Diving and Altitude Medicine

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CAPT MC (UMO/DMO/SMO) USN

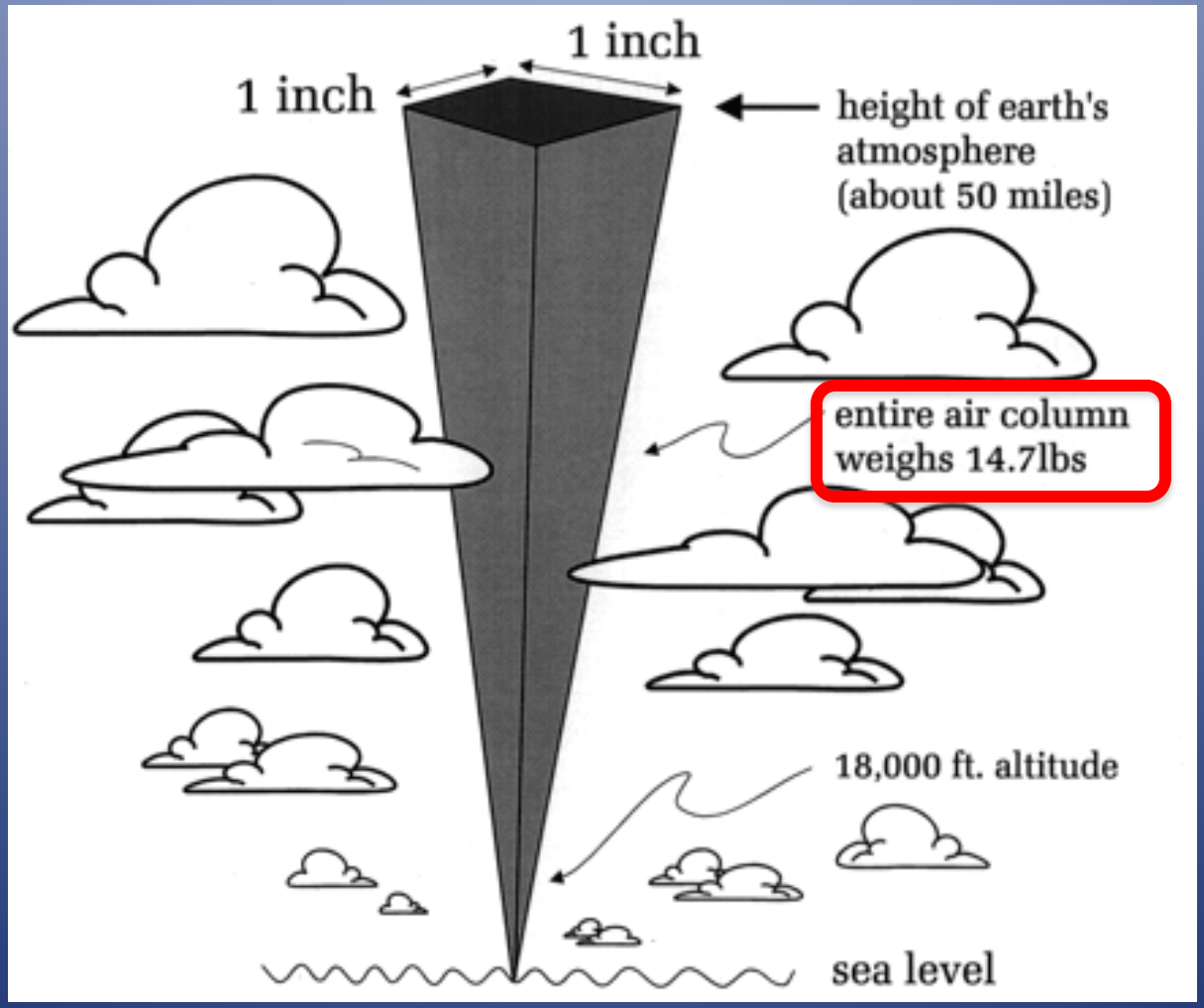
Background

- Estimated to be 1.5 to 3.5 million certified divers in the U.S. (100-200K new/year)
- >100 million people visit ≥ 2,500m (~8,000 ft) annually
- Many travel the world to prime destinations
- Each carries risks of both travel and environment.
  - Pressure (Direct and Indirect Effects)
  - Temperature

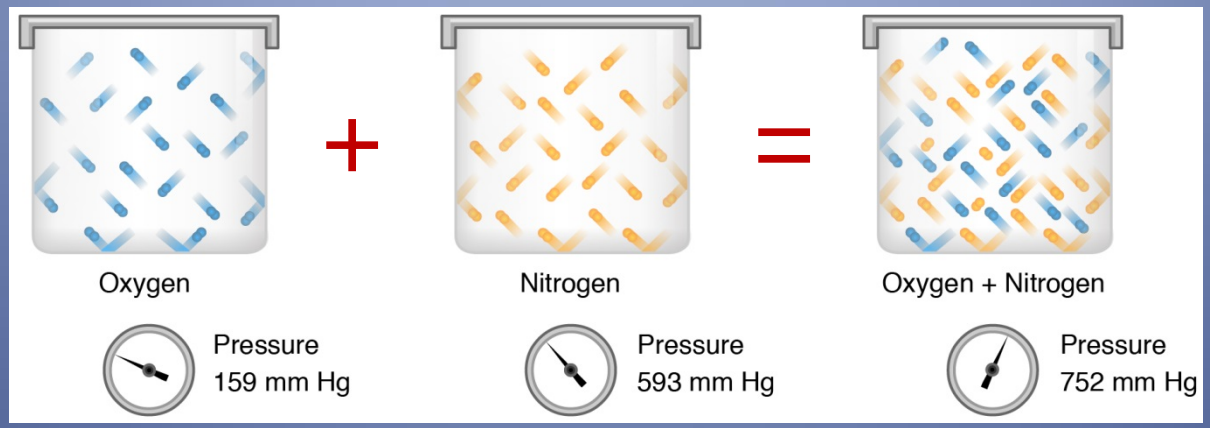
Trip of a Lifetime Mentality

- Usually large investment in time, money and training
- Pressure to make the dives/summit
- Overestimations of abilities
- Incorrect assumptions WRT fitness etc.
- Competition within group
- Leader/dive master reluctant to split group.
  - Fear of being left behind
- Climbing/Trekking commercial outfits:
  - Published itinerary's are average schedules
  - Not meant to prevent AMS
    - Inflexible schedule = left behind
    - Flexible schedule = acclimatize within a day and can continue
  - Underestimating the first case of AMS by the trip leader

We are all saturation divers at 1 atm



Dalton's Law : $P_{O2} + P_{N2} = P_{AIR}$



Metabolically CONSUMED

Metabolically INERT

BUBBLES & DECOMPRESSION SICKNESS (DCS)

http://philschatz.com/anatomy-book/resources/2318_Partial_and_Total_Pressure_of_a_Gas.jpg

Boyle's Law

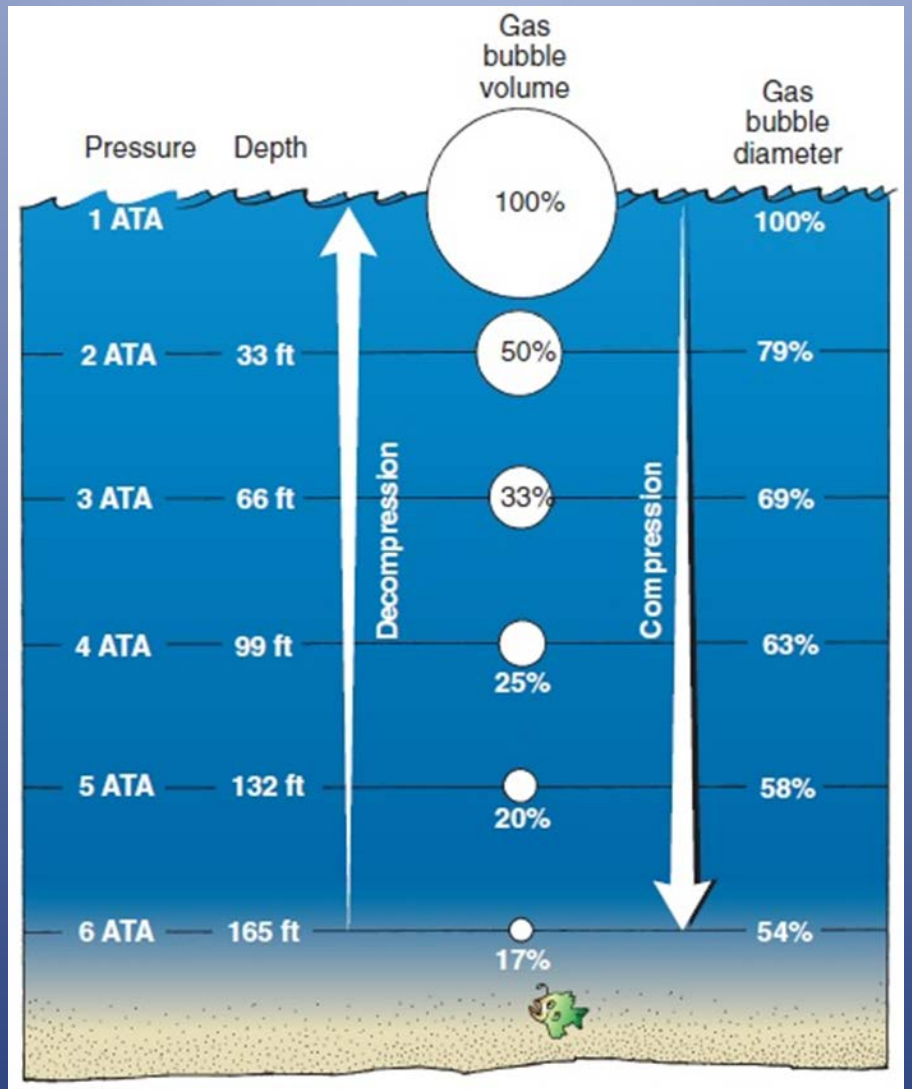


FIGURE 77-3 Boyle's law. The volume of a given quantity of gas at constant temperature varies inversely with pressure: $P_1V_1 = P_2V_2$.

http://dokteraldi.files.wordpress.com/2013/03/boyles-law.jpg

DIVING

Introduction

- 3-9/100,000 diving deaths per year
  - Drowning most common cause (60%)
- Pre-disposing risk factors/mitigators
  - Fitness
  - Age
  - Concurrent illness (acute or chronic)
  - Sex?
  - Training
- All risks directly related to effects of pressure

Risk Factors/Mitigators

- Fitness
  - Being physically fit reduces risk of Decompression Sickness (DCS)
    - May be more directly related to BMI
- Age
  - Some related to above plus acquisition of chronic illnesses
  - Dive certification usually not allowed until 12 yrs

Risk Factors/Mitigators

- Concurrent illness/Conditions
  - Short/long term meds may preclude from diving
  - Dehydration; Alcohol; obesity; cold
  - PFO controversial: 20% of population; 40% DCS cases
- Women
  - No clear relationship with DCS: Risk 0-3x vs Men
  - Menses DOES NOT increase risk of shark attack
  - Pregnancy contraindicated

