Hypothermia: Practices and Considerations for the Respiratory Therapist

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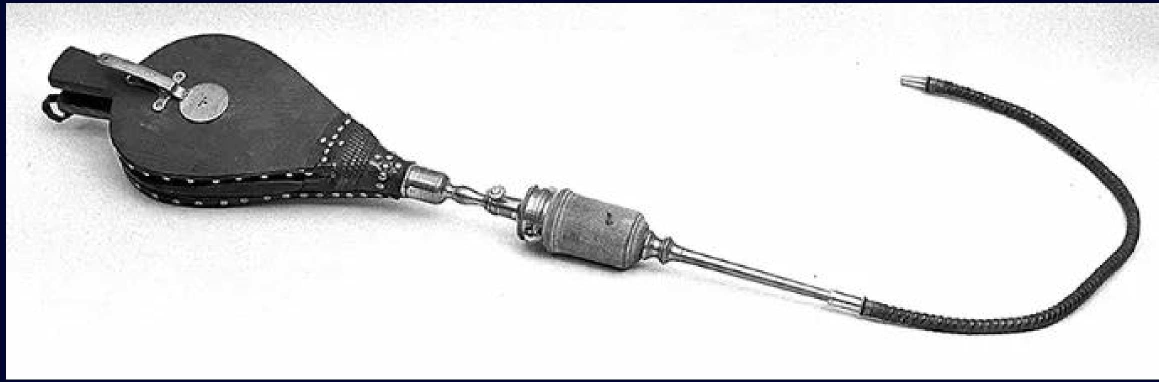
0 50 KM 50 Miles

Objectives

- Describe the impact of hypothermia in the perioperative and trauma space.
- Summarize thermodynamic principles relevant to the airway.
- Discuss the role of thermoregulation, and its feasibility, via the airway of critically ill patients.

Old is new again...



Wijdicks, 2022, Neuro crit care

Epidemiology of Hypothermia in the Perioperative and Trauma Space

Epidemiology of Hypothermia

How is hypothermia defined?

Definition of Hypothemia

Body temperature ≤ 35° C

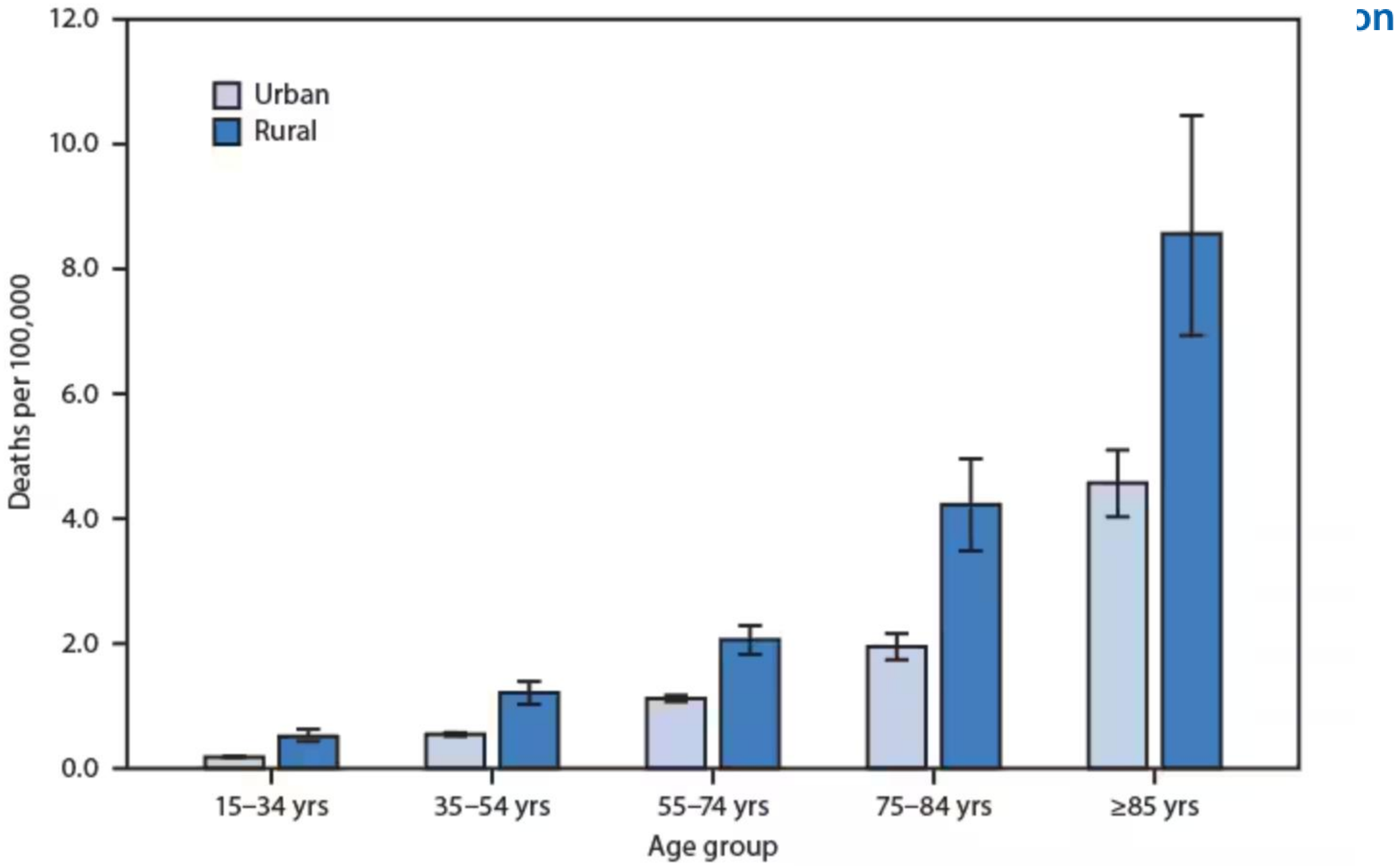
Mild: 32-35° C
Moderate: 28-32° C
Severe: ≥ 28° C

Primary or Secondary?

Intentional or Unintentional?

Threshold: 36.5°C–37.5°C

(A very brief) Epidemiology of Hypotherima



CDC: Death Rates Attributed to Excessive Cold; National Vital Statistics System, 2018–2020

(A very brief) Epidemiology of Hypotherima

Risk Factors[1]

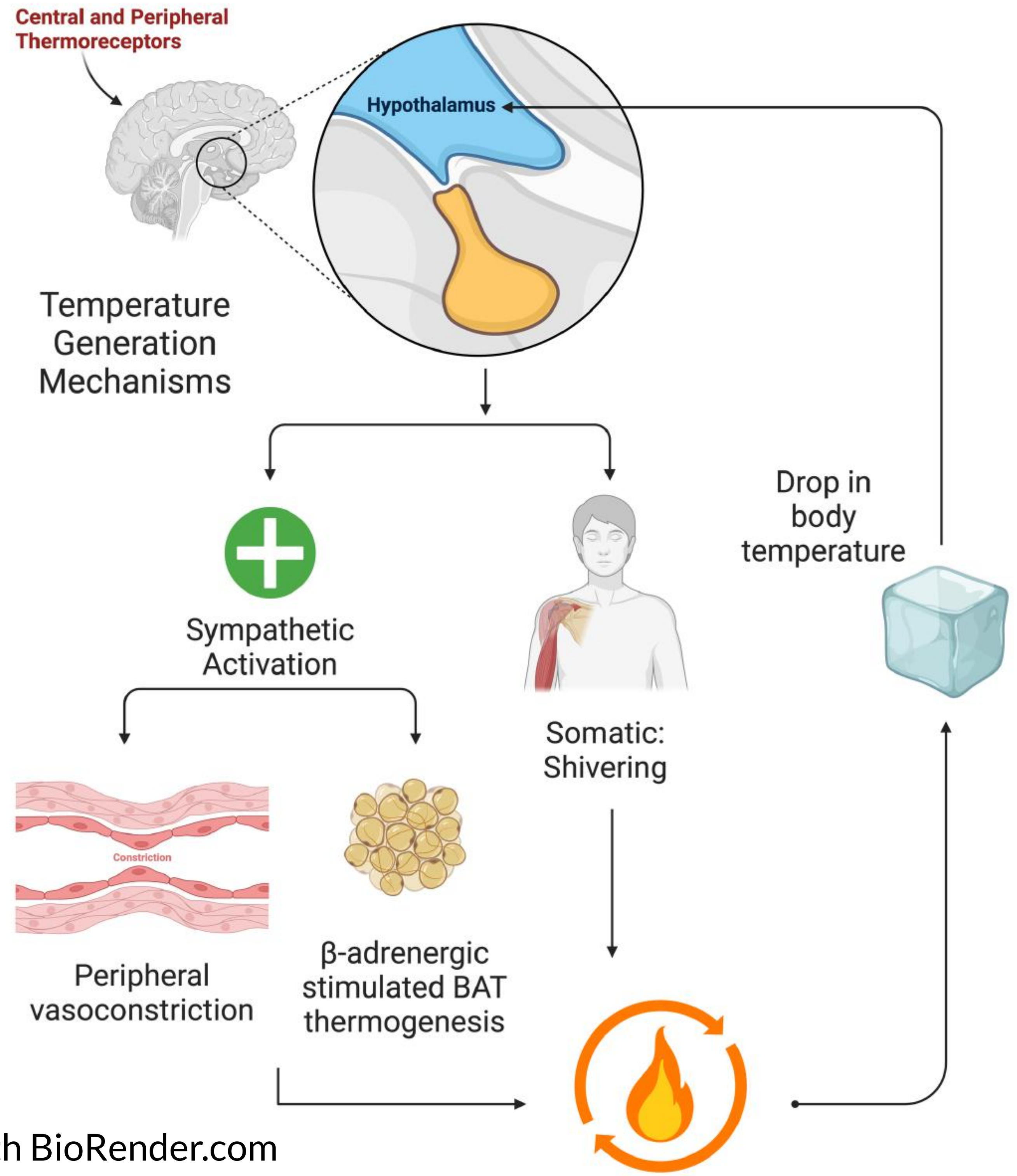
- Age
- Weight
- Environmental Exposure
- Trauma
- Surgical Procedures
- ECMO
- CNS injury
- Metabolic disorders
- ....the list goes on

Cumulative Incidence*

Pre-hospital (Trauma)[2-4]	13% »»» 43%
Perioperative[5]	~54%
ICU[6]	5% »»» 13%

*Primary and/or secondary hypothermia

Basic Physiology of Hypothermia: Thermoregulatory Response



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Basic Physiology of Hypothermia: Thermoregulatory Response

Threshold

Gain

Maximal Response

Where does all of the heat go?

