TOWARDS A PROBABILISTIC ASSESSMENT OF HYPOBARIC DECOMPRESSION SICKNESS TREATMENT

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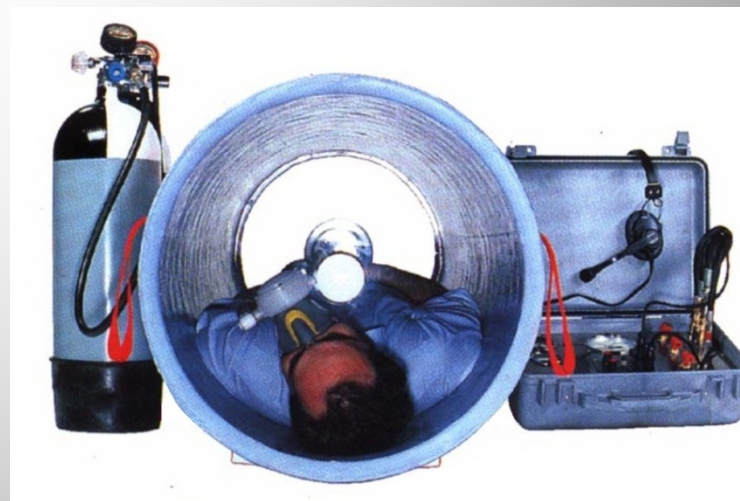
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DCS treatment in space

Matching needs to resources.

probabilistic nature of symptoms and symptom resolution

- DCS symptom during EVA is probabilistic;

    no guarantee of a symptom, just a probability.

- Symptom resolution during treatment is also probabilistic;

    no guarantee of symptom resolution, just a probability.

- You maximize the P(symptom resolution) with additional pressure, oxygen, and time.
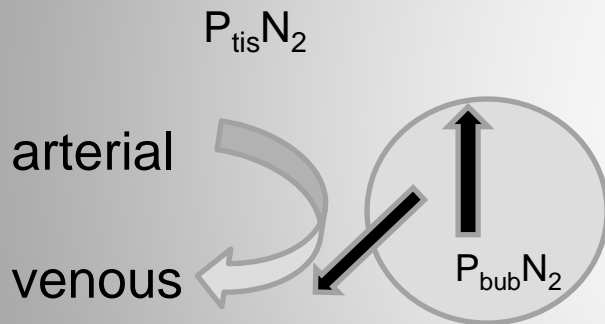
- Also adjunctive therapy to support tissue recovery.

symptom resolution = bubble dissolution

- Boyle's Law compression (closed, isothermal, ideal gas system):
$$P_2 - P_1 = V_1/V_2 \times P_1 - P_1$$
$P_2 - P_1$ is ΔP, as psid.

- Bubble-to-tissue N_2 diffusion gradient and the O_2 window:
$$P_{bub}N_2 = P_B + 2\gamma/r + M - P_{bub}O_2 - P_{bub}CO_2 - P_{bub}H_2O$$

