

# TOWARDS A PROBABILISTIC ASSESSMENT OF HYPOBARIC DECOMPRESSION SICKNESS TREATMENT

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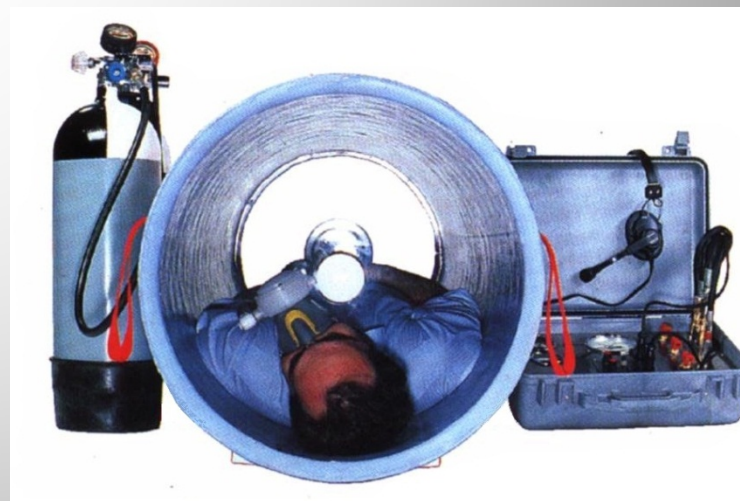
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# DCS treatment in space



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.

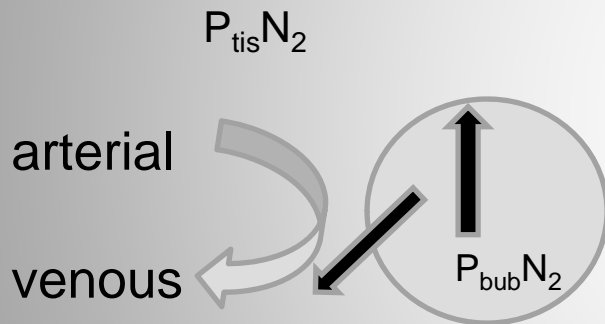
# symptom resolution = bubble dissolution

- Boyle's Law compression (**closed**, isothermal, ideal gas system):

$$P_2 - P_1 = V_1/V_2 \times P_1 - P_1 \quad P_2 - P_1 \text{ is } \Delta P, \text{ as psid.}$$

- Bubble-to-tissue  $N_2$  diffusion gradient and the  $O_2$  window:

$$P_{\text{bub}} N_2 = P_B + 2\gamma/r + M - P_{\text{bub}} O_2 - P_{\text{bub}} CO_2 - P_{\text{bub}} H_2O$$