2nd law of thermodynamics Hot → Cold

Four sources of body heat loss

1. Radiation - 60%
2. Evaporation - 'wicking'
3. Conduction - Contact
4. Convection - Air/Water

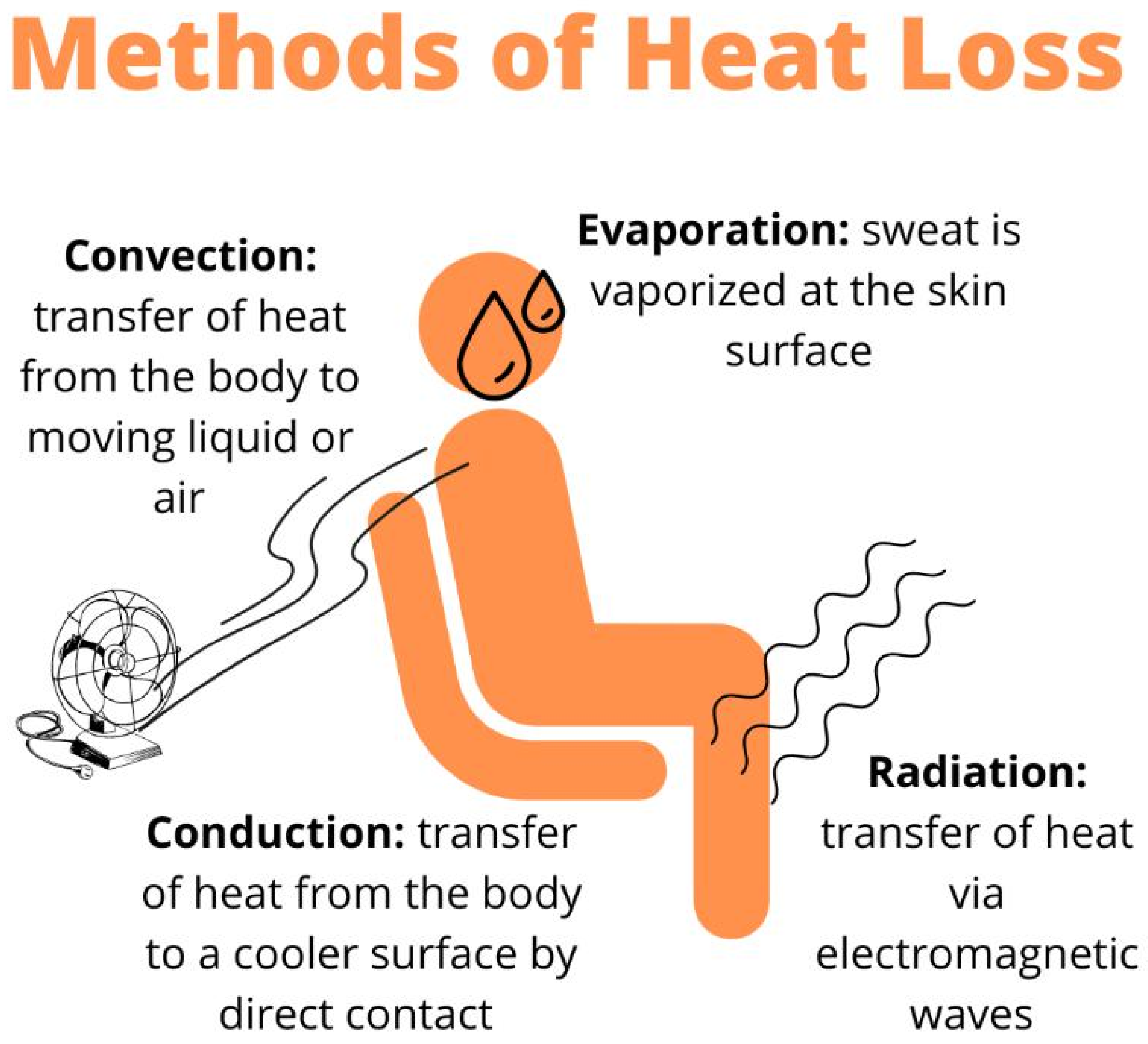
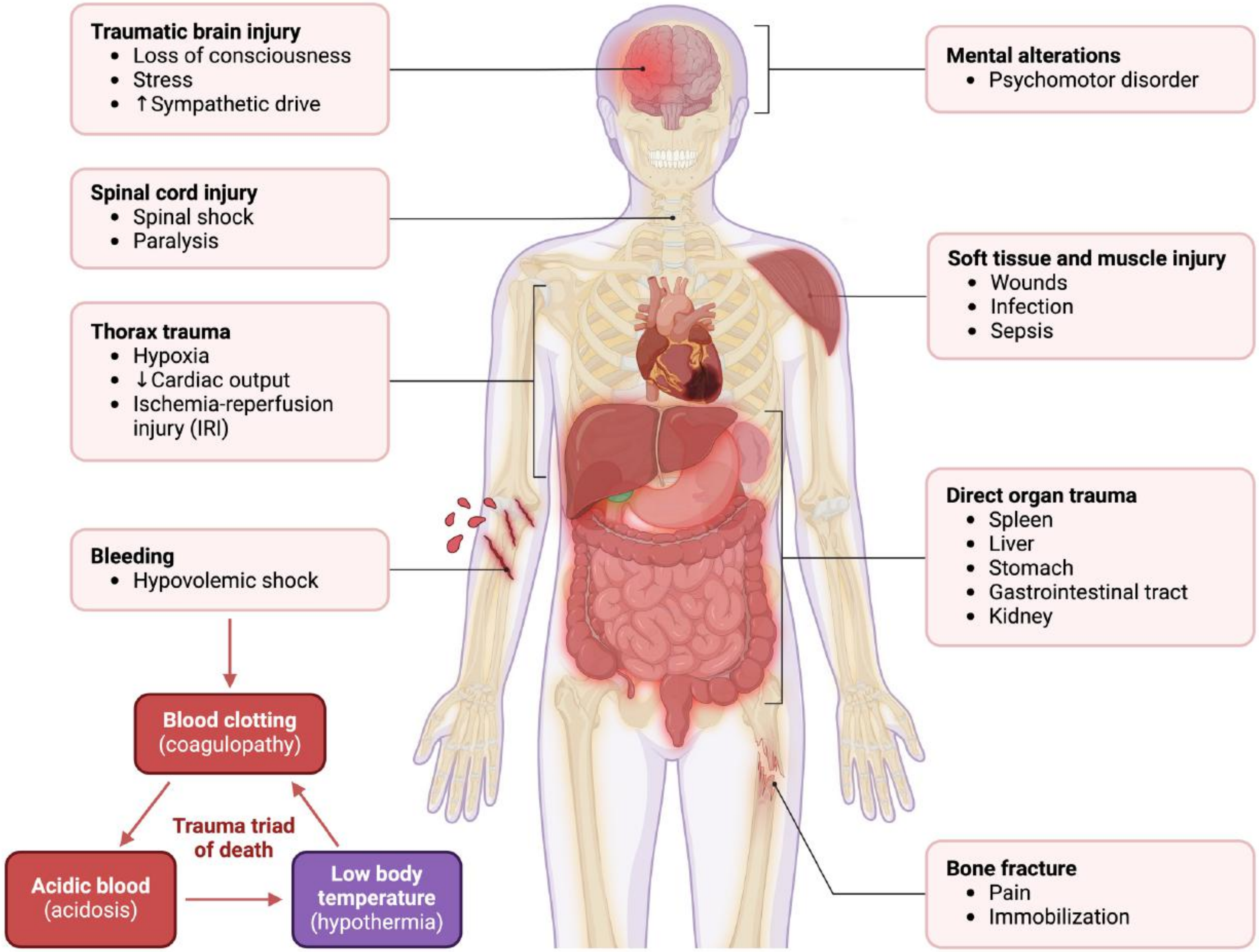


Image retreived from https://www.louisvillelectures.org/the-ll-blog-1/heat-related-illness/lehto

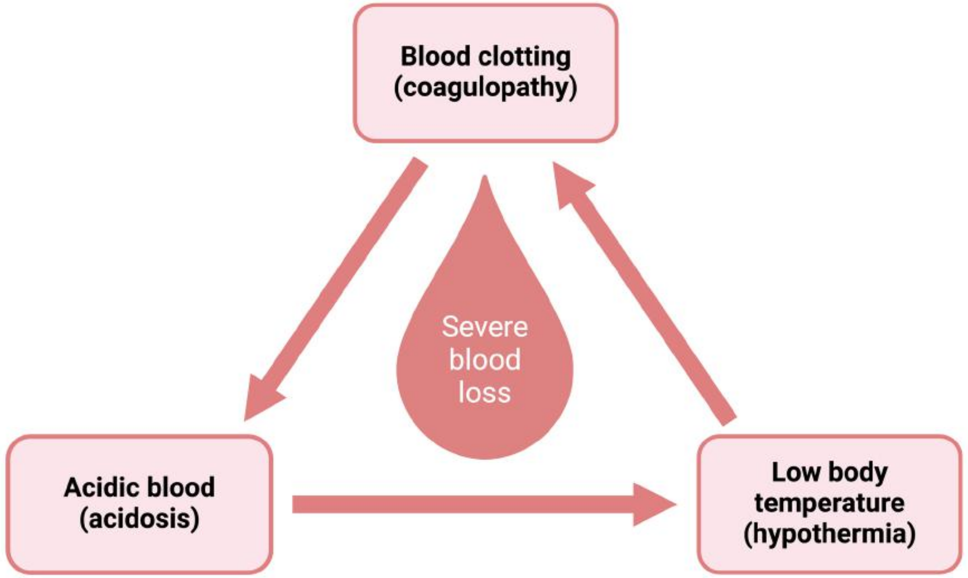
Where does all of the heat go?

1. **Radiation - 60%**
2. **Evaporation - 'wicking'**
3. **Conduction - Contact**
4. **Convection - Air/Water**

Frequent Trauma Sites and Complications



Trauma Triad of Death



Perioperative Setting

Three Primary Causes:

1. Anesthesia

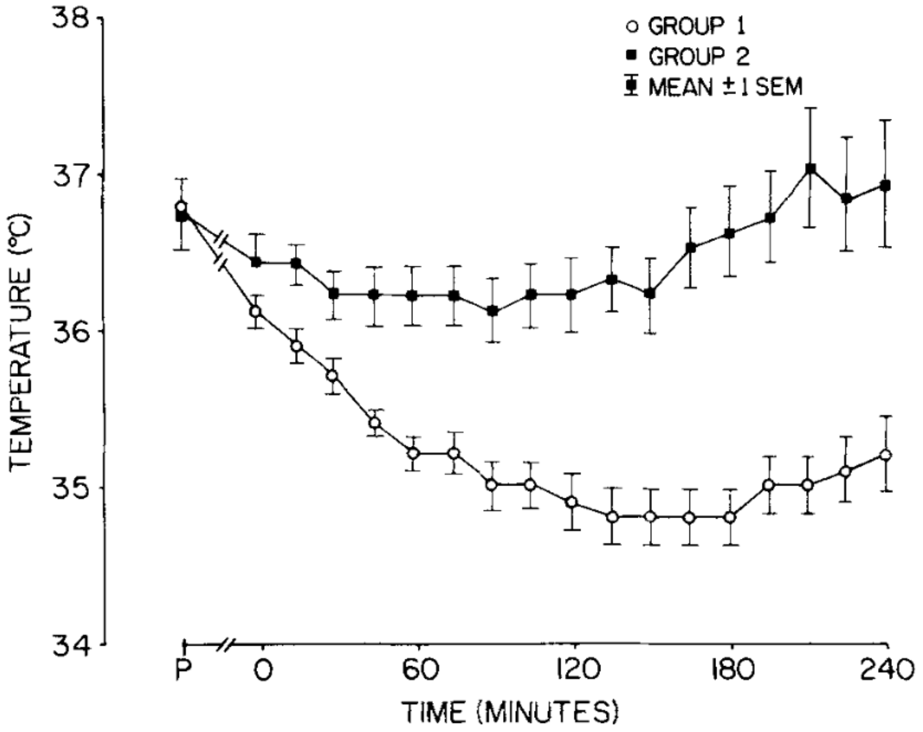


FIG 2. Mean values ± SEM for nasopharyngeal temperatures of patients in groups 1 and 2. P indicates preoperative oral temperatures. Differences in mean nasopharyngeal temperature values were statistically significant after 60 minutes ($p < 0.001$), 120 minutes ($p < 0.001$), 180 minutes ($p < 0.001$), and 240 minutes ($p < 0.01$).