$P_{tis}N_2$

arterial

venous
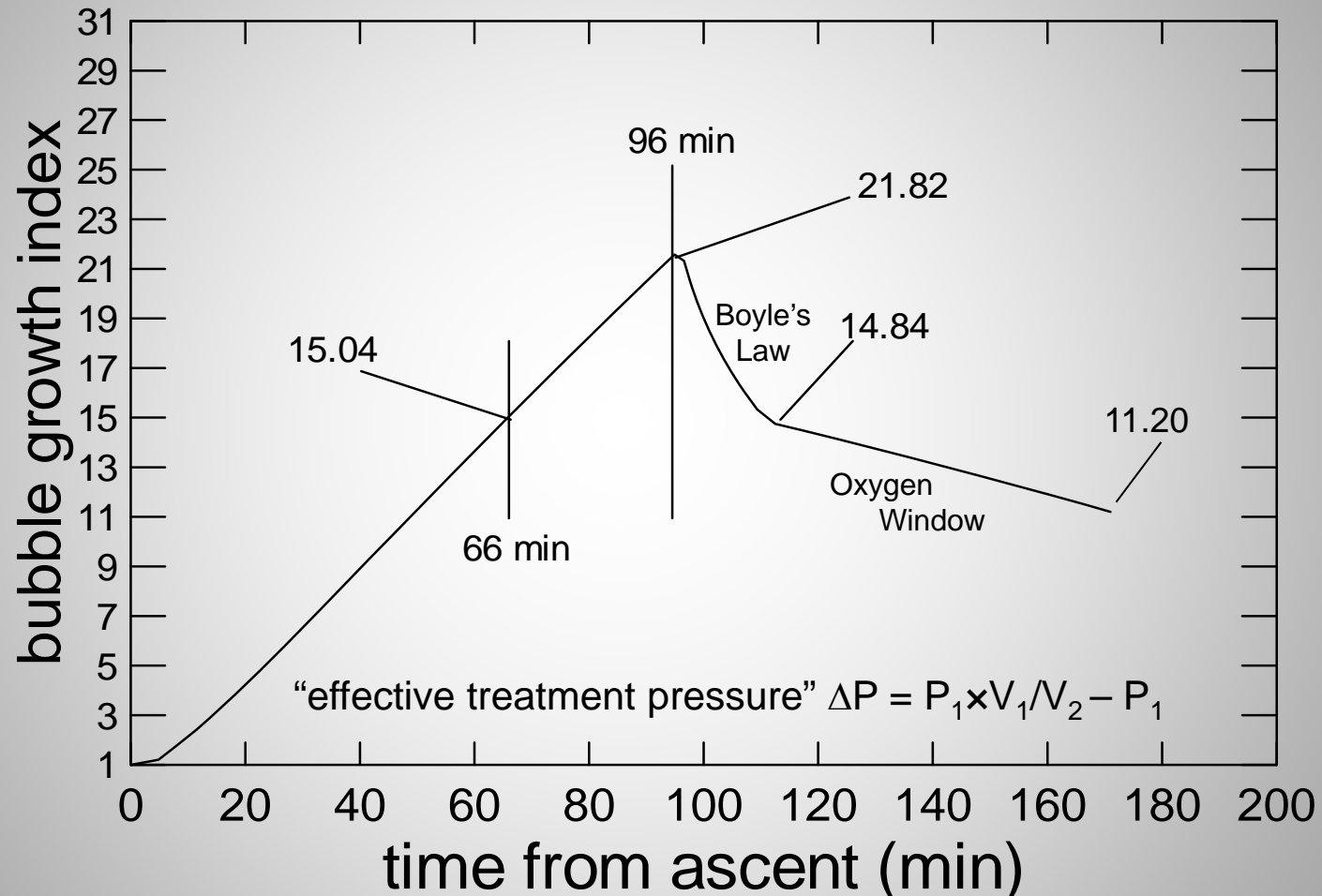
$P_{bub}N_2$

- Tissue Bubble Dynamics Model integrates both through time as dr/dt:

$$\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{-\frac{\alpha D}{h}\left(P_B - vt + \frac{2\gamma}{r} + \frac{4}{3}\pi r^3 M - P_t - P_{\mathrm{met}}\right) + \frac{rv}{3}}{P_B - vt + \frac{4\gamma}{3r} + \frac{8}{3}\pi r^3 M}$$

Tissue Bubble Dynamics Model (TBDM)

- An open, isothermal system where mass enters or leaves.

96 min

21.82

15.04

Boyle's Law

14.84

66 min

11.20

Oxygen Window

"effective treatment pressure" $\Delta P = P_1 \times V_1/V_2 - P_1$

bubble growth index

time from ascent (min)

- Note that "time" to achieve a ΔP is available from the TBDM.

Gernhardt ML. *Development and Evaluation of a Decompression Stress Index Based on Tissue Bubble Dynamics* [dissertation]. Philadelphia: University of Pennsylvania; 1991.