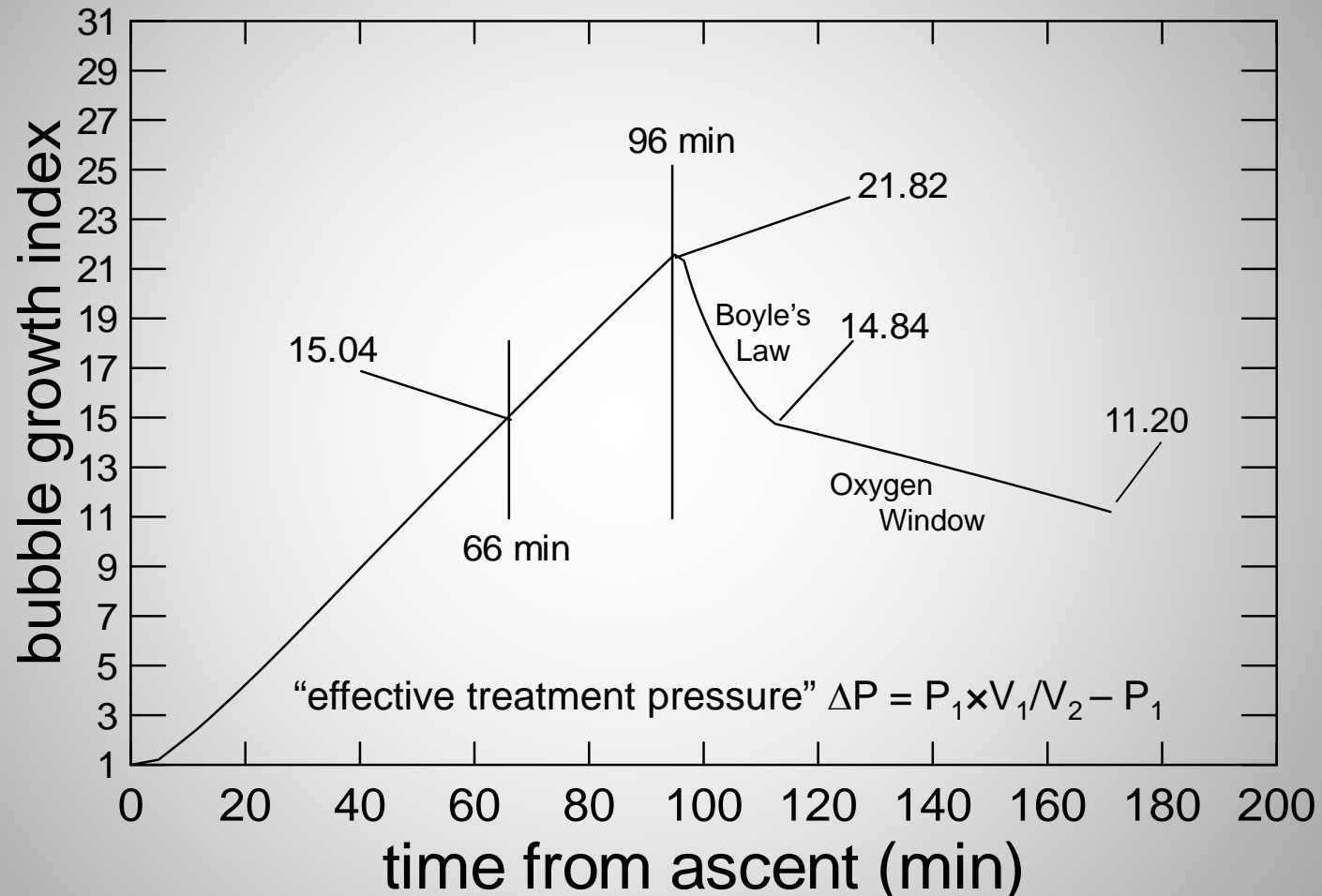


- Tissue Bubble Dynamics Model integrates both through time as  $dr/dt$ :

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

# Tissue Bubble Dynamics Model (TBDM)

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



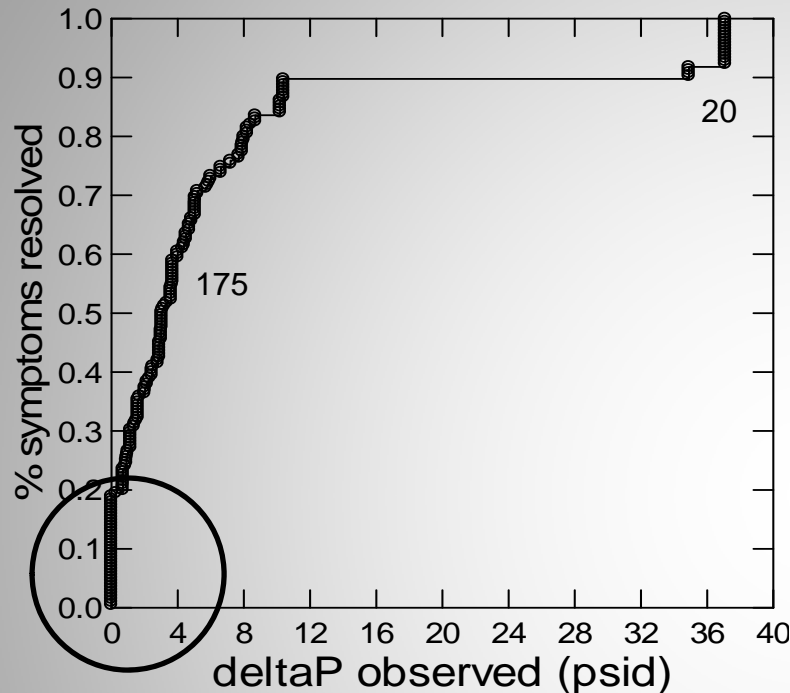
- Note that “time” to achieve a  $\Delta P$  is available from the TBDM.

