ACUTE MOUNTAIN SICKNESS AND HEMOCONCENTRATION IN NEXT GENERATION SPACECRAFT

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ESA Workshop on Hypoxic Bed Rest Study
November 15, 2009

topics

Is there a problem with the equivalent air altitude concept to assess hypobaric hypoxia?

Is there a medical concern about secondary polycythemia?

A bed rest hypoxia study can help.

equivalent air altitude concept

10.3 ALTITUDE-PRESSURE TABLE

(1) Altitude m	(2) Altitude ft.	(3) P_B mm Hg	(4) (P_B-47) mm Hg	(5) $.209\,(P_B-47)$ mm Hg
0	0	760	713	149
610	2000	707	660	138
1220	4000	656	609	127
1830	6000	609	562	118
2440	8000	564	517	108
3050	10000	523	476	100
3660	12000	483	436	91
4270	14000	446	399	83
4880	16000	412	365	76
5490	18000	379	332	69
6100	20000	349	302	63
6710	22000	321	274	57
7320	24000	294	247	52
7930	26000	270	223	47
8540	28000	247	200	42
9150	30000	226	179	37
9760	32000	206	159	33
10370	34000	187	140	29
10980	36000	170	123	26
11590	38000	155	108	23
12200	40000	141	94	20
12810	42000	128	81	17
13420	44000	116	69	14
14030	46000	106	59	12
14640	48000	96	49	10
15250	50000	87	40	8
19215	63000	47	0	0

21% O_2 @ 10,000 ft
or
50% O_2 @ 28,000 ft
or
14% O_2 @ 0 ft (sea level)
etc.

$$P_IO_2 = (P_B - 47) * F_IO_2$$

Rahn H, Fenn WO. A graphical analysis of the respiratory gas exchange: the O_2 - CO_2 diagram. 2nd ed. Washington, DC: The American Physiological Society; 1956:38, from a 1935 reference.

spacecraft atmosphere trade study – 2006

- Underlying Assumptions:
  - Efficient and frequent EVAs will drive exploration program.
  - Low pressure suit is always preferred to high pressure suit.
  - There is operational value to a short in-suit prebreathe.
  - Vehicle atmosphere may not prevent risk of DCS during EVA.
    - Shuttle and ISS atmospheres are examples.
  - Dedicated hyperbaric treatment capability may not be present.
- Atmosphere Design Considerations:
  - No significant risk of fire – bad experience with 100% O_2.
  - Limit hypoxia – you need O_2 with every breath.
  - Prevent DCS and VGE.
    - Better to prevent than treat DCS, or to constantly embolize the lung.
  - Optimize atmosphere to allow safe and efficient EVAs.