Stone et al. 1981 ANESTH ANALG

2. Exposure and 3. Blood Loss

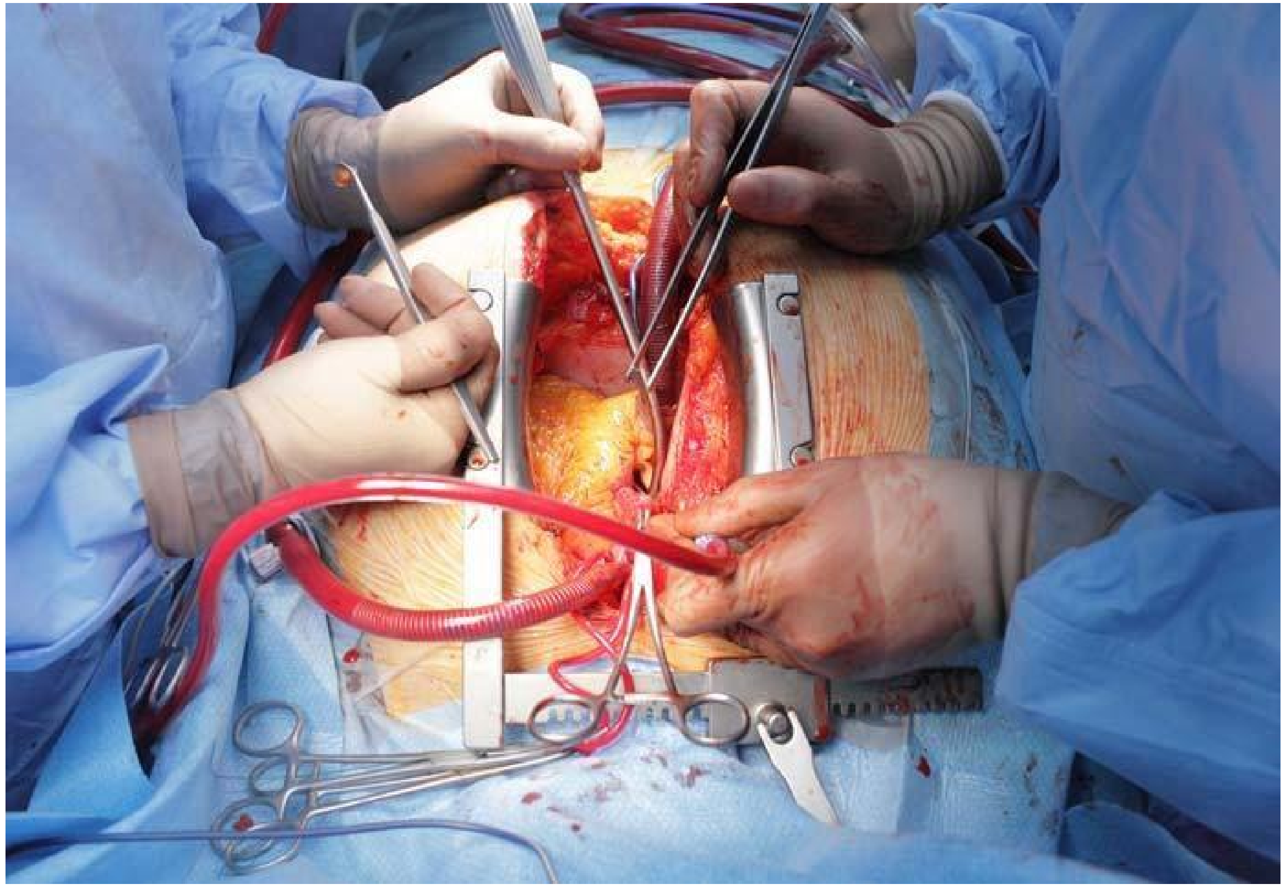
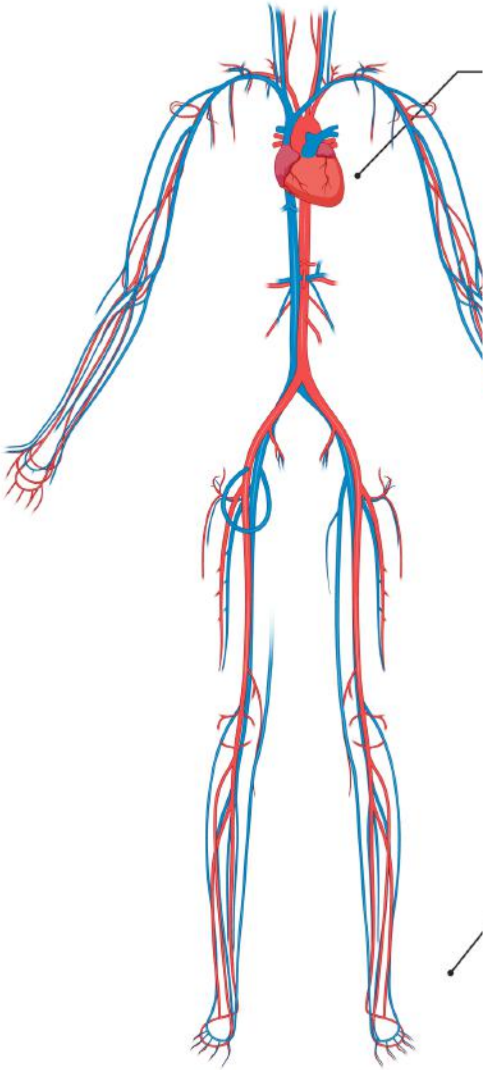
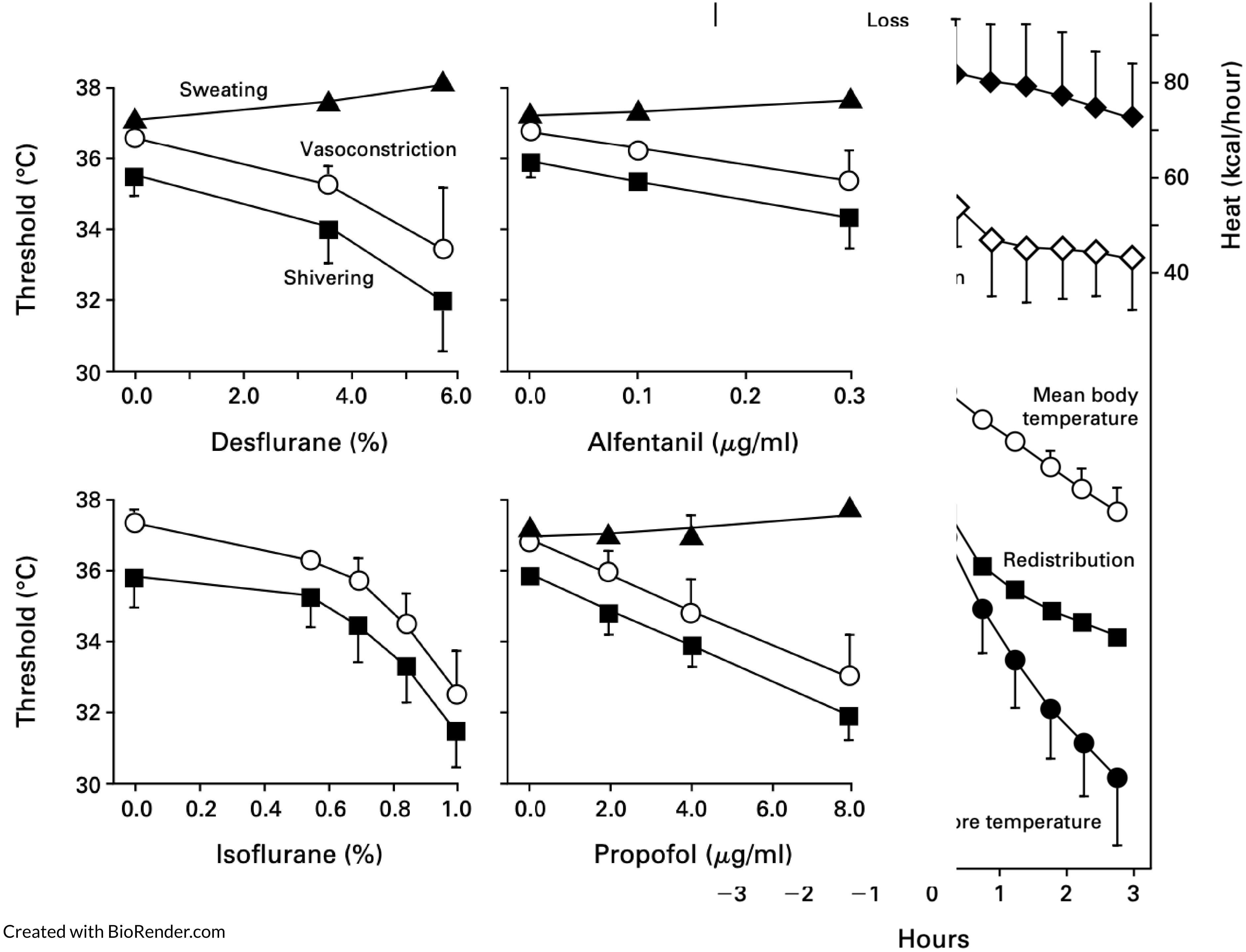


Image retrieved from https://coutureinclinic.com/home/rotation-recap-cardiothoracic-surgery

Anesthesi





Stone et al. 1981 ANESTH ANALG

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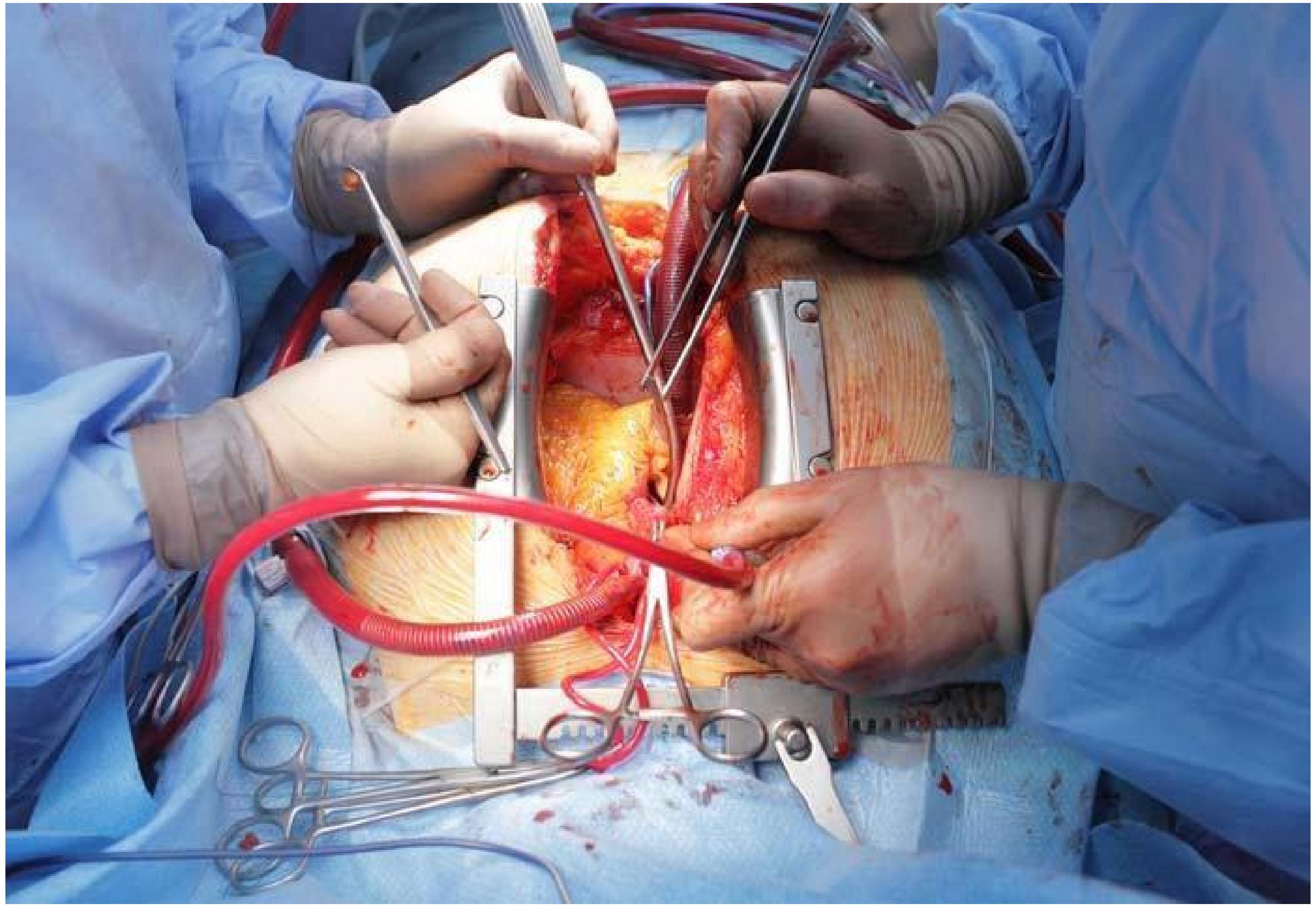
Perioperative Setting

2. Exposure and 3. Blood loss



- Abdominal/Thoracic
- Prolonged procedures > 2hrs
- Preop fasting
- Body surface exposure
- Patient-related factors

Image retrieved from
https://coutureinclinic.com/home/rotation-recap-cardiothoracic-surgery

PACU/Intensive Care Unit - Problems follow from the OR

Sessler, 1997 NEJM

TABLE 1. EFFECTS OF MILD PERIOPERATIVE HYPOTHERMIA IN PUBLISHED STUDIES.*

STUDY	NO. OF PATIENTS	DIFFERENCE IN CORE TEMPERATURE (°C)	EFFECT MEASURED	VALUE IN NORMOTHERMIC PATIENTS	VALUE IN HYPOTHERMIC PATIENTS	P VALUE
Kurz et al.[46]	200	1.9	Duration of hospitalization	12.1±4.4 days	14.7±6.5 days	<0.01
			Surgical-wound infection	6%	19%	<0.01
Schmied et al.[49]	60	1.6	Intraoperative blood loss	1.7±0.3 liters	2.2±0.5 liters	<0.001
			Allogeneic blood transfused	1 unit	8 units	<0.05
Frank et al.[50]	300	1.3	Cardiac events	1%	6%	<0.05
			Postoperative ventricular tachycardia	2%	8%	<0.05
Carli et al.[45]	12	1.5	Urinary excretion of nitrogen	728±254 mmol/day	1240±558 mmol/day	<0.05
Heier et al.[52]	20	2.0	Duration of action of vecuronium	28±4 min	62±8 min	<0.001
Leslie et al.[51]	6	3.0	Duration of action of atracurium	44±4 min	68±7 min	<0.05
Just et al.[16]	14	2.3	Postoperative shivering†	141±24 ml/min/m²	269±159 ml/min/m²	<0.05
Lenhardt et al.[53]	150	1.9	Duration of post-anesthesia recovery	53±36 min	94±65 min	<0.001
Frank et al.[54]	74	1.5	Adrenergic activation‡	330±182 pg/ml	480±425 pg/ml	<0.05
Kurz et al.[55]	74	2.6	Thermal discomfort§	50±10 mm	18±9 mm	<0.001

*Only prospective, randomized trials are included; subjective responses were evaluated by observers blinded to treatment group and core temperature. The difference in core temperature is the difference between the normothermic and hypothermic patients. Plus–minus values are means ±SD.