# NASA 1982 - 2009 symptom data

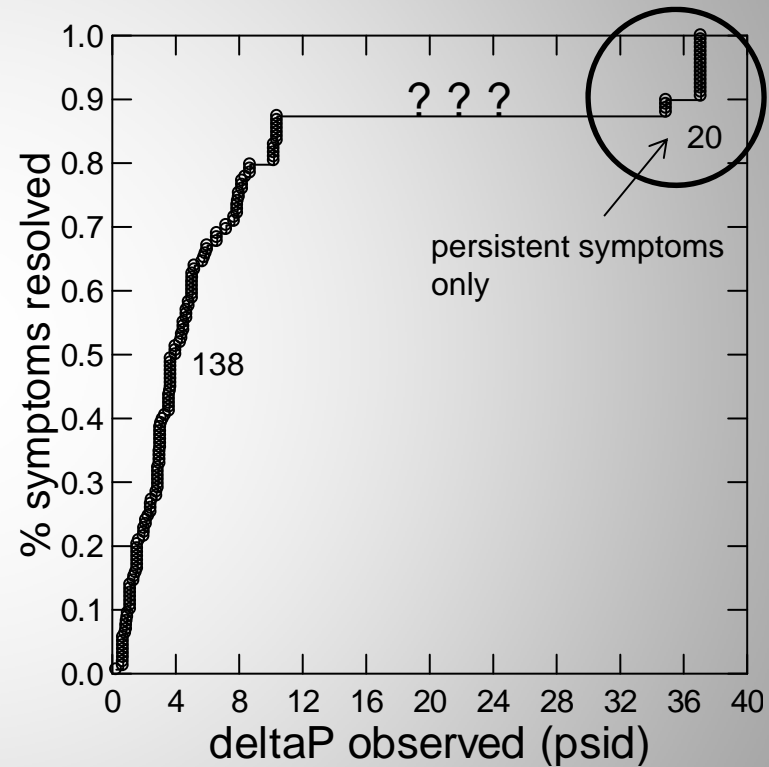
- The JSC Hypobaric DCS Database documents 969 exposures from 47 different altitude tests.
- Symptoms are from 119 subjects diagnosed with DCS.

