The Case for Metabolic Acidosis as the Cause of Death in Arrest-related Deaths

Victor W. Weedn, M.D., J.D

This presentation is adapted from a presentation given at the NAME 58th Annual Meeting, Sept 21, 2024, Denver, CO. representing the work of Victor Weedn, Alon Steinberg, and Pete Speth
* Eric Jaeger also made valuable contributions

Take Home Points

- **Metabolic acidosis** is the primary cause of in-custody death involving prone restraint
- Metabolic acidosis arises due to **a combination of stress, physical struggle,** often stimulant drugs, and, in some cases, ECW application
- **Prone restraint interferes with the ability to compensate** for metabolic acidosis by restricting the patient's ability to breathe
- Important **EMS data**, can yield valuable clues to the cause of death but is often overlooked
- These deaths should be characterized as **homicides**

AP PBS FRONTLINE

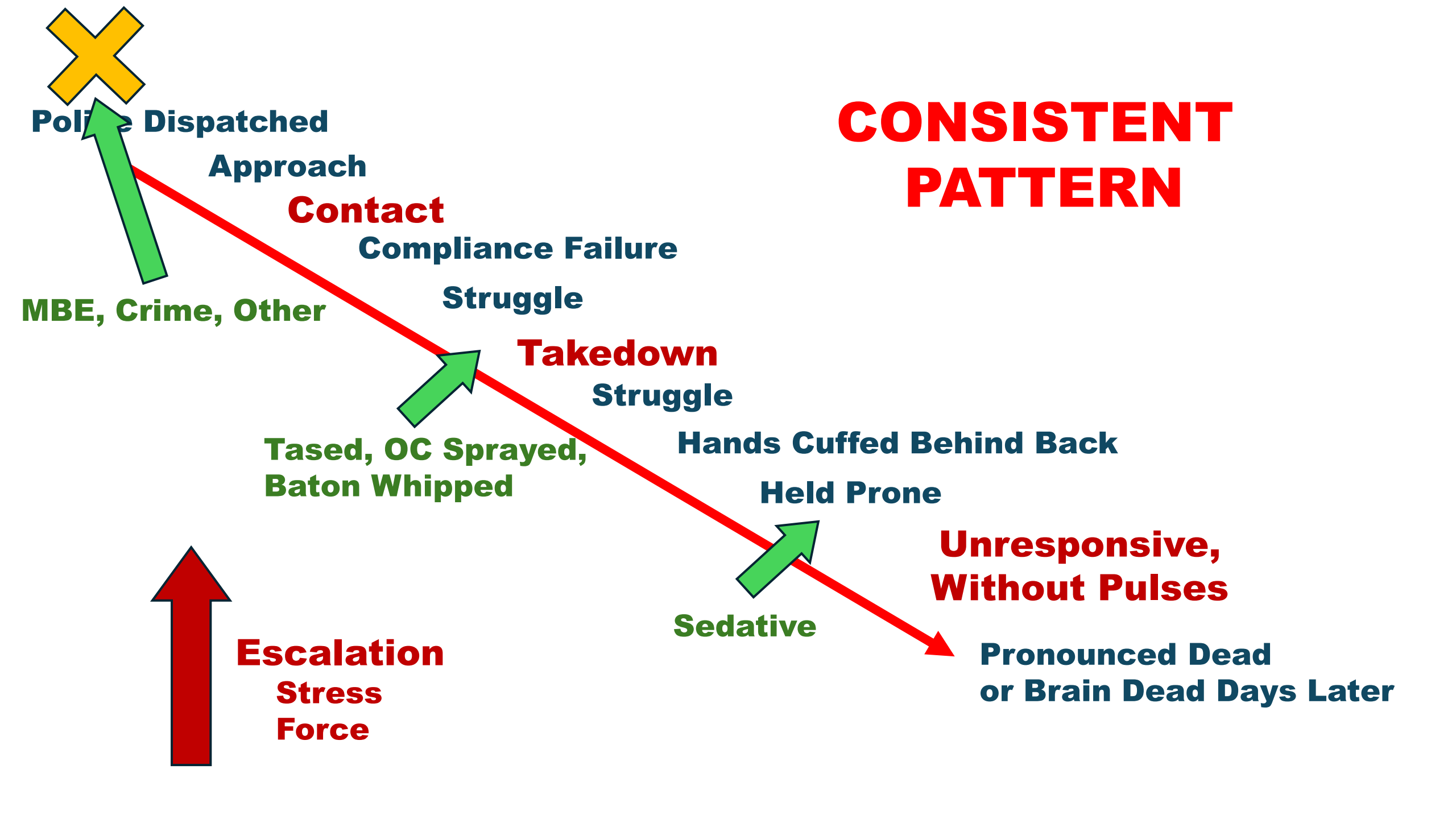
LETHAL RESTRAINT

Why did > 1000 people die after police subdued them with force that wasn't meant to kill?

An avg. of 2 / week

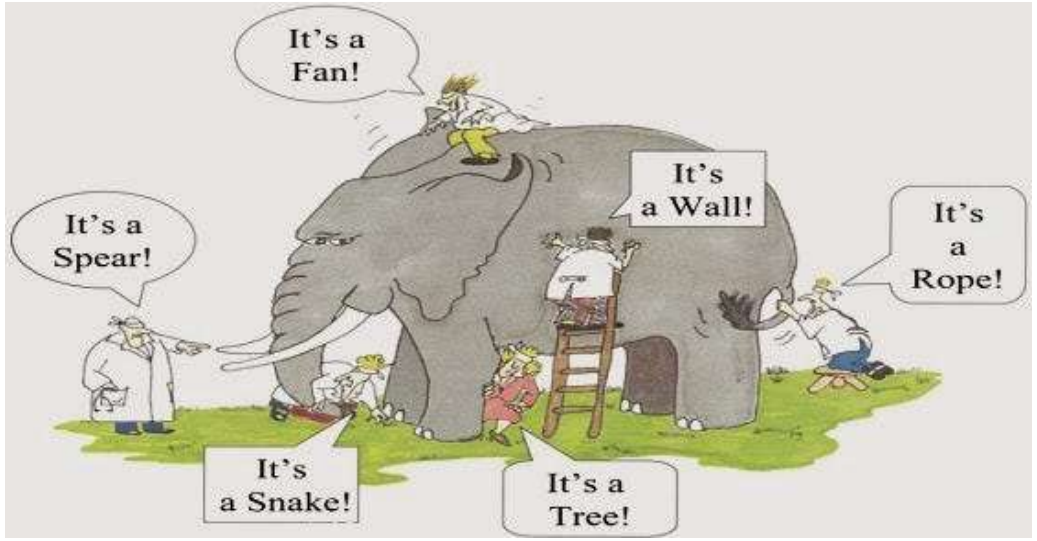
- Only a tiny fraction of police encounters

- While **30%** involved people who were a ***threat to others***
- **25%** involved people who posed little or no risk to others


CONSISTENT PATTERN
Police Dispatched
Approach
Contact
Compliance Failure
Struggle
Takedown
Struggle
Hands Cuffed Behind Back
Held Prone
Unresponsive, Without Pulses
Pronounced Dead or Brain Dead Days Later
MBE, Crime, Other
Tased, OC Sprayed, Baton Whipped
Sedative
Escalation
Stress
Force

Proposed Mechanisms/Causes of Death

- Restraint (Positional, Mechanical) Asphyxia
- Excited Delirium Syndrome (Catecholamine Storm)
- [Excited Delirium Syndrome (Catecholamine Depletion)]
- [Excited Delirium Syndrome (Hyperthermia)]
- Stress-related Myocardial Infarction
- Stress-related Arrhythmia
- Stress-related Cardiomyopathy
- Stress + Channelopathy
- Stress + Underlying Cardiac Disease
- Stress + Drugs
- Neck Pressure / Carotid Sinus Stimulation
- Stimulant Drug Overdose
- Metabolic Acidosis/Prone Restraint Cardiac Arrest
- Sedative Medication Overdose