RELATIVE CONTRAINDICATIONS	
Asthma	Absolute contraindication for commercial and military; regulations vary country to country; controversial topic – control of illness, medications, maturity of diver[9-19]
Diabetes mellitus[19-25]	Depends on control and whether episodes of hypoglycemia occur
Cardiovascular problems	Those with mitral valve prolapse should have evaluation to make sure no concurrent problems[25]
Migraine headaches	Symptoms can be confused with those of DCS
Limited visual acuity	Contact lenses are safe;[33] post radial keratotomy patients should probably wait 2-5 months (mask squeeze prior to complete healing can be harmful);[34] no problem for those with previously repaired retinal detachments or controlled glaucoma[27, 35]
Post-operative patients	Usually safe to dive when asymptomatic; ostomies fine; those with airtight Kock pouches should not dive; those with breast implants may have higher risk of bubble formation, though appears tissue damage minimal[32]
Hernias	Inguinal or abdominal hernias must be repaired prior to diving
Disabilities	Depends on nature of disability; many who undergo proper training after screening do extremely well[37]
Infectious diseases	Active upper and lower respiratory infections are a temporary contraindication
Pregnancy	Controversial; most do not recommend.[5] May be higher incidence of DCS II;[4, 6, 7] no data to suggest greater risk of spontaneous abortion,[8] though fetal death in utero has been associated with diving[7]
Orthopedic injuries	Contraindicated until healed
Migraine headaches	Diving contraindicated during active headaches

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Table 39.1	Contraindications to diving
ABSOLUTE CONTRAINDICATIONS	
Medical condition	Comments
Seizure disorders	Exclusions include childhood febrile seizures, or those due to medication.[27] EEG may be done if indicated, particularly following head trauma[27]
Cardiovascular problems	Heart disease accounts for up to 25% scuba deaths;[26] myocardial infarction within previous year, symptomatic coronary artery disease, arrthymia, congestive heart failure, atrial septal defect,[28] history of cerebrovascular accident, uncontrolled hypertension[26, 30]
Psychological	Depression, schizophrenia, anxiety/panic disorder,[2, 36] history of psychosis or suicide attempts;[27] children with hyperactivity disorder require evaluation[3]
Sickle cell disease	Homozygous sicklers; risk to heterozygotes as well[3, 31]
Unexplained syncope	
Vertigo	
Inability to equalize middle ear pressures	Temporary contraindication if due to temporary condition
Chronic lung disease Previous POPS	Bullous, emphasematous lung disease, history of spontaneous pneumothorax
Tympanic membrane perforation	Unless healed or surgically repaired

Table 39.2 Medications and diving

Medication or Medication Class	Comments
Sedatives/ Analgesics	Narcotics contraindicated;[6, 29] Nonsteroidal anti-inflammatory drugs safe[20] Acetominophen safe
Cardiovascular agents	Beta-blockers relatively contraindicated[29, 39, 40] ACE inhibitors, vasodilators use with caution Cardiac glycosides (digoxin) safe[20]
Birth control pills	Little data; appear safe[37]
Insulin	Insulin requirements may change; Lower levels of glucose/glucagon measured while diving in some diabetics
Antipsychotics	Contraindicated[20]
Anticonvulsants	Contraindicated[27]
Antimicrobial agents	Appear safe, unless underlying acute illness for which there is a contraindication[39]
Antimalarials	Mefloquine may induce adverse events confused with decompression sickness.[41] Test doses may be taken prior to diving to make sure tolerated.[39] Atovaquone-proguanil or doxycycline may be better choices depending upon the circumstances
Antihistamines/ decongestants	Depends on medication and underlying cause for its administration; pseudoephedrine may decrease risk and severity of otic barotraumas[42, 43]
Anti-motion sickness agents	Some may cause sedation; scopolamine has been used safely[44]

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Training (or lack there of)

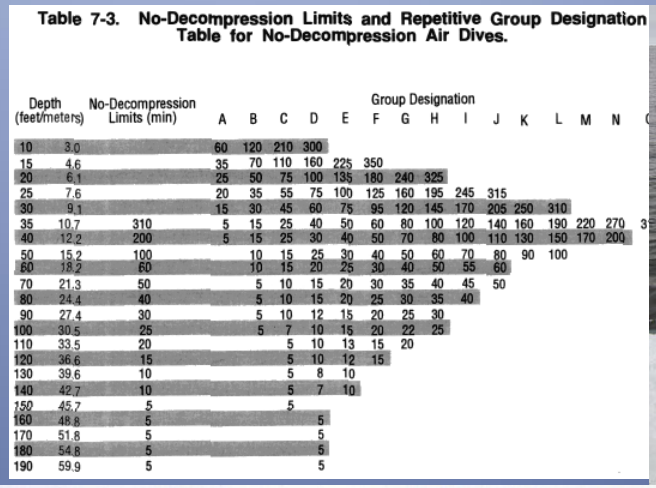
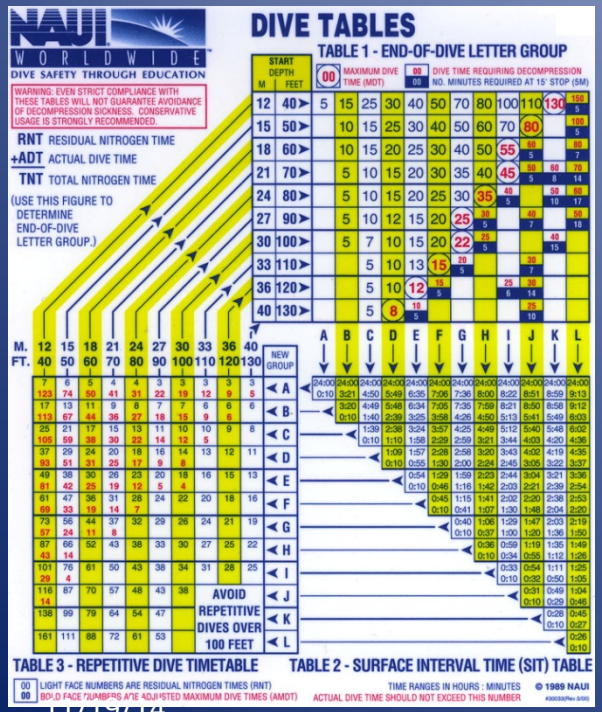


Table 7-3. No-Decompression Limits and Repetitive Group Designation Table for No-Decompression Air Dives.

Depth (feet/meters)		No-Decompression Limits (min)	Group Designation A	B	C	D	E	F	G	H	I	J	K	L	M	N
10	3.0		60	120	210	300										
15	4.6		35	70	110	160	225	350								
20	6.1		25	50	75	100	135	180	240	325						
25	7.6		20	35	55	75	100	125	160	195	245	315				
30	9.1		15	30	45	60	75	95	120	145	170	205	250	310		
35	10.7	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270
40	12.2	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200
50	15.2	100		10	15	25	30	40	50	60	70	80	90	100		
60	18.2	60		10	15	20	25	30	40	50	55	60				
70	21.3	50		5	10	15	20	30	35	40	45	50				
80	24.4	40		5	10	15	20	25	30	35	40					
90	27.4	30		5	10	12	15	20	25	30						
100	30.5	25		5	7	10	15	20	22	25						
110	33.5	20			5	10	13	15	20							
120	36.6	15			5	10	12	15								
130	39.6	10			5	8	10									
140	42.7	10			5	7	10									
150	45.7	5			5											
160	48.8	5				5										
170	51.8	5				5										
180	54.8	5				5										
190	59.9	5				5										



NAUI WORLDWIDE
DIVE SAFETY THROUGH EDUCATION

WARNING: EVEN STRICT COMPLIANCE WITH THESE TABLES WILL NOT GUARANTEE AVOIDANCE OF DECOMPRESSION SICKNESS. CONSERVATIVE USAGE IS STRONGLY RECOMMENDED.

RNT RESIDUAL NITROGEN TIME
+ADT ACTUAL DIVE TIME
TNT TOTAL NITROGEN TIME
(USE THIS FIGURE TO DETERMINE END-OF-DIVE LETTER GROUP.)

DIVE TABLES

TABLE 1 - END-OF-DIVE LETTER GROUP

START DEPTH M | FEET — 00 MAXIMUM DIVE TIME (MDT) — 00 DIVE TIME REQUIRING DECOMPRESSION 00 NO. MINUTES REQUIRED AT 15' STOP (5M)

M	FEET	A	B	C	D	E	F	G	H	I	J	K	L
12	40➤	5	15	25	30	40	50	70	80	100	110	130	150 / 5
15	50➤		10	15	25	30	40	50	60	70	80		100 / 5
18	60➤		10	15	20	25	30	40	50	55	60 / 5		80 / 7
21	70➤		5	10	15	20	30	35	40	45	50 / 5	60 / 8	70 / 14
24	80➤		5	10	15	20	25	30	35	40 / 5	50 / 10	60 / 17	
27	90➤		5	10	12	15	20	25	30 / 5	40 / 7	50 / 18		
30	100➤		5	7	10	15	20	22	25 / 5		40 / 15		
33	110➤			5	10	13	15 / 5	20 / 5		30 / 7			
36	120➤			5	10	12 / 5			25 / 6	30 / 14			
40	130➤			5	8 / 5	10 / 5				25 / 10			

TABLE 3 - REPETITIVE DIVE TIMETABLE

M.	12	15	18	21	24	27	30	33	36	40
FT.	40	50	60	70	80	90	100	110	120	130
A	123 / 7	74 / 6	50 / 5	41 / 4	31 / 4	22 / 3	19 / 3	12 / 3	9 / 3	5 / 3
B	113 / 17	67 / 13	44 / 11	36 / 9	27 / 8	18 / 7	15 / 7	9 / 6	6 / 6	6
C	105 / 25	59 / 21	38 / 17	30 / 15	22 / 13	14 / 12	12 / 10	5 / 10	9	8
D	93 / 37	51 / 29	31 / 24	25 / 20	17 / 18	9 / 16	14 / 14	13 / 13	12	11
E	81 / 49	42 / 38	25 / 30	19 / 25	12 / 21	5 / 18	4 / 16			
F	69 / 61	33 / 47	19 / 36	14 / 31	7 / 26	4 / 24	22	20	18	16
G	57 / 73	24 / 56	11 / 44	11 / 37	32	29	26	24	21	19
H	43 / 87	14 / 66	52	43	38	33	30	27	25	22
I	29 / 101	4 / 76	61	50	43	38	34	31	28	25
J	14 / 116	87	70	57	48	43	38	AVOID REPETITIVE DIVES OVER 100 FEET		
K	138	99	79	64	54	47				
L	161	111	88	72	61	53				

TABLE 2 - SURFACE INTERVAL TIME (SIT) TABLE

NEW GROUP	A	B	C	D	E	F	G	H	I	J	K	L
A	24:00 / 0:10	24:00 / 3:21	24:00 / 4:50	24:00 / 5:49	24:00 / 6:35	24:00 / 7:06	24:00 / 7:36	24:00 / 8:00	24:00 / 8:22	24:00 / 8:51	24:00 / 8:59	24:00 / 9:13
B		3:20 / 0:10	4:49 / 1:40	5:48 / 2:39	6:34 / 3:25	7:05 / 3:58	7:35 / 4:26	7:59 / 4:50	8:21 / 5:13	8:50 / 5:41	8:58 / 5:49	9:12 / 6:03
C			1:39 / 0:10	2:38 / 1:10	3:24 / 1:58	3:57 / 2:29	4:25 / 2:59	4:49 / 3:21	5:12 / 3:44	5:40 / 4:03	5:48 / 4:20	6:02 / 4:36
D				1:09 / 0:10	1:57 / 0:55	2:28 / 1:30	2:58 / 2:00	3:20 / 2:24	3:43 / 2:45	4:00 / 3:05	4:19 / 3:22	4:36 / 3:37
E					0:54 / 0:10	1:29 / 0:46	1:59 / 1:16	2:23 / 1:42	2:44 / 2:03	3:04 / 2:21	3:21 / 2:39	3:36 / 2:54
F						0:45 / 0:10	1:15 / 0:41	1:41 / 1:07	2:02 / 1:30	2:20 / 1:48	2:38 / 2:04	2:53 / 2:20
G							0:40 / 0:10	1:06 / 0:37	1:29 / 1:00	1:47 / 1:20	2:03 / 1:36	2:19 / 1:50
H								0:36 / 0:10	0:59 / 0:34	1:19 / 0:55	1:35 / 1:12	1:49 / 1:26
I									0:33 / 0:10	0:54 / 0:32	1:11 / 0:50	1:25 / 1:05
J										0:31 / 0:10	0:49 / 0:29	1:04 / 0:46
K											0:28 / 0:10	0:45 / 0:27
L												0:26 / 0:10