spacecraft atmospheres -- 2006

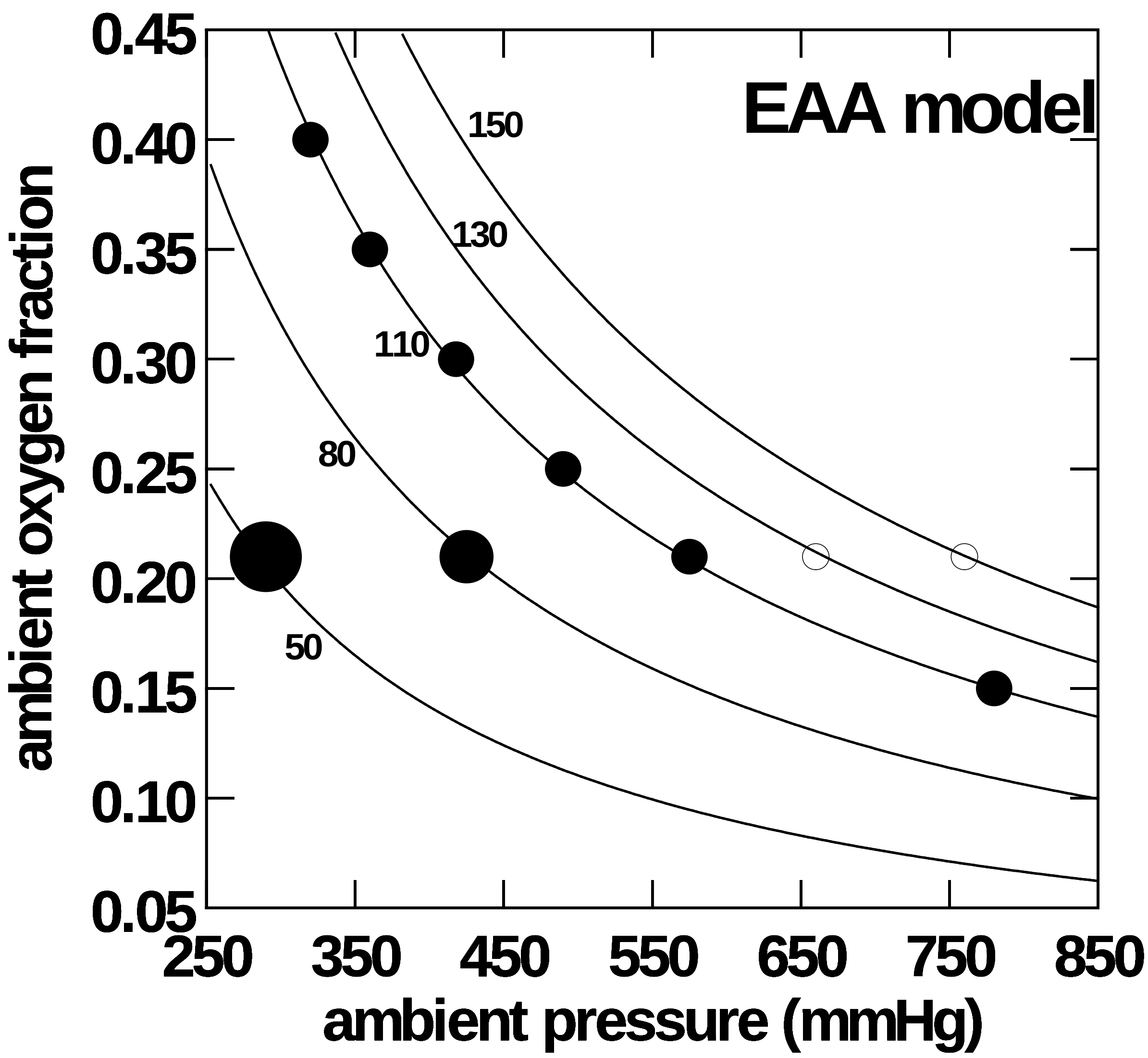
Environment	P_B psia	F_IO_2 (%)	P_IO_2 mmHg	P_AO_2 mmHg	Actual Altitude ft	Equivalent Air Altitude ft
CEV	**10.2**	**26.5**	**127**	**85**	**9,750**	**4,000**
our model*						**6,000**
LSAM	**8.0**	**32.0**	**117**	**77**	**16,000**	**6,000**
our model*						**9,500**
HABITAT	**7.6**	**32.0**	**111**	**71**	**17,000**	**7,500**
our model*						**11,000**

P_IO_2 is inspired O_2 partial pressure, computed as (P_B mmHg – 47) * F_IO_2 (as decimal fraction).
P_AO_2 is computed acute alveolar oxygen partial pressure from alveolar oxygen equation.

*Conkin J, Wessel JH III. Critique of the equivalent air altitude model. Aviat Space Environ Med 2008; 79:975-82.

*Conkin J, Wessel JH III. A model to predict acute mountain sickness in future spacecraft. NASA Technical Publication NASA/TP-2009-214791, Johnson Space Center, July 2009.

equivalent air altitude model - ascent on enriched O_2



$$F_IO_2 = \frac{P_IO_2}{(P_B - 47)}$$

acute mountain sickness

Signs and symptoms include headache, nausea, dizziness, fatigue, vomiting and sleeplessness following a recent gain in altitude with at least several hours at the new altitude in a hypoxic environment; *likened to a bad hangover.*

incidence of mild AMS

- The incidence of AMS is *highly variable*.

  - Roach (1998) reports that 25% of people are affected by a quick ascent to 2,000 m (6,600 ft).
  - Montgomery (1989) shows 25% incidence of three or more symptoms at 2,000 m and that half with these symptoms took medication for relief of symptoms.
  - Houston (1982) starts his list of AMS symptoms at altitudes above 2,100 m (7,000 ft).
  - Muhm (2007) reports 11% AMS in large sample during 20 hrs at 2,438 m (8,000 ft).

- So about 15% expected at 7,000 ft.