-- NEGATIVE AUTOPSY --

ASSOCIATION v. CAUSALITY

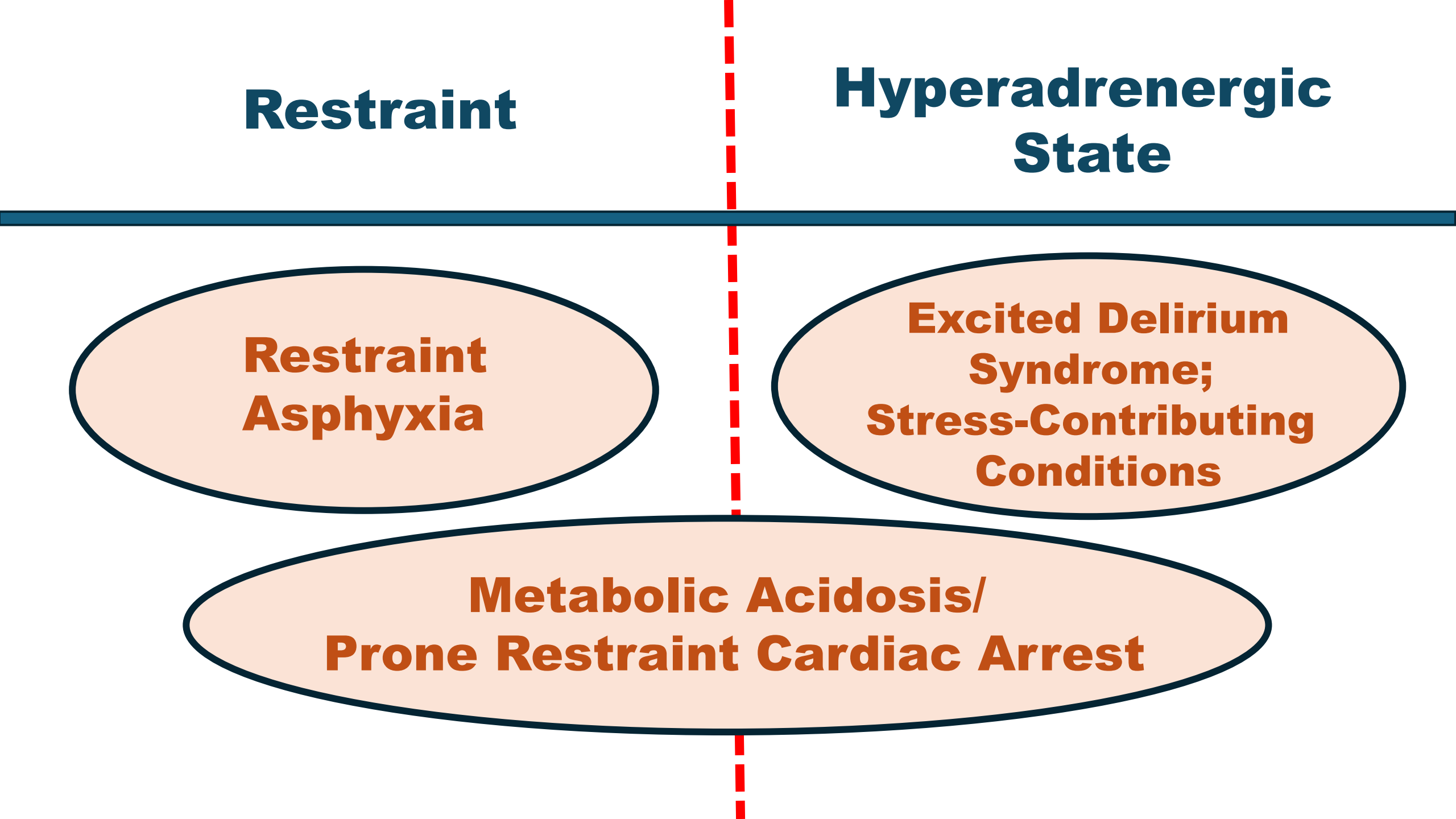
temporal relationship is suggestive

Logical fallacy: post hoc ergo propter hoc

We see:	We certify:
Cocaine psychosis → death	COD: cocaine psychosis
Excited delirium → death	COD: excited delirium
Restraint → death	COD: restraint asphyxia
ASCVD + Subdual → death	COD: ASCVD + subdual
Tox + Subdual → death	COD: tox + subdual
Sedative use →	COD: sedative use

Excuses

- Functional causes of death
- There is nothing to see at autopsy
- We are not concerned with mechanisms of death


Restraint
Hyperadrenergic State
Restraint Asphyxia
Excited Delirium Syndrome; Stress-Contributing Conditions
Metabolic Acidosis/ Prone Restraint Cardiac Arrest

RESTRAINT ASPHYXIA

What We Should See in Hypoxic Deaths

Clinically: **Prodrome -** **Cyanosis/Ashen Discoloration**
Slowing Cognition
PEA/Asystole & Possibly VT/VF

At Autopsy: **No Pathognomonic Signs**
Possibly Petechiae

Evidence For

None

Evidence Against

Absence of reports of cyanosis before arrest
No cases of petechiae
San Diego studies
No neuropathology of anoxic changes
Prolonged restraint

Common Denominator of Fatal ExDS is Restraint

O'Halloran

1993

Restraint Asphyxiation in Excited Delirium

O'Halloran, Ronald L. M.D.; Lewman, Larry V. M.D.

Author Information

The American Journal of Forensic Medicine and Pathology 14(4):p 289-295, December 1993.

2000

Asphyxial Death During Prone Restraint Revisited

A Report of 21 Cases

O'Halloran, Ronald L. M.D.; Frank, Janice G. M.D.

Author Information

The American Journal of Forensic Medicine and Pathology 21(1):p 39-52, March 2000.

Strommer, Leith, Zeegers, Freeman

2020

The role of restraint in fatal excited delirium: a research synthesis and pooled analysis

Review | Open access | Published: 22 August 2020

Volume 16, pages 680–692, (2020) Cite this article

Studies of Prone Position & Prone Restraint

Table 1. Ventilatory capacity in prone and restrained prone subjects.

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						−12%
						−22%
						−30%
Sloane et al., 2014[26]	10					0
Roeggla et al., 1997[27]	6			−40%	−42%	
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Meredith et al., 2005[32]	8	NR	Prone and PMRP	NS[a]	NS[a]	
Barnett et al., 2013[33]	25	24.8	Prone position	−16%	−16%	
			Supported prone	−11%	−10%	

SpO2 was maintained

[a]Not statistically significant in 5/8 enrolled subjects who completed protocol.
FVC: forced vital capacity; FEV1: forced expiratory volume in one second; MVV: maximum voluntary ventilation; PMRP: prone maximal restraint position; NR: not reported; NS: not significant.

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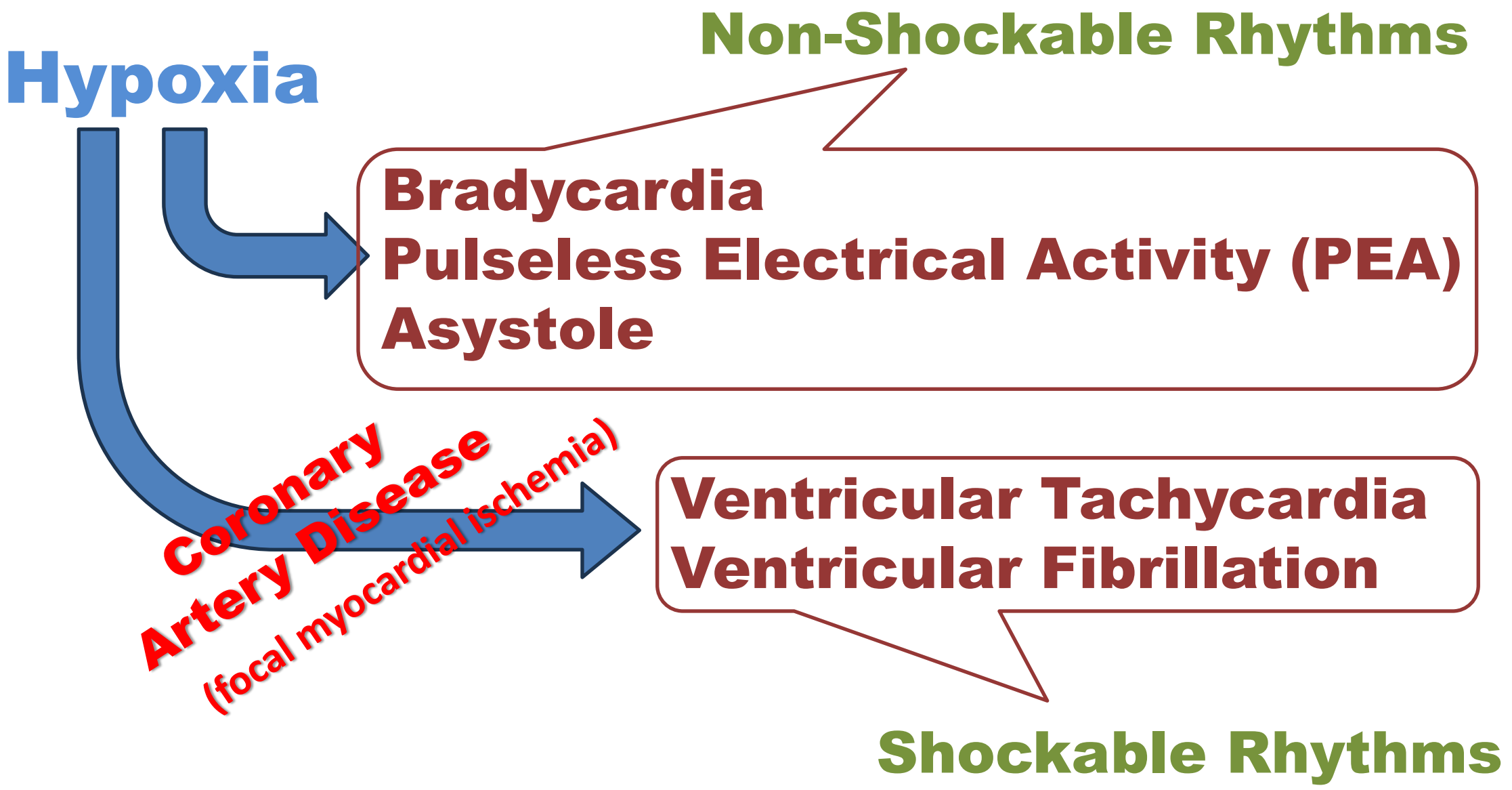

