of emergency medicine* 13.6 (1995): 619-622.

Husain, Farah A., et al. "Serum lactate and base deficit as predictors of mortality and morbidity." *The American journal of surgery* 185.5 (2003): 485-491.

Floccard B, Rugeri L, Faure A, Saint Denis M, Boyle EM, Peguet O, et al. Early coagulopathy in trauma patients: an on-scene and hospital admission study. *Injury* 2012;43:26-32





Level of shock – correlated with level of coagulopathy and inflammation

Macleod JBA, Lynn M, McKenney MG, et al. Early coagulopathy predicts mortality in trauma. *J Trauma* 2003; 55:39–44

Hess et al, *J Trauma* 2008 (ACOTS)

Maegle M, Lefering R, Yucel N, et al. Early coagulopathy in multiple injury: an analysis from the German Trauma Registry on 8724 patients. *Injury* 2007; 38:298 – 304

Brohi K, Singh J, Heron M, et al. Acute traumatic coagulopathy. *J Trauma* 2003; 54:1127–1130





Hypoperfusion and shock is probably the primary initiator of coagulopathy (ACoT)



Blood doesn't coagulate



“Blood failure”

Brohi K, Cohen MJ, Ganter MT, et al. Acute traumatic coagulopathy: initiated by hypoperfusion: modulated through the protein C pathway? *Ann Surg* 2007; 245:812–818





Definitions

- Shock:
 - A physiologic state where oxygen delivery (DO_2) is not sufficient to meet the metabolic requirements (VO_2) of the body.
- Critical DO_2
 - Level of DO_2 below which anaerobic metabolism begins and cellular function deteriorates
 - Lactate increases
- Compensated Shock:
 - A physiologic state where DO_2 is decreased but oxygen extraction increases to continue to meet VO_2 demands of the body.



Oxygen requirement (VO_2) beyond oxygen supply (DO_2) organ failure



Rixen D, Siegel JH: Bench-to-bedside review: oxygen debt and its metabolic correlates as quantifiers of the severity of hemorrhagic and post-traumatic shock. Crit Care 9:441Y453, 2005.





Definitions

- Oxygen deficit:
 - *The difference between the metabolic demand and supply at a certain time.*
- Oxygen debt:
 - *The magnitude and length of the oxygen deficit.*
 - *“The time spent below critical DO₂”*
 - *Oxygen debt kills you!*

DOSE OF SHOCK!