00 LIGHT FACE NUMBERS ARE RESIDUAL NITROGEN TIMES (RNT)
00 BOLD FACE NUMBERS ARE ADJUSTED MAXIMUM DIVE TIMES (AMDT)

TIME RANGES IN HOURS : MINUTES
ACTUAL DIVE TIME SHOULD NOT EXCEED THIS NUMBER

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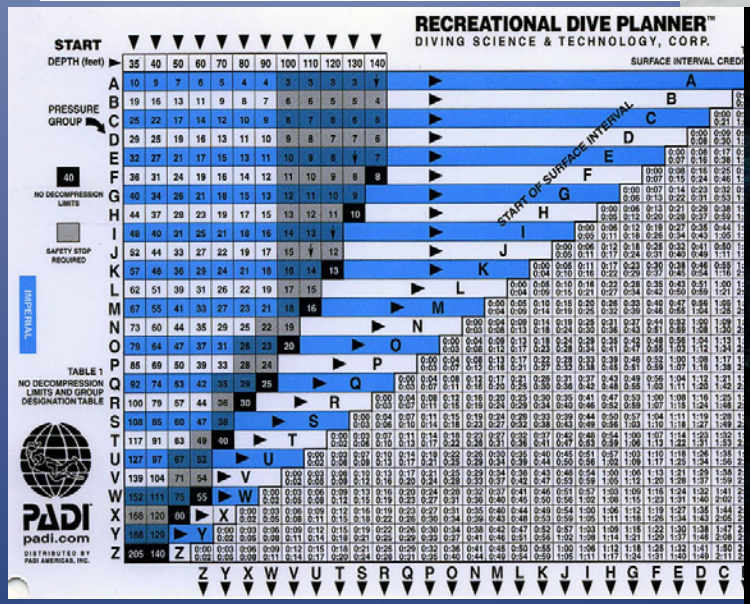

RECREATIONAL DIVE PLANNER™
DIVING SCIENCE & TECHNOLOGY, CORP.

START DEPTH (feet) ▶ 35 40 50 60 70 80 90 100 110 120 130 140

PRESSURE GROUP

START OF SURFACE INTERVAL

SURFACE INTERVAL CREDI

	35	40	50	60	70	80	90	100	110	120	130	140
A	10	9	7	6	5	4	4	3	3	3	3	↓
B	19	16	13	11	9	8	7	6	6	5	5	4
C	25	22	17	14	12	10	9	8	7	6	6	5
D	29	25	19	16	13	11	10	9	8	7	7	6
E	32	27	21	17	15	13	11	10	9	8	↓	7
F	36	31	24	19	16	14	12	11	10	9	8	8
G	40	34	26	21	18	15	13	12	11	10	9	
H	44	37	28	23	19	17	15	13	12	11	10	
I	48	40	31	25	21	18	16	14	12	↓		
J	52	44	33	27	22	19	17	15	↓	12		
K	57	48	36	29	24	21	18	16	14	13		
L	62	51	39	31	26	22	19	17				
M	67	55	41	33	27	23	21	18	16			
N	73	60	44	35	29	25	22	19				
O	79	64	47	37	31	26	23	20				
P	85	69	50	39	33	28	24					
Q	92	74	53	42	35	29	25					
R	100	79	57	44	36	30						
S	108	85	60	47	38							
T	117	91	63	49	40							
U	127	97	67	52								
V	139	104	71	54								
W	152	111	75	55								
X	168	120	80									
Y	188	129										
Z	205	140										

40 NO DECOMPRESSION LIMITS
SAFETY STOP REQUIRED
IMPERIAL

TABLE 1
NO DECOMPRESSION LIMITS AND GROUP DESIGNATION TABLE

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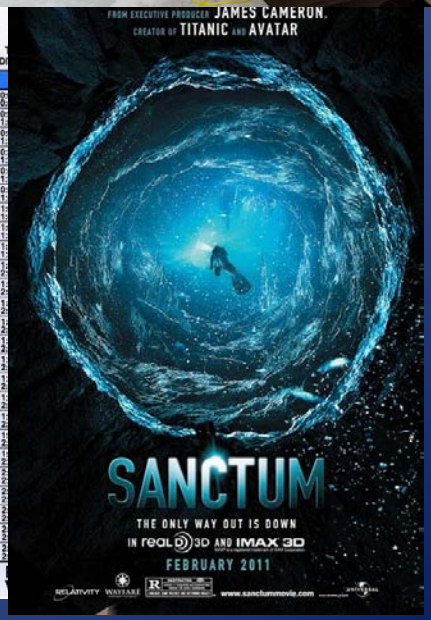
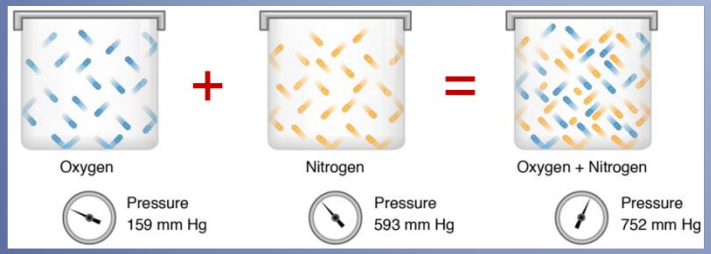




Metabolically CONSUMED

Metabolically INERT

BUBBLES & DECOMPRESSION SICKNESS (DCS)

DIVING PROBLEMS

Barotrauma (Dysbarism)

- Otic
- Sinus
- Dental
- GI
- Mask
- Pulmonary (POIS = POPS)

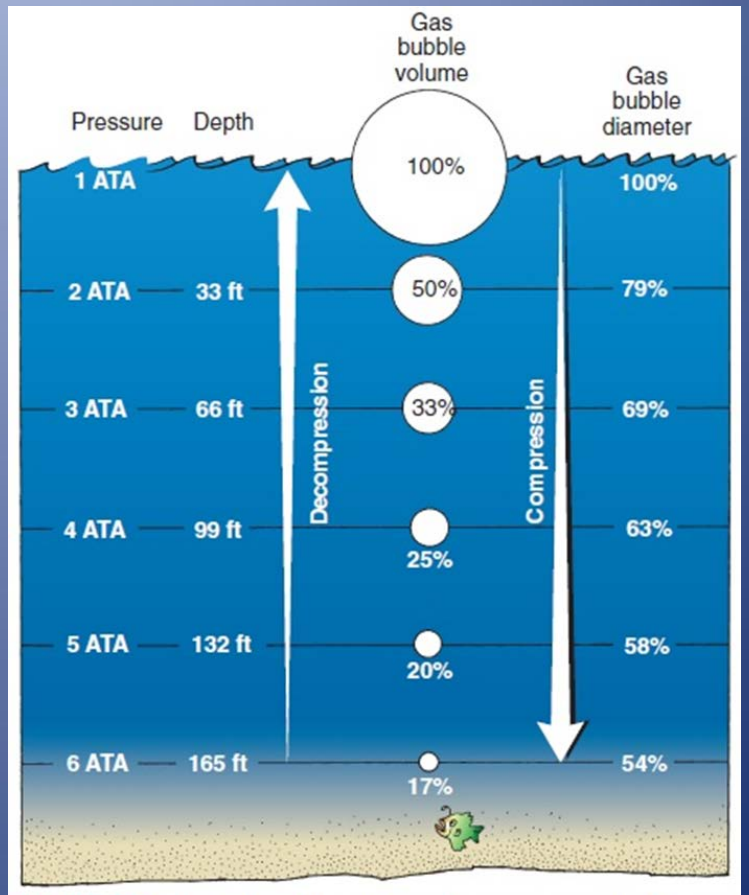
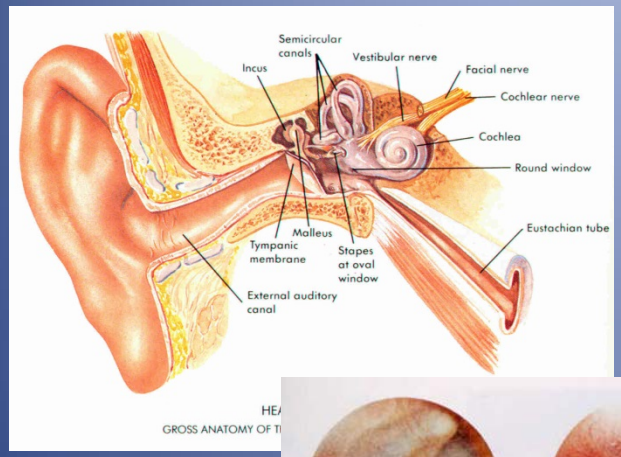


FIGURE 77-3 Boyle's law. The volume of a given quantity of gas at constant temperature varies inversely with pressure: $P_1V_1 = P_2V_2$.

Otic Barotrauma



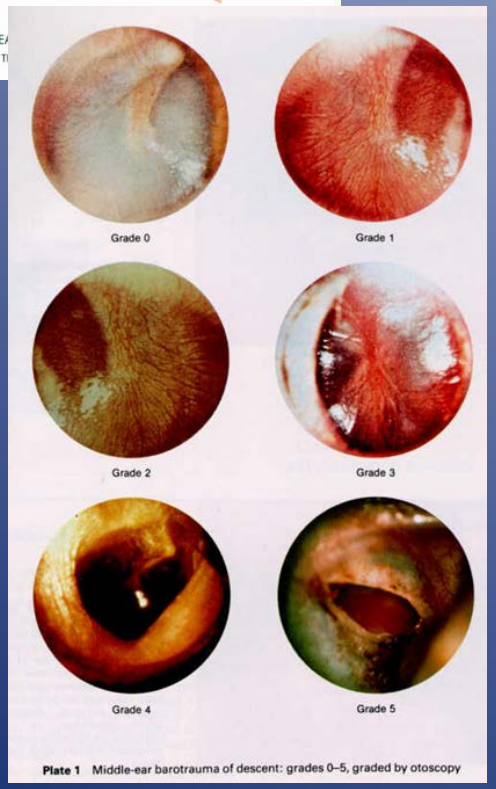
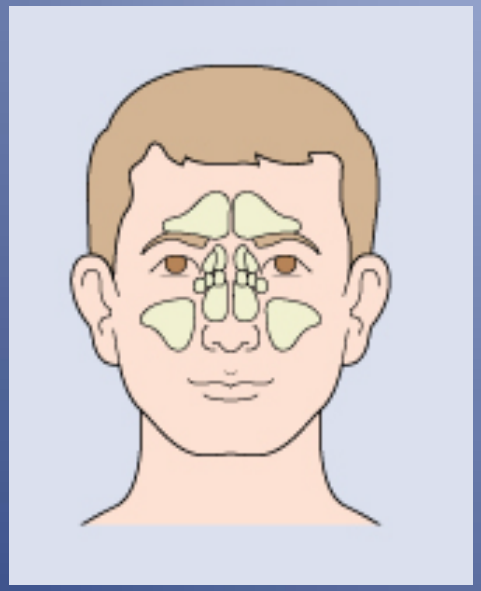


Plate 1 Middle-ear barotrauma of descent: grades 0–5, graded by otoscopy

- Squeeze
  - On descent
- Reverse Squeeze
  - On Ascent
- Other related issues
  - Alternobaric Vertigo
    - Usually on ascent
    - Brief, self limited
  - Caloric Vertigo
    - Colder water
    - Brief, self limited