Non-Shockable Rhythms
Hypoxia
Bradycardia
Pulseless Electrical Activity (PEA)
Asystole
Coronary Artery Disease
(focal myocardial ischemia)
Ventricular Tachycardia
Ventricular Fibrillation
Shockable Rhythms

HYPERADRENERGIC STATES (ExDS, Stress-related Conditions)

Two Reasons for Skepticism of Catecholamine as Cause of Death

1. Epinephrine is widely used in the ED for cardiac arrest
2. Pheochromocytoma crisis presents as ↑BP & headaches

What We Should See in ExDS

Clinically: Tachycardia, Tachypnea
Pupillary dilatation
VT/VF

At Autopsy: Myocardial Contraction Bands
Subendocardial Hemorrhage of the Left Ventricular Outflow tract
Wavy fibers

Evidence For

None

Evidence Against

Routine epinephrine administration in ExDS
Absence of case reports of deaths from excessive epinephrine
Clinical picture is not consistent with pheochromocytoma crisis
Not all deaths involve aggressive and delirious subjects
Non-Shockable Rhythms

Table 1: ExDS Prehospital Potential Features and Frequencies with 95% Confidence Intervals

FEATURE	FREQUENCY % (95% CI)
Pain Tolerance	100 (83-100)
Tachypnea	100 (83-100)
Sweating	95 (75-100)
Agitation	95 (75-100)
Tactile Hyperthermia	95 (75-100)
Police Noncompliance	90 (68-99)
Lack of Tiring	90 (68-90)
Unusual Strength	90 (68-90
Inappropriately Clothed	70 (45-88)
Mirror/Glass Attraction	10

2009

American College of Emergency Physicians®
ADVANCING EMERGENCY CARE

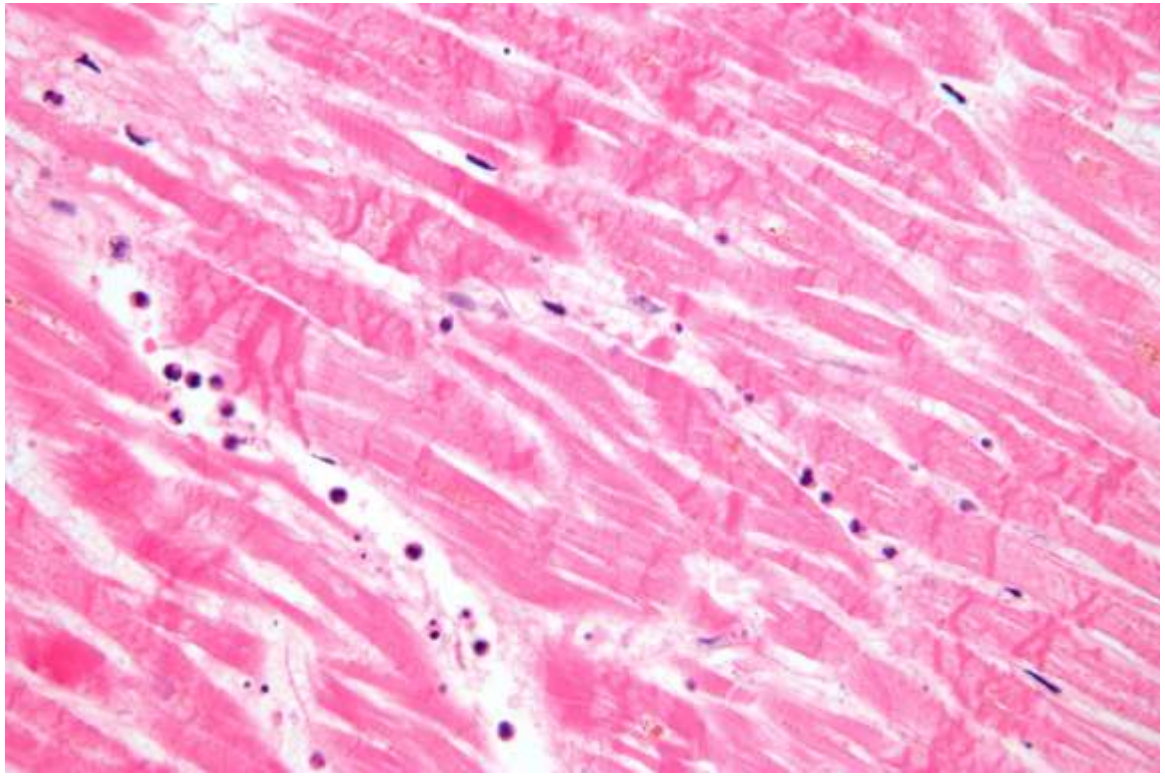
White Paper Report on Excited Delirium Syndrome

ACEP Excited Delirium Task Force

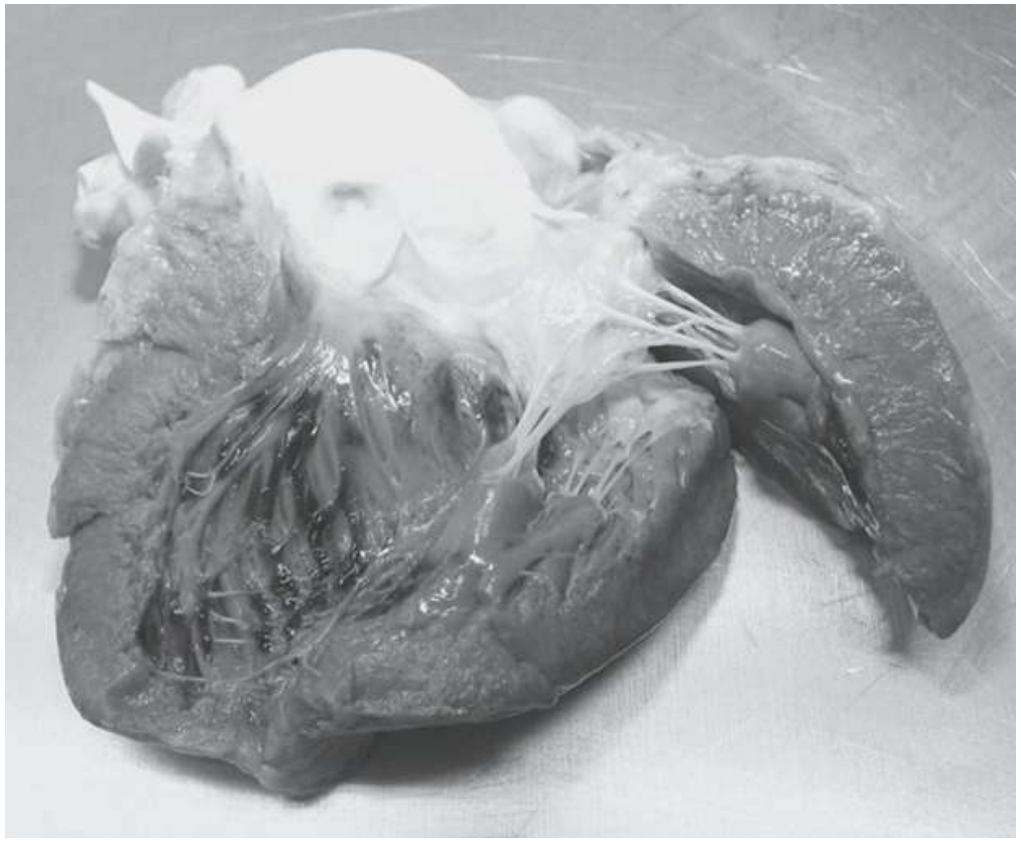
But Note:
In **2023**, the ACEP withdrew this white paper and now use:
Hyperactive Delirium with Severe Agitation

Elevated Epinephrine

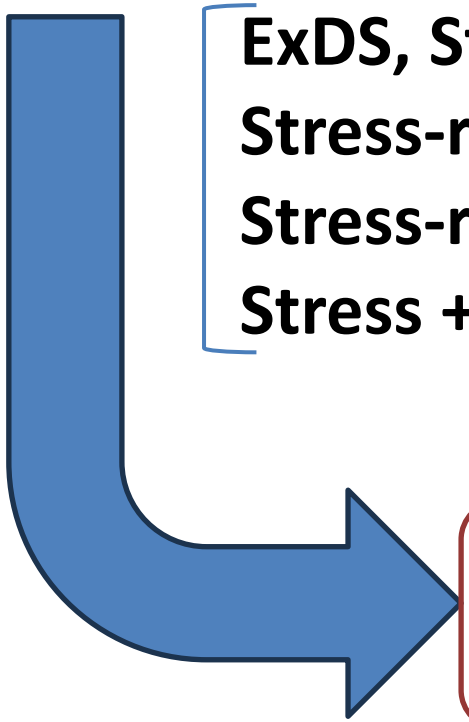
Myocardial Contraction Bands



Subendocardial Hemorrhage in the Left Ventricular Outflow Tract



Hyperadrenergic State



ExDS, Stress-related myocardial infarction
Stress-related cardiomyopathy
Stress-related channelopathy
Stress + drugs, Stress + underlying cardiac pathology