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

# cumulative fraction of resolved symptoms with $\Delta P$

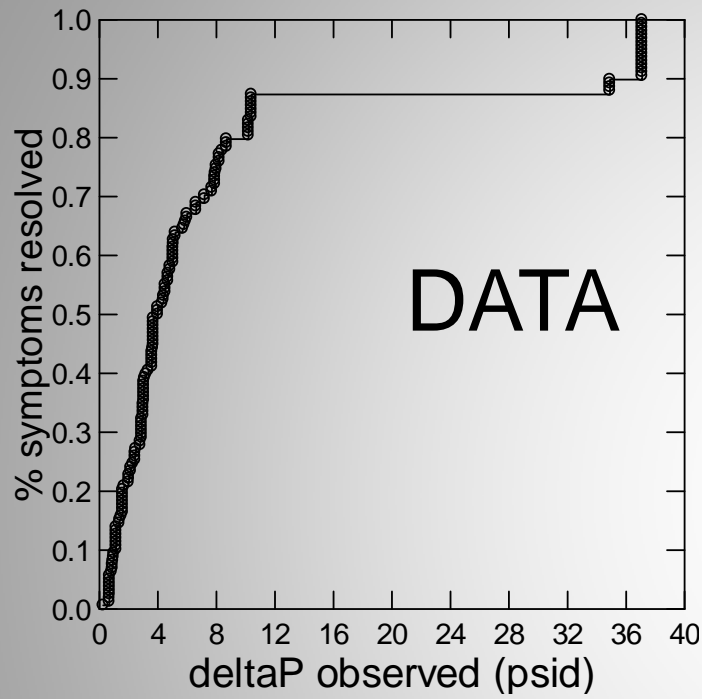


removed 37 that resolved before repress



- P(symptom resolution) modeled as a log-logistic function of observed  $\Delta P$  and two other explanatory variables.
- We used 154 symptoms from 119 subjects diagnosed with DCS.

# symptoms linked to TBDM through $\Delta P$



DATA



STATS

$P(\text{symptom resolution})$



computed  $\Delta P$

TBDM simulations

- pressure
- oxygen
- time



# regression results (n=154 symptoms)

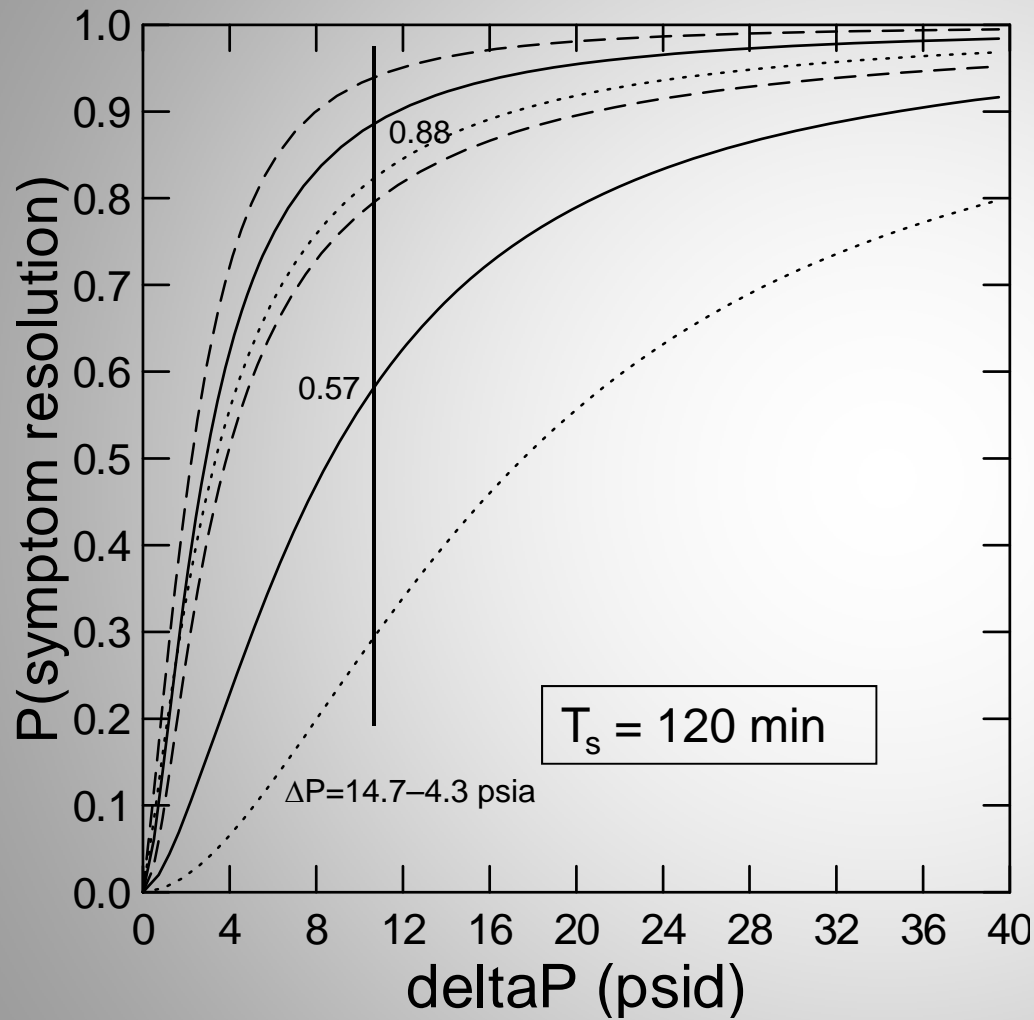
parameter	Estimate ± 95% CI	standard error*	z-score	p-value
<b>B<sub>1</sub></b>	0.633 0.50 to 0.80	0.077	-3.75	<0.001
<b>B<sub>2</sub></b>	1.682 1.00 to 2.35	0.344	4.89	<0.001
<b>AMB</b>	-1.089 -1.96 to -0.22	0.444	-2.45	0.014
<b>T<sub>s</sub> (min)</b>	0.00395 0.001 to 0.007	0.0015	2.61	0.009