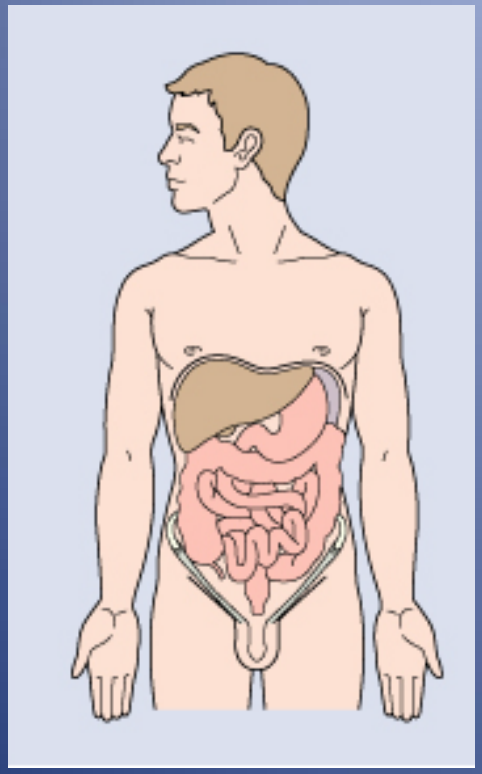
Sinus/Tooth (Barodontalgia) Squeeze



-Anatomy
-Allergies/Illness
-Medications

-Bad dentition
-Filling defect
-May need DDS/DMD

GI Distention/Mask Squeeze

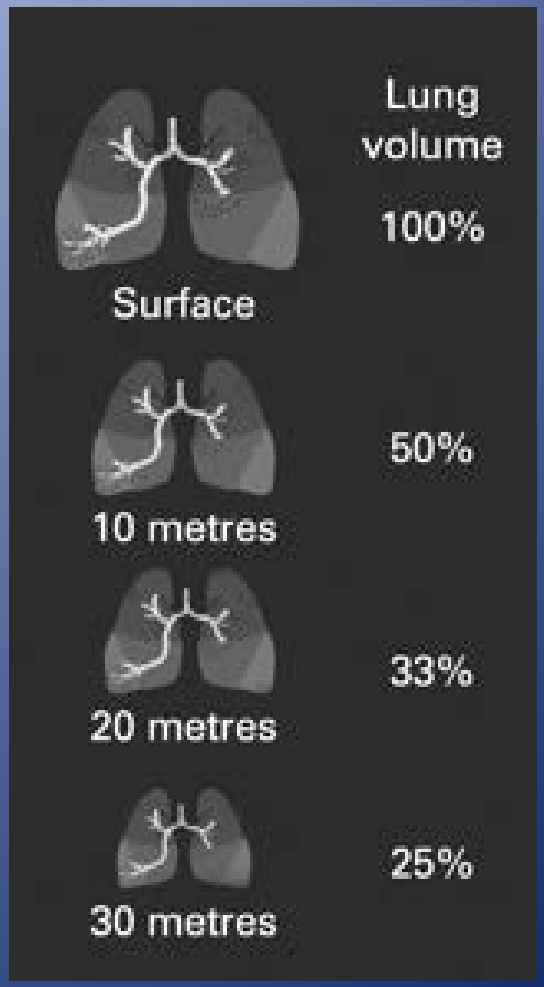


-Ill fitting mask (too tight)
-Not clearing properly
-Will resolve on own

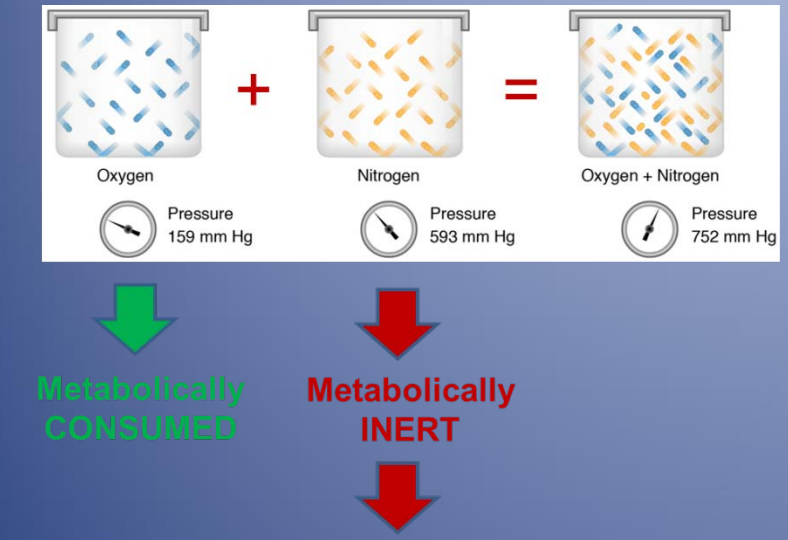
-Swallowing Air on Descent
-Vigorous/Freq Clearing
-Burping/distention Ascent

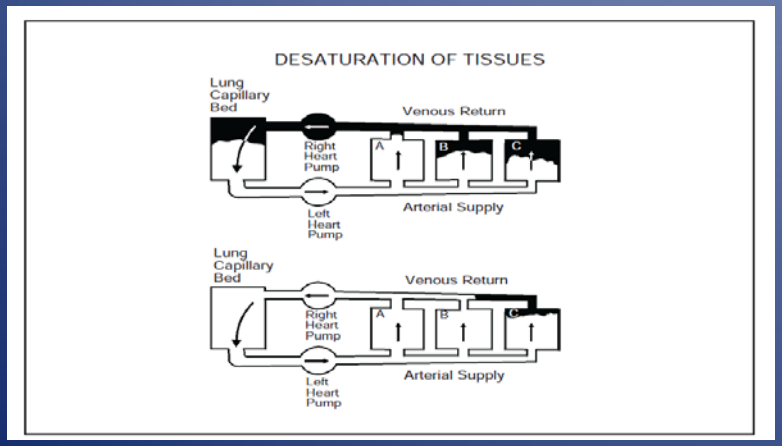
Pulmonary Over-Inflation/Pressure Syndrome (POIS/POPS)

- Due to pulmonary barotrauma
  - Breath-holding or too rapid ascent
  - Expanding gas bubbles into blood stream
  - Risk greatest near the surface
- 4 important entities:
  - Arterial Gas Embolism
    - 2nd most common cause of death in divers
    - Usually occurs within 10 minutes of surfacing
  - Pneumomediastinum
  - Pneumothorax
  - Subcutaneous emphysema
- Tx: Oxygen, Recompression
- NEEDS F/U TO R/O Underlying cause



Decompression Sickness





- Due To Rapid Decrease in Pressure
- Tissues/Blood Supersaturated
- Bubble Formation
  - Not all w/bubbles get DCS
  - Vessel occlusion
  - Tissue trapping
  - Inflammatory Cascade

Decompression Sickness

Latent time	Case (n)	Number of cases with different severity [n(%)]*		
		Mild	Moderate	Severe
≤10 min	1,139	545 (47.8%)	436 (38.3%)	158 (13.9%)
10–30 min	1,409	828 (58.8%)	471 (33.4%)	110 (7.8%)
30 min–1 h	1,648	1445 (87.7%)	154 (9.3%)	49 (3.0%)
1 h–3 h	905	841 (92.9%)	58 (6.4%)	6 (0.7%)
3 h–6 h	120	116 (96.7%)	4 (3.3%)	0 (0.0%)
6 h–24 h	49	48 (98.0%)	1 (2.0%)	0 (0.0%)
24 h–48 h	8	8 (100.0%)	0 (0.0%)	0 (0.0%)
Total	5,278	3,831 (72.6%)	1,124 (21.3%)	323 (6.1%)

*Kendall correlation analysis showed a weak negative correlation between the severity and the latent time ($\tau = -0.3604$, $P < 0.0001$).
doi:10.1371/journal.pone.0050079.t003

Symptoms by frequency	
Symptoms	Frequency
local joint pain	89%
arm symptoms	70%
leg symptoms	30%
dizziness	5.3%
paralysis	2.3%
shortness of breath	1.6%
extreme fatigue	1.3%
collapse/unconscious usness	0.5%

PLoS One. 2012;7(11):e50079: Decompression Illness: Clinical Aspects of 5278 Consecutive Cases Treated in a Single Hyperbaric Unit

Decompression Sickness

- Caisson's Disease

http://4.bp.blogspot.com/-M4Nfj7Tn4m0/TzECFjwo8VI/AAAAAAAAArI/_JEoMa3LWSg/s320/Caisson+Disease.jpg

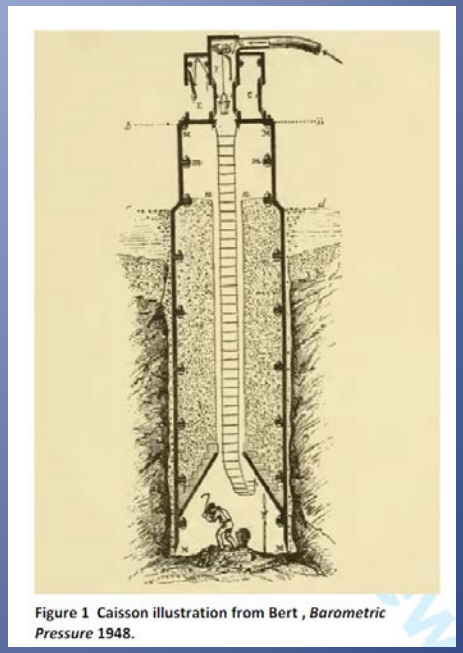


Figure 1 Caisson illustration from Bert , *Barometric Pressure* 1948.

- Categorized into Type I and Type II but argument for more of a spectrum of 'Illness'
- No dive is without DCS risk but generally ≤ 1-2% range for recreational if follow training/tables.

Decompression Sickness

- DCS Type I
  - Affects bones/joints manifesting as pain = 'The Bends'

http://ontanomagico.altervista.org/praties-grow_file/image006.jpg

  - Skin/lymphatics manifesting as *Cutis Marmorata*
    - Skin marbling
    - Itching