Ventricular Tachycardia
Ventricular Fibrillation

Shockable Rhythms

VT/VF

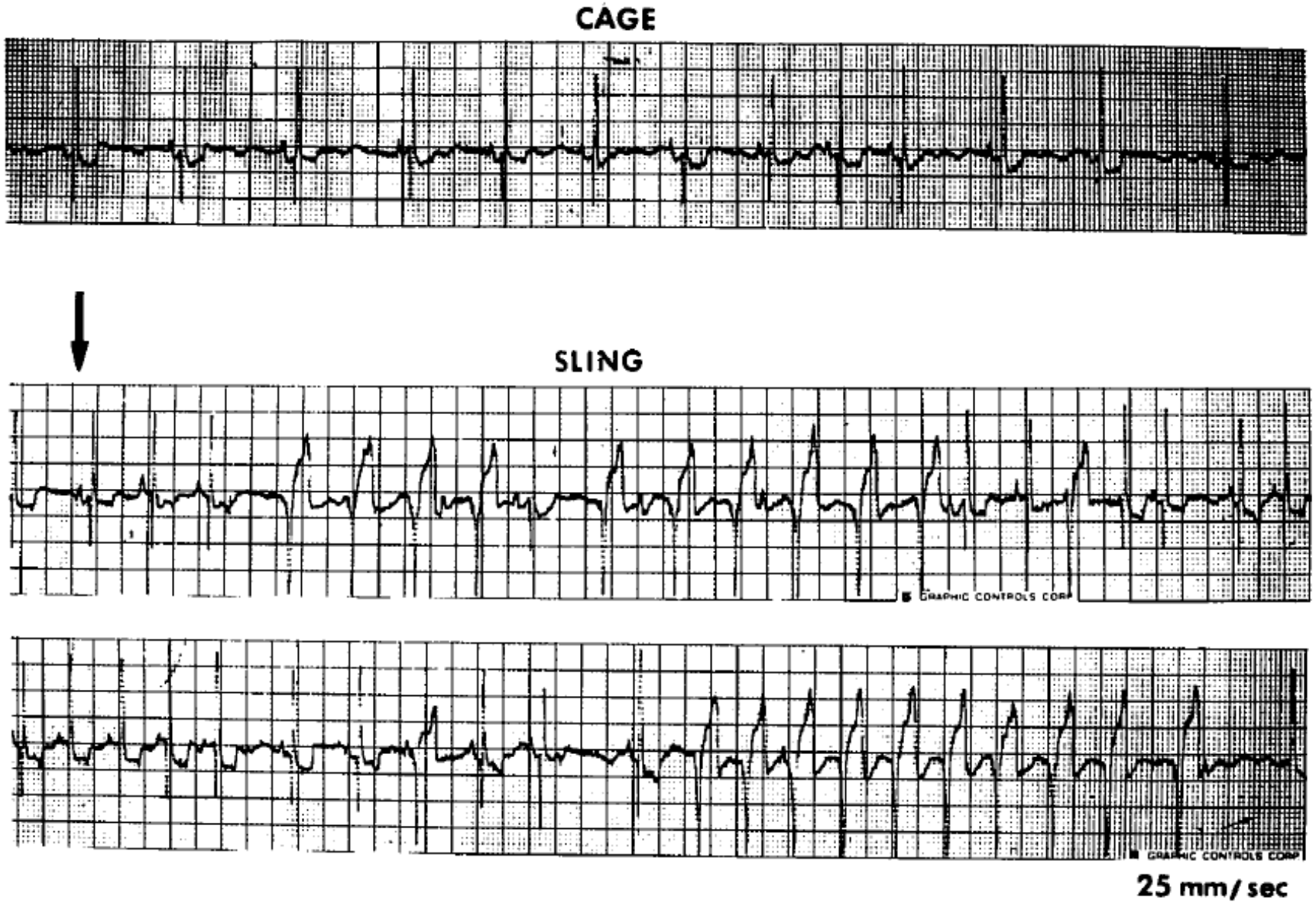
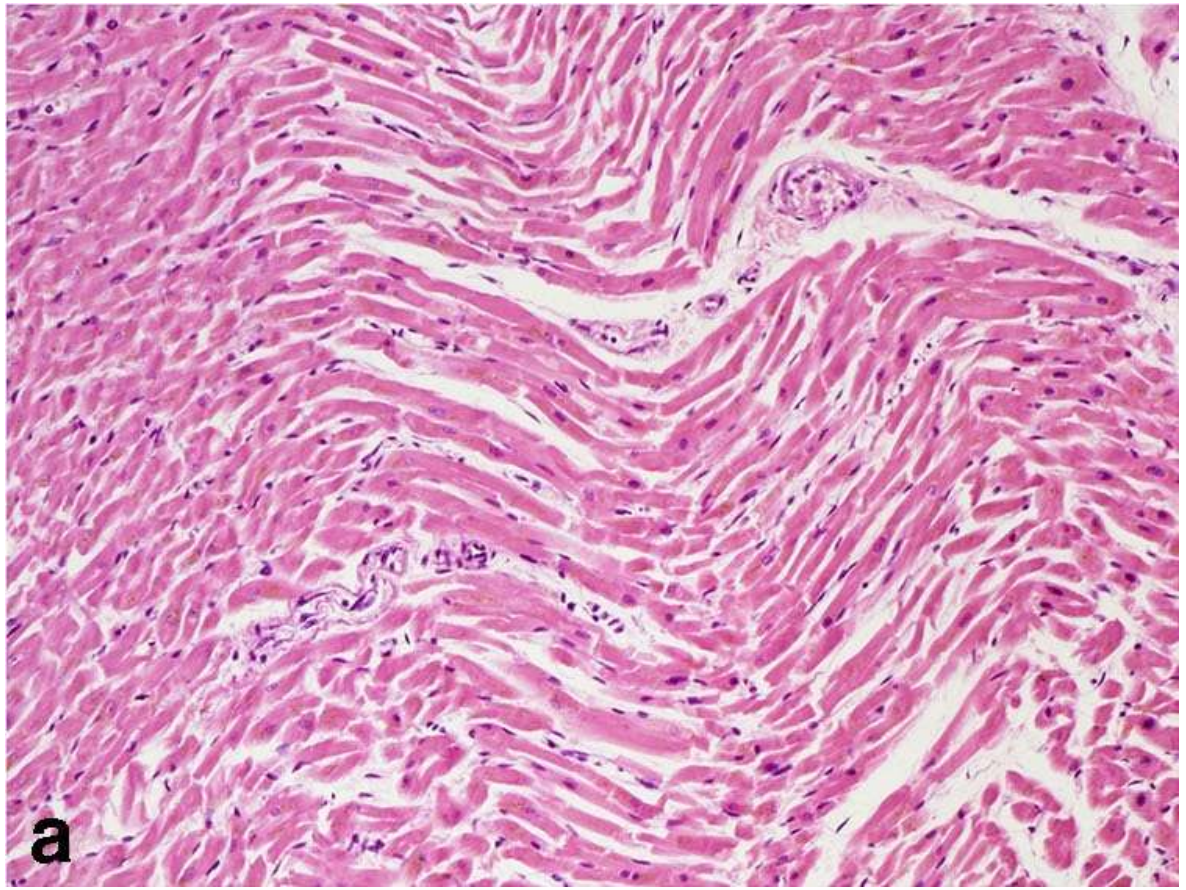


FIGURE 7. Psychologic stress provokes ventricular tachycardia in an animal with previous coronary occlusion. While the animal is in a tranquil cage environment, there is sinus arrhythmia without ventricular ectopic activity. By contrast, when it is in the stressful sling environment there is frequent and sustained ventricular tachycardia.

Lown B, Verrier RL, Rabinowitz SH. Neural and psychologic mechanisms and the problem of sudden cardiac death. Am J Cardiol 1977;39(6):890-902.

Ventricular Fibrillation

Myocardial Wavy Fibers



No Agitation Prior to Police Encounter in a Significant Number of Cases

In a significant percentage of deaths, the subject was not agitated or was exhibiting only minor agitation prior to being restrained by police

- 25% in the AP News database exhibited at most minor agitation
- Well-publicized examples:
  - Eric Garner
  - George Floyd
  - Elijah McClain

PRONE RESTRAINT CARDIAC ARREST / METABOLIC ACIDOSIS

What We Should See in PRCA

Clinically: Tachypnea, Tachycardia
"I can't breathe"
PEA/Asystole

At Autopsy: No Pathognomonic Signs
Possible Myocardial Contraction Bands
Possible Subendocardial Hemorrhage in the Left Ventricular Outflow tract

