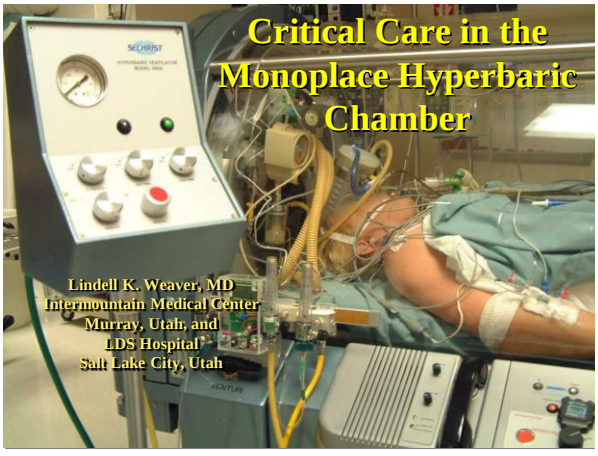


Critical Care - Monoplace

- 30 minutes, so only key points
- Highly suggest critical care medicine is involved
- Pitfalls
- Ventilator and IV issues

Critical Care in the Monoplace Chamber

- Weaver LK. Operational Use and Patient Care in the Monoplace Chamber. In: Resp Care Clinics of N Am-Hyperbaric Medicine, Part I. Moon R, McIntyre N, eds. Philadelphia, W.B. Saunders Company, March, 1999: 51-92
- Weaver LK. The treatment of critically ill patients with hyperbaric oxygen therapy. In: Brent J, Wallace KL, Burkhart KK, Phillips SD, and Donovan JW, (ed). Critical care toxicology: diagnosis and management of the critically poisoned patient. Philadelphia: Elsevier Mosby; 2005:181-187.
- Weaver, LK. Critical care of patients needing hyperbaric oxygen. In: Thom SR and Neuman T, (ed). The physiology and medicine of hyperbaric oxygen therapy. Philadelphia: Saunders/Elsevier, 2008:117-129.
- Weaver LK. Management of critically ill patients in the monoplace hyperbaric chamber. In: Whelan HT, Kindwall E., Hyperbaric Medicine Practice, 4th ed.. North Palm Beach, Florida: Best, Inc. 2017; 65-95.
- Gossett WA, Rockswold GL, Rockswold SB, Adkinson CD, Bergman TA, Quickel RR. The safe treatment, monitoring and management of severe traumatic brain injury patients in a monoplace chamber. Undersea Hyperb Med. 2010;37(1):35-48

Key points

- Staff must be certified and experienced in CCM
- Proximity to CCM services
- Must have study patient in chamber quickly
- CCM equipment
  - Without certain modifications, treating critically ill patients is compromised.

CCM Issues for HBO_2 Therapy

- All will be intubated, sedated, so will require pressors
- IV capability (number, special pass-throughs)
- IV pumps
- Monitoring (ECG, invasive BP, $EtCO_2$, ABG, ICP, brain PO2)
- Minimize perturbations (insulin, nutrition, sedation, analgesia, other ICU care)
- Transport

HBO_2 and Critical Care

ICU Checklist

Before the door closes...

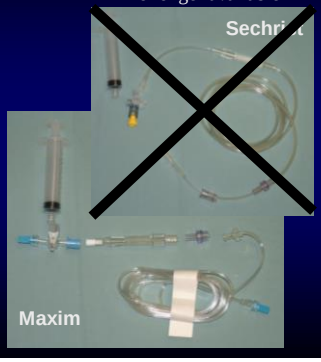
IV Therapy (9 Pumps)

Levophed
Dobutamine
Neosyneph
Epi-Ca
Propofol
Fentanyl
Bicarb
FFP
KCl, Mg, Ca
LR

IV Pass-throughs

- Sechrist and Maxim
  - Maxim - removable back-check valve so we can sample blood
  - Dead space:
    - Sechrist – 8cc
    - Maxim – 6cc