http://journal.nzma.org.nz/journal/124-1340/4814/content01.jpg

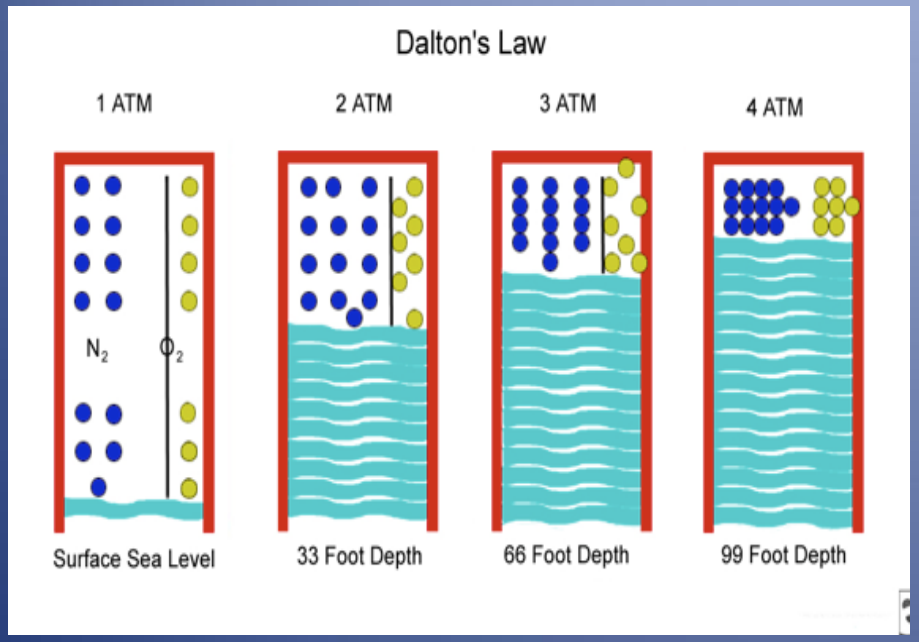
Decompression Sickness

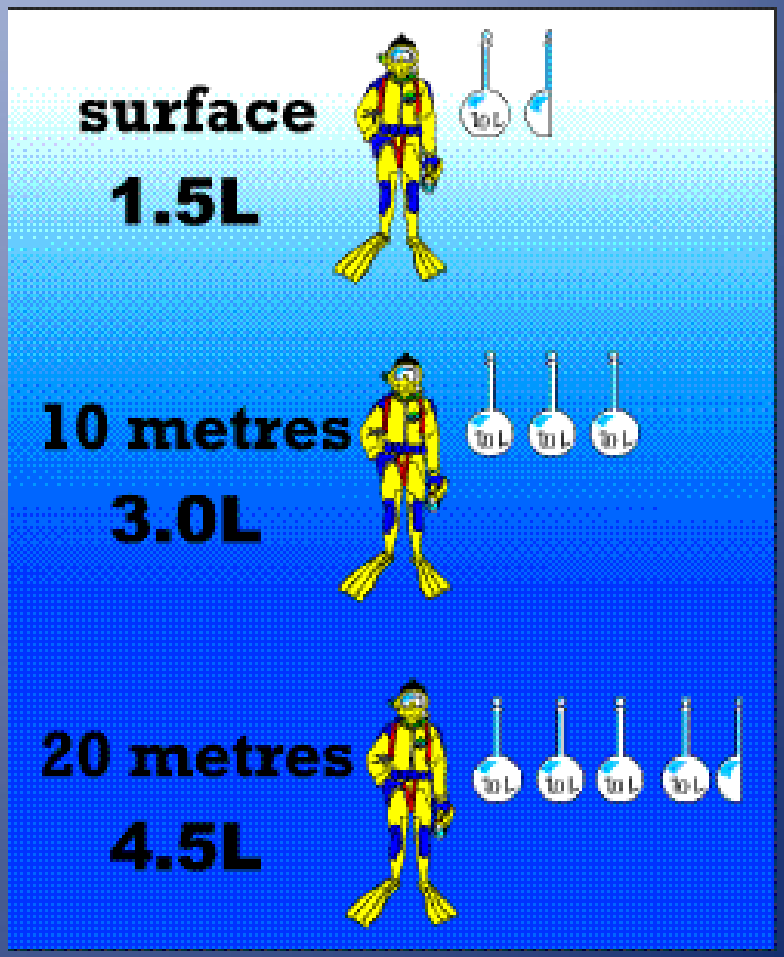
- DCS Type II
  - Life/Limb Threatening Emergency
  - Neurologic
    - Peripheral and CNS symptoms
  - Cardiopulmonary ("Chokes")
    - Overwhelming Lung/CV congestion
    - Usually from deep dive 'blow-up'
  - Vestibular ("Staggers")
    - Most common with Heliox Diving

DCS Treatment

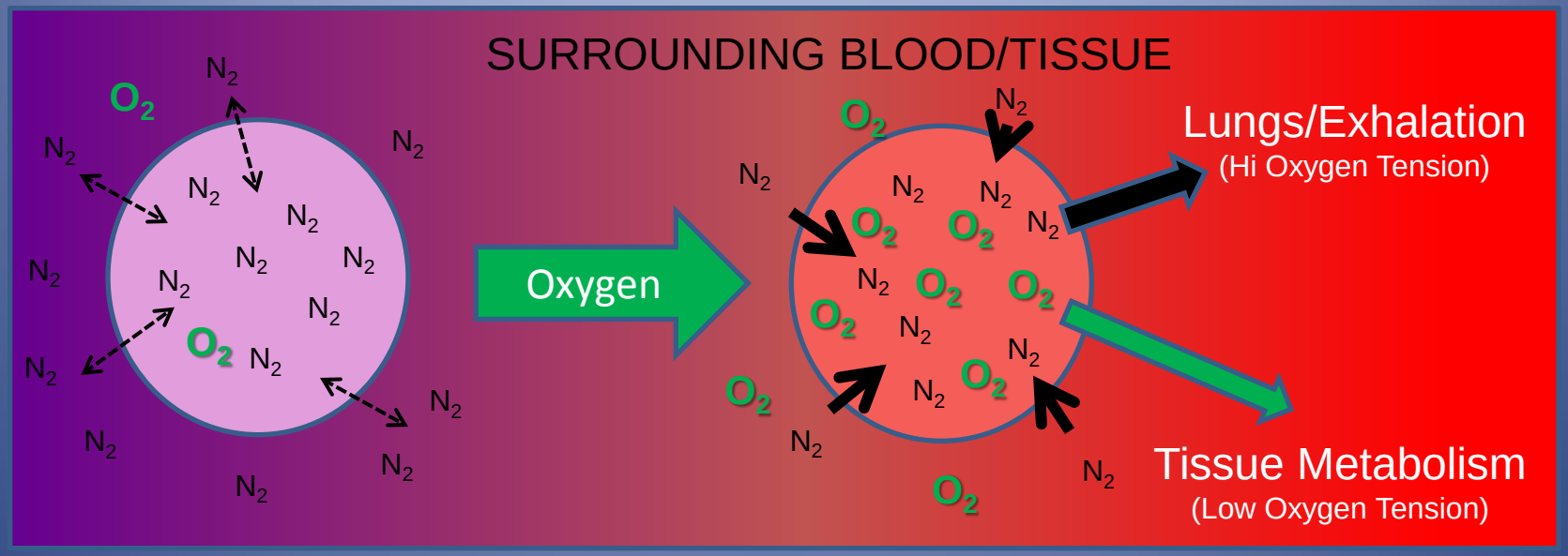
- High flow O_2
- Rest
- Hydrate
- Treat Symptoms
- Pain control
- Steroids not recom.
- For serious DCS pt likely unstable
- RECOMPRESSION TX

Nitrogen Tissue Saturation



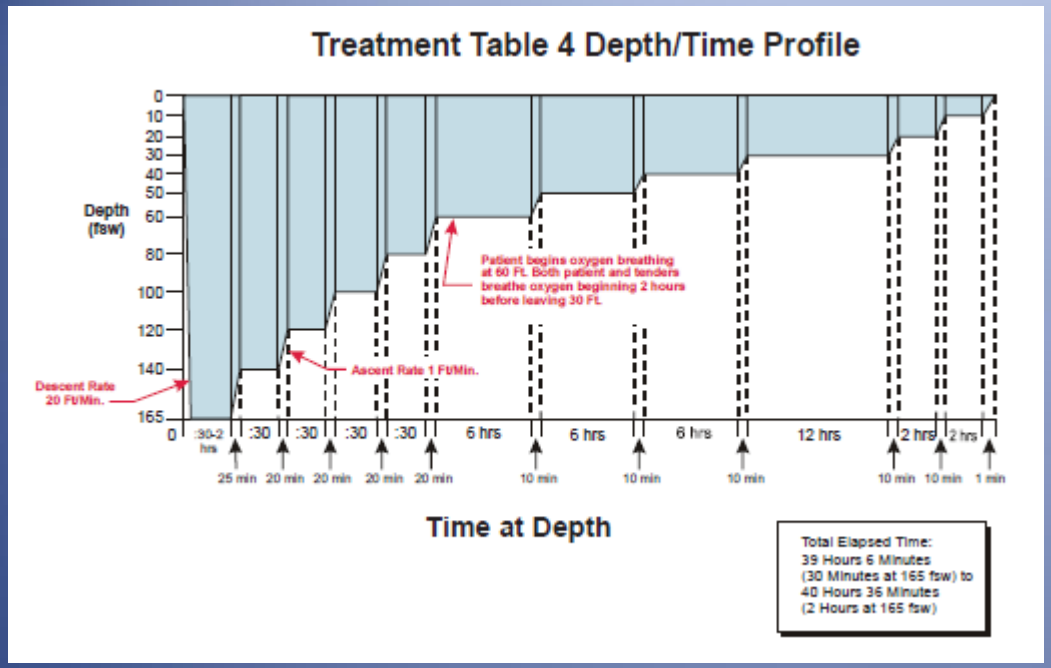


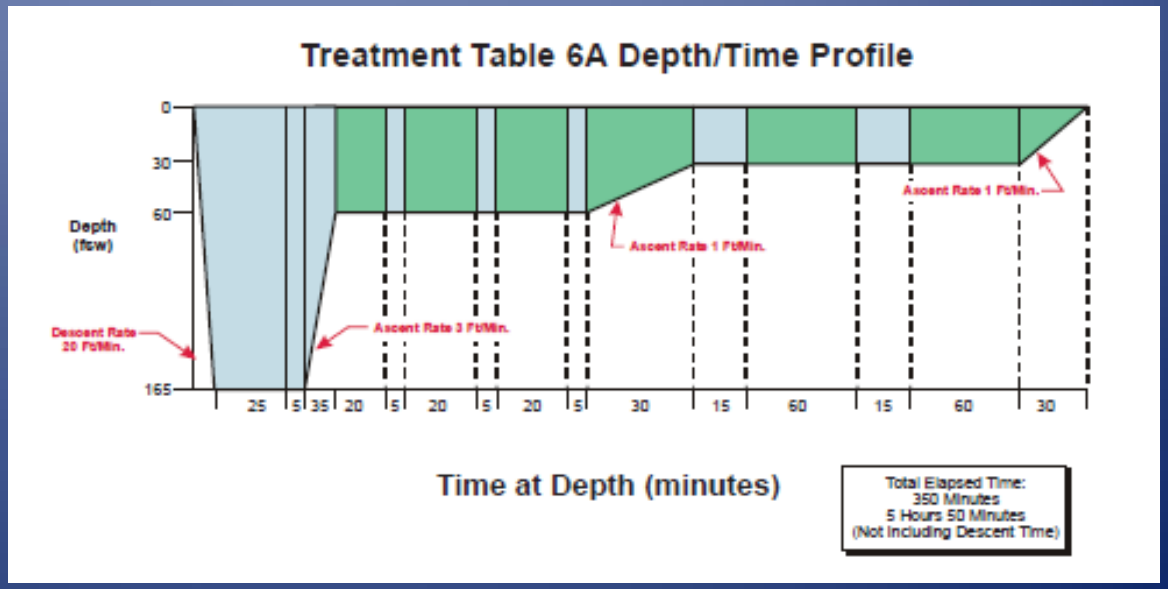
Oxygen 'Window'



- Utilizes concentration gradient
- Used to Treat & Prevent DCS

More Rapid Decompression Treatments with Oxygen





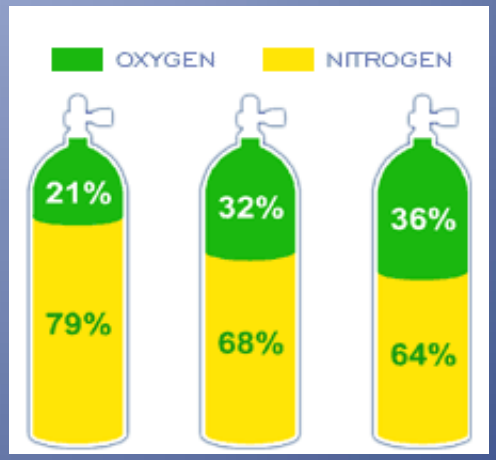
Gas Problems

Nitrogen Narcosis

- Rapture of the Deep
- Generally ≥ 100 fsw
- Martini's Law
- Loosened inhibitions
- Agitation
- Tunnel Vision
- Tinnitus/Rushing Sound
- Poor Judgement
- Simple Tasks Become Difficult
- LOC
- Resolves with ascent or He

Hypoxia/Hyperoxia

- Issue with Nitrox Diving and Rebreathers
- Hypoxia
  - Similar to Narcosis
- Hyperoxia
  - VENTID-C
    - Visual
    - Ear
    - Nausea/Vomitting
    - Twitching/tingling
    - Irritability
    - Dizziness
    - Convulsions



Carbon Dioxide/Monoxide Poisoning

- Usually from bad air source
  - Compressor intakes near exhausts
- CO_2 also from over-breathing equipment
  - Hyperventilation
  - CO_2 Scrubber Failure (Rebreathers)

- Increased RR
- Irritability
- Sweating/N/V
- Drowsiness
- HA
- Difficulty Concentrating
- Seizures (CO_2)
- LOC

Flying After Diving

- Most commercial flights pressurized to 8000 feet – USN Dive Manual has recommendations
- Each certifying organization has their own as well
- In general as follows:
  - No decompression diving: 12 hours
  - Decompression Diving: 24 hours or longer
  - Multiple days of multiple dives: 24 hours

http://www.supsalv.org/00c3_publications.asp?destPage=00c3&pageId=3.9

Returning To Diving After . . .