Evidence For

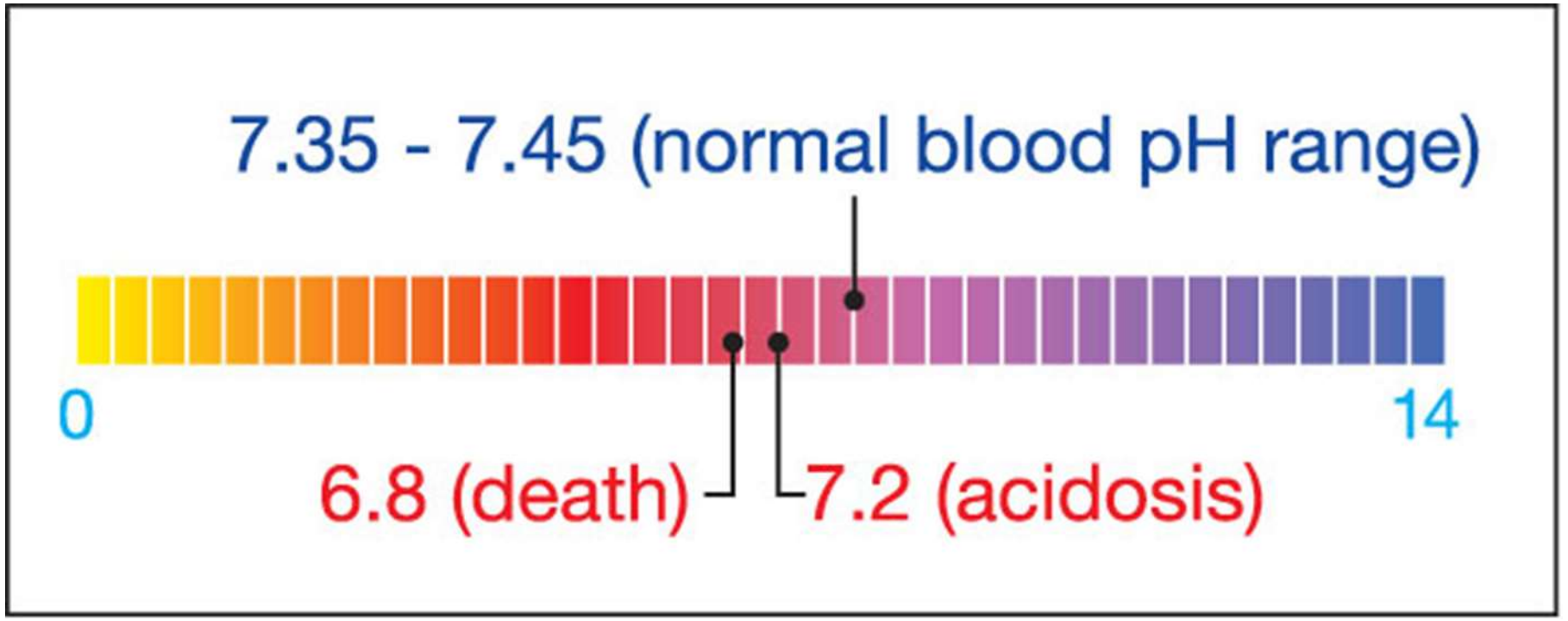
AED advises non-shockable rhythm
PEA/Asystole
Low End-Tidal CO2
Low pH, Elevated Lactate, High pCO2

Consistent findings

Evidence Against

None

METABOLIC ACIDOSIS occurs when metabolic demand exceeds the anaerobic threshold and hydrogen ions and lactic acid are released.



The major buffer system of blood is the carbon dioxide-bicarbonate balance

$$pH = 6.1 + \log_{10}\left(\frac{[HCO_3^-]}{0.03 \times pCO_2}\right)$$

- Carbon dioxide functions as an acid
- Bicarbonate functions as a base

METABOLIC DEMAND

- **Physical Exertion (struggle)**
- **Stress (Fear/Anxiety/Pain)**
- **Stimulant Drugs (Cocaine, Meth, PCP)**

… also ECDs

PHYSIOLOGIC RESPONSE
to short periods of maximal exercise

Tachcardia

→ increase cardiac output ~4-6x

Tachypnea "blowing off CO2"

→ increase ventilation ~20x

(5-6 L/min to 150 L/min)

- increase respiratory rates 2-3x
  (16-20 breaths/min to 40-50 breaths/min)
- increase in depth of breath 4-6x
  (0.5 L/breath to 3 L/breath)

Police restraint prevents respiratory compensation

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			PMRP+23–34 kg			−12%
			PMRP+57–68 kg			−22%
			PMRP+91–102 kg			−30%
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FVC: forced vital capacity; FEV1: forced expiratory volume in one second; MVV: maximum voluntary ventilation; PMRP: prone maximal restraint position; NR: not reported; NS: not significant.

UCSD

European Researchers

8-22%

11-40%

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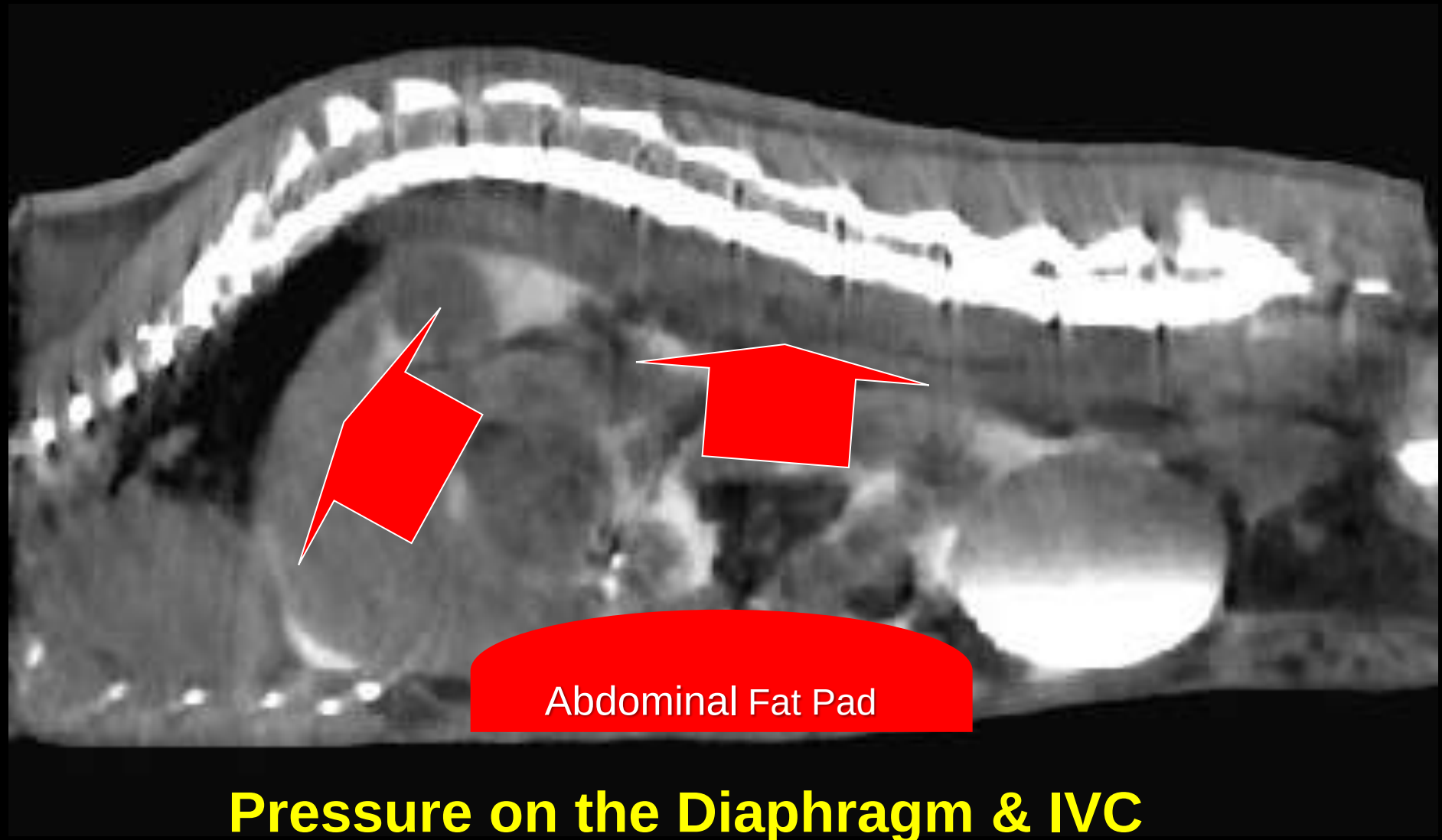
Obesity is a risk factor



Pressure on the Diaphragm & IVC

Metabolic Acidosis in Restraint-associated Cardiac Arrest: A Case Series

JOHN L. HICK, MD, STEPHEN W. SMITH, MD, MICHAEL T. LYNCH, MD

1991

"These cases suggest that a profound metabolic acidosis is associated with cardiovascular collapse following exertion in a restrained position."

5 cases with cardiac arrest

pH avg <6.62 (6.25-6.81)

-all died, except one with pH of 6.46*

***The lactate level in the survivor was 24 meq/L, which is much greater than that produced by athletes**

5 cases without cardiac arrest

pH avg 7.01 (6.76-7.16)

Dybvik, et al. 257 hospital cardiac arrest deaths pH avg 7.25 (7.20-7.26)

Hick JL, Smith SW, Lynch MT. Metabolic acidosis in restraint-associated cardiac arrest. A case series. Acad Emerg Med. 1999;6:239–43.

CASE REPORT • RAPPORT DE CAS

2014

Prehospital resuscitation of a man with excited delirium and cardiopulmonary arrest

Patrick Joseph Maher, MD*; Mimi Walsh, PhD†; Thomas Burns, BA†; Jared Strote, MD, MS*

ABG pH <6.8

pCO2 - 70 mm Hg (nl 35-45)

Lactate >30 mmol/L

Troponin - negative

Maher PJ, Walsh M, Burns T, Strote J. Prehospital resuscitation of a man with excited delirium and cardiopulmonary arrest. CJEM. 2014 Jan;16(1):80-3.