NASA 1982 - 2009 symptom data

- The JSC Hypobaric DCS Database documents 969 exposures from 47 different altitude tests.
- Symptoms are from 119 subjects diagnosed with DCS.

symptom category	symptom resolution details	count	% of 220 symptoms	resolution pressure data available	% of 195 pressure data available
A	resolved at altitude	37	16.8	37	19.0
B	resolved on repressurization	137	62.2	121	62.0
C	resolved at site pressure	17	7.7	17	8.7
D	resolved after HBO for a persistent symptom at site pressure	20	9.1	20	10.2
E	no treatment pressure information exits	9	4.1	0	0
	total	220	100.0	195	100
F	resolved but then reoccurred or was new and treated with HBO	13			

cumulative fraction of resolved symptoms with ΔP
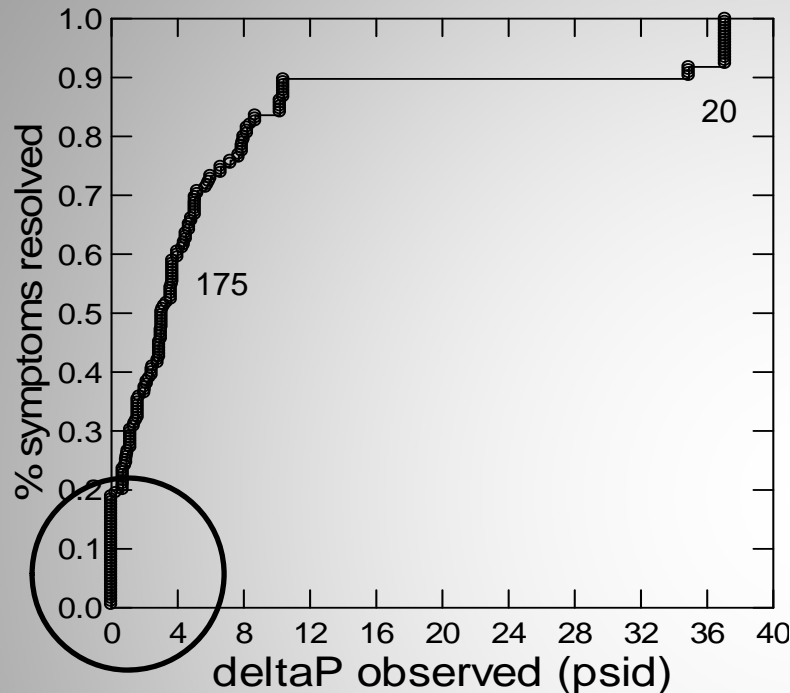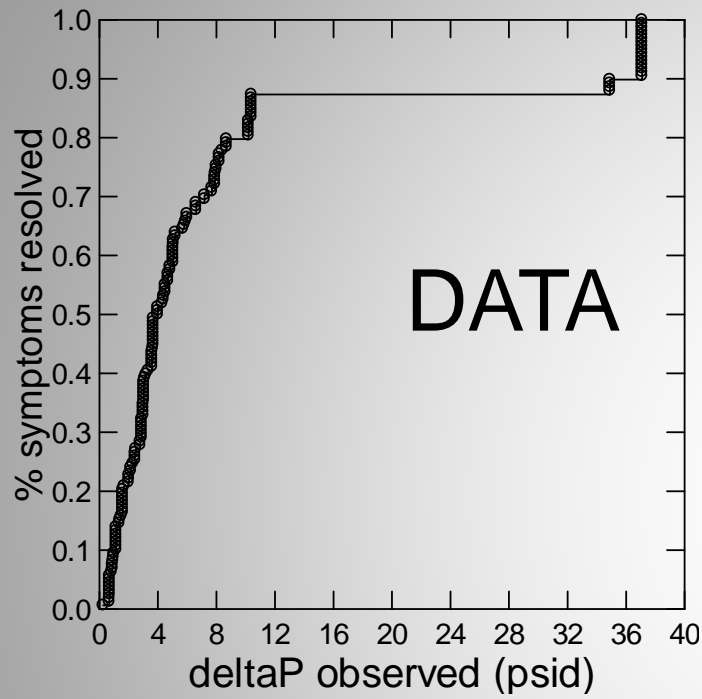