- How do results from these actual altitudes translate to our equivalent air altitudes?

observations through the years

- Rahn and Fenn (1956) disproved the simple notion of equivalent air altitude, and conclude, *"It is evidently not enough to equate the inspired O_2 tensions …"*

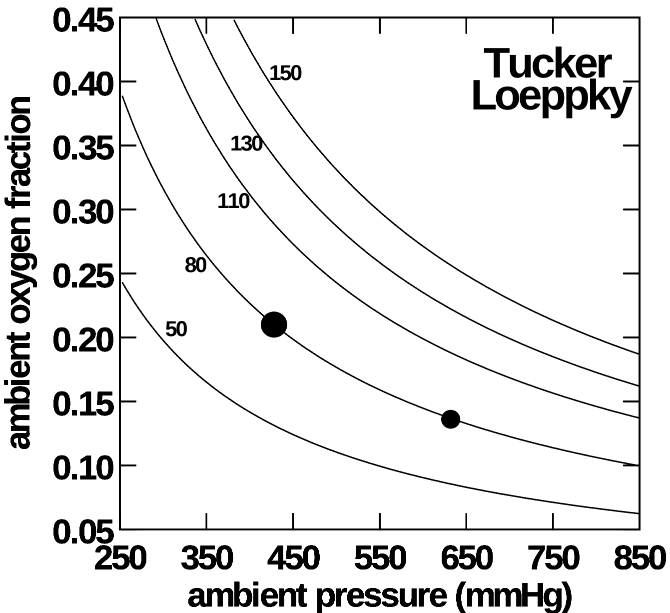
- Since 1980s researchers have questioned the conventional wisdom that the symptoms of AMS are solely due to low O_2 partial pressure.

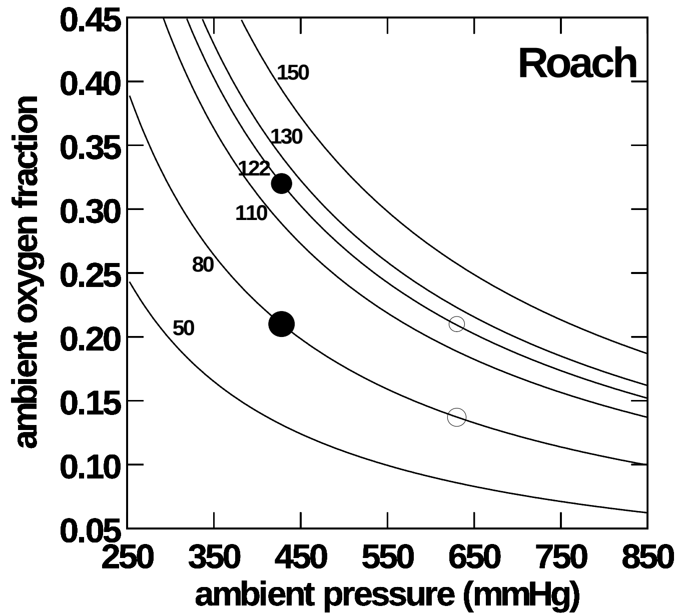
  - Accumulated anecdotal evidence shows descent is more effective for relief of AMS than enriched O_2 alone.

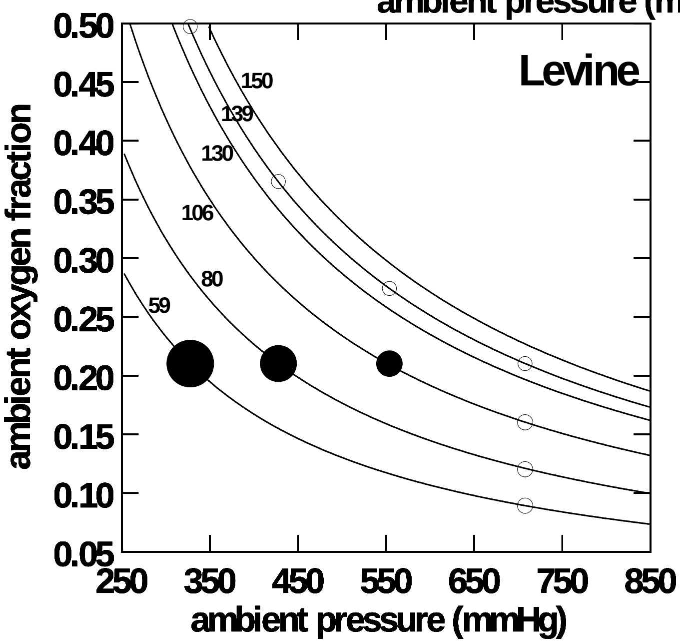
- Savourey (2003) speaks of the "specific response to hypobaric hypoxia".