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JOURNAL OF FORENSIC SCIENCES AAFS

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ORIGINAL PAPER

Pathology/Biology

Prone restraint cardiac arrest in in-custody and arrest-related deaths

Victor Weedn MD, JD[1,2,3] | Alon Steinberg MD[4] | Pete Speth MD[5]

Case 1.

ABG: pH 7.01

pCO2 70.6 mm Hg

(nl 35-45)

95 min post-arrest

Case 2.

VBG: pH 6.64

pCO2 157 mm Hg

(nl 41-51)

16 min post-arrest

Oxygen and carbon dioxide targets during and after resuscitation of cardiac arrest patients

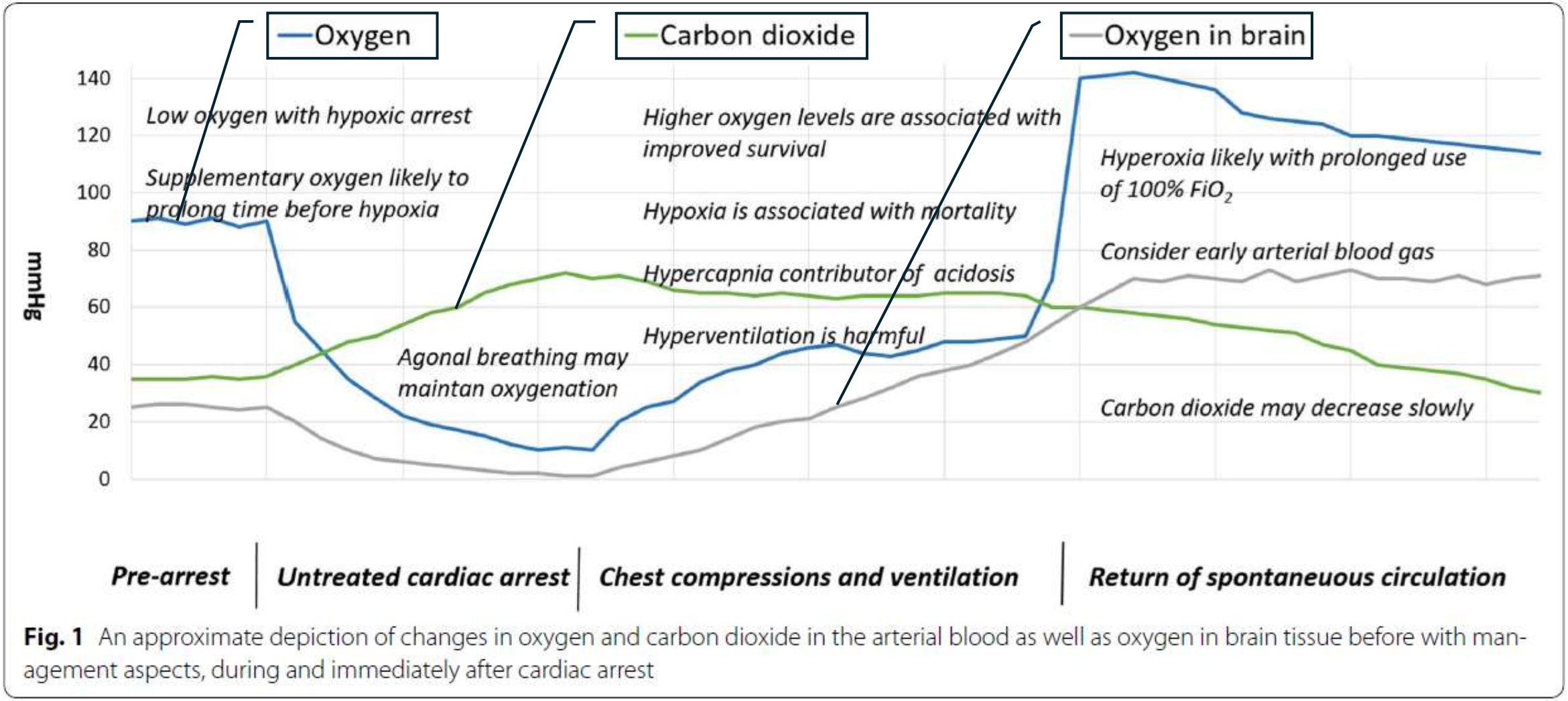
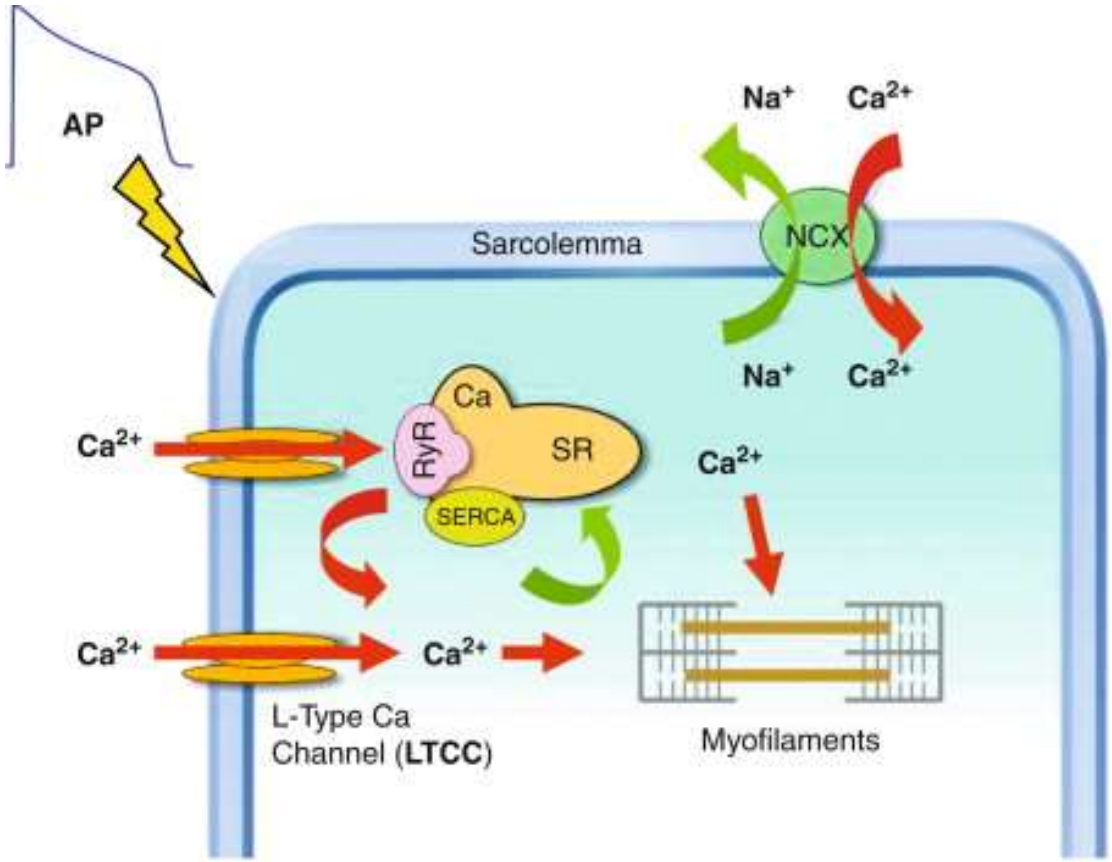


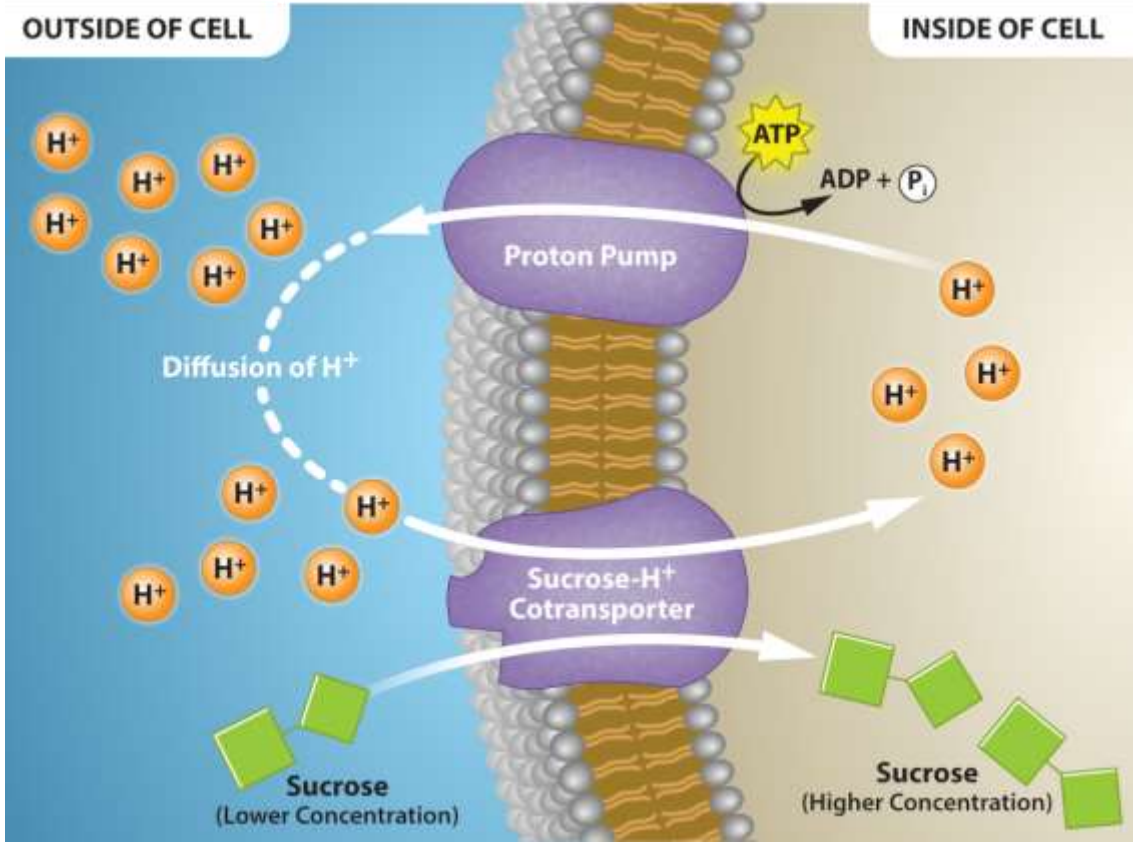
Fig. 1 An approximate depiction of changes in oxygen and carbon dioxide in the arterial blood as well as oxygen in brain tissue before with management aspects, during and immediately after cardiac arrest