\* Symptom dependency considered.

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

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

# Hypobaric DCS Treatment Model Example 1

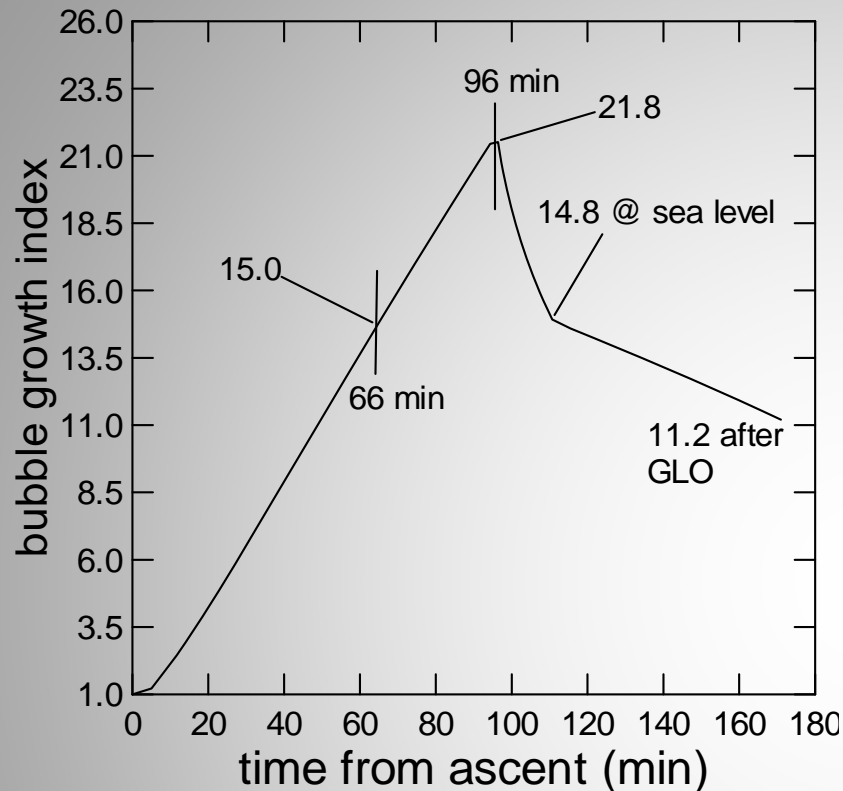


ambulation

no ambulation

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.

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

$$9.37 = 4.3 \times 1176964 \mu\text{m}^3 / 370255 \mu\text{m}^3 - 4.3$$

after 15 min

$$27.5 = 4.3 \times 1176964 \mu\text{m}^3 / 159167 \mu\text{m}^3 - 4.3$$

after 75 min

simulation	symptom onset	BGI	BGI @ repress	BGI @ Rx	computed $\Delta P$	P(symptom resolution) $\pm$ 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