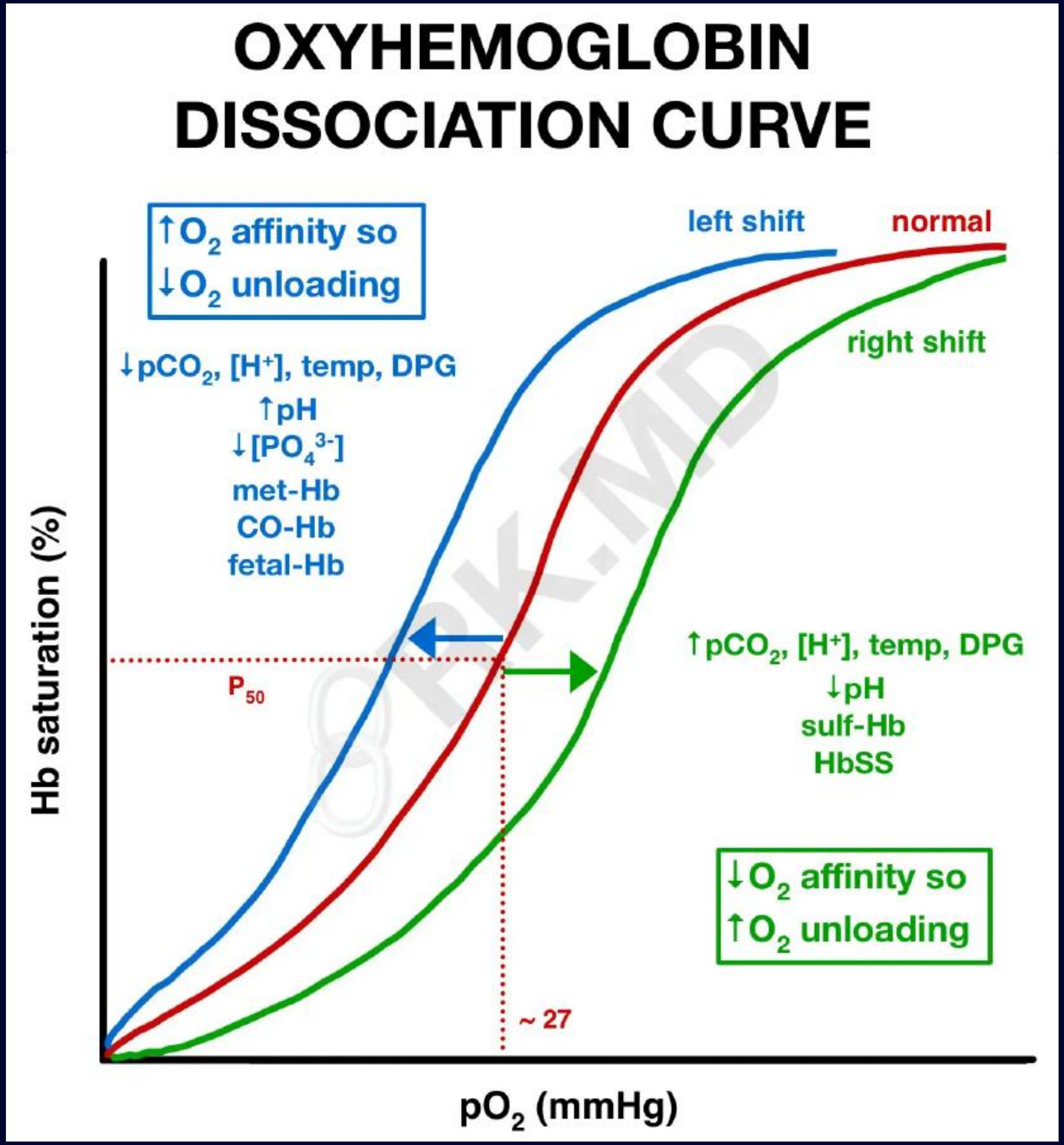
†Postoperative shivering was measured in terms of oxygen consumption.

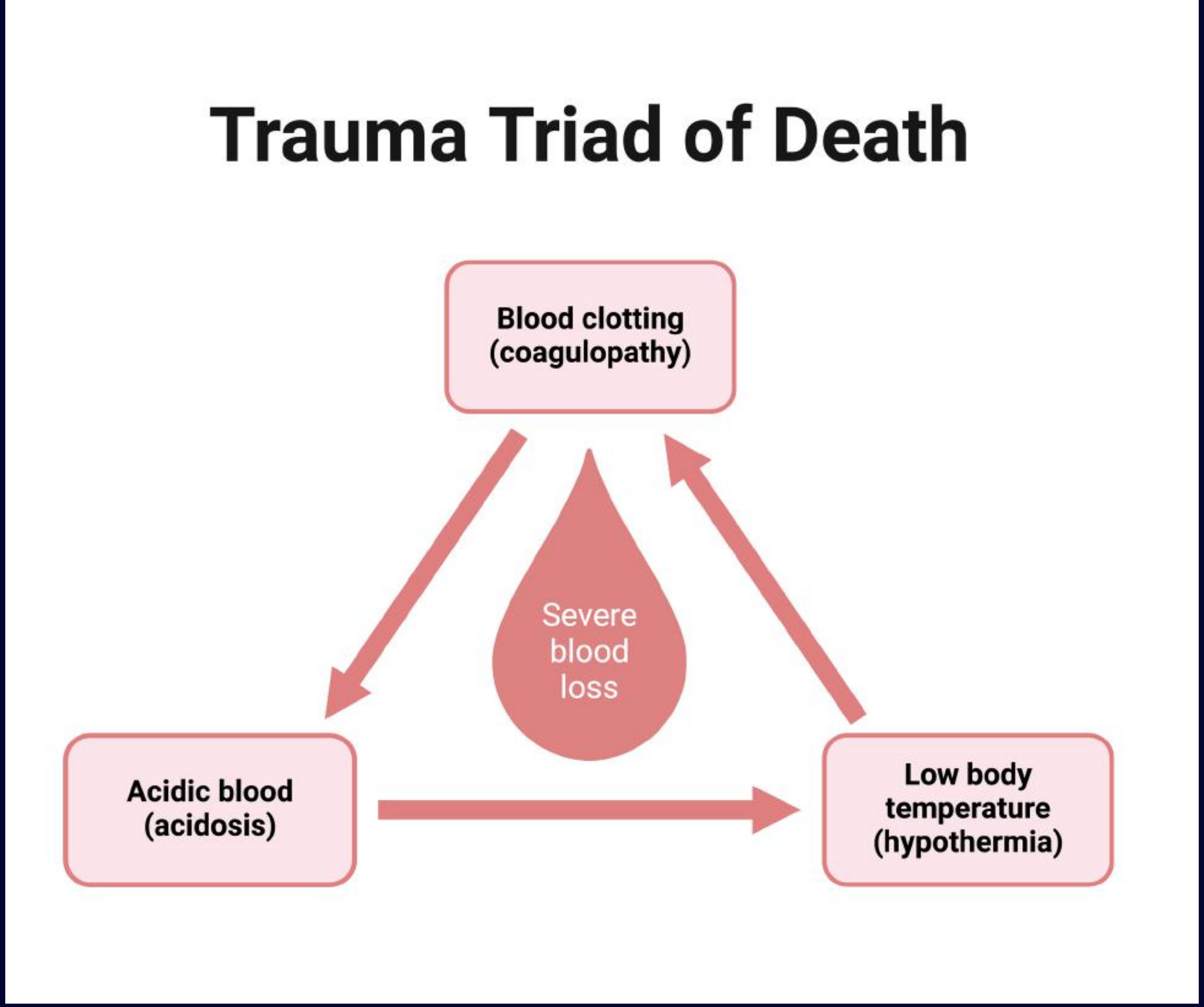
‡Adrenergic activation was measured in terms of plasma norepinephrine concentration.

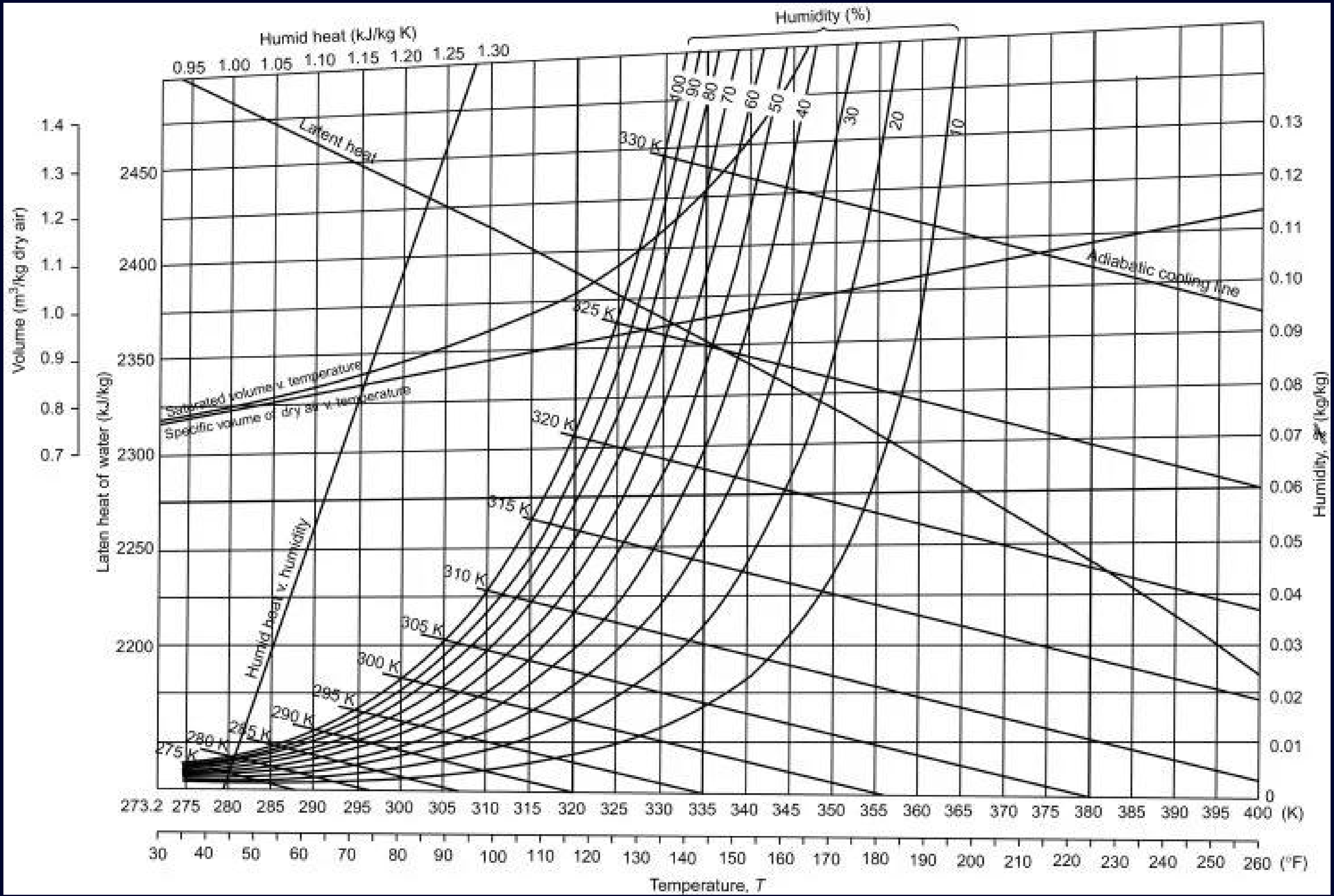
§Thermal discomfort was measured on a visual analogue scale on which patients indicated their responses; the markings ranged from 0 mm (intense cold) to 100 mm (intense heat).

What does any of this have to do with me?

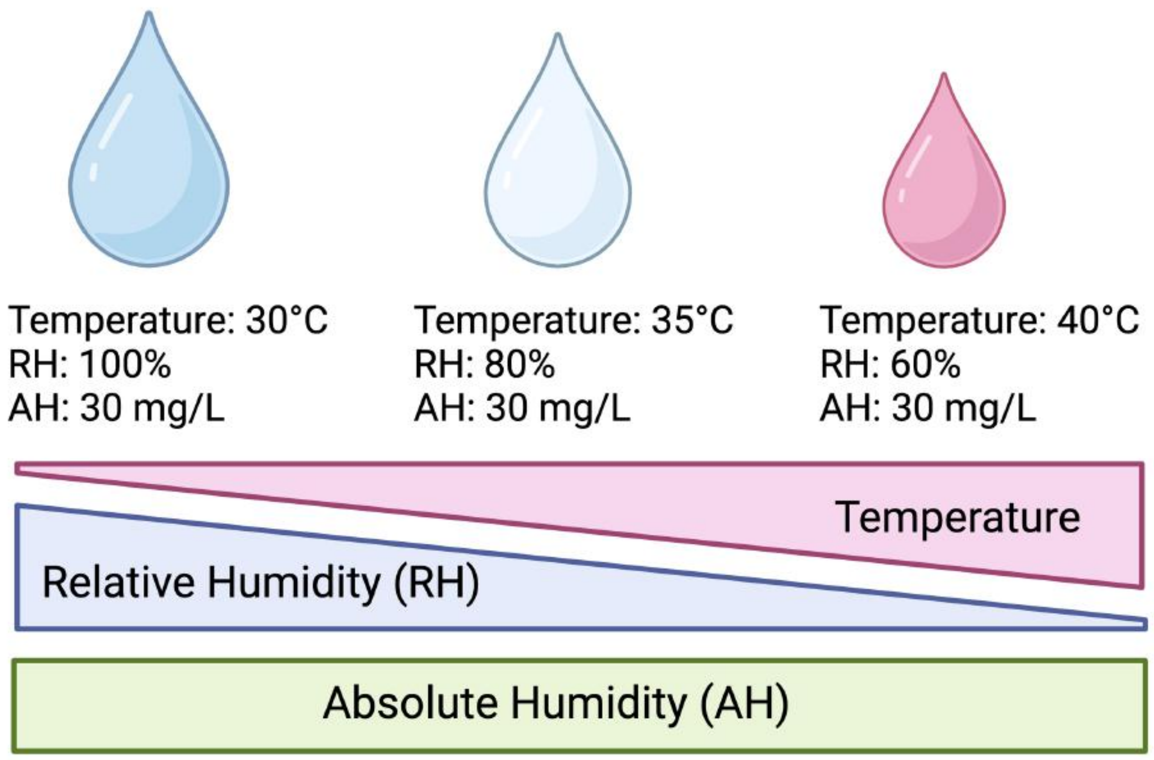
Acid-Base?
Oxyhemoglobin Dissociation Curve shift?