No longer available



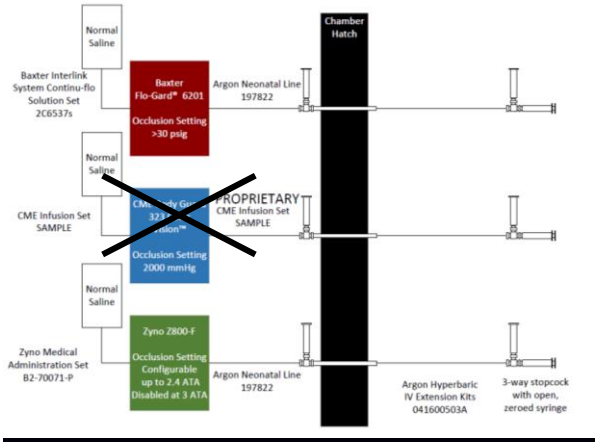
INTRODUCTION

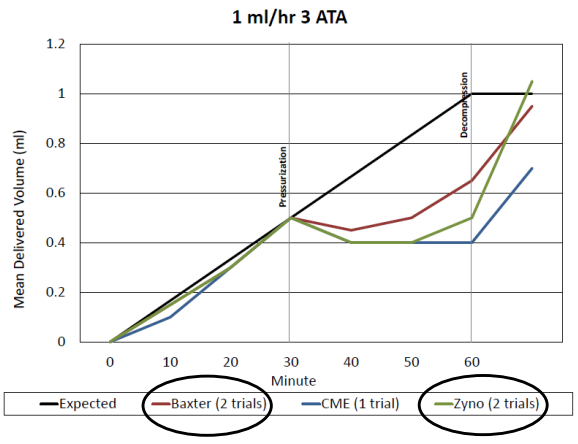
- No FDA cleared infusion pumps for use with monoplace or multiplace chambers
- Two infusion pumps will work:
  - Zyno Medical Z-800F
  - Baxter Flo-Gard® 6201 infusion pumps

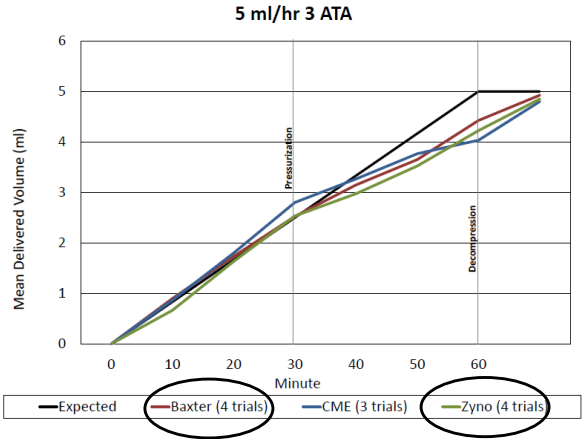
Ray D, et al. Baxter Flo-Gard 6201 Volumetric Infusion Pump for Monoplace Chamber Applications. Undersea Hyperb Med 2000;27(2):107-111.
Weaver LK, et al. Comparison of Three Monoplace Hyperbaric Chamber Intravenous Infusion Pumps. Undersea Hyperb Med 2005;32(6):451-6.
Bell J, et al. Performance of the Hospira Plum A+ (HB) hyperbaric infusion pump. Undersea Hyperb Med 2014; 41(3):235-43.