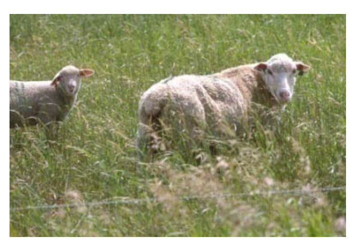
- So the door is open to investigate an independent P_B effect on AMS.

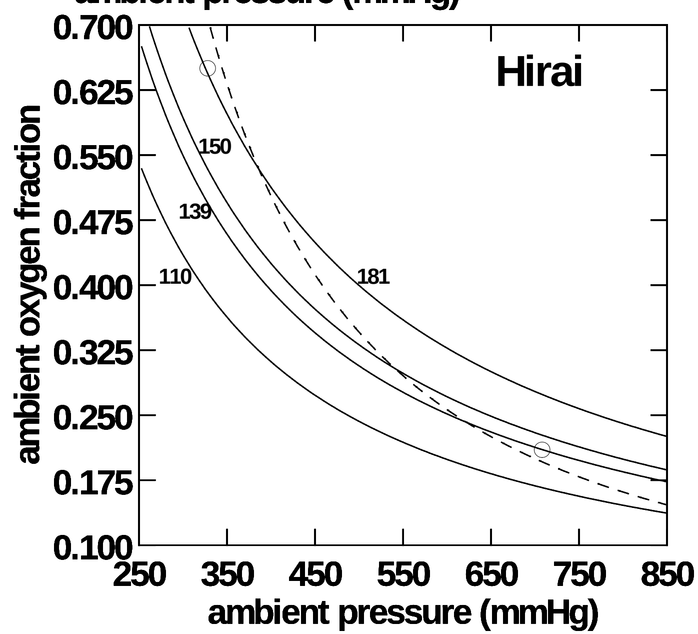
normobaric hypoxia, hypobaric hypoxia, and hypobaric normoxia