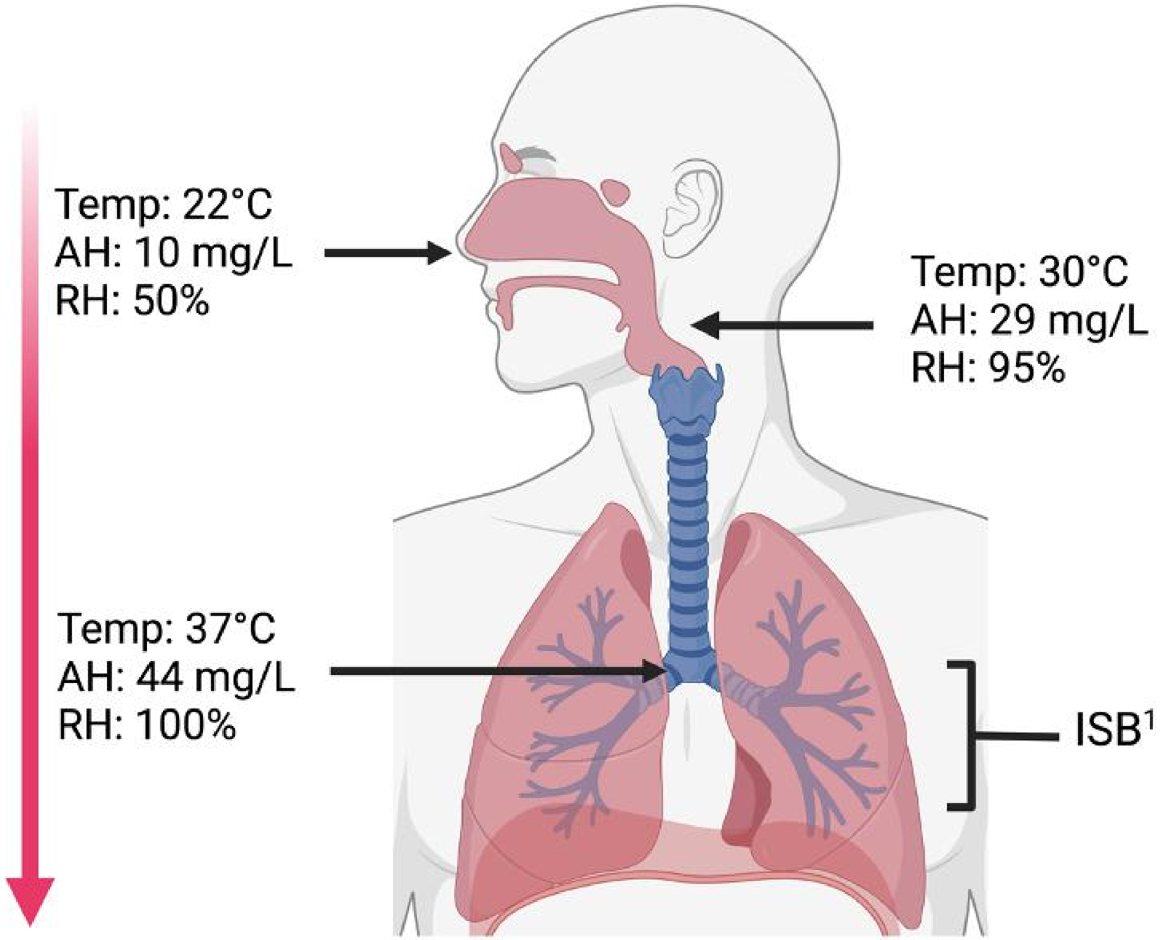





Humid heat (kJ/kg K)
0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30
Humidity (%)
100 90 80 70 60 50 40 30 20 10
Latent heat
Adiabatic cooling line
Saturated volume v. temperature
Specific volume of dry air v. temperature
Humid heat v. humidity
330 K 325 K 320 K 315 K 310 K 305 K 300 K 295 K 290 K 285 K 280 K 275 K
Volume (m³/kg dry air)
1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7
Laten heat of water (kJ/kg)
2450 2400 2350 2300 2250 2200
Humidity, 𝒳 (kg/kg)
0.13 0.12 0.11 0.10 0.09 0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 0
273.2 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 (K)
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 (°F)
Temperature, T

Heat loss via the airway





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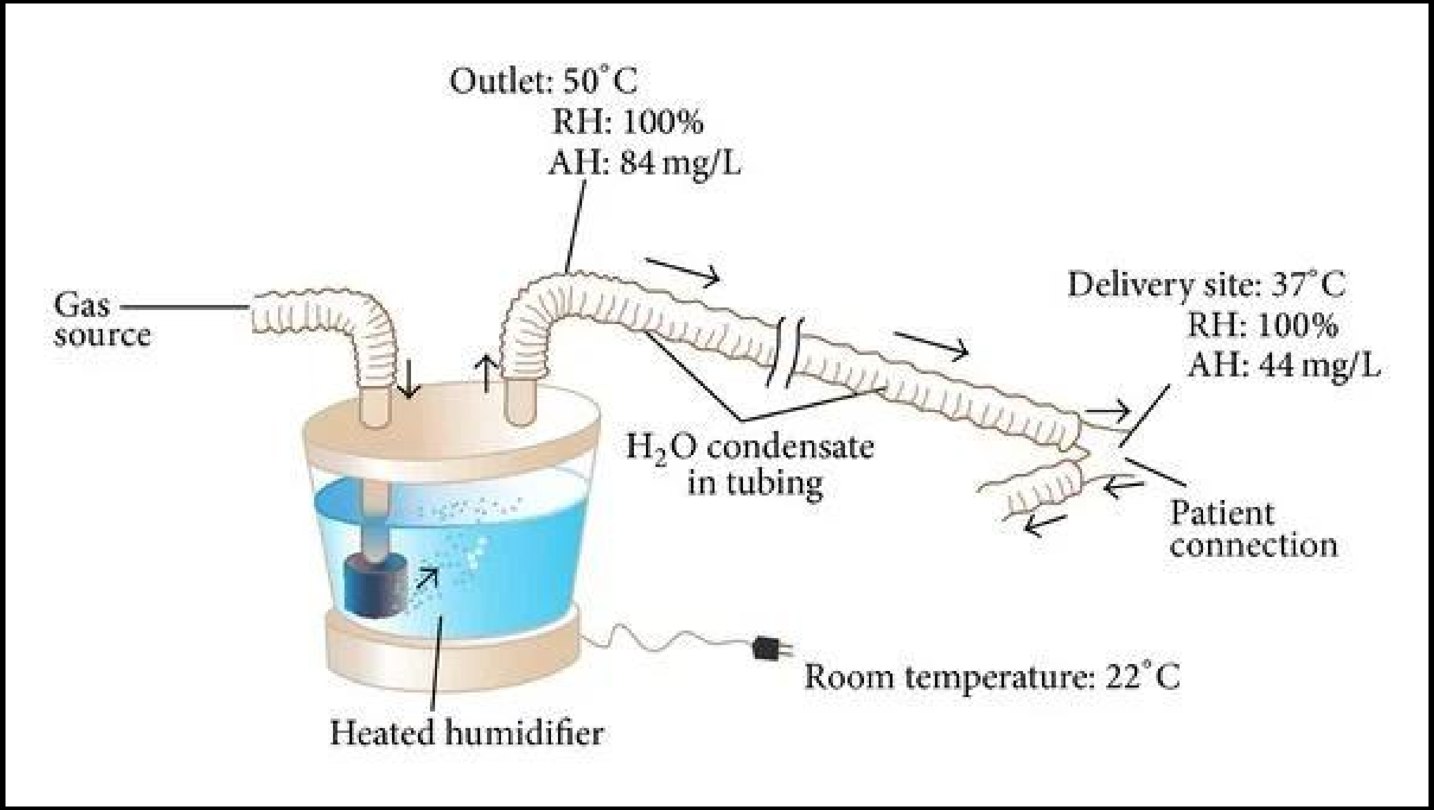
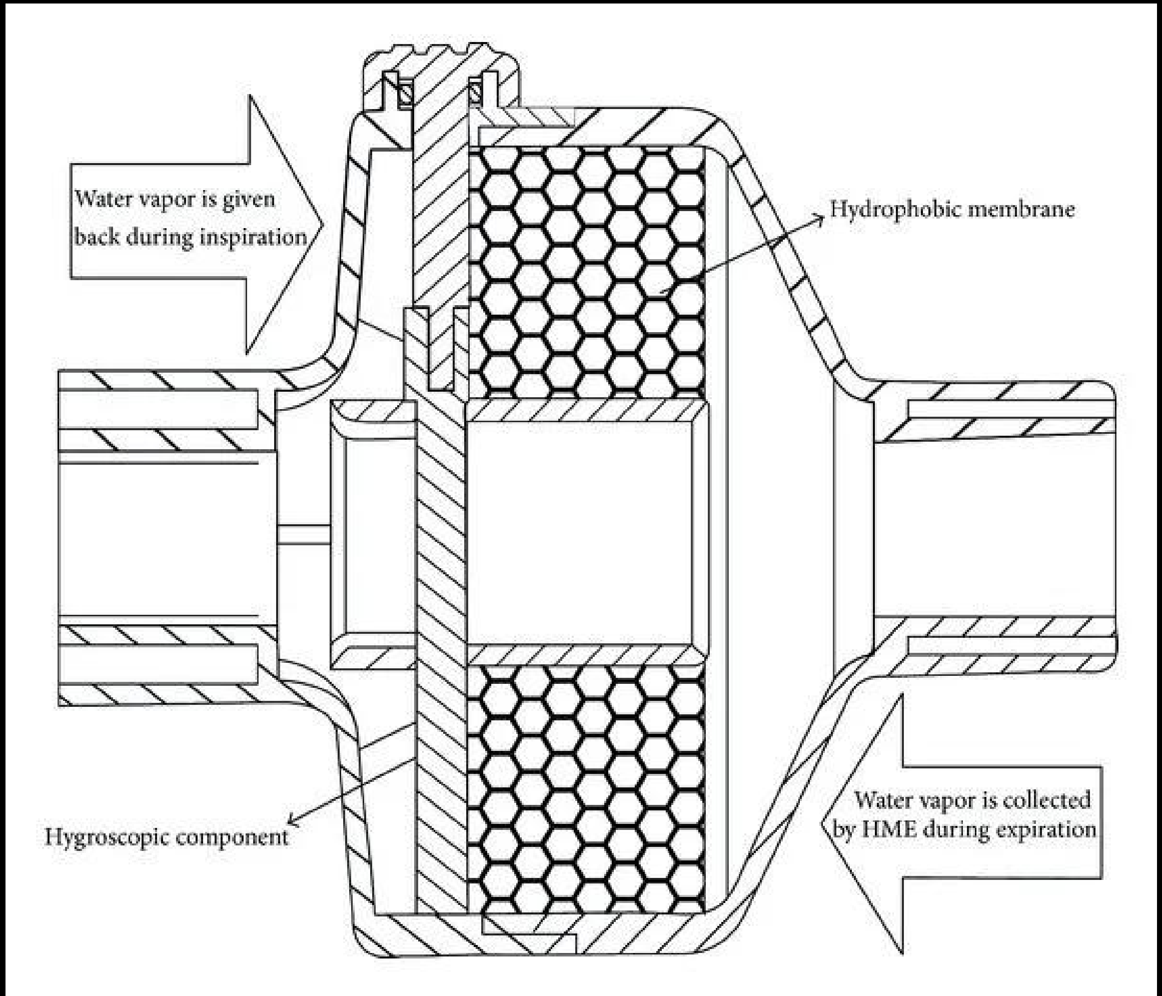
Brief on HMEs and Active Humidification (HH)





Brief on HMEs and Active Humidification (HH)

AARC Clinical Practice Guideline

Humidification During Invasive and Noninvasive Mechanical Ventilation: 2012

Ruben D Restrepo MD RRT FAARC and Brian K Walsh RRT-NPS FAARC

Regardless of HH or HME, either must be able to supply, at minimum, an absolute humidity of 30 mg/L, a gas temperature of 34°C, and 100% relative humidity

However...not all devices perform as expected during hypothermic states

Intensive Care Med (2006) 32:1014–1021
DOI 10.1007/s00134-006-0192-8

ORIGINAL

François Lellouche
Siham Qader
Solenne Taille
Aissam Lyazidi
Laurent Brochard

Under-humidification and over-humidification during moderate induced hypothermia with usual devices

During (intentional) Mild Hypothermia (N=9):

HME = no bueno! Avg AH = 25 mg/L

HH = better but...a few subjects recieved OVERhumidification (up to AH of39.9 mg/L)
Why is this a problem?

Of note!
Neither the HME or HH prevented (intentional) hypothermia

Heat Exchange in the Airway - An active proccess

$$\Delta HT + \Delta H_{H2O} = \dot{V}\,[1.26(T_g^2 - T_g^1) + 2.45(C_g^2 - C_g^1)]$$

Theoretical applicaiton: Mechanically ventilated 75kg patient with respiratory distress receiving dry room temperature gas (someone didn't turn on the humidifier!)