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Ficks equation





$$DO_2 = 1.34 \times Hgb \times SaO_2 \times CO$$

CO= Cardiac output = Heart rate/min x Stroke volume

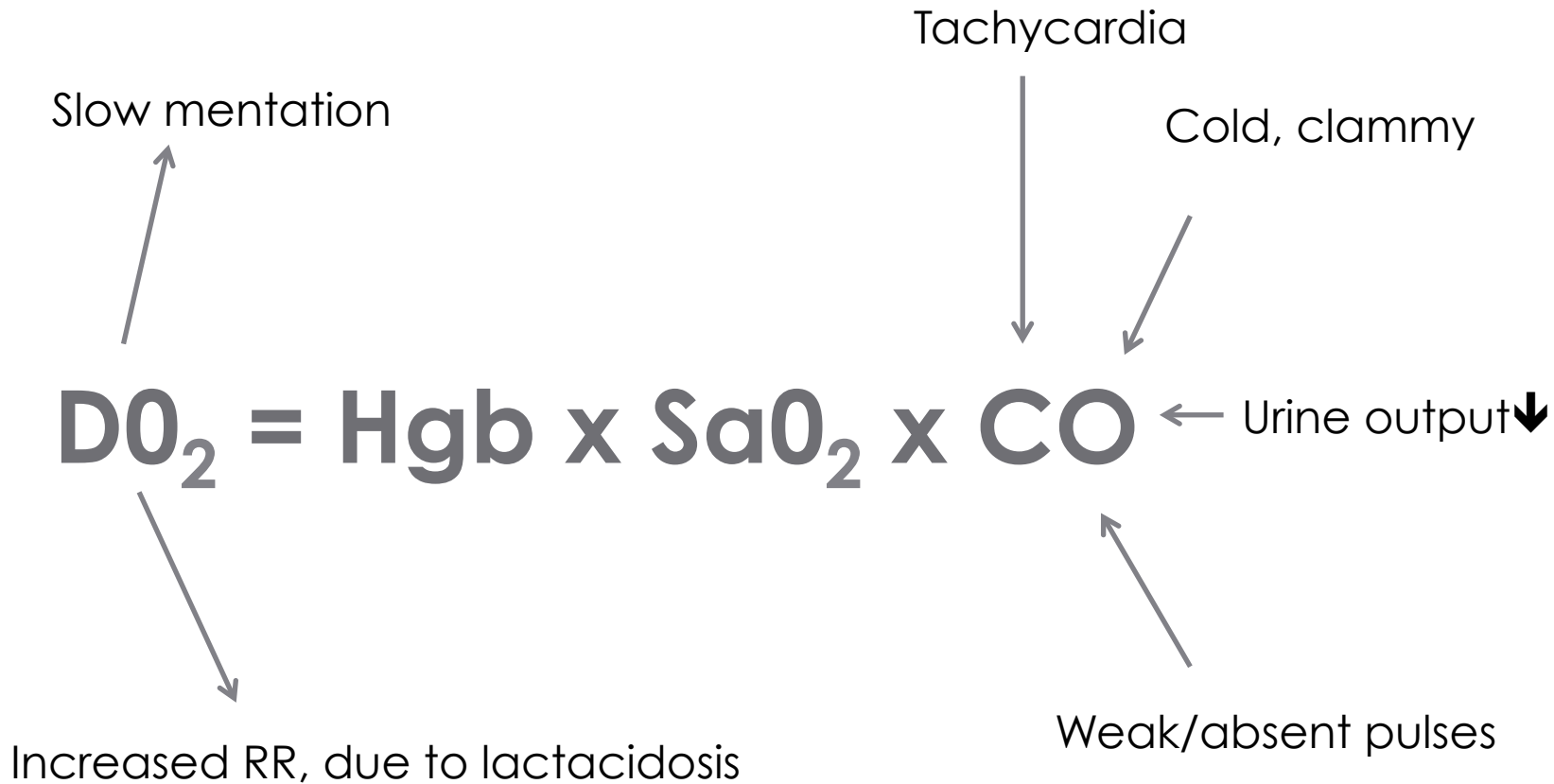
SaO₂= Oxygen saturation

Hgb= Hemoglobin concentration





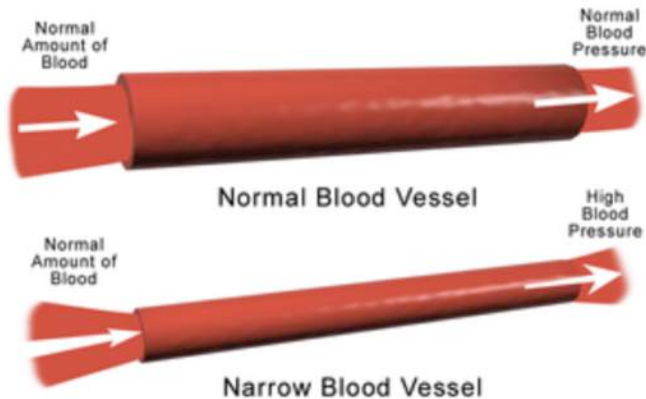
Compensation/consequences of decreased DO_2 (due to bleeding)