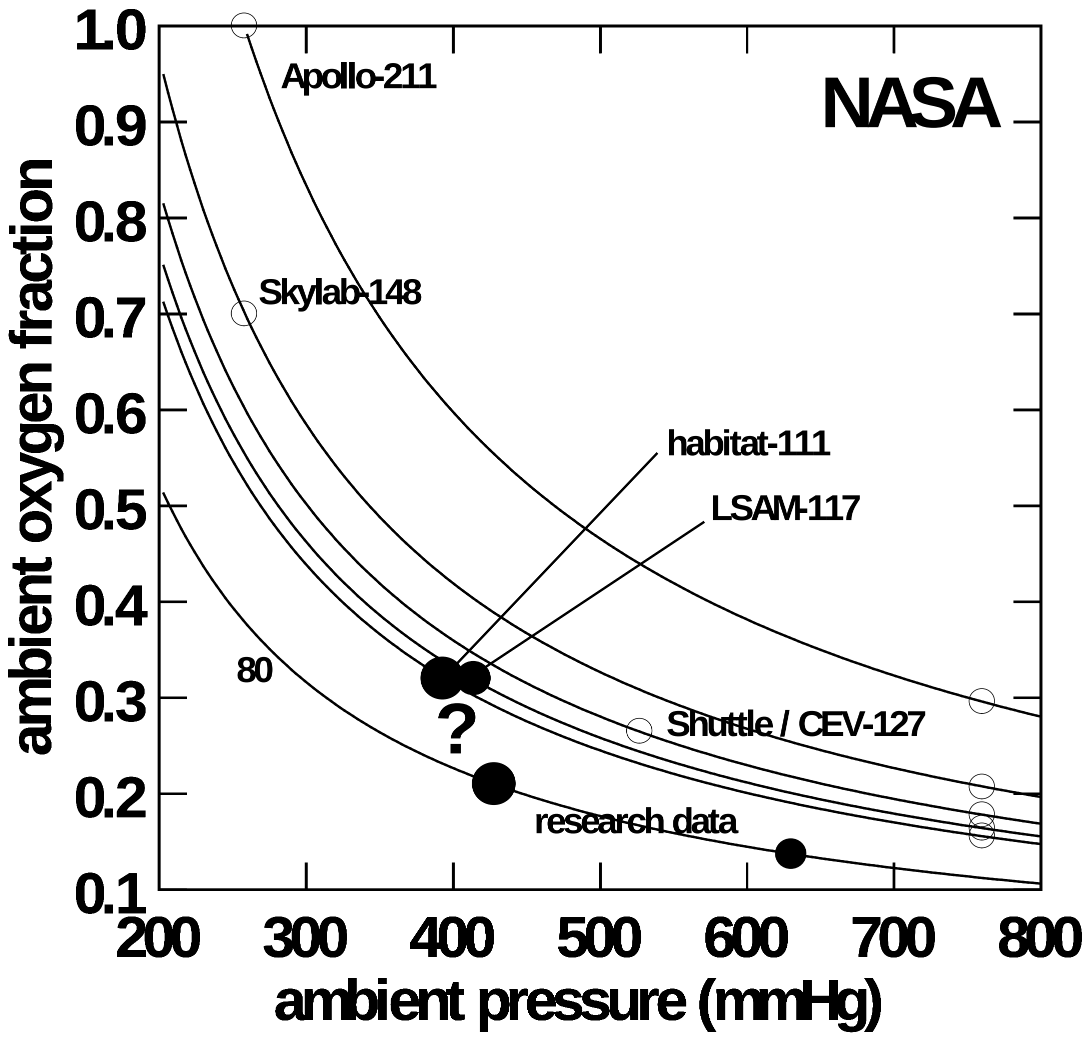




the P_B effect!

- The pressure effect is real, so to understand the total hypoxic stress means you have to understand the interaction between hypoxic P_IO_2 and P_B.
- Any bed rest hypoxia study should use the actual atmospheric conditions and not the equivalent air altitude, even if it makes the study more complicated.

NASA atmosphere experience



So…..

- Are astronauts at potential risk for AMS? About 25% worst case probability (guesstimate) with 0% once acclimatization occurs.

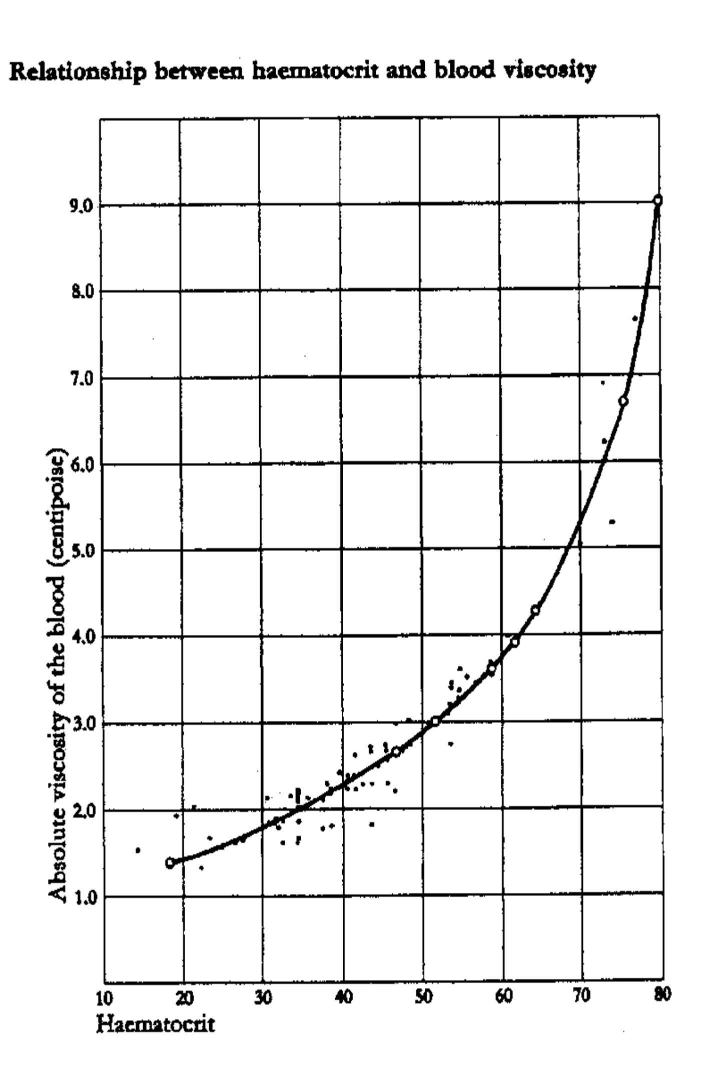
- This is baseline estimate given direct ascent to 8.0 psia with 32% O_2 and no consideration of µG-AMS interaction.