Skrifvars MB, Olasveengen TM, Ristagno G. Oxygen and carbon dioxide targets during and after resuscitation of cardiac arrest patients. Intensive Care Med. 2019 Feb;45(2):284-286.

- **Metabolic acidosis can develop rapidly**
- **At some point, the heart just stops beating**

The flow of ions is sensitive to pH





Acidosis and Catecholamine Evaluation Following Simulated Law Enforcement "Use of Force" Encounters

2010

Jeffrey D. Ho, MD, Donald M. Dawes, MD, Rebecca S. Nelson, Erik J. Lundin, MS, Frank J. Ryan, PhD, Kenneth G. Overton, Adam J. Zeiders, EMT-P, and James R. Miner, MD

within 1 minute

Simulating physical exertion of resisting arrest:

45 sec of hitting and punching a heavy bag

pH: 7.36 → 7.04 → 10 min later 7.06

Lactate: 1.44 → 15.46 → 10 min later 17.33

Simulating fleeing on foot:

150 m sprint & 44" hurdle

pH: 7.32 → 7.16 → 10 min later 7.22

Lactate: 1.19 → 10.98 → 10 min later 11.47

Ho JD, Dawes DM, Nelson RS, Nelson RS, Lundin EJ, Ryan FJ, et al. Acidosis and catecholamine evaluation following simulated law enforcement "use of force" encounters. Acad Emerg Med. 2010;17:e60–8.

… same article

Acidosis and Catecholamine Evaluation Following Simulated Law Enforcement "Use of Force" Encounters

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The acidosis will continue to build for a few minutes

Gass et al.[5] found that **lactate peaked at the sixth minute** of inactive recovery in subjects completing a maximum exercise regimen on a motor-driven treadmill. The mean peak lactate was 14.2 mmol/L.

Allsop et al.[6] found that venous pH decreased from 7.39 to 7.04 after a 30-second maximal sprint. The pH was 7.29 at 30 minutes. **Lactate peaked** at 15.76 mmol/L **5 minutes after** the completion of the sprint, declining to 10.30 mmol/L at 30 minutes.[6]

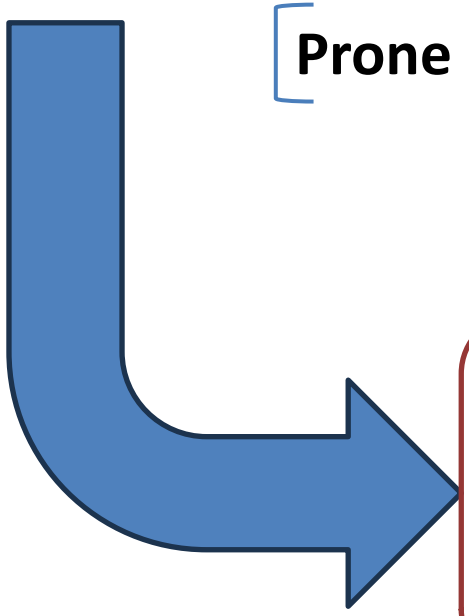
Ho JD, Dawes DM, Nelson RS, Nelson RS, Lundin EJ, Ryan FJ, et al. Acidosis and catecholamine evaluation following simulated law enforcement "use of force" encounters. Acad Emerg Med. 2010;17:e60–8.

“I can’t breathe!!!”

CONSISTENT WITH METABOLIC ACIDOSIS

Metabolic Acidosis

Prone Restraint Cardiac Arrest



Bradycardia
Pulseless Electrical Activity (PEA)
Asystole

Non-Shockable Rhythms

Causes of Non-Shockable Rhythms

Pulseless Electrical Activity

5 Hs

1. Hypovolemia
2. Hypoxia
3. Hydrogen ion (acidosis)
4. Hypo/hyperkalemia
5. Hypothermia

5 Ts

1. Tension pneumothorax
2. Trauma
3. Tamponade
4. Thrombosis, pulmonary
5. Thrombosis, coronary
   - **Global ischemia**
   - **Ruptured papillary muscle**
   - **Cardiac tamponade**

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***The lactate level in the survivor was 24 mEq/L, which is much greater than that produced by athletes**

3 Bradycardia
1 Asystole
1 VF

5 cases without cardiac arrest

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Dybvik, et al. 257 hospital cardiac arrest deaths
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Patrick Joseph Maher, MD*; Mimi Walsh, PhD†; Thomas Burns, BA‡; [illegible]ote, MD, MS*

ABG pH <6.8

pCO2 70 mm Hg

(nl 35-45)

Lactate >30 mmol/L

Troponin - negative

AED: non-shockable

PEA

Maher PJ, Walsh M, Burns T, Strote J. Prehospital resuscitation of a man with excited delirium and cardiopulmonary arrest. CJEM. 2014 Jan;16(1):80-3.

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Bradycardia

PEA

Case 1.

ABG pH 7.01 5

pCO2 70.6 mm Hg (nl 35-45)

95 min post-arrest

PEA

Asystole

Case 2.

VBG pH 6.64

pCO2 157.0 mm Hg (nl 41-51)

16 min post-arrest

Factors Associated With Sudden Death of Individuals Requiring Restraint for Excited Delirium

2001

SAMUEL J. STRATTON, MD, MPH,*† CHRISTOPHER ROGERS, MD,‡
KAREN BRICKETT, RN, MSN,§ AND GINGER GRUZINSKI, RN, BSN †

TABLE 2. Physical Findings on Initial EMS Contact in the Field

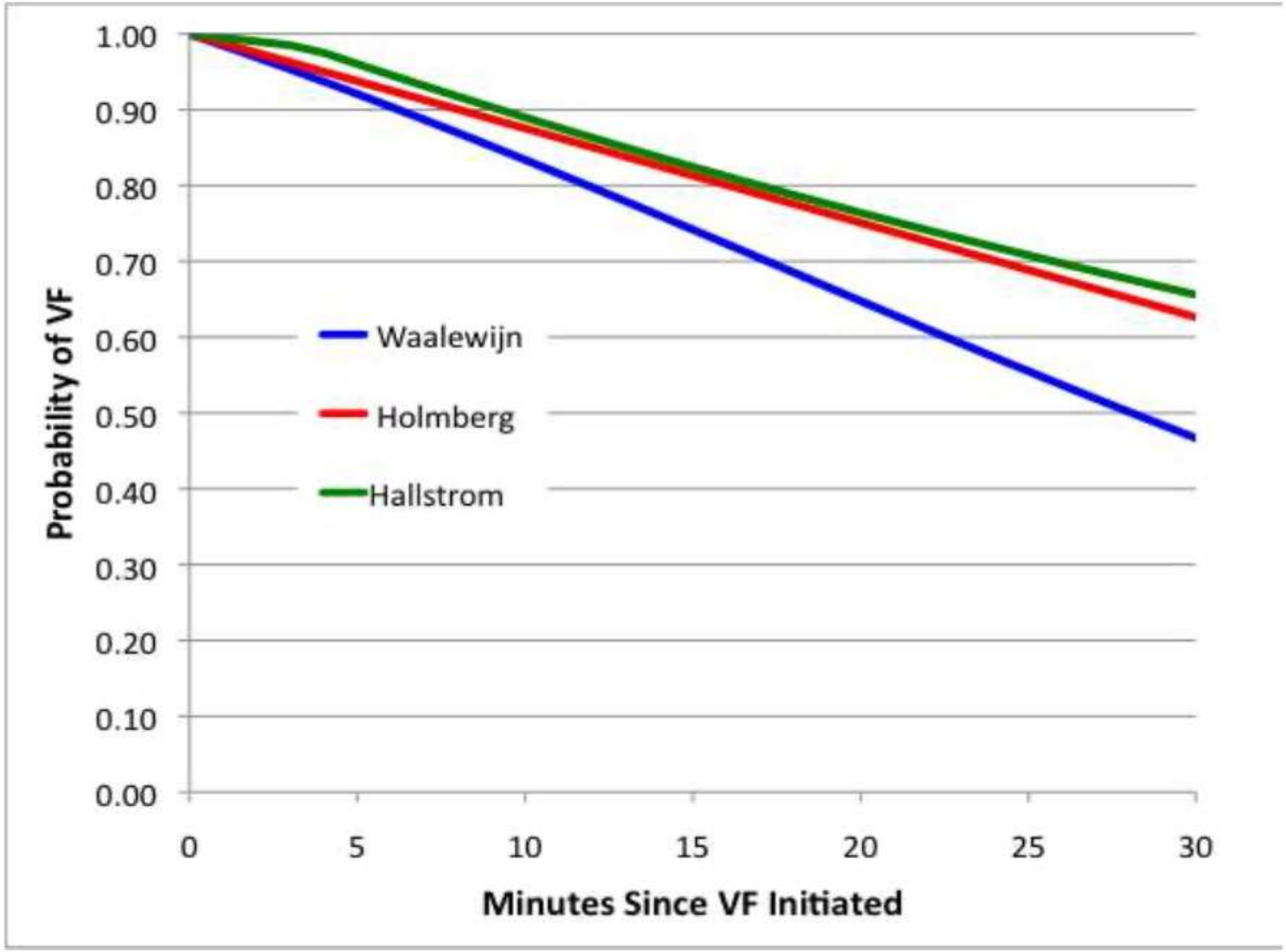
Patient	Resp Rate (min)	Response	Cardiac Rhythm	Heart Rate (min)	Choke/Taser/ Pepper
1	Agonal	Obtunded	VT	NA	
2	0	Unconscious	ASY	0	
3	Agonal	Obtunded	ASY	0	Taser
4	24	Agitated	ST	136	
5	Agonal	Agitated	AGO	50-60	
6	Agonal	Obtunded	ASY	0	
7	Agonal	Obtunded	ASY	0	
8	0	Unconscious			Taser/pepper
9	0	Unconscious			Pepper
10	Agonal	Obtunded	JUNCT	50-60	Taser
11	0	Unconscious			Taser/pepper
12	0	Unconscious			
13*	3-5	Agitated	JUNCT	40	Taser
14	Agonal	Obtunded			
15	Agonal	Obtunded	ASY	0	
16	Agonal	Obtunded	ASY	0	Pepper
17	Agonal	Obtunded	BRADY	50	Pepper
18	22	Agitated	ST	140	Pepper