Poiseuilles law

$$F = \frac{\Delta P}{R} = \frac{(P_A - P_V)}{R}$$



Flow

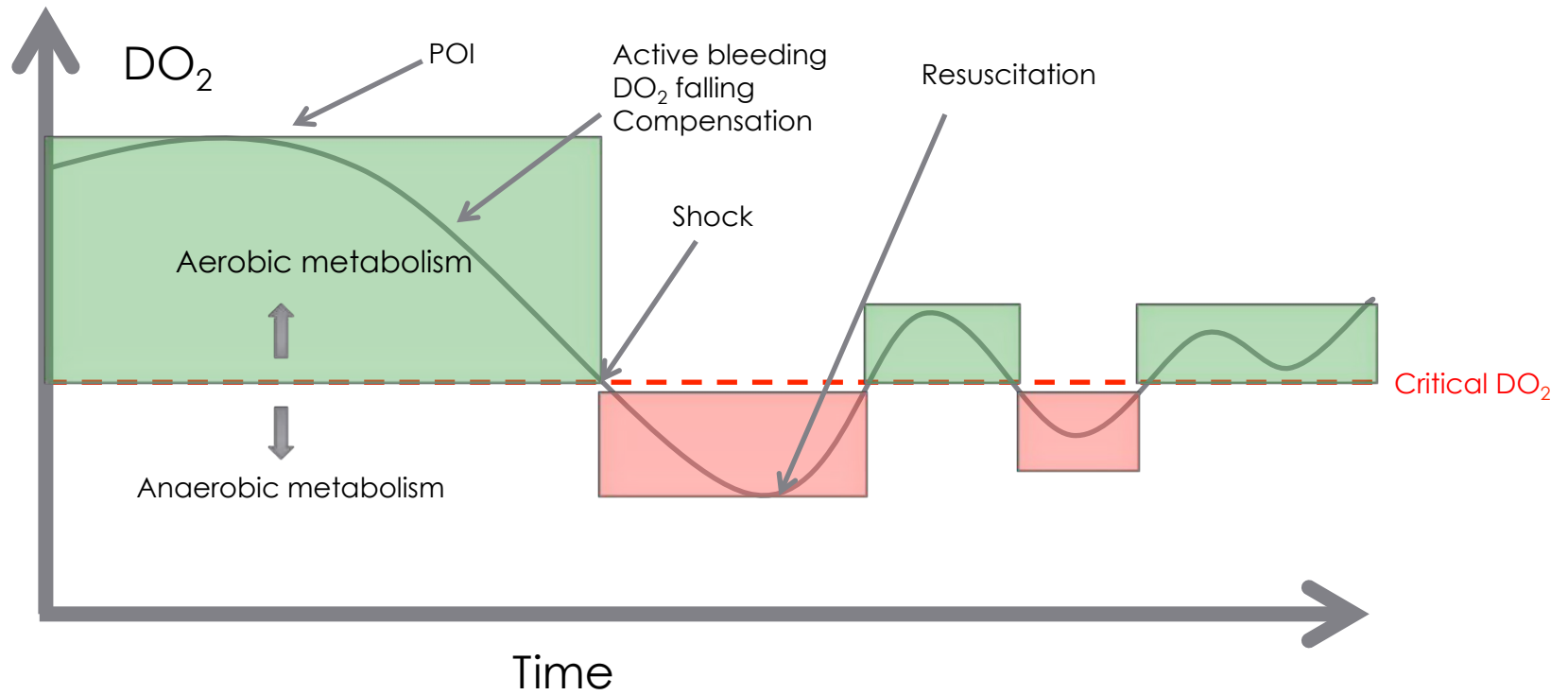


Perfusion Pressure (ΔP)