- Otic BT: When healed and can clear.
- Eye surgery (Lasek): 1 month w/Opth approv
- Pulmonary BT (known cause): 1 month + w/u
  - 6 months for traumatic PTX with neg w/u
- +PPD/LTBI post Tx and neg w/u
- Abd Surgery: After 3 months and neg w/u
- Successful DCS Tx post 1 Tx
  - Type I: 2d-1 week - Type II: 30+ days
- **NOTE: These are for guidelines only. Consult a DMO on case by case basis.**

US Navy Manual of the Medical Department (MANMED) Ch15-102.

Diving Key Points

- The hazards of diving and the sophistication of advising travelers are underappreciated by the travel medicine community
- Many with underlying chronic illnesses or with disabilities may dive
- Barotrauma results from the uncontrolled expansion of gas within body compartments
- Decompression sickness results from too rapid a return to atmospheric pressure
- Consider doing a detailed neuro exam on any traveling diver
- Encourage refresher courses for infrequent divers.
- There are many organizations and resources for diving travelers and travel medicine physicians

Table 39.4 Recreational and professional scuba diving organizations and resources

American Canadian Underwater Certification Inc. (ACUC)
1264 Osprey Drive, Ancaster, Ontario L9G 3L2 Canada
Tel: 905 648 5500
Fax: 905 648 5440
www.acuc.es

American Nitrox Divers International (ANDI)
74 Woodcleft Avenue, Freeport, NY 11520 USA
Tel: 516 546 2026
Fax: 516 5446 6010
www.andihq.com

British Sub-Aqua Club (BSAC)
16 Upper Woburn Place, London WC1 0QW, UK
or, Telford's Quay, Ellesmere Port, South Wirral,
Cheshire L65 4FY, UK
Tel: 44 0151 350 6200
Fax: 44 0151 350 6215
www.bsac.com/

The Canadian Association for Underwater Science
P.O. Box 13, Station C
St. John's NF A1C5H5 CANADA
www.caus.ca/

CMAS – Confed. Mondiale Des Activites Subaquatique
Viale Tiziana, 74 Rome, Italy
Tel: 011 39 6 36858480
Fax: 011 39 6 36858490
www.cmas2000.org

Defense and Civil Institute of Environmental Medicine (DCIEM)/Defence R&D Canada (DRDC Toronto)
1133 Sheppard Ave. West, Toronto, ON M3M 3B9 Canada
Tel: 1 416 635 2000
Fax: 1 416 635 2104
www.drdc-rddc.dnd.ca/success/diving_e.html

Divers Alert Network
The Peter Bennett Center
6W Colony Pl, Durham, NC 27705-9815 USA
Tel: 919 684 2948
www.diversalertnetwork.org
This organization is an international diving medicine network, which has taken a high profile lead in promoting dive medicine and dive safety.

Handicapped Scuba Association
1104 El Prado, San Clemente, CA 92672-4637
Tel./Fax: 714 498 6128
www.hsascuba.com/

International Association of Nitrox & Technical Divers (IANTD)
9628 NE 2nd, Suite D, Miami Shores FL 33138 USA
Tel: 305 751 4873
Fax: 305 751 3958
www.iantd.com/

Japan Underwater Leaders & Instructors Assoc.
Let's Bld 1F 2-18-5, Kohama-Nishi Suminoe-Ku,
Osaka, 559, Japan
Tel: 011 816 6751228
Fax: 011 816 6751229
www.julia.ne.jp/

Korea Underwater Association
Rm. 149, #2 Gymnasium, Oryun-dong, Songpa-ku, Seoul, 138-151, Korea
Tel: 011 822 4204293
www.kua.or.kr

International Diving Educators Association (IDEA)
P.O. Box 8427, Jacksonville, FL 32239 USA
Tel: 904 744 5554
Fax: 904 743 5425
www.idea-scubadiving.com/

MDEA - Multinational Diving Educators Assoc.
Box 3162, 200 22 Malmö, Sweden
Tel: +46 40 290240
Fax: +46 40 290240
www.mdeaeurope.com/

National Association of Underwater Instructors (NAUI)
P.O. Box 14650 Montclair, CA 91763 USA
Tel: 909 621 5801
Fax: 909 621 6405
www.naui.org

Professional Association of Diving Instructors (PADI)
1251 East Dyer Road, #100 Santa Ana, CA 92705
Tel: 714 540 7234
Fax: 714 540 2609
www.padi.com

Scuba Schools International (SSI)
2619 Canton Ct., Fort Collins, CO 80525 USA
Tel: 970 482 0883
Fax: 970 482 6157
www.ssiusa.com/

Sub-Aqua Association (SAA)
19 Harrier Drive, Canford Marina, Wimborne, Dorset BH21 1XG UK
Tel: 0151 287 1001
Fax: 0151 287 1026
www.saa.org.uk

South Pacific Undersea Medical Society (SPUMS)
c/o Australian and New Zealand College of Anaesthetists
630 St Kilda Road, Melbourne, Victoria 3004, Australia
www.spums.org.au/index.html

Surf Life Saving Australia
Locked Bag 2, Bondi Beach, NSW, 2026, Australia
Tel: 02 9130 7370
Fax: 02 9130 8312
www.slsa.asn.au/

Undersea and Hyperbaric Medical Society
10531 Metropolitan Ave, Kensington, MD 20895
Tel: 301 942 2980
Fax: 301 942 7804
www.uhms.org

YMCA National Scuba Program
5825-2A Oakbrook Parkway, Norcross GA 30093
Tel: 404 662 5172
Fax:404 242 9059
www.ymcascuba.org/

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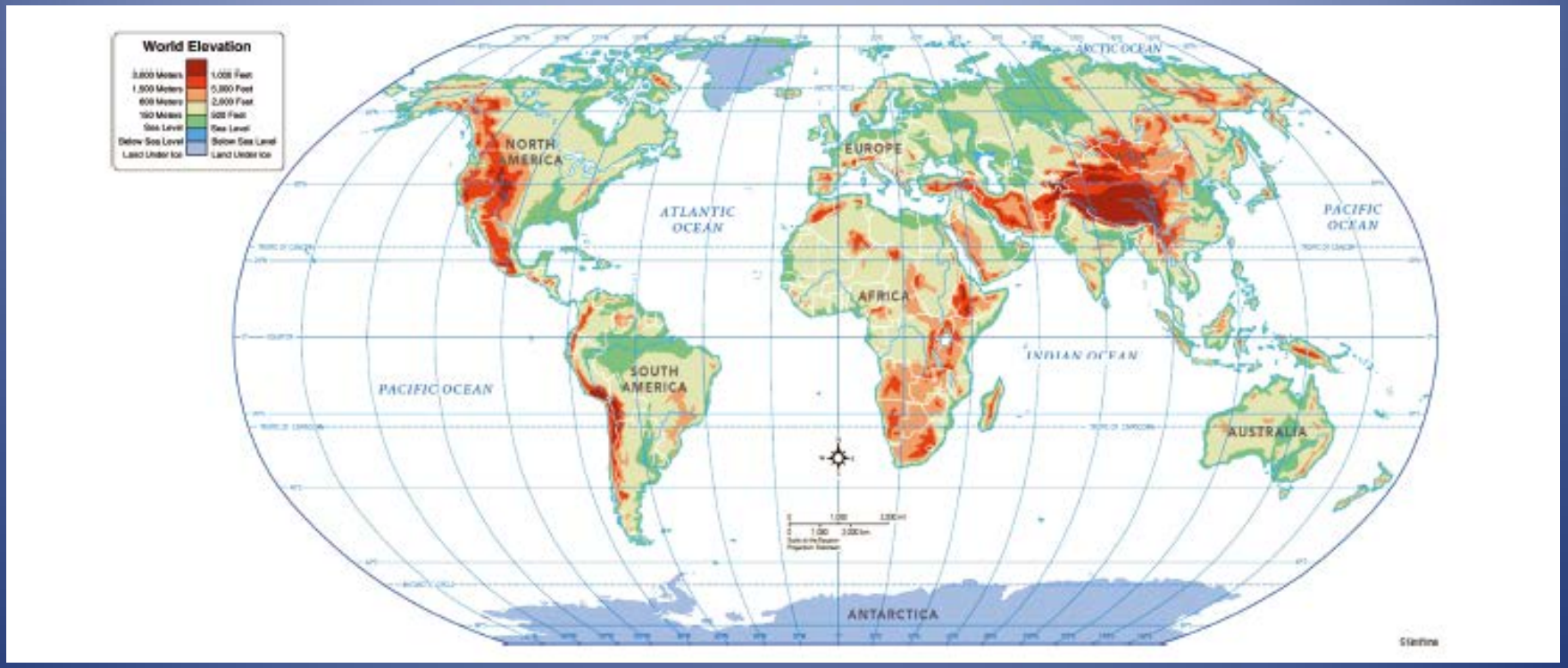
Problems with Altitude

Problems with Altitude

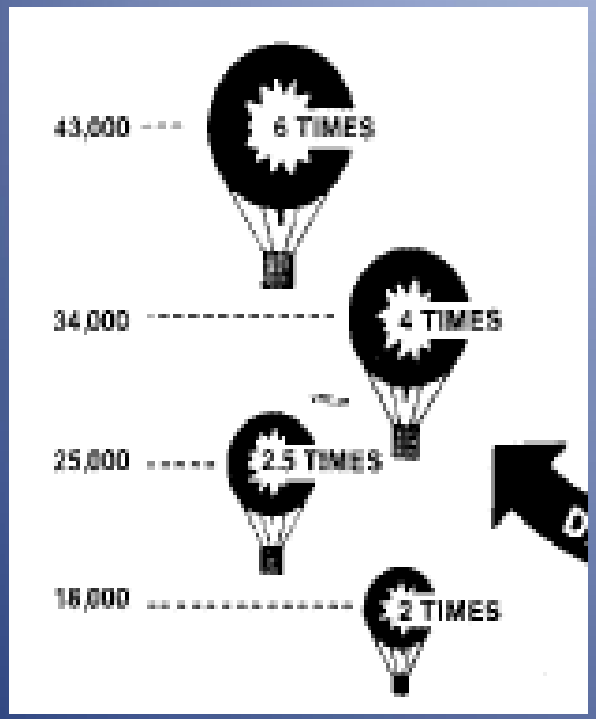
High Altitude Definitions

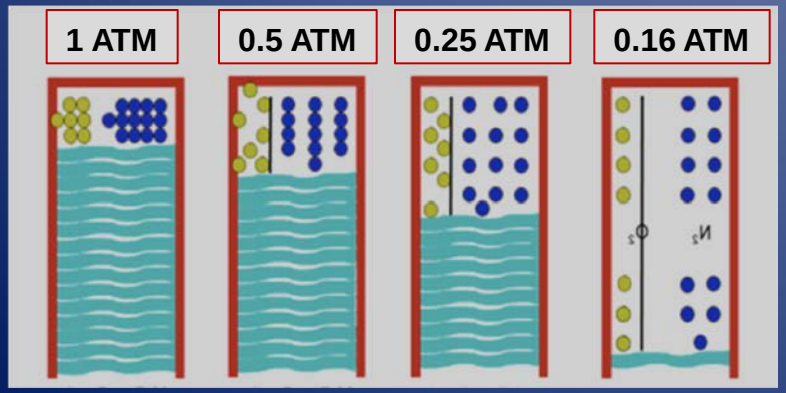
- **Over 1500m (4900 ft)**
- **Moderate altitude is 2000-3500m (6600 to 11,500 ft)**
  - Mild tissue hypoxia from low arterial PO2 and altitude sickness is common
- **Very high altitude is 3500-5500m (18,000 ft)**
  - Arterial oxygen saturation is not maintained
  - HAPE and HACE most common in this range
- **Extreme altitude is over 5500m (18,000 ft)**
  - Successful long-term acclimatization is “impossible”