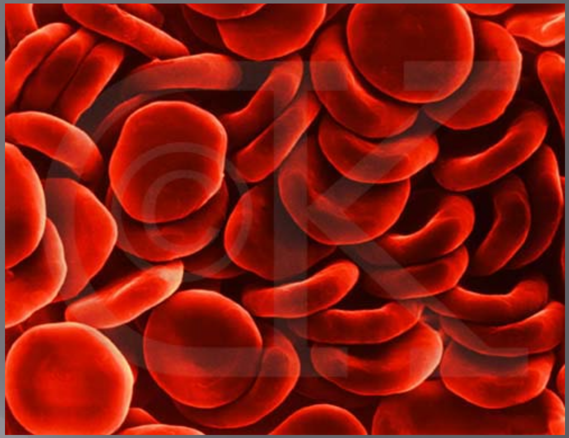
- Greater potential risk of AMS than the current EAAs suggest.

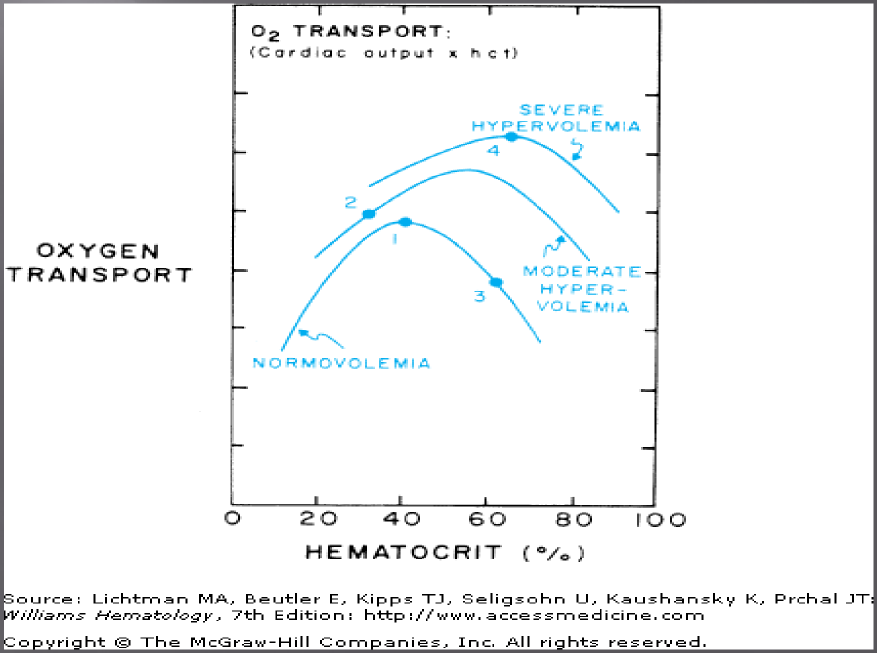
    - Finalize a plan to mitigate the risk even if risk is unclear.

    - Take the opportunity to quantify the risk with focused research.