$$DO_2 = 1.34 \times Hgb \times SaO_2 \times CO$$

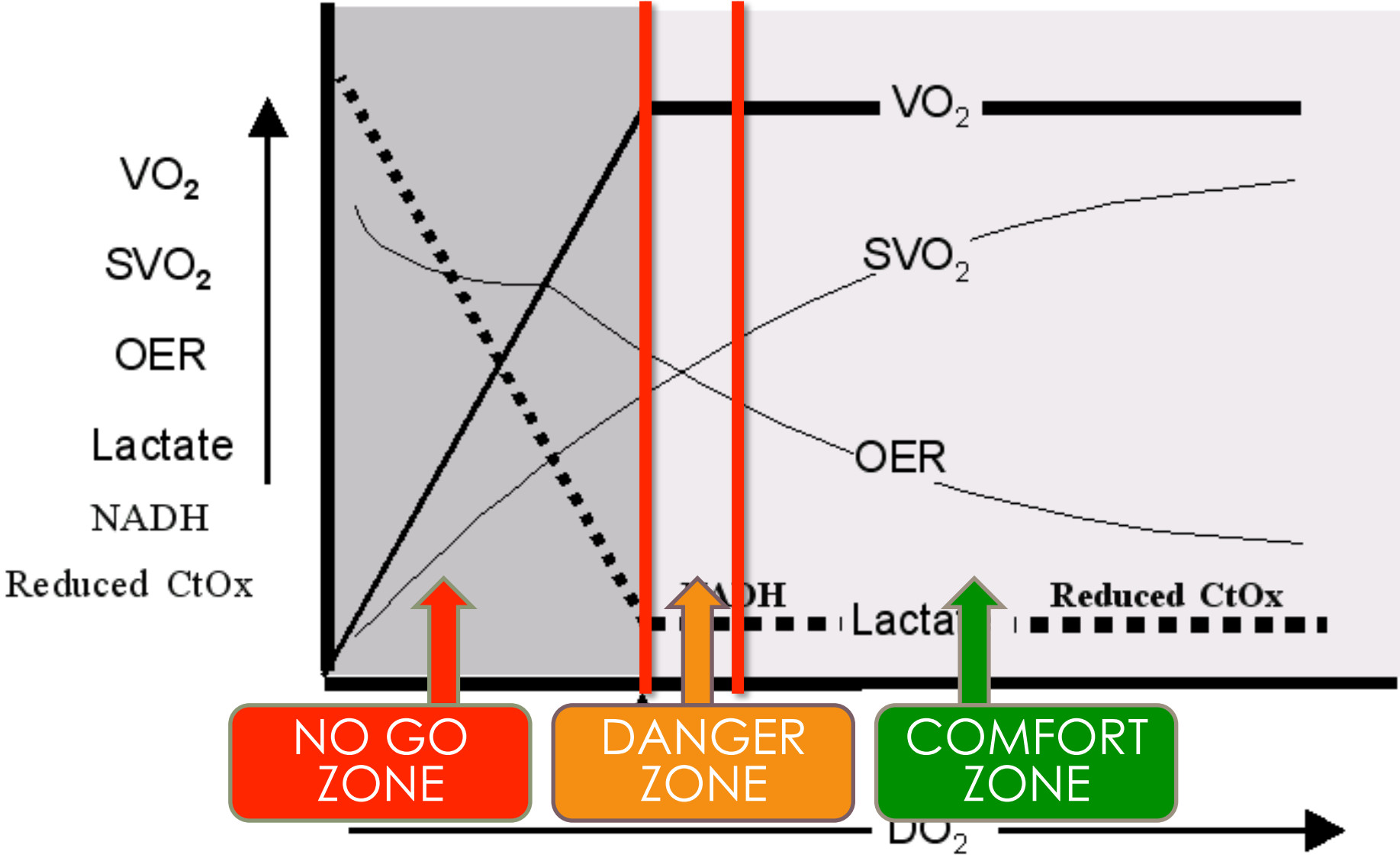


Dose of shock



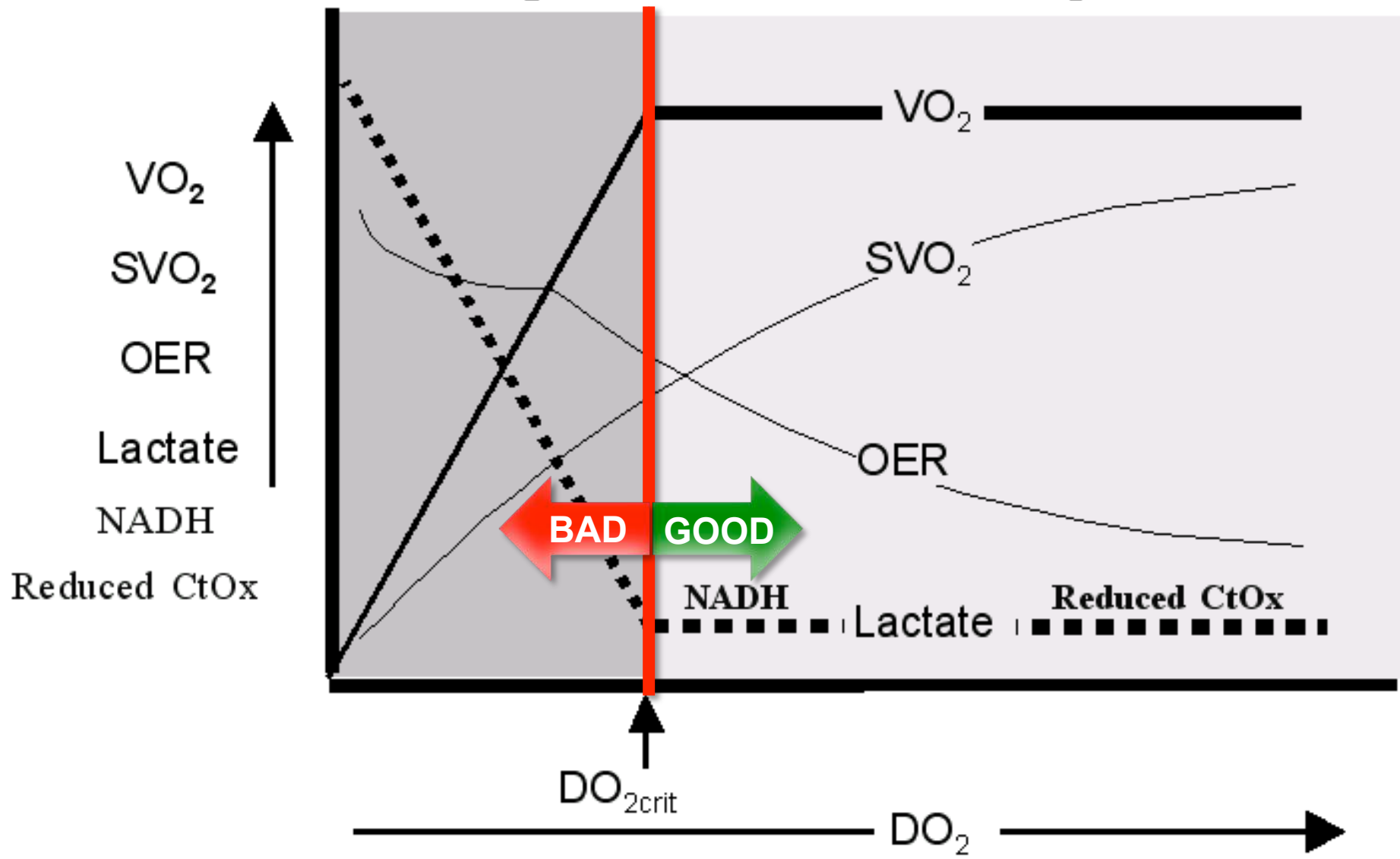