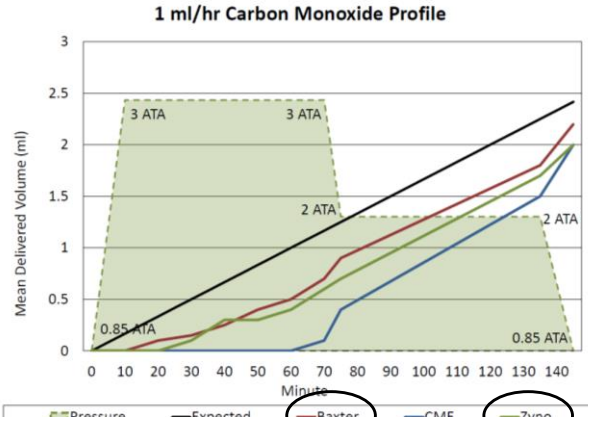
MATERIALS AND METHODS

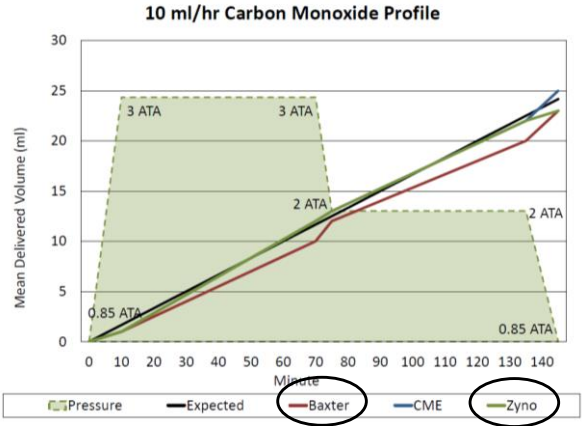
- Occlusion pressure was adjusted for all three pumps
- Pump flow accuracy was tested for the monoplace hyperbaric chambers at different rates, pressures, and volumes

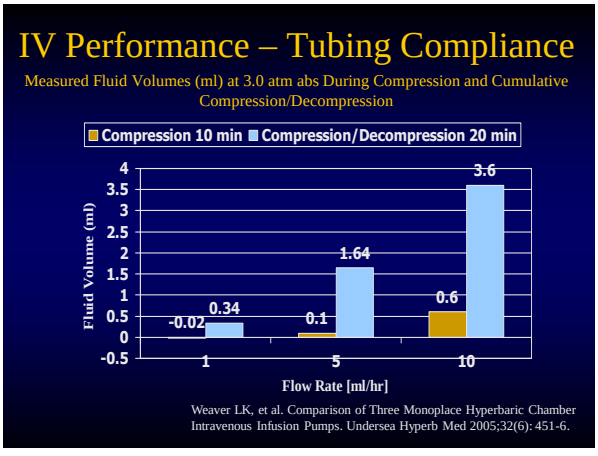



1 ml/hr 3 ATA
Mean Delivered Volume (ml)
Minute
Pressurization
Decompression
Expected
Baxter (2 trials)
CME (1 trial)
Zyno (2 trials)


5 ml/hr 3 ATA
Mean Delivered Volume (ml)
Minute
Pressurization
Decompression
Expected
Baxter (4 trials)
CME (3 trials)
Zyno (4 trials)


1 ml/hr Carbon Monoxide Profile
Mean Delivered Volume (ml)
Minute
3 ATA
3 ATA
2 ATA
2 ATA
0.85 ATA
0.85 ATA


10 ml/hr Carbon Monoxide Profile
Mean Delivered Volume (ml)
Minute
3 ATA
3 ATA
2 ATA
2 ATA
0.85 ATA
0.85 ATA
Pressure
Expected
Baxter
CME
Zyno


IV Performance – Tubing Compliance
Measured Fluid Volumes (ml) at 3.0 atm abs During Compression and Cumulative Compression/Decompression
Compression 10 min
Compression/Decompression 20 min
Fluid Volume (ml)
-0.02
0.34
0.1
1.64
0.6
3.6
1
5
10
Flow Rate [ml/hr]
Weaver LK, et al. Comparison of Three Monoplace Hyperbaric Chamber Intravenous Infusion Pumps. Undersea Hyperb Med 2005;32(6): 451-6.