# 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.

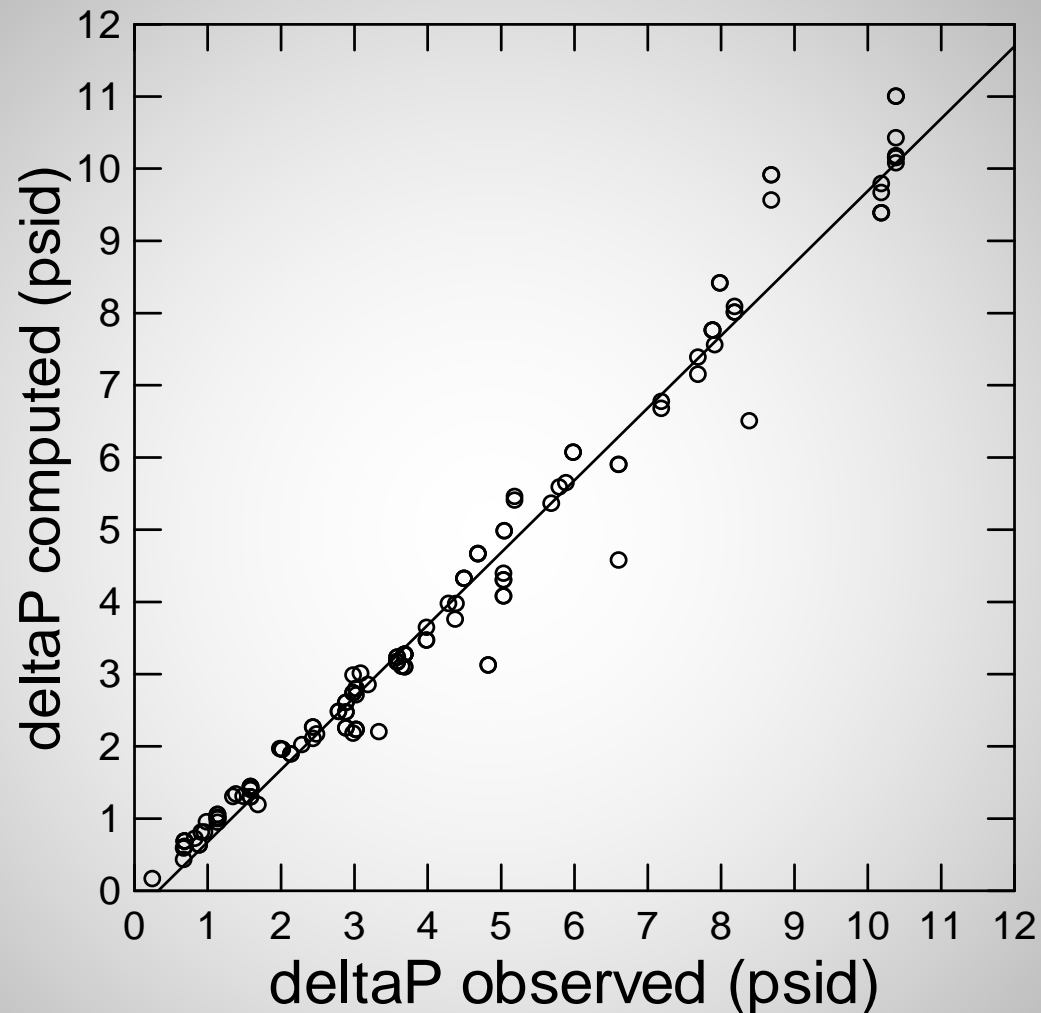
Muehlberger PM, *et al.* Altitude decompression sickness symptom resolution during descent to ground level. *Aviat Space Environ Med* 2004; 75:496-9.