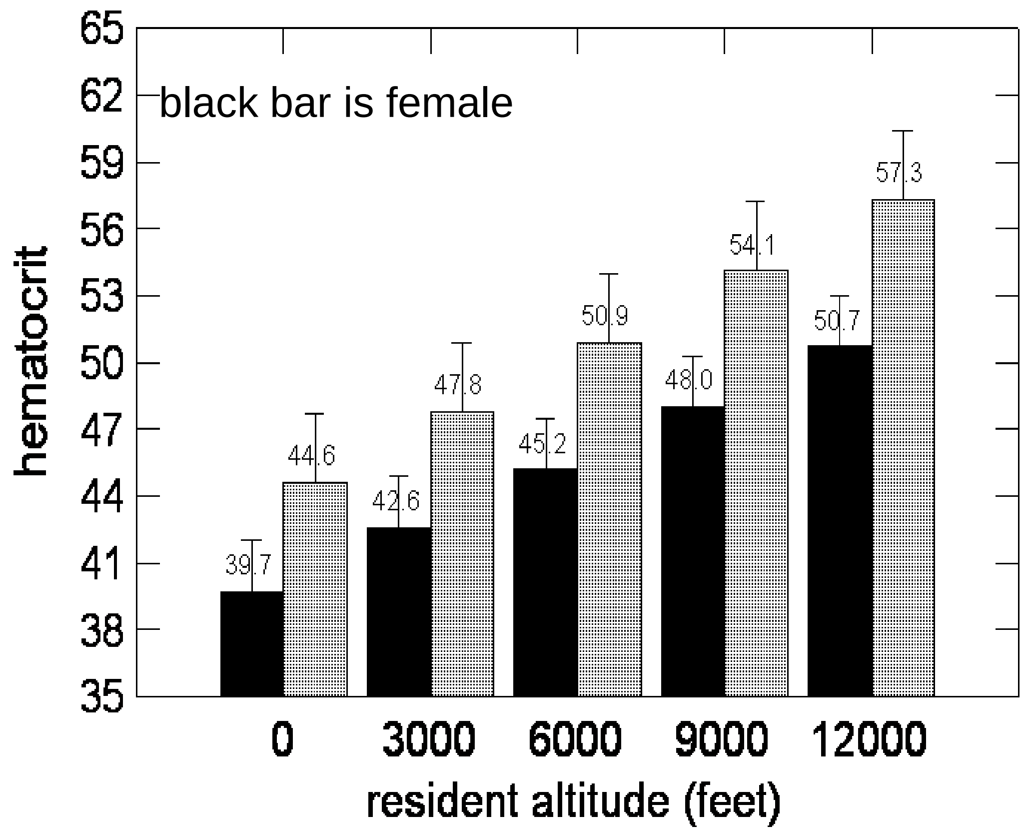
secondary polycythemia







large sample Chinese study -- 2003



Miao Ge. Creating an altitude-adjusted hematocrit reference standard for adults 18-40 years of age in China. Arc of Environ Health 2003.

hypoxia plus bed rest - all there is

reference	pre – post HCT		upper range	time hrs	supine	6-HD	PIO2 mmHg	plasma volume
Stevens (1966) and Lynch (1967)	44	51	54	624 (4 wks)	✓	___	95	2928 to 2318 ml PV (-21%) 2265 to 2398 ml RBC (+6%) 5193 to 4716 ml TBV (-9%)
Waligora (1982)	43	46*	47	28	___	✓	108	no data
Fulco (1985)	42	48	52	114	✓	___	84	19% ↓ PV, 10% ↓TBV, 15.1 to 16.8 g/dl HB
Martin (1986)	42	46**	50	144	___	✓	150	3704 to 3271 ml PV (-12%)
Loeppky (1993a,b)	47+#	49	53	168	___	___	98	5% ↓ PV, 16.5 to 17.5 g/dl HB
	47#	52	54	168	___	✓	98	20% ↓ PV, 16.5 to 19.0 g/dl HB

* only 8 hrs were at 8,000 ft (PIO2 was 108 mmHg)
** normoxic 6-HD
\+ hypoxic exposure only

\# subjects lived at 5,400 ft (PIO2 was 120 mmHg)

other considerations

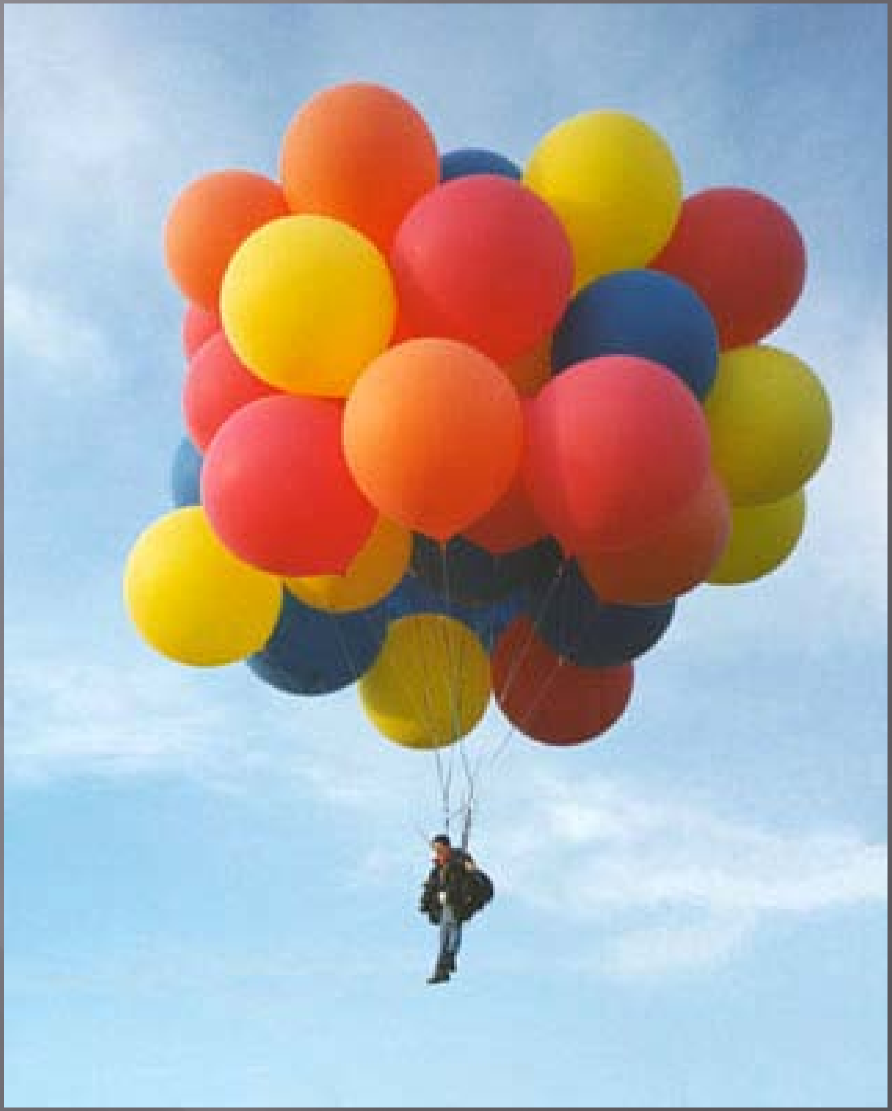
- Does μG modify the likelihood or character of AMS?
  - Redistribution of lung fluid – 25% increase in CapBV
  - Increased interstitial edema – puffy face response
  - Increased incidence of HAPE?