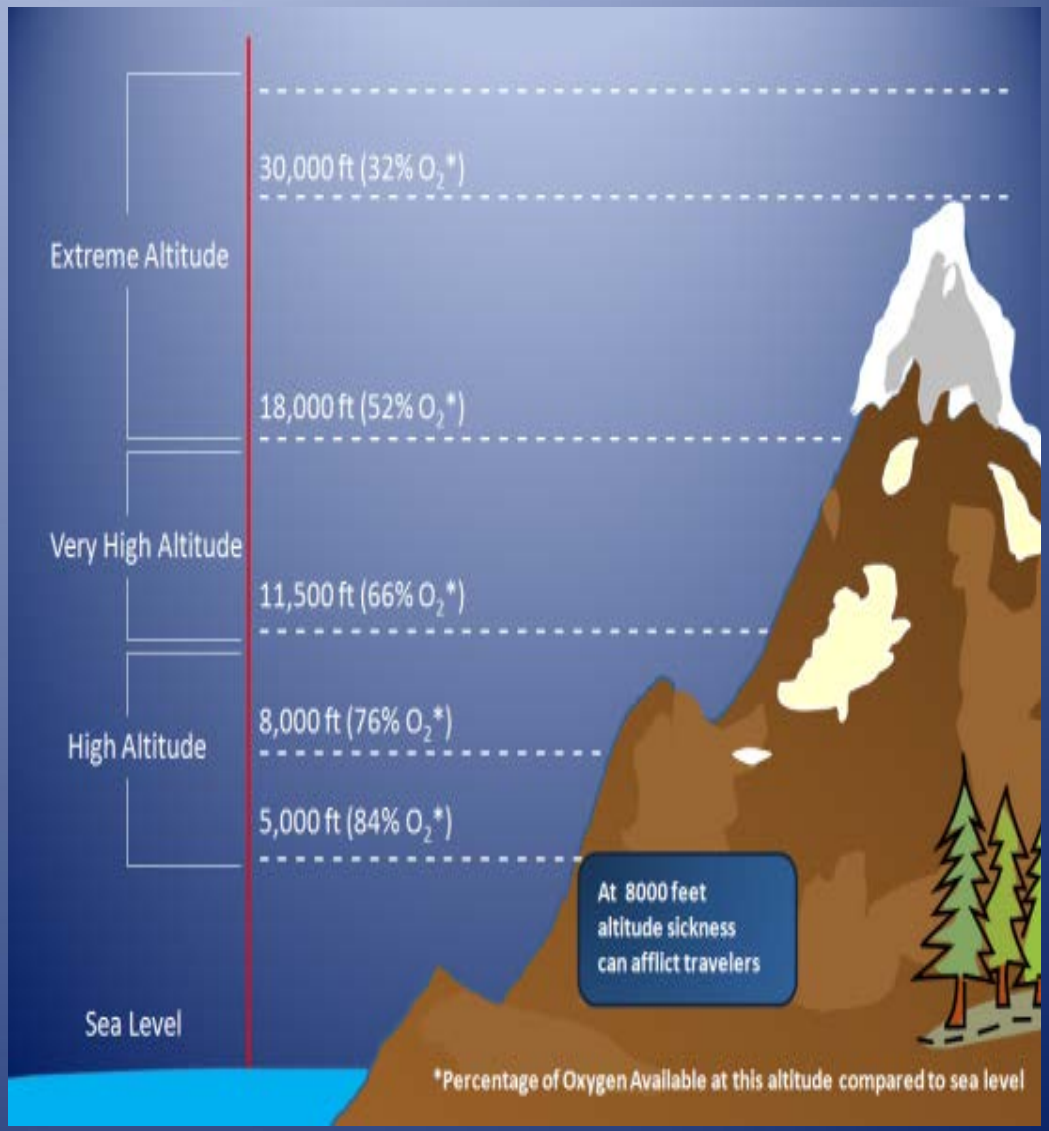


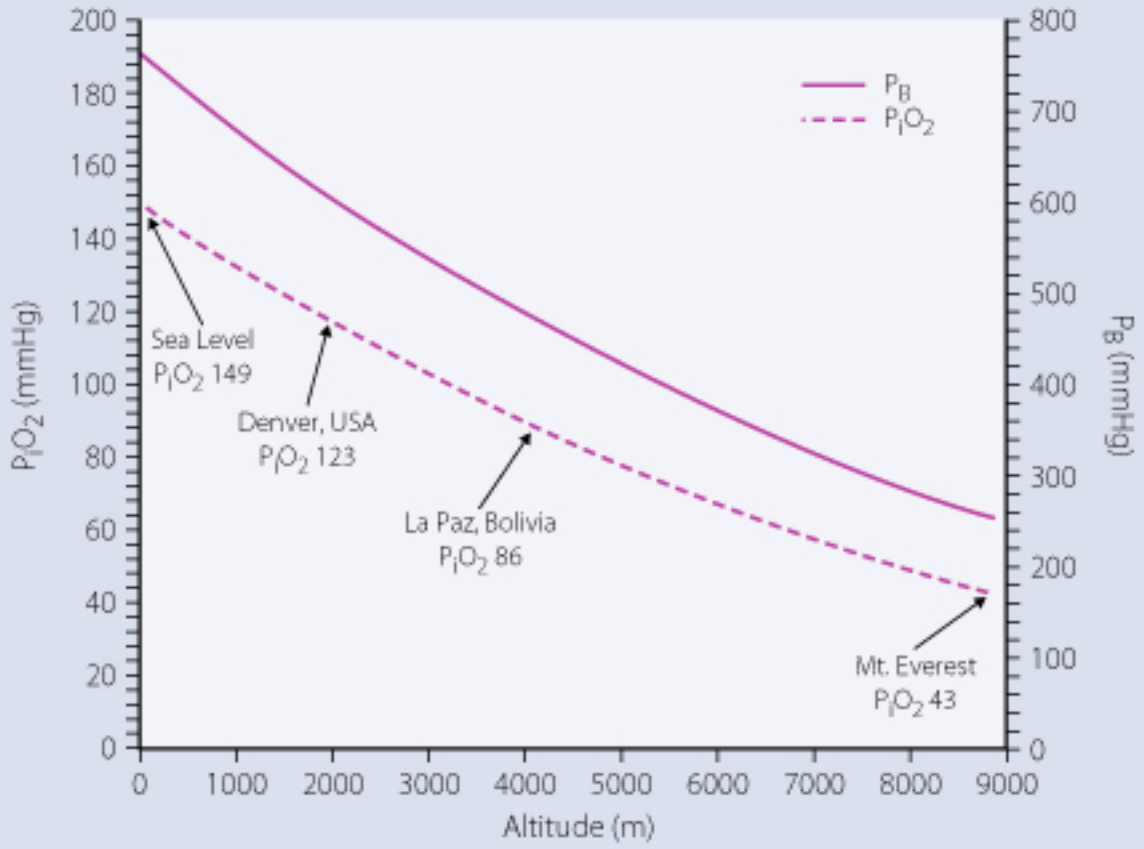
Journal of Travel Medicine 2013; Volume 20 (Issue 4): 247–255

Boyle & Dalton . . . Again!









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Temperature and other issues

- **Decreases up to 12° F (6.5° C) per 3300ft (1000m).**
  - Effects of hypothermia can be additive
    - HAPE
    - Frostbite
- **UV exposure increases 4%/1000ft (300m)**
  - Sunburn
  - UV keratoconjunctivitis
  - Cataracts
- **Dry air predisposes to dehydration/dry airways**

Demographics

	Persons	Activities	N
High altitude 1500 - 3500 m (5,000 - 11,500)	Everyone	Skiing/Air Travel Touring Trekking Mountaineering	Millions
Very High altitude 3500-5500 m (11,500 - 18,000)	Healthy adults	Skiing Trekking Mountaineering	Many thousands
Extreme altitude 5500 m > 18,000 feet	Extreme athletes	Mountaineering	Few thousands

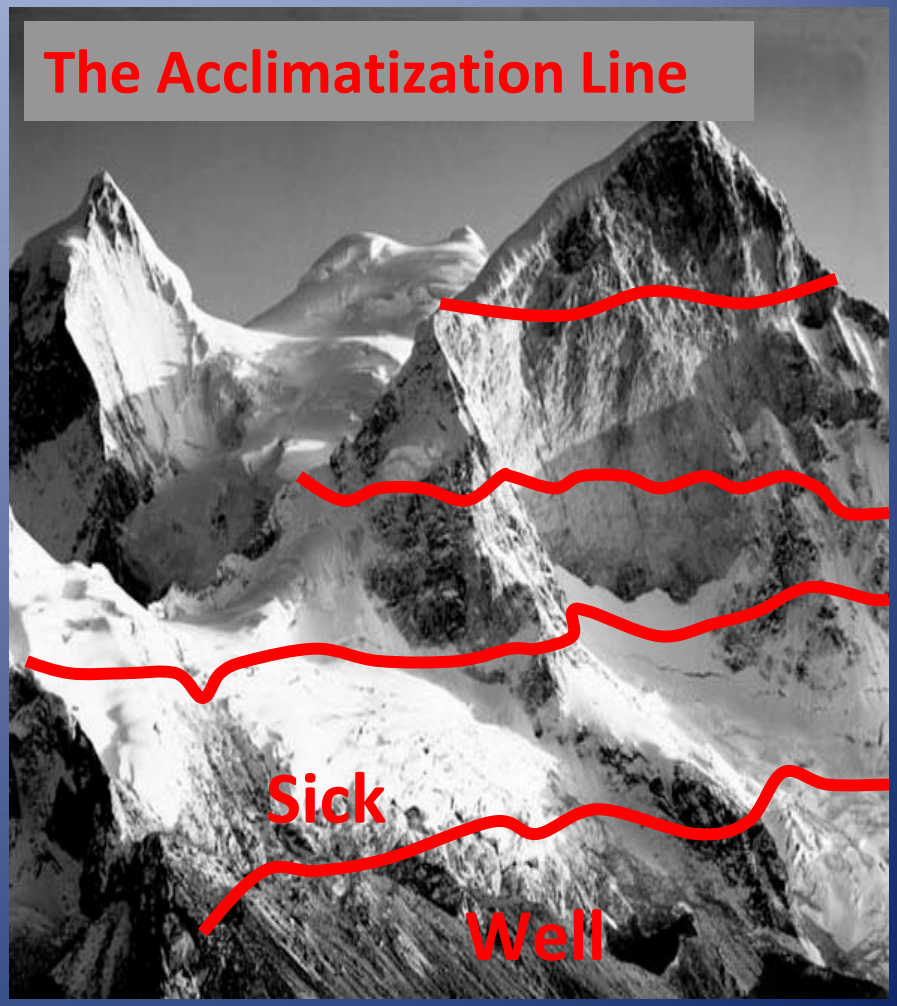
Acclimatization is Key!