removed 37 that
resolved before repress
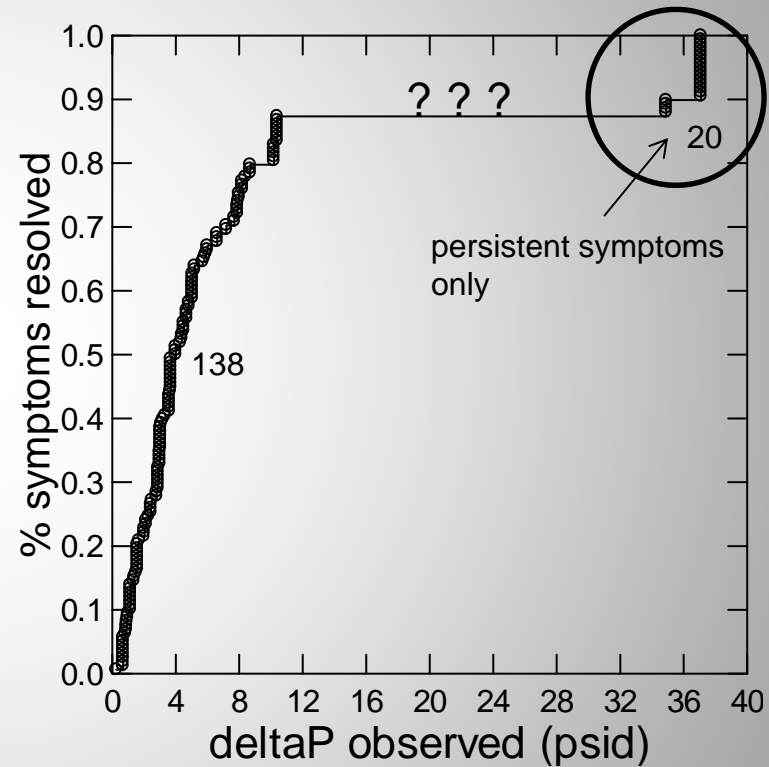
- P(symptom resolution) modeled as a log-logistic function of observed ΔP and two other explanatory variables.
- We used 154 symptoms from 119 subjects diagnosed with DCS.

symptoms linked to TBDM through ΔP

DATA → STATS   P(symptom resolution)

computed ΔP

TBDM simulations
- pressure
- oxygen
- time

regression results (n=154 symptoms)