- Potential negative synergy on combining mild hypoxia and adaptation to μG – increase in hematocrit leads to increased blood viscosity.
  - Six reports suggest this may not be a significant concern – keep hematocrit below 55%.

summary

- Baseline "worst case" potential risk of AMS is about 25% based on direct ascent to 8.0 psia with 32% O_2.
  - EAA model should be replaced with an iso-hypoxic model.
- Staged depressurization scheme is a practical mitigation approach.
- Current depressurization to 10.2 psia in CEV and 4-day transit to moon is not anticipated to induce signs or symptoms of AMS.
- Eventual transition to LSAM at 8.0 psia and 32% O_2 after some acclimatization will reduce potential risk << 25%, **but precise estimate is not yet available.**
- Due to uncertainty about potential AMS risk:
  - Flight Surgeons should prepare.
  - Focused research should proceed.
  - Current analytical efforts should continue.

Questions ?



Lake Louise AMS Scoring System

- Based on this 1991 committee's recommendations:
  - A diagnosis of AMS is based on a recent gain in altitude, at least several hours (>2) at the new altitude, and the presence of headache and at least one of the following symptoms: gastrointestinal upset, fatigue or weakness, dizziness or lightheadedness and difficulty sleeping.
- A score of three points or greater on the AMS Self-Report Questionnaire alone or in combination with the clinical assessment score is diagnostic of AMS.
- **Several signs and symptoms of AMS are shared with motion sickness – confounding a diagnosis of each!**

Self Report Questionnaire

Each question asked and the sum is calculated as the AMS self report score.

1. Headache	0	No headache
	1	Mild Headache
	2	Moderate Headache
	3	Severe Headache, incapacitating
2. Gastrointestinal Symptoms	0	No gastrointestinal symptoms
	1	Poor appetite or nausea
	2	Moderate nausea or vomiting
	3	Severe nausea & vomiting, incapacitating
3. Fatigue and/or Weakness	0	Not tired or weak
	1	Mild fatigue/weakness
	2	Moderate fatigue/weakness
	3	Severe fatigue / weakness, incapacitating
4. Dizziness / lightheadedness	0	Not Dizzy
	1	Mild dizziness
	2	Moderate dizziness
	3	Severe dizziness, incapacitating
5. Difficulty sleeping	0	Slept as well as usual
	1	Did not sleep as well as usual
	2	Woke many times, poor night's sleep
	3	Could not sleep at all

Clinical Assessment

The interviewers ratings of three signs is added to the self-report score.

6. Change in Mental Status	0	No Change in Mental Status
	1	Lethargy / lassitude
	2	Disoriented/confused
	3	Stupor / semiconsciousness
	4	Coma
7. Ataxia (heel to toe walking)	0	No Ataxia
	1	Maneuvers to maintain balance
	2	Steps off line
	3	Falls down
	4	Can't stand
8. Peripheral Edema	0	No peripheral edema
	1	Peripheral edema at one location
	2	Edema at two or more locations