Abbreviations: VT, ventricular tachycardia; ASY, asystole; AGO, slow, wide complex (agonal); JUNCT, junctional; ST, sinus tachycardia.
NOTE. Agonal respiratory rate indicates slow, shallow breathing pattern. Obtunded indicates conscious but moaning response only. Pepper indicates use of capsicum spray.
* Female.

Only 1/18 ExDS/ARD cases, EMS Witnessed Cardiac Arrests, had VT/VF

Stratton SJ, Rogers C, Brickett K, Gruzinski G. Factors associated with sudden death of individuals requiring restraint for excited delirium. Am J Emerg Med. 2001 May;19(3):187-91.

Probability of still finding VF after an arrest



SUMMARY

Evidence for PRCA

CONSISTENTLY FOUND

- Tachypneic
- “I can’t breathe!”
- AED: advises no shock
- ECG: PEA or asystole
- End tidal CO2: low
- pH: low
- Lactate: high
- pO2: normal
- pCO2: high

WHY IS THIS IMPORTANT?

These deaths are due to the Volitional actions of police restraining subjects in the prone position

→ Homicide

These deaths should be certified as HOMICIDES

Table 2. Cause-of-death statement categorizations by manner of death (N = 940 Deaths) Based upon the AP Lethal Restraint database.

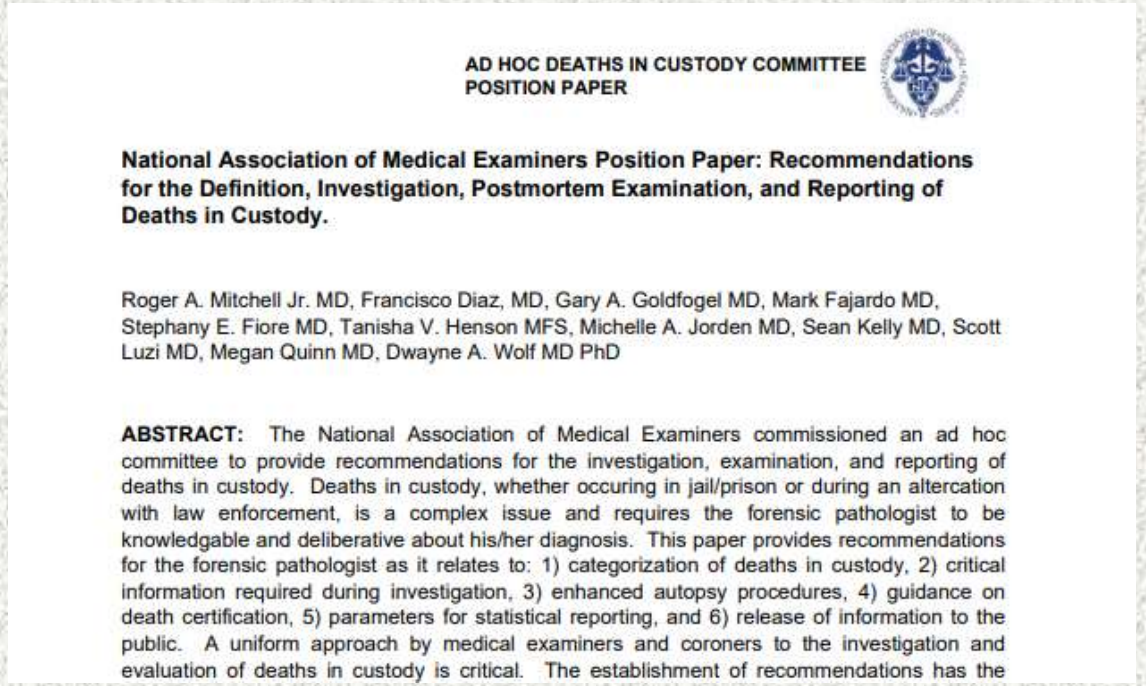
Underlying Cause of Death	Manner of Death											
	Homicide		Accidental		Undetermined		Natural		Suicide		Any Manner	
	(28.5%)[1]		(46.9%)[1]		(19.5%)[1]		(5.0%)[1]		(0.1%)[1]		(100.0%)[1]	
	N	%	N	%	N	%	N	%	N	%	N	%
Any Cause of Death	268	100.0	441	100.0	183	100.0	47	100.0	1	100.0	940	100.0
Cause-of-Death Statement												
Force-related injury/condition mentioned	82	30.6										
Any mention of force	200	74.6										
No mention of force or force-related injury/condition	68	25.4										
Drugs mentioned	168	62.7	401	90.9	119	65.0	6	12.8	1	100.0	695	73.9
Excited/agitated delirium mentioned	27	10.1	92	20.9	32	17.5	8	17.0	0	0.0	159	16.9

28.5% Homicide

AP: "…significant police force went unmentioned and drugs or preexisting health conditions were blamed instead"

[1] Percentages in parentheses refer to total deaths by manner. Other percentages refer to deaths in particular manner-cause combination strata.

Forensic Pathologists Need to pay attention to EMS data



AD HOC DEATHS IN CUSTODY COMMITTEE
POSITION PAPER

National Association of Medical Examiners Position Paper: Recommendations for the Definition, Investigation, Postmortem Examination, and Reporting of Deaths in Custody.

Roger A. Mitchell Jr. MD, Francisco Diaz, MD, Gary A. Goldfogel MD, Mark Fajardo MD, Stephany E. Fiore MD, Tanisha V. Henson MFS, Michelle A. Jorden MD, Sean Kelly MD, Scott Luzi MD, Megan Quinn MD, Dwayne A. Wolf MD PhD

ABSTRACT: The National Association of Medical Examiners commissioned an ad hoc committee to provide recommendations for the investigation, examination, and reporting of deaths in custody. Deaths in custody, whether occuring in jail/prison or during an altercation with law enforcement, is a complex issue and requires the forensic pathologist to be knowledgable and deliberative about his/her diagnosis. This paper provides recommendations for the forensic pathologist as it relates to: 1) categorization of deaths in custody, 2) critical information required during investigation, 3) enhanced autopsy procedures, 4) guidance on death certification, 5) parameters for statistical reporting, and 6) release of information to the public. A uniform approach by medical examiners and coroners to the investigation and evaluation of deaths in custody is critical. The establishment of recommendations has the

In addition to bodycam video

Need: **EMS data**

AED advice

initial EKG rhythm

EtCO2

In Summary

- **Metabolic acidosis** is the primary cause of in-custody death
  - Metabolic acidosis arises due to **a combination of struggles, in some cases, stimulant drugs and/or ECWs**
  - **Prone restraint interferes with the ability to compensate** for metabolic acidosis by restricting the patient's ability to breath
- These are challenging cases; all data must be scrutinized
  - EMS patient care reports and vital signs
  - Body camera or other video evidence
- Homicides
  - These deaths are due to the volitional actions of the police restraining subjects in the prone position and should be characterized as **homicides**

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