Parameters:

Vt = 450 mL
RR= 28 bpm
Inspired gas: 22°C;
50% RH; 10mg/L AH
*Ve = 0.60 m/hr

How much heat energy is this patient losing?

$$\Delta HT + \Delta H_{H2O} = 0.60\,[1.26(22 - 37) + 2.45(10 - 44)] = -62\ kJ/hr$$

Heat Exchange in the Airway: An active process

How much heat energy is this patient losing?

$$\Delta HT + \Delta H_{H2O} = 0.60\,[1.26(22 - 37) + 2.45(\dot{1}0 - 44)] = -62\ kJ/hr$$

Assuming a BMR of 200 kJ/hr...

31% of body heat is lost via the airway (62kJ/hr x 200 kJ/hr ^-1)

This amount of heat loss will reduce body temperature of the body by 0.24°C/hr *

*Assuming this is the only source of body heat loss

A little more realistic...

1 Assuming no heat loss over instrumental dead space
2 Parameters associated with an optimally functioning HME
3 Inspiratory energy – Expiratory energy = Net gain/loss
HH: Heated Humidification; HME: Heat and Moisture Exchanger

75kg patient @ 10L/min Ve

Including other sources of body heat loss (kJ/hr):

Radiation : -167

Convection : -41

Conduction : -11

Evaporation : -24

$$Q=mc(\Delta T)$$

Active Humidification

HH

Inspiratory Energy[1]

Temp: 40°C
AH: 51 mg/L
RH: 100%

146 kJ/kg

Expiratory Energy

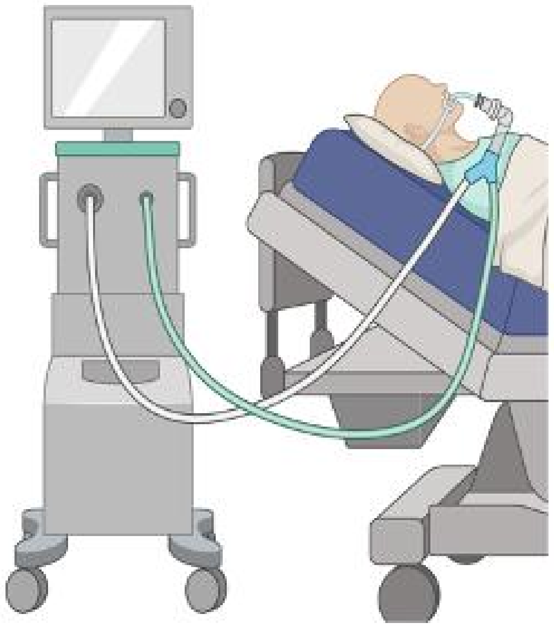
Temp: 37°C
AH: 44 mg/L
RH: 100%

143 kJ/kg

Net gain[3]**: +3 kJ/kg**

Total heat balance: -38 kJ/hr

Body Temp Change: -0.15°C/hr



Passive Humidification

HME

Inspiratory Energy[2]

Temp: 30°C
AH: 30 mg/L
RH: 100%

100 kJ/kg

Expiratory Energy

Temp: 33°C
AH: 36 mg/L
RH: 100%

117 kJ/kg

Net loss[3]**: -17 kJ/kg**

Total heat balance: -58 kJ/hr

Body Temp Change: -0.20°C/hr

But theoretically....

1 Assuming no heat loss over instrumental dead space
2 Parameters associated with an optimally functioning HME
3 Inspiratory energy – Expiratory energy = Net gain/loss
HH: Heated Humidification; HME: Heat and Moisture Exchanger

75kg patient @ 10L/min Ve

Including other sources of body heat loss (kJ/hr):

Radiation : 0

Convection : 0

Conduction :0

Evaporation : 0

$$Q=mc(\Delta T)$$

Active Humidification

HH

Inspiratory Energy[1]

Temp: 40°C
AH: 51 mg/L
RH: 100%

146 kJ/kg

Expiratory Energy

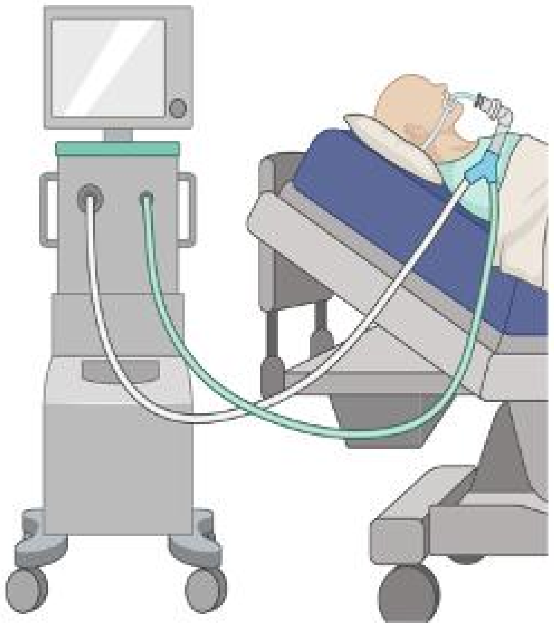
Temp: 37°C
AH: 44 mg/L
RH: 100%

143 kJ/kg

Net gain[3]**: +3 kJ/kg**

Total heat balance: +204 kJ/hr

Body Temp Change: +0.78°C/hr



Passive Humidification

HME

Inspiratory Energy[2]

Temp: 30°C
AH: 30 mg/L
RH: 100%

100 kJ/kg

Expiratory Energy

Temp: 33°C
AH: 36 mg/L
RH: 100%

117 kJ/kg

Net loss[3]**: -17 kJ/kg**

Total heat balance: +185 kJ/hr

Body Temp Change: +0.70°C/hr

Let's go to the literature...

Elimination

Attenuation

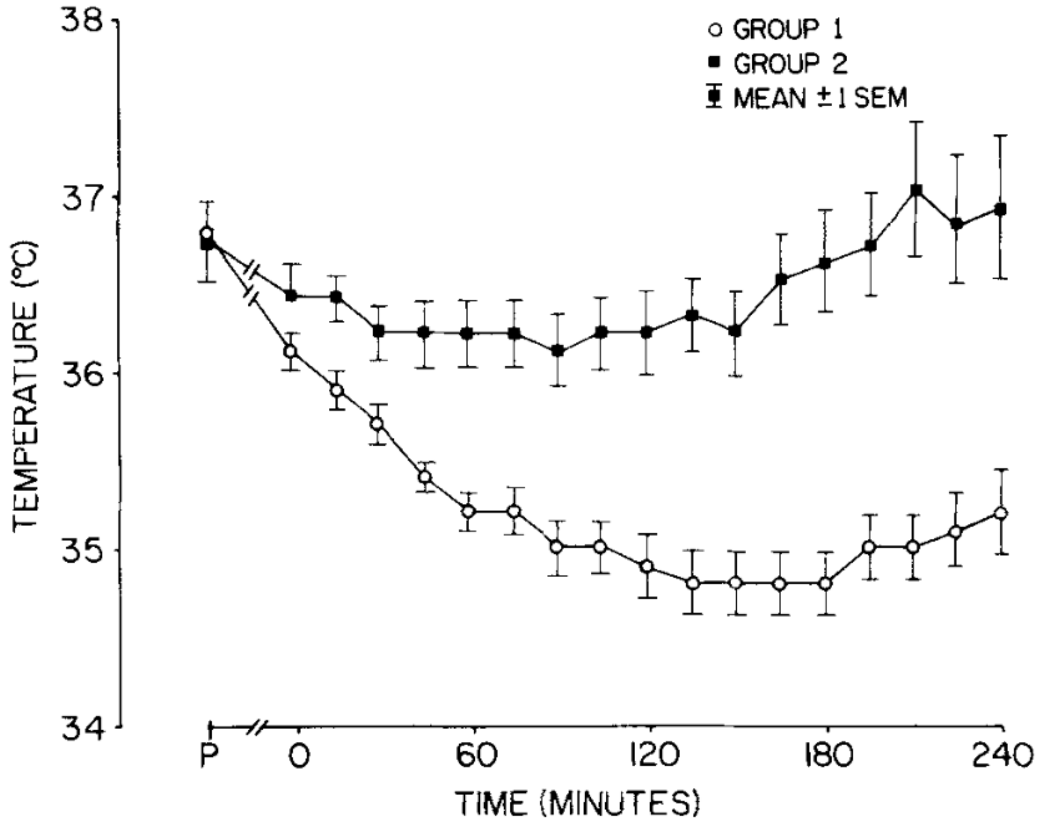


FIG 2. Mean values ± SEM for nasopharyngeal temperatures of patients in groups 1 and 2. P indicates preoperative oral temperatures. Differences in mean nasopharyngeal temperature values were statistically significant after 60 minutes ($p < 0.001$), 120 minutes ($p < 0.001$), 180 minutes ($p < 0.001$), and 240 minutes ($p < 0.01$).

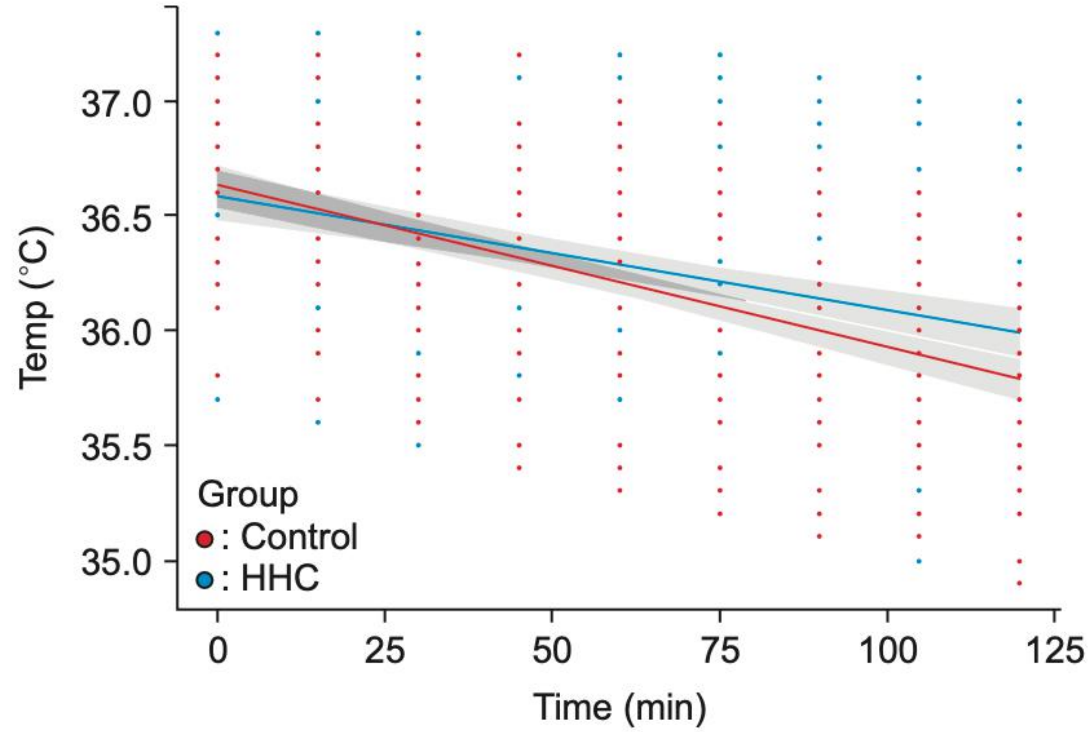
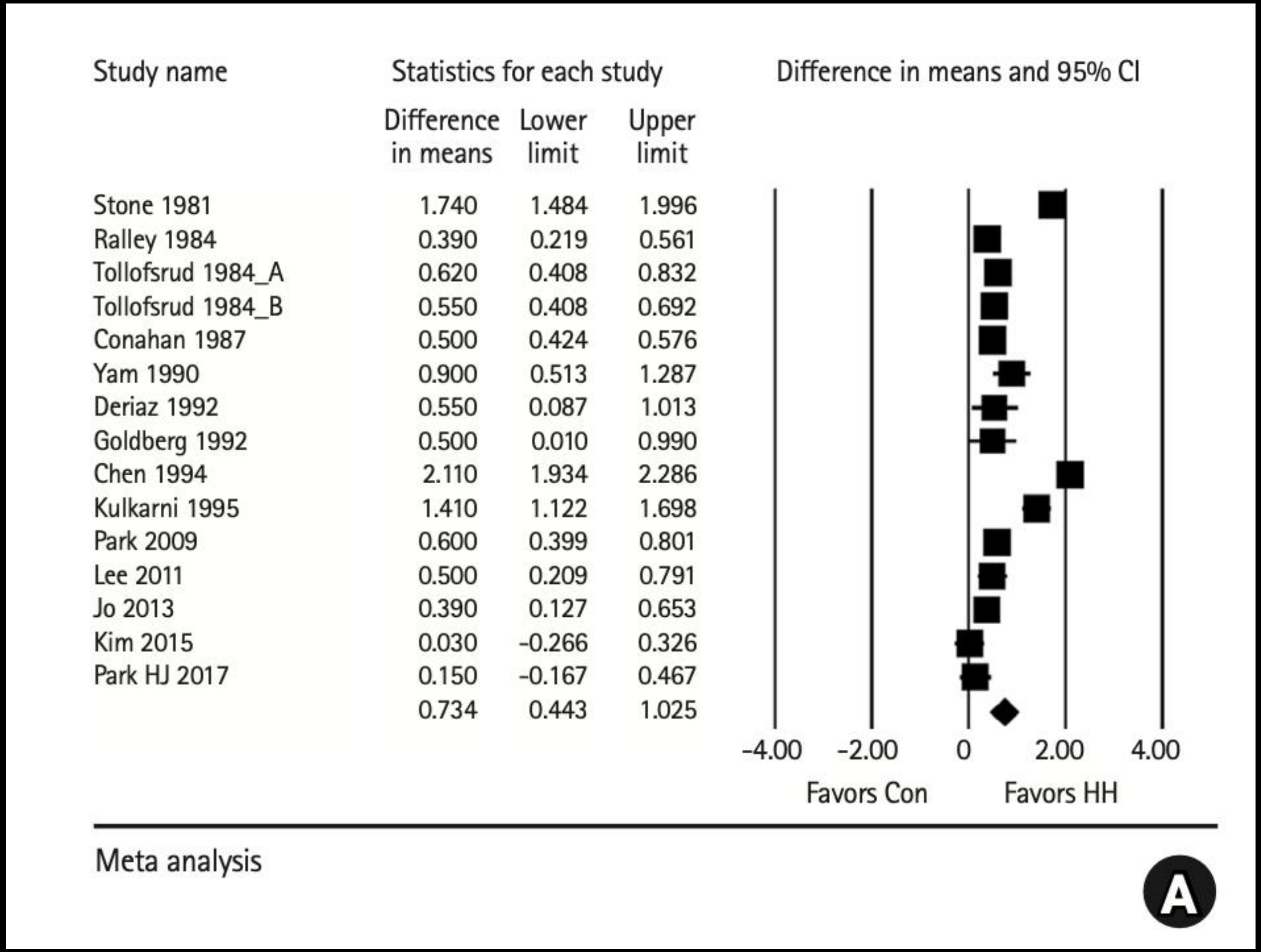