IV Administration Issues

- IV tubing compliance
- Lack of drug administration for more than 10 minutes with HBO_2 compression
- Bolus during decompression

Weaver LK, et al. Comparison of Three Monoplace Hyperbaric Chamber Intravenous Infusion Pumps. Undersea Hyperb Med 2005;32(6): 451-6.

A Solution to Tubing Compression

- Hard tubing plumbed from the door of the pump to the chamber
- Use Baxter pump for very low rates
- Pull IV set up as far as possible

IV, 5 or more lines

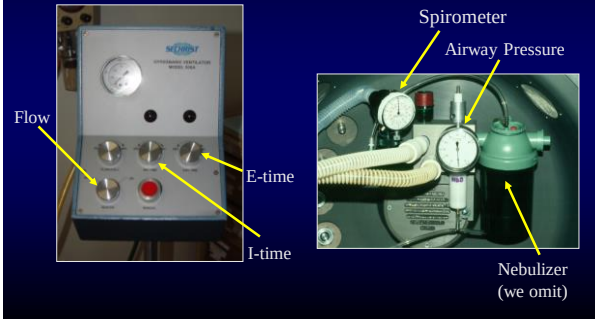
- Saline
- Levophed
- Insulin
- Fentanyl
- Propofol (“propofed”)

Custom IV Penetrators

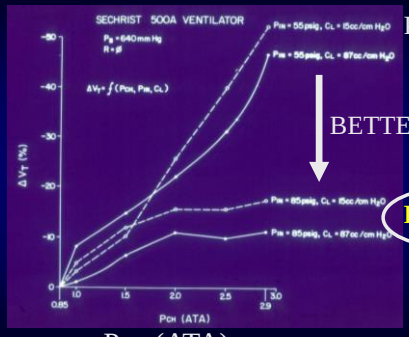
Ventilator Issues

- Marginal in performance, antiquated in function
  - No assist modes
  - No alarms
- Limited Options
  - Sechrist 500A
  - Omni-vent (Max O_2, Magellan, Atlantis)
  - Atlantis (based on Omni-vent)

Sechrist 500AVentilator



Sechrist 500A performance

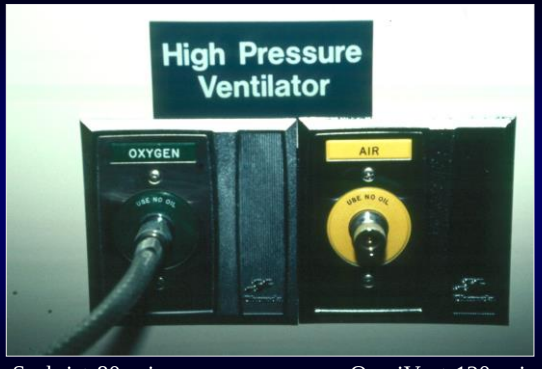


Weaver, et al. JHyperMed 1988

High Pressure Gases for Optimal Ventilator Operation

Manifold (85 psig)

Source (140 psig)



Sechrist-80 psi

OmniVent-120 psi

Ventilator Limitations

Sechrist 500A

< 15 l/m if PEEP >10 cm H_2O at >2.4 atm abs

Weaver LK, et al. Performance of the Sechrist 500A Hyperbaric Ventilator in a Monoplace Hyperbaric Chamber. J Hyperbaric Med 1988;3(4):215-225.

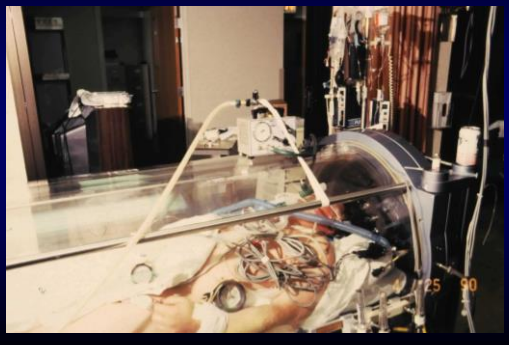
Omni-Vent (Max O2 or Magellan)

22 l/m at 3 ATA

Monitor RR, Vt!!