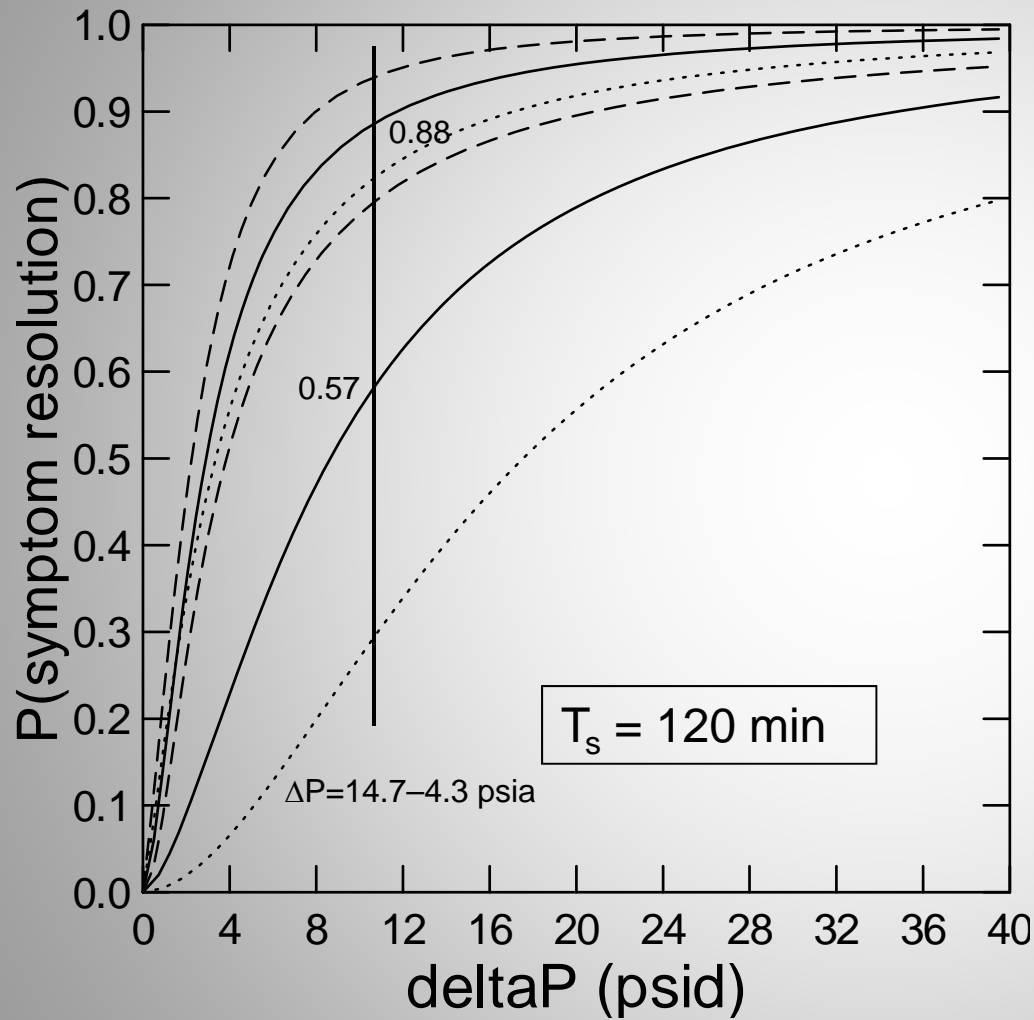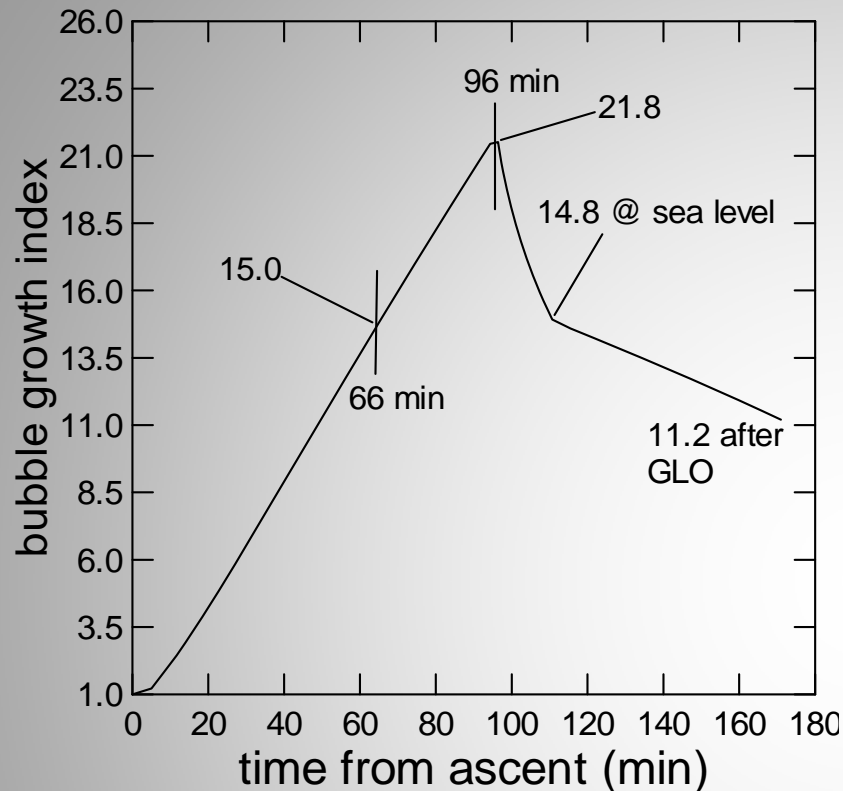| parameter	Estimate ± 95% CI	standard error*	z-score	p-value
B_1	0.633 0.50 to 0.80	0.077	-3.75	<0.001
B_2	1.682 1.00 to 2.35	0.344	4.89	<0.001
AMB	-1.089 -1.96 to -0.22	0.444	-2.45	0.014
T_s (min)	0.00395 0.001 to 0.007	0.0015	2.61	0.009