Fig. 1. Changes in core temperature (temp) in patients using an unheated respiratory circuit (●) or an electrically heated circuit (●) during hip arthroscopy. Linear mixed effect modeling: Temp = 36.75 + time (min) × (-0.007) + sex × (-0.2244) + group × (0.002) (sex = 1: male, 0: female, group = 1: HHC, 0: control).

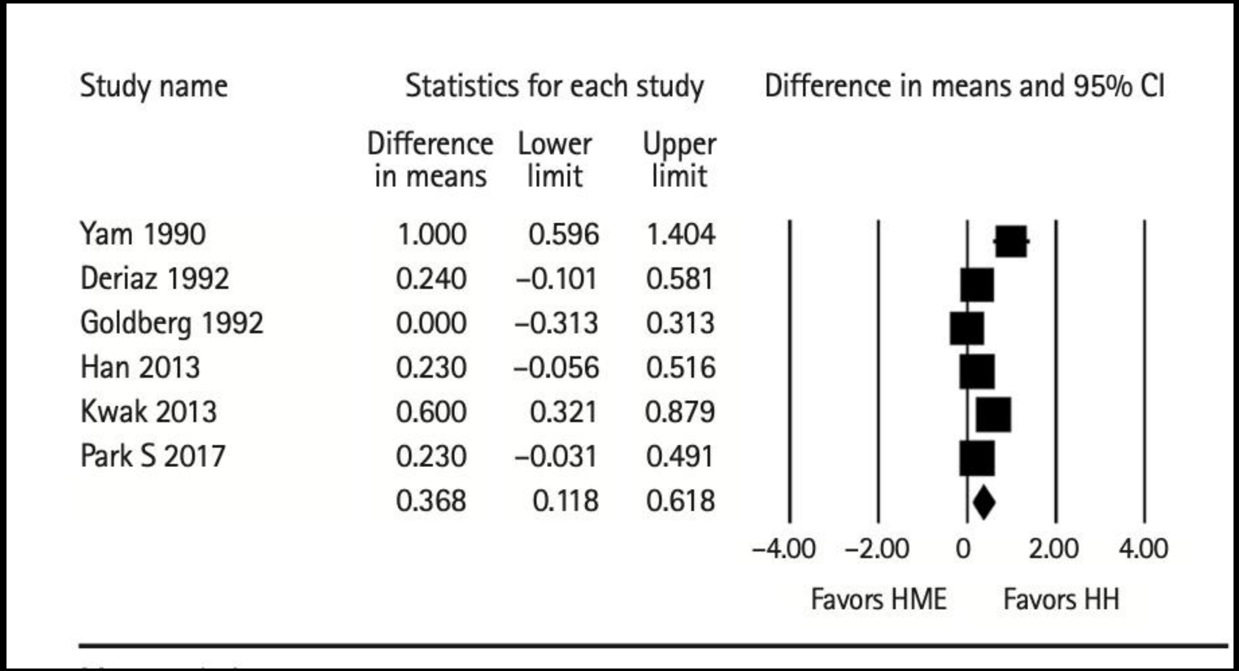
Stone et al. 1981 ANESTH ANALG

Park et al. 2017 KJOA

Intraop core temp at the end of surgery



(WMD = 0.734, 95% CI [0.443, 1.025], I2 = 96.65, τ2 = 0.31, P < 0.001)



(WMD = 0.368, 95% CI [0.118, 0.618], I2 = 74.60, τ2 = 0.07, P = 0.060

Lee et al. 2023 KJOA

Didn't you say something about trauma?!

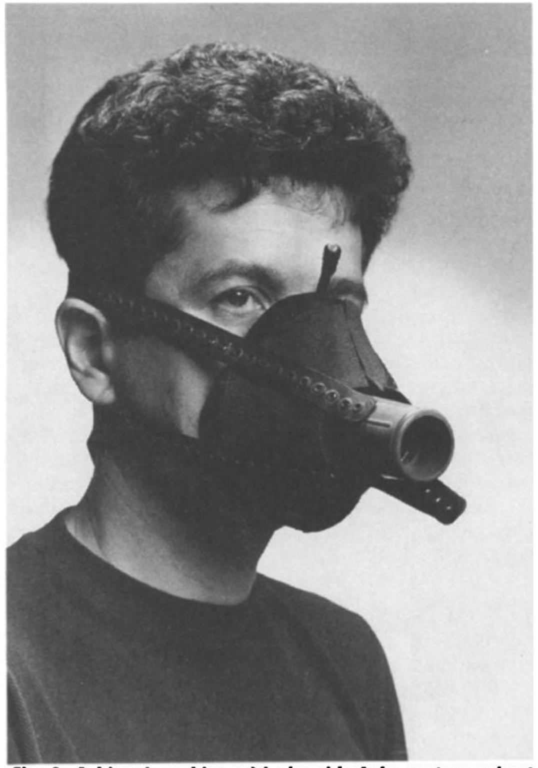


Fig. 1. Subject breathing with the aid of the prototype heat and moisture exchanger (HME).

TABLE 2. *Rewarming phase, afterdrop (C) (mean ± SD, n = 8)*

	Bag 1 (Cold)	Bag 2 (Cold)	Bag 2 (Warm)	Bag 2 (Cold) + Inhalation Rewarming	Bag 2 (Warm) + Inhalation Rewarming	Mean ± SE	Significance
Tr	35.1 ± 0.4	35.1 ± 0.6	[illegible] ± 0.6	35.0 ± 0.7	35.0 ± 0.6	35.0 ± 0.0	NS
Te	35.1 ± 0.7	34.9 ± 0.7	[illegible]	35.1 ± [illegible]	34.9 ± 0.4	34.9 ± 0.1	NS

NOPE

~ insp temp 45°C 'Heat Treat'

Sterba et al et al., 1991 ANN EMMED

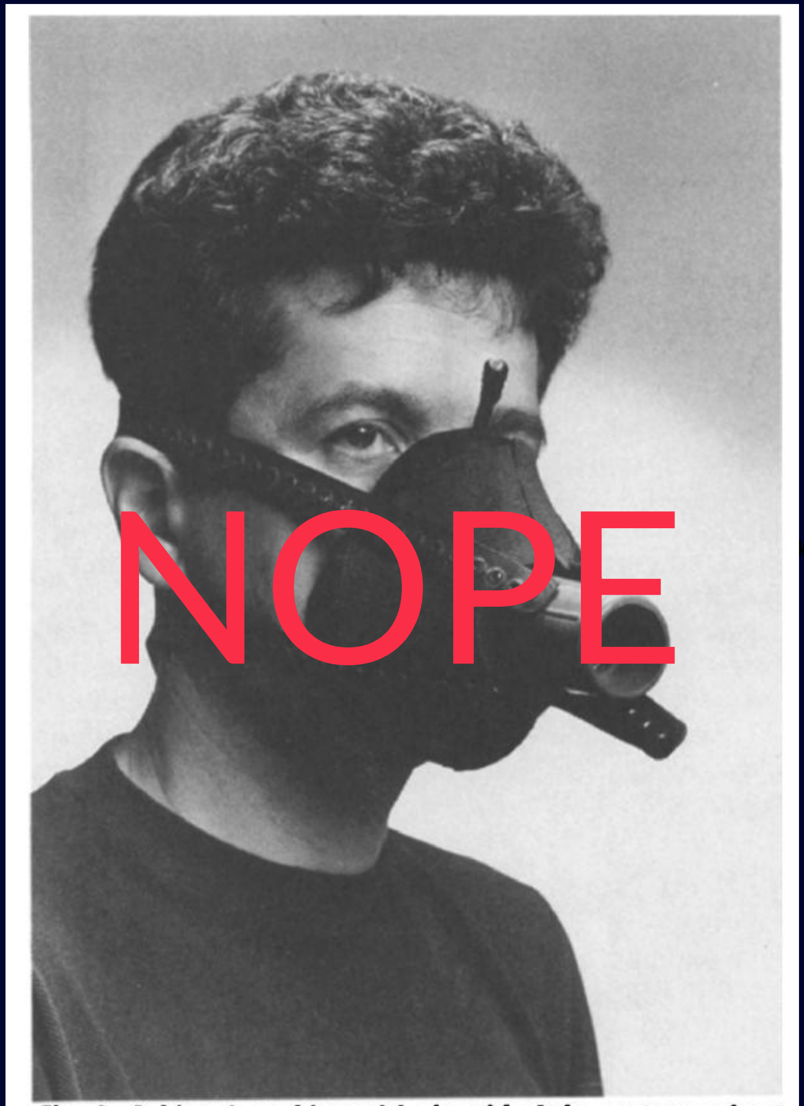
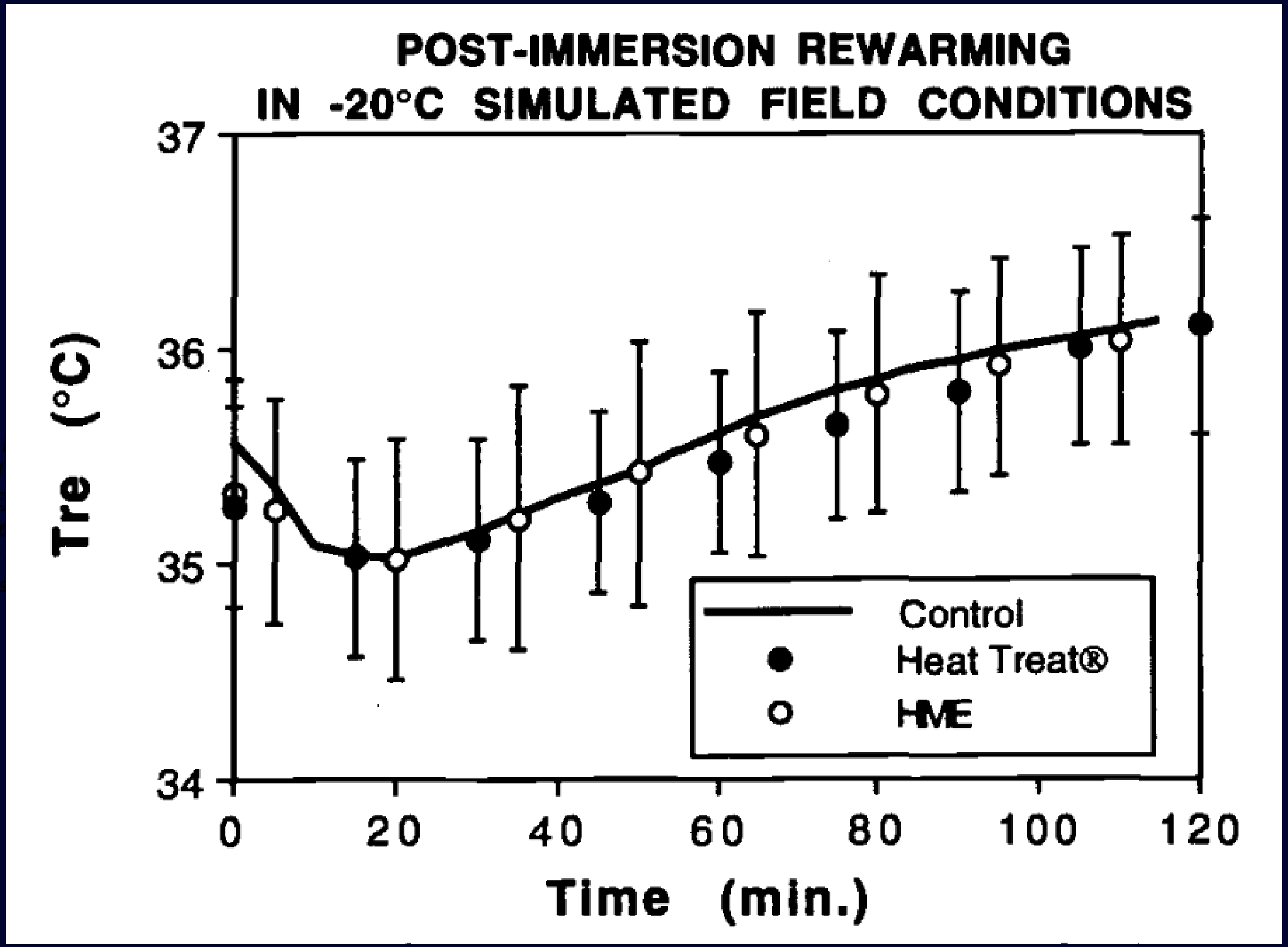


Fig. 1. Subject breathing with the aid of the prototype heat and moisture exchanger (HME).