Churchill S, et al. Performance of the Omni-vent Mechanical Ventilator for use with the Monoplace Hyperbaric Chamber. Undersea Hyper Med 1999;26(Suppl):70-71.

Omni-Vent (Magellan); 3 ATA Septic shock, PP = 22 cm H_2O



Mechanical Ventilation Concerns

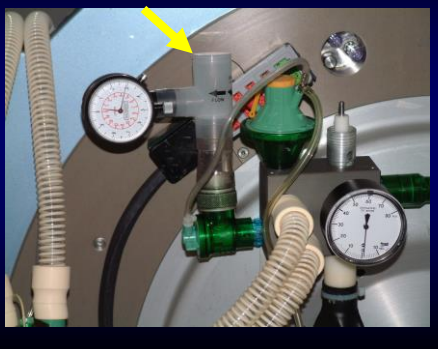
- Air-trapping and hyper-expansion are risks, and seen often with V_E > 15 l/m, PP > 5 cm H_2O
- Attempts to maintain V_E prolong I-time, invert I/E, and stack breaths
- Result: decreased BP, pneumothorax, AGE
- If decrease RR to increase E-time, reduce air-trapping, but $PaCO_2$ increases (CNS risk for O_2 toxicity and increase in ICP)

PEEP and the Intubated Patient

- If patient needs >40% O_2, will need PEEP and higher chamber pressures to have PaO_2 values >1000 torr and brain PO2 >150 torr.
- If PaO2 is lower than desired, elevate by:
  - ~~Increasing chamber pressure~~ (per allocation)
  - Increasing PEEP
  - Improving lung function (bronchodilators, suctioning, diuresis)
  - Reducing $CaO_2 – CvO_2$ (dobutamine?)

PEEP Valve – CPAP Valves

Vital Signs, Inc. Totowa, NJ



500 A does NOT give 100% O2!

500 A does NOT give 100% O2!

Entrainment valve entrains ambient gas (air, until the chamber fills with oxygen: 15 minutes)

Ambient gas

Air Breathing & Mechanical Ventilation

(We rarely provide air breathing unless specified by protocol)

Anesthesia bag filled externally

One-way pop-off to prevent over-inflation

Weaver LK. Management of Critically Ill Patients in the Monoplace Hyperbaric Chamber. In: Kindwall EP, Whelan HT, eds., Hyperbaric Medicine Practice, 2nd ed.. Flagstaff, AZ: Best, Inc. 1999;245-294.

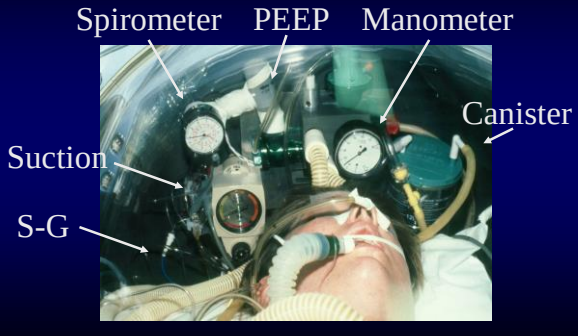
Oxygen Entrainment Valve

Sedation for HBO_2

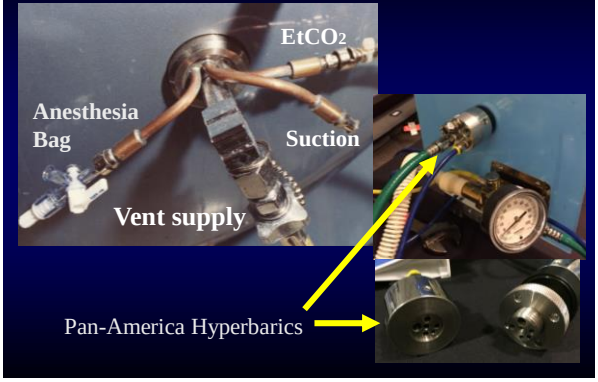
- Ventilator asynchrony is expected
- Deep sedation and analgesia
  - Fentanyl/Remifentanyl infusion
  - Propofol infusion
  - Levophed ("PropoFed")
  - Alternative (e.g. Morphine +/or Ativan)
- Paralysis? Prefer none, but if ventilator asynchrony is pronounced, and gas exchange is affected, paralyze (Vecuronium, Cis-atricurium if renal insufficiency).