* Symptom dependency considered.

$$P(\text{symptom resolution}) = 1 / [1+\exp(-(\ln(\Delta P) - 1.682 + 1.089 \times AMB - 0.00395 \times T_s) / 0.633)],$$

where AMB = 1 if ambulation was as part of the exposure, otherwise AMB = 0; and where T_s is time (min) to onset of a DCS symptom.

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Hypobaric DCS Treatment Model Example 1

Plot: P(symptom resolution) vs deltaP (psid)

Labels on plot:
- ambulation
- no ambulation
- 0.88
- 0.57
- $T_s = 120$ min
- $\Delta P = 14.7 - 4.3$ psia

Box:
154 symptoms with 20 HBO
=========================
100 ambulation with 3 HBO
54 no ambulation with 17 HBO

simulation example 2

120 min PB, 6-min ascent to 4.3 psia, DCS 60 min into an ambulatory EVA, 30 min delay, 15 min repress to 14.7 psia, and 60 min GLO.

$$\Delta P = P_1 \times V_1 / V_2 - P_1$$

$9.37 = 4.3 \times 1176964 \mu m^3 / 370255 \mu m^3 - 4.3$ after 15 min

$27.5 = 4.3 \times 1176964 \mu m^3 / 159167 \mu m^3 - 4.3$ after 75 min

simulation	symptom onset	BGI	BGI @ repress	BGI @ Rx	computed ΔP	P(symptom resolution) ± 95% CI
2-hr PB @ 14.7 psia	60	15.0	21.8			
repress to 14.7				14.8	9.37	0.90 0.78 – 0.96
1-hr 100% GLO @ 14.7				11.2	27.5	0.98 0.93 – 0.99

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discussion / forward work

- Approaches to validate the model:
    - Our results agree with 12-times more data: 89.0% (121/136) for NASA compared to 92.8% (1,516/1,633) for USAF symptoms that resolved during repressurization (Muehlberger *et al.* 2004).
    - Results from Duke University micronuclei research.
    - Some data do exist on symptom resolution with GLO (Krause *et al.* 2000).
    - No data exists on time to symptom resolution with or without GLO.

- The treatment model applies to symptoms detected early with a prompt treatment response.

- Time to symptom resolution is not explicit in the treatment model; it was not available for our symptom data.
    - However, an estimate of resolution time is available from the TBDM.