Delivery Dependent
 VO_2

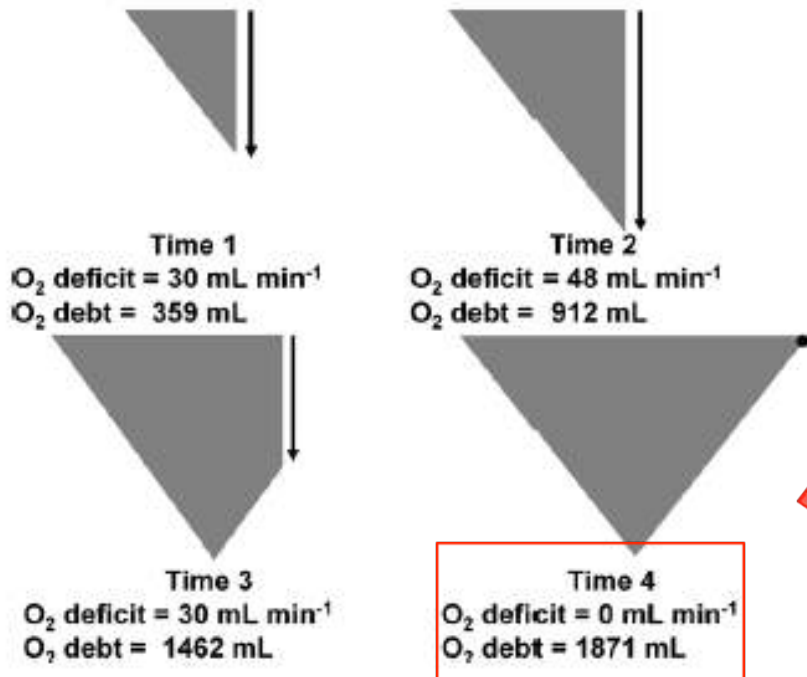
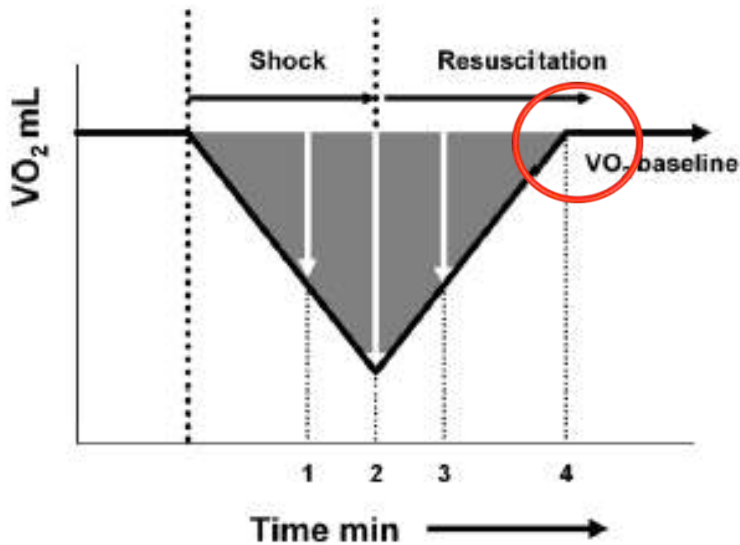
Delivery Independent
 VO_2