HBO_2 & CCM Monitoring

S-G, Vent, PEEP, Suction



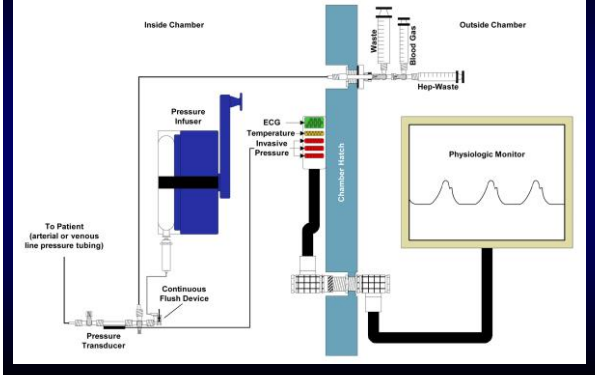
Multiple gas pass-through



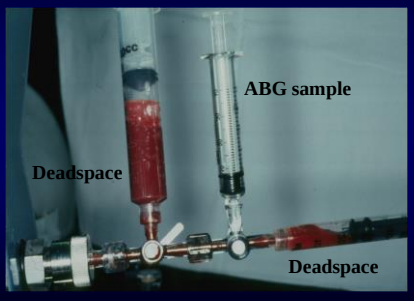
Oxygenation Monitoring During HBO_2

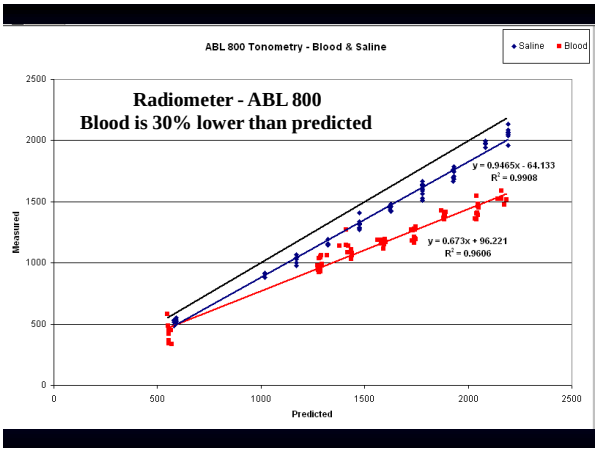
- Arterial blood gases:
  We perform measurements routinely to assess arterial CO_2 and O_2 tensions (ABL 525)
- Transcutaneous O_2 and CO_2?
  Often accurate, occasionally highly <u>inaccurate</u>.

Arterial Blood Gases



Blood gas sampling



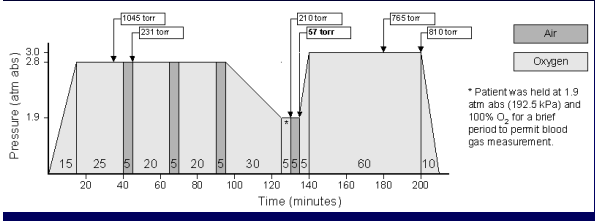


Hypoxemia During HBO_2

PaO_2 = 346 torr (expected 1500 torr)

Weaver LK, Larson-Lohr V. Hypoxemia During Hyperbaric Oxygen: A Case Report. CHEST 1994;105:1270-1271.