- Management ultimately concurs on an acceptable P(symptom resolution).
    - The hard work is to balance limited treatment resources with the likelihood of effective treatment.
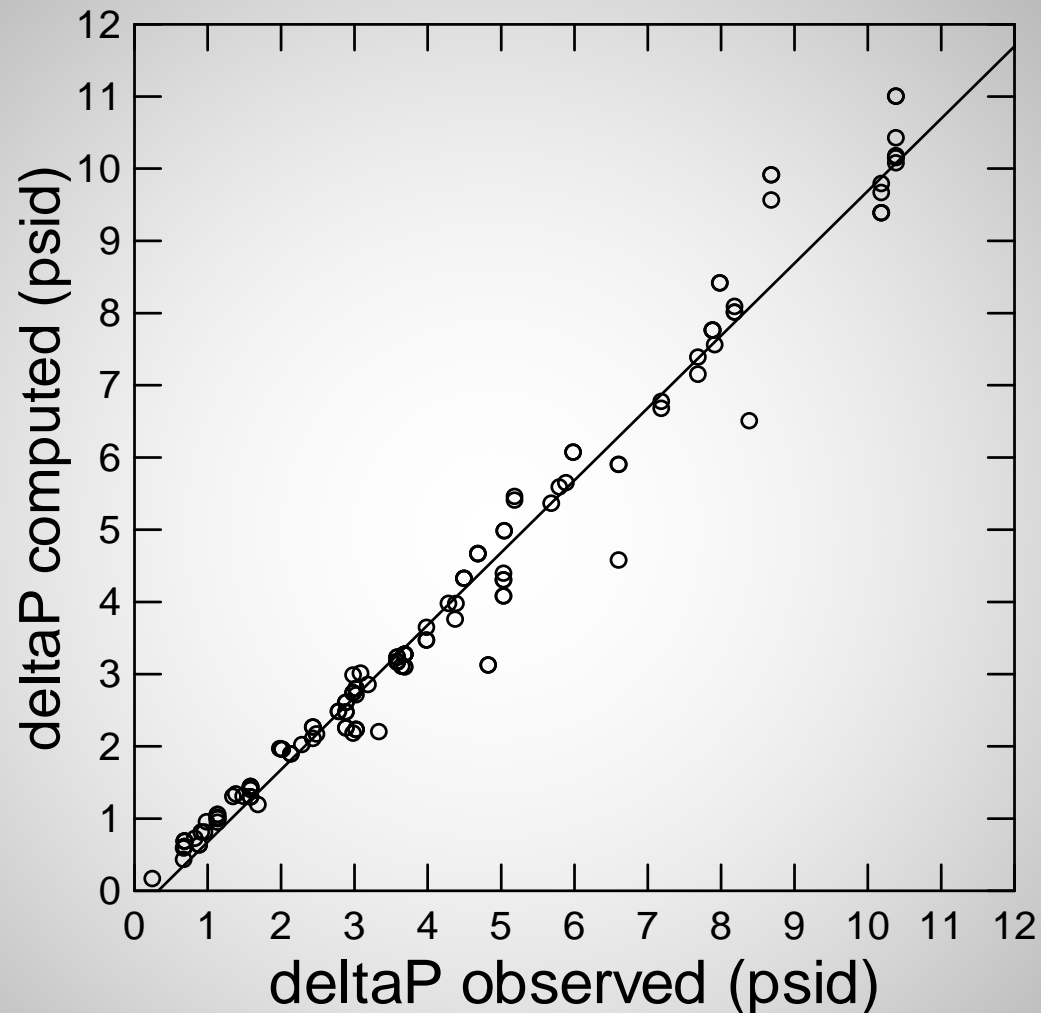
Muehlberger PM, *et al.* Altitude decompression sickness symptom resolution during descent to ground level. *Aviat Space Environ Med* 2004; 75:496-9.
Krause KM, Pilmanis AA. The effectiveness of ground level oxygen treatment for altitude decompression sickness in human research subjects. *Aviat Space Environ Med* 2000; 71:115-8.