Delivery Dependent
 VO_2

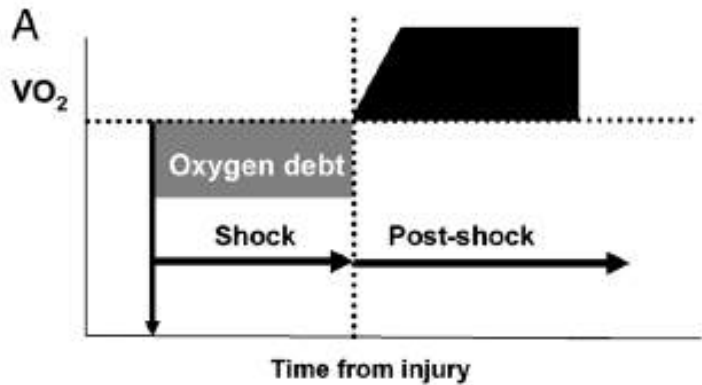
Delivery Independent
 VO_2





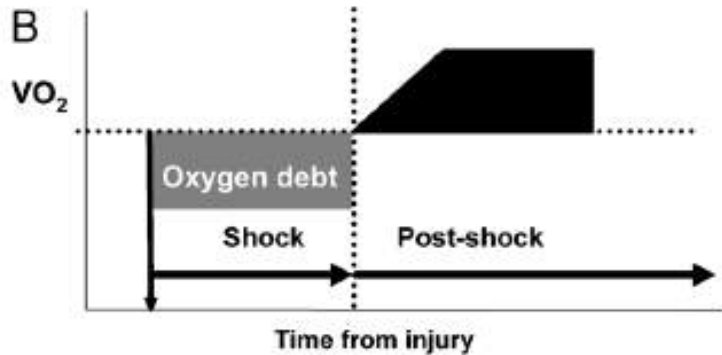
Barbee, Robert Wayne, Penny S. Reynolds, and Kevin R. Ward. "Assessing shock resuscitation strategies by oxygen debt repayment." *Shock* 33.2 (2010).





No cellular damage

Bolus – Immediate 100% Repayment



Minimal/moderate cellular damage

Bolus – Immediate 64% Repayment



Severe organ injury, early death

Bolus – Immediate 28% Repayment

Siegel JH, Fabian M, Smith JA, Kingston EP, Steele KA, Wells MR: Oxygen debt criteria quantify the effectiveness of early partial resuscitation after hypovolemic hemorrhagic shock. *J Trauma* 54:862Y880, 2003

Barbee, Robert Wayne, Penny S. Reynolds, and Kevin R. Ward. "Assessing shock resuscitation strategies by oxygen debt repayment." *Shock* 33.2 (2010): 113-122.





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To sum up:

What is “Shock?”

- Inadequate blood flow to the body tissues
- Leads to inadequate oxygen delivery and cellular dysfunction
- Reduced oxygen delivery over time – “oxygen debt”/”Shock dose”
- Leads to organ failure including “blood failure”
- Blood failure = Coagulopathy
- May cause death
- Shock can have many causes, but on the battlefield, it is typically caused by severe blood loss
- Hemorrhagic shock is the leading cause of preventable death on the battlefield