Hypoxemia with air, Table 6

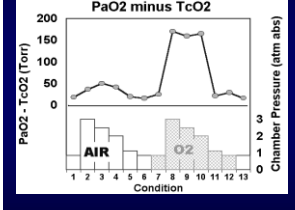


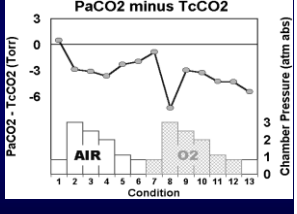
66 y/o female, AGE following IJ CVC removal. Hypoxemia with air at 1.9 ata (30 fsw).

Weaver, Churchill. Hypoxemia with air breathing, US Navy TT6. UnderseaHyperbMed 2006.

Can transcutaneous ($P_{tc}O_2$) replace PaO_2? Not always

$P_{tc}O_2$ and $P_{tc}O_2$ v. PaO_2 and $PaCO_2$

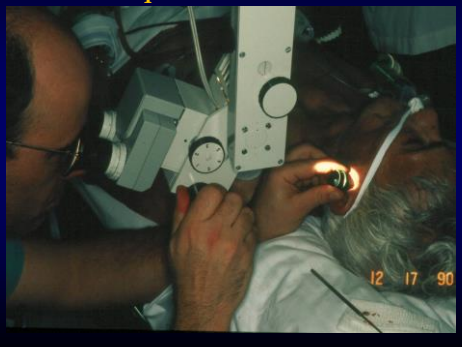




10 healthy subjects

UHM 1999

Myringotomies: Intubated Patients Required in HOBIT



Myringotomies: Intubated Patients

- Variable, some do them, others do not
- We did them routinely until 1992, then stopped because of CO RCT and survey results (of 20 centers half did them and half did not).
- No apparent damage to inner ear
- Patients need to be deeply sedated for compression
- Study warranted

Hypotension

- Compression – insufficient pressors
- At pressure
  - Auto-peep
  - Sepsis
  - Pressor dosing
- Decompression – Auto-peep, increasing tidal volume, pneumothorax
- Anytime – sedation level, esp. propofol

PEEP, sedation, paralysis

(Improve oxygenation)

- Auto-PEEP is common. If BP falls during HBO_2, often due to auto-PEEP
- We increase PEEP to improve lung function
- Recruitment (PEEP) before HBO_2
- Sedation (Fentanyl, Ativan, Propofol)
- Propofol: have levophed ready ("propofed")
- Paralysis – rarely, but do this if PaO_2 marginal and HBO_2 continued

Cardiac Arrest and HBO_2

- 66 y/o female, AGE following IJ CVC removal, severe hypoxemia. Arrest with dropping PaO2 as chamber depressurized. Prolonged CPR. Brain injury, died days later (published).
- 60 y/o female, epidural spinal abscess, CRF, shock, levophed, epi; VT – synch cardioversion. MOF, withdrawal days later.
- 55 y/o female, DM, chest wall necrotizing fasciitis, shock, pressors, cardiac arrest: emergent decompression, Defib unsuccessful, pulled chest dressings off, Defib again in the wound, successful. MOF, withdrawal days later.
- Breast Ca, XRT, chronic chest wound, Aortic stenosis, stable heart failure; 3rd HBO2, acute lung edema…OK; HBO2 resumed, acute lung edema, then arrest, died (published)

Mortality and APACHE II

Diagnosis (n)	APACHE II	Mortality (%)	Predicted Mortality (%)
AGE/VGE (5)	29	40	45
Osteomyelitis (2)	26	100	40
Necrotizing Fasc. (45)	**23**	**11**	**42**
Acute Ischemia (3)	22	33	30
Mucormycosis (2)	22	50	30
Crush (8)	**20**	**0**	**30**
Gas Gangrene (6)	**20**	**16**	**30**
CO/Cyanide (13)	**17**	**8**	**25**
Failing Flaps (3)	16	0	15