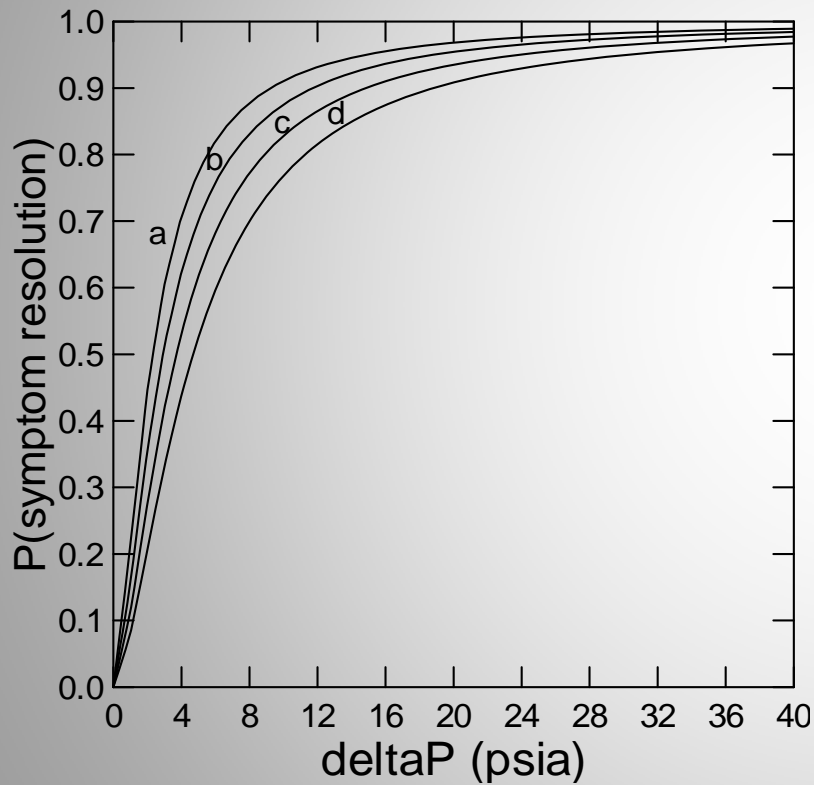thank you

observed versus computed ΔP

Observed ΔP to resolve 138 symptoms compared to the computed ideal gas ΔP from TBDM. Linear regression for ΔP computed = $1.0016 \times \Delta P$ observed – 0.324, $r^2 = 0.977$.
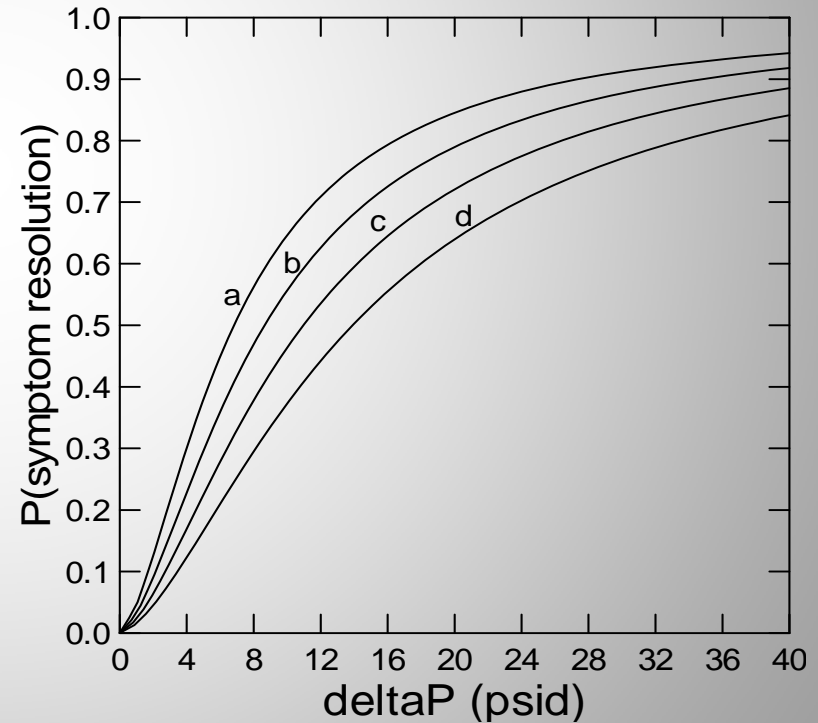
Hypobaric DCS Treatment Model Results

154 symptoms

a = 60 min DCS
b = 120 min DCS
c = 180 min DCS
d = 240 min DCS

100 ambulation (historical data)

54 no ambulation (ARGO + PRP data)

Muehlberger's ΔP data

symptom category	symptom resolution details	treatment pressure data	fraction of total 1,669
A	resolved at altitude	66	3.8
B	resolved on repressurization	1,433	84.3
C	resolved on repressurization but without documented resolution pressure	83	4.9
D	resolved at site pressure	117	6.9
	total symptoms resolved	1,699	100.0

- Of 117 symptoms that resolved at site pressure, 112 were referred to HBO Rx.
- Of 1,433 symptoms that resolved during repress, 52 were referred to HBO Rx.
- For 93% of 1,433 symptoms that resolved during repress the subjects continued with 2-hr of GLO.

Muehlberger PM, Pilmanis AA, Webb JT, Olson JE. Altitude decompression sickness symptom resolution during descent to ground level. *Aviat Space Environ Med.* 2004;75:496-499.