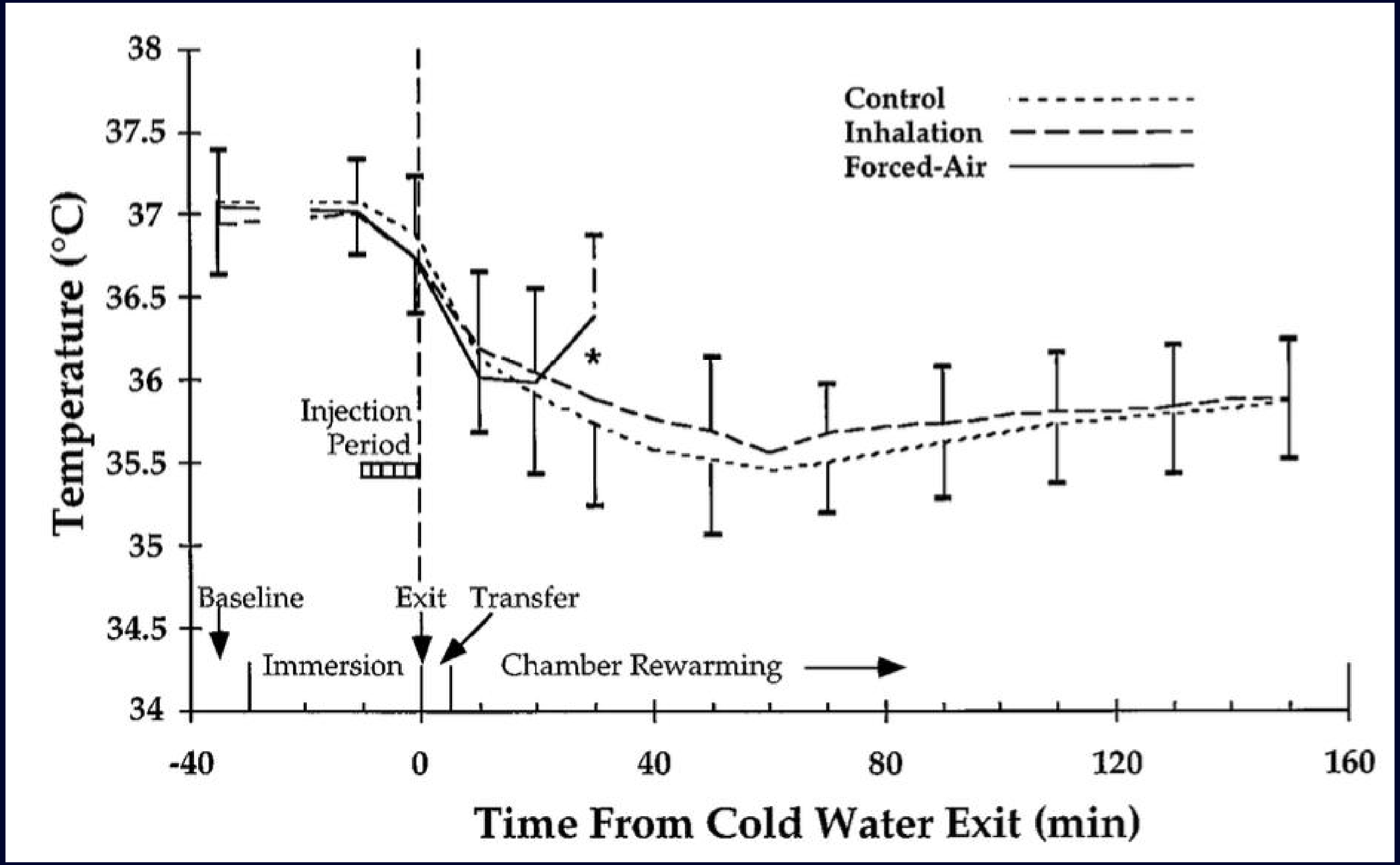
kjavic, I.B. and O. Eiken,
degrees C simulated
Goheen, M., et al.,
model for severe hyp
Sterba, J.A., Efficacy
hypothermia. Annals



~ insp temp 38°C 'Heat Treat'

Mekjavic et al et al., 1995 Aviat Space Environ Med

NOPE



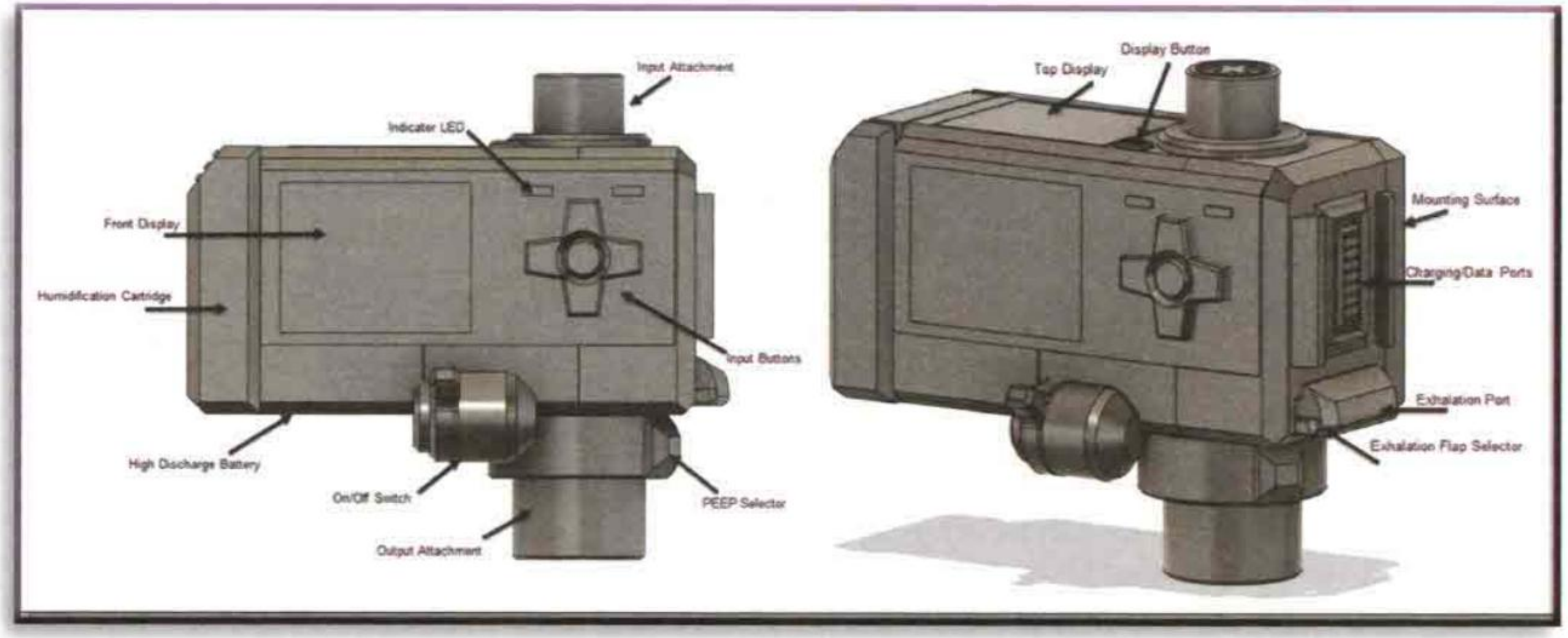
~ insp temp 43°C non-invasively

Goheen et al., 1995 JOAP

Airway and Hypothermia Prevention and Treatment via STEAM

The System for Thermogenic Emergency Airway Management†

Ryan A. Stevens, MD[1‡]; Bradley Pierce, MD[2‡]; Laura Tilley, MD, FACEP[3‡]*

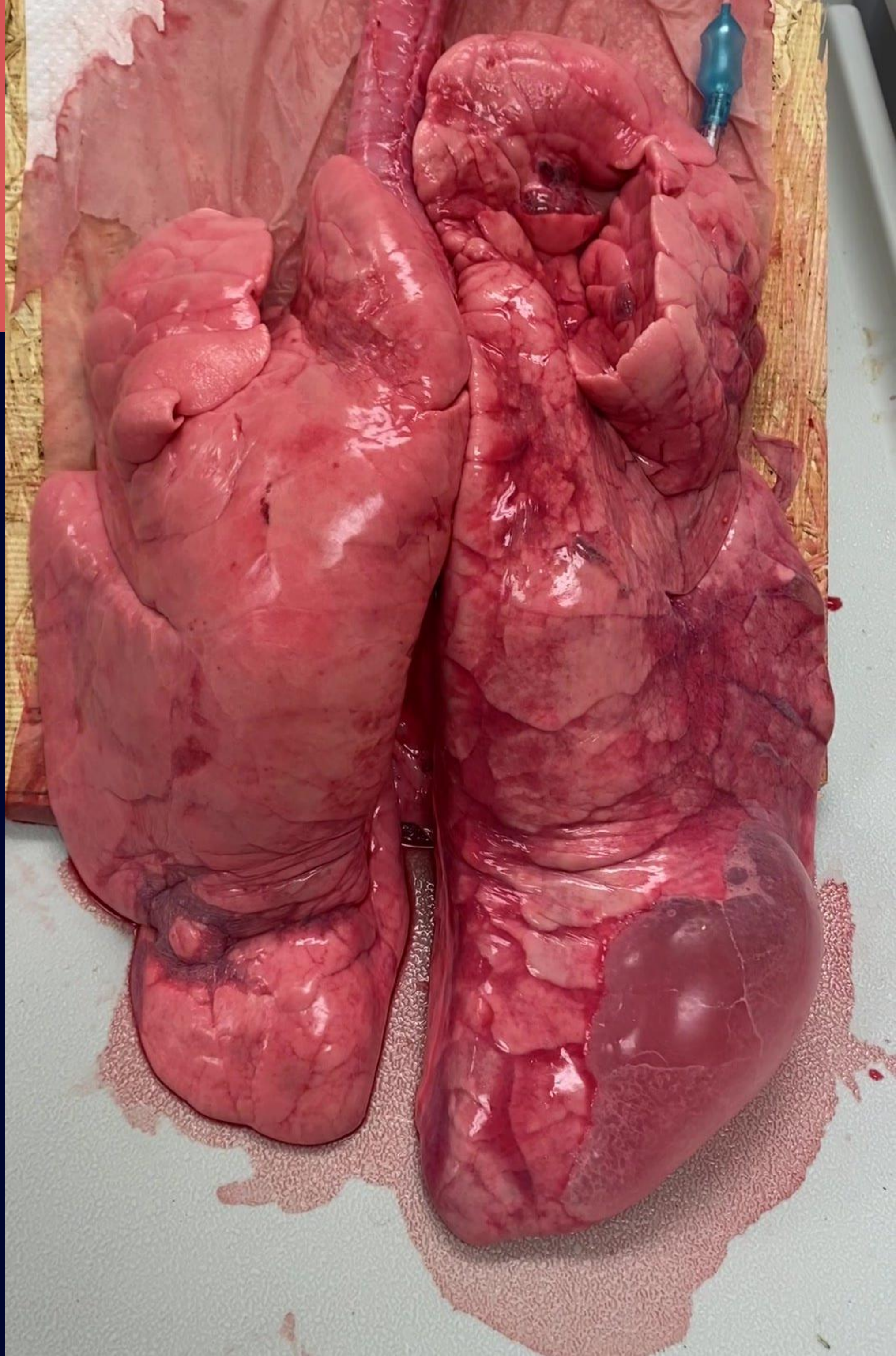


Why do I care?

Interest persists

Misinformation

I'm an RT at the end of the day...



So, what's the point?

Appropriate interventions

Context

Physiological arugment

Future research

...it doesn't 'not do anything'

Summary

The Gestalt of thermoregulation should encompass interventions to reduce total body heat loss from multiple sources. The prevention total body heat loss due to conduction, convection, radiation, and evaporation from the mechanically ventilated patient, in addition to providing heated and humidified inspired gases to support thermoregulation, appears to be the most reasonable approach as available.

Any Questions?

Thank you!