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 $\Delta P$



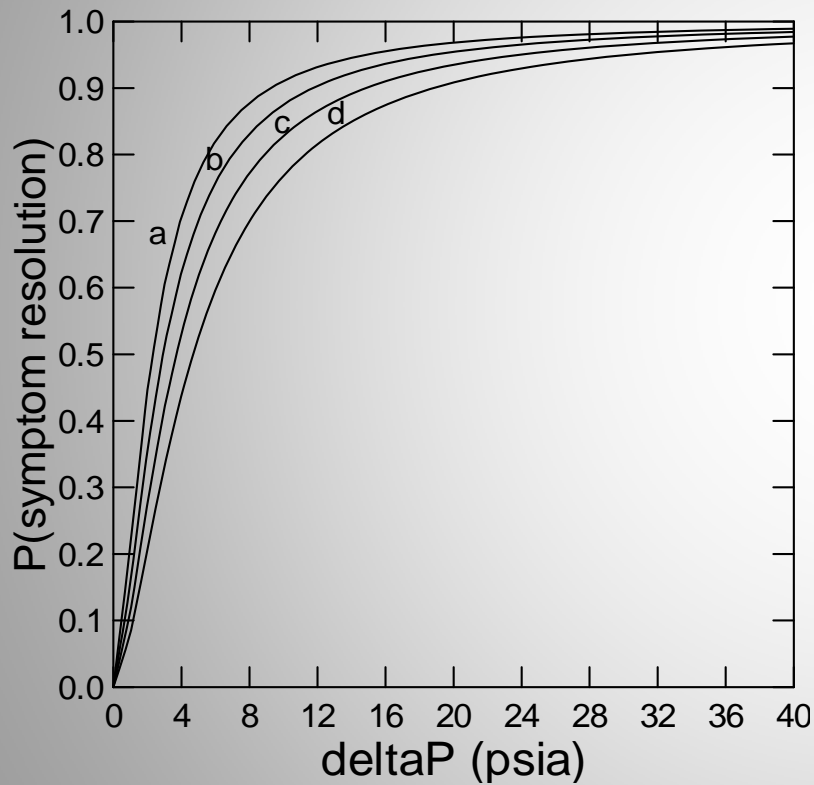
Observed  $\Delta P$  to resolve 138 symptoms compared to the computed ideal gas  $\Delta P$  from TBDM. Linear regression for  $\Delta P$  computed =  $1.0016 \times \Delta P$  observed - 0.324,  $r^2 = 0.977$ .

# Hypobaric DCS Treatment Model Results

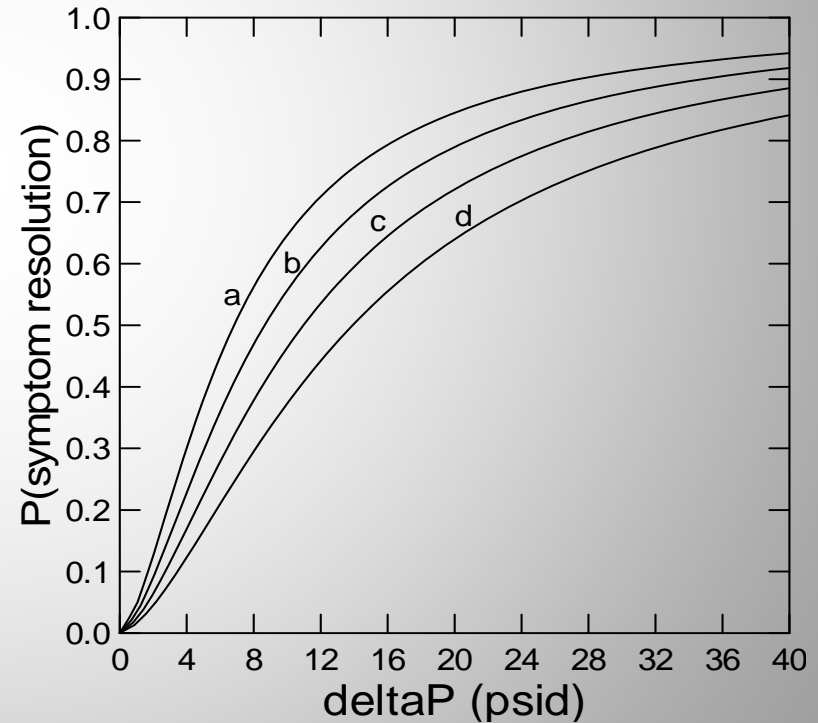
154 symptoms

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 $\Delta P$ data

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