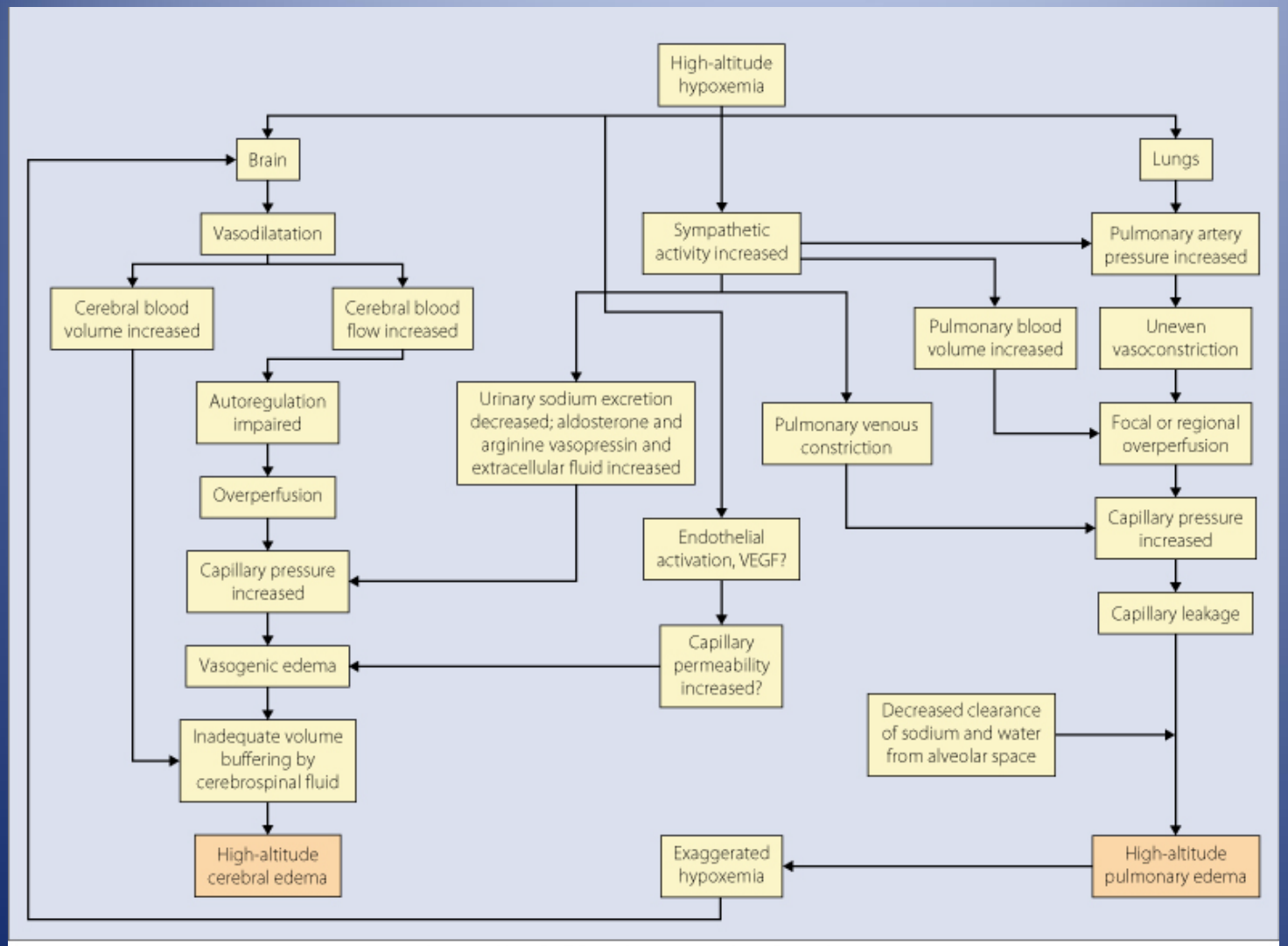
- If you could immediately "dissaparate" to the summit of Everest (P_iO_2 43)→ LOC w/in 2 minutes.
- Normal Physiologic Changes:
  - Hyperventilation (Resp Alkalosis)
  - SOB w/exercise (↓VO_2 max 10%/1000m > 1500m)
  - Increased urination (Bicarb excretion)
  - Increased Cerebral Blood Flow (HA?)
  - Increased Hgb
  - Changed breathing pattern at night (Cheyne-Stokes)
  - Awakening frequently at night/Headache (up to 80%)

Acclimatization

- **Initially @ 8,000 to 10,000 ft for most**
  - This line can move up the mountain
    - @ 400m/day (1300ft/d)*
  - If you get too far above the line it only gets worse, no acclimatization possible
- **Avoid heavy excersion**
- **Don't ascend when symptomatic**

* Am J Respir Crit Care Med 2012; 185:192–198





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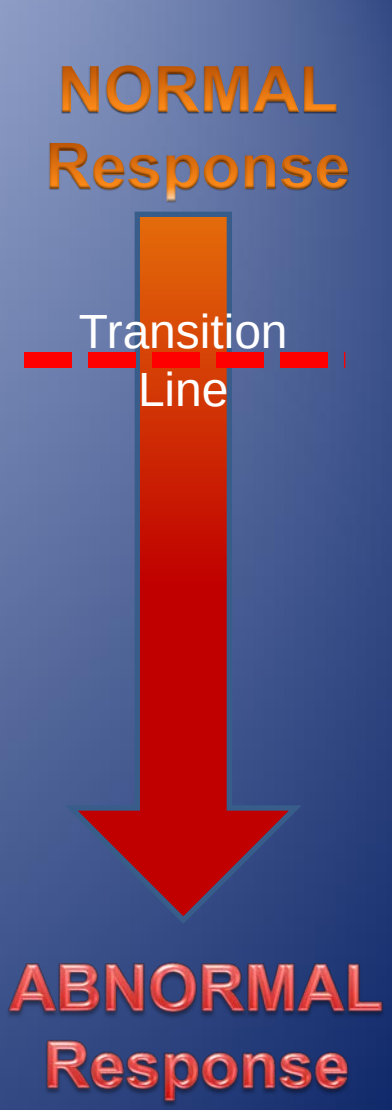


HIGH ALTITUDE SYNDROMES

High Altitude Syndromes

- Cerebral and pulmonary syndromes that develop in non-acclimatized persons
- **Cerebral**
  - Acute mountain sickness (AMS)
  - High altitude cerebral edema (HACE)
- **Pulmonary**
  - High altitude pulmonary edema (HAPE)
- **Pathophysiology of hypoxia in otherwise healthy persons**

High Altitude Syndromes

Frequency of AMS, crackles, and HAPE in adults on ascent to moderately high altitudes (3600 – 4600 m)

Study	Location	Altitude	Frequency of: Number	AMS	Lung crackles	Clinically relevant HAPE*
Hackett and Rennie[4]	Pheriche, Nepal	4243 m	278	53%	"Common"	2·5%
Houston[2]†	Mt Rainier, USA	4400 m	141	··	15%	0·5%
Hackett and Rennie[12]	Pheriche, Nepal	4243 m	200	43%	23%	4·5%
Maggiorini et al[6]	Swiss Alps	3650 m	82	34%	27%	2·4%
		4559 m	209	53%	26%	3·8%
Basnyat et al[13]	Gosaikund, Nepal	4300 m	228	68%	··	4·8%
Cremona et al[17]	Monte Rosa, Italy	4559 m	262§	··	15%‡§	0·4%

*Definition varies from study to study

†Unpublished data as cited by the author and by Hultgren and Marticorena[14]

‡Includes both crackles and radiographic evidence of oedema

§Excludes the one identified case of clinically relevant HAPE, for whom data were incomplete.

Lancet 359, Issue 9303, 26 January 2002 Pages 276-277

High Altitude Syndromes

- Rate of ascent (>1300 ft/day)
- Altitude
  - Altitude reached and slept at
  - Incidence of AMS at 2000-3500m is 10-40%
  - 25-50% above 4000m
- Variable susceptibility
- Past history of AMS is best predictor
  - Muted response & desaturation to hypoxia
- Slight decrease in risk after age 50
- Physical fitness NOT protective
  - But obesity/smoking may be a risk factor
- HTN, CAD and DM do not increase risk

Acute Mountain Sickness AMS & High-Altitude Cerebral Edema (HACE)

- **Spectrum of disease**
- Pathophysiology poorly understood
  - Effects and response to hypoxia
    - Cerebral vasodilation
    - Impaired cerebral autoregulation
    - Elevated capillary pressures
    - Cytokine induced changes in BBB permiability
      - Capillary leaks
      - Edema
- Edema is what will cause herniation and death

AMS/HACE

- **Occurs within 48 hrs of ascent to > 8000 ft**
  - After rapid ascent (1 day or less)
  - Usually within hours of arrival but up to 3 days out
- **Similar to 'hangover' or afebrile viral illness**
  - HA that is throbbing /bilateral
  - Anorexia, N/V
  - Weakness, lightheadedness
  - Often report reduced UOP (vs expected increase)
  - Most resolve 1-2 days depending on situation
- Can worsen to ataxia, MS changes = HACE
  - < 10% go on to HACE (40% mortality with limited medical care.)

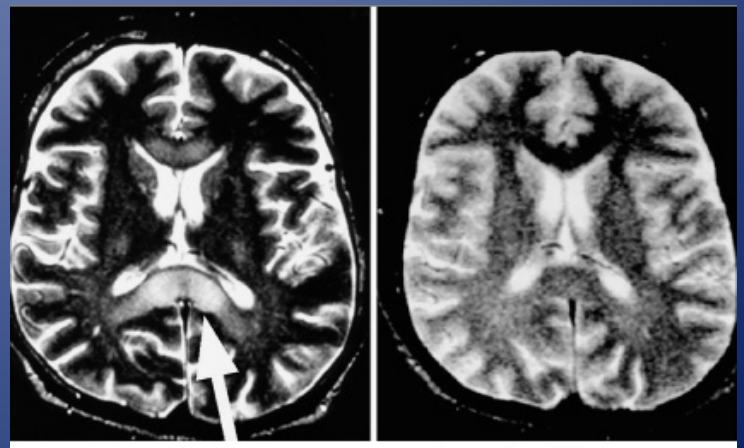
AMS Worksheet

"The Lake Louise Consensus on the Definition and Quantification of Altitude Illness" in Sutton JR, Coates G, Houston CS(Eds), Hypoxia and Mountain Medicine. Queen City Printers, Burlington, Vermont, 1992.

TIME					
Altitude					
SYMPTOMS					
Headache + 1 other symptom = AMS					
0 – None					
1 – Mild					
2 – Mod					
3 – Severe					
GI					
0- None					
1- Nausea					
2 - Mod N/V					
3 - Severe					

AMS/HACE Treatment

- No further ascent until asymptomatic
- Descend to lower altitude if no improvement with therapy
  - 500-1000m (1600-3200ft) usually sufficient
- Descend at first sign of HACE
- 0_2 if available



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AMS/HACE Treatment

- Acetazolamide
  - Speeds acclimatization
  - Hastens resolution in 12-24hrs
- Dexamethasone
  - Rapidly reverses symptoms 2-4 hrs
  - Does not affect acclimatization
  - Rebound
    - Continue 1-2 days post descent or when MS clears
- No evidence for Coca leaf tea or garlic

AMS/HACE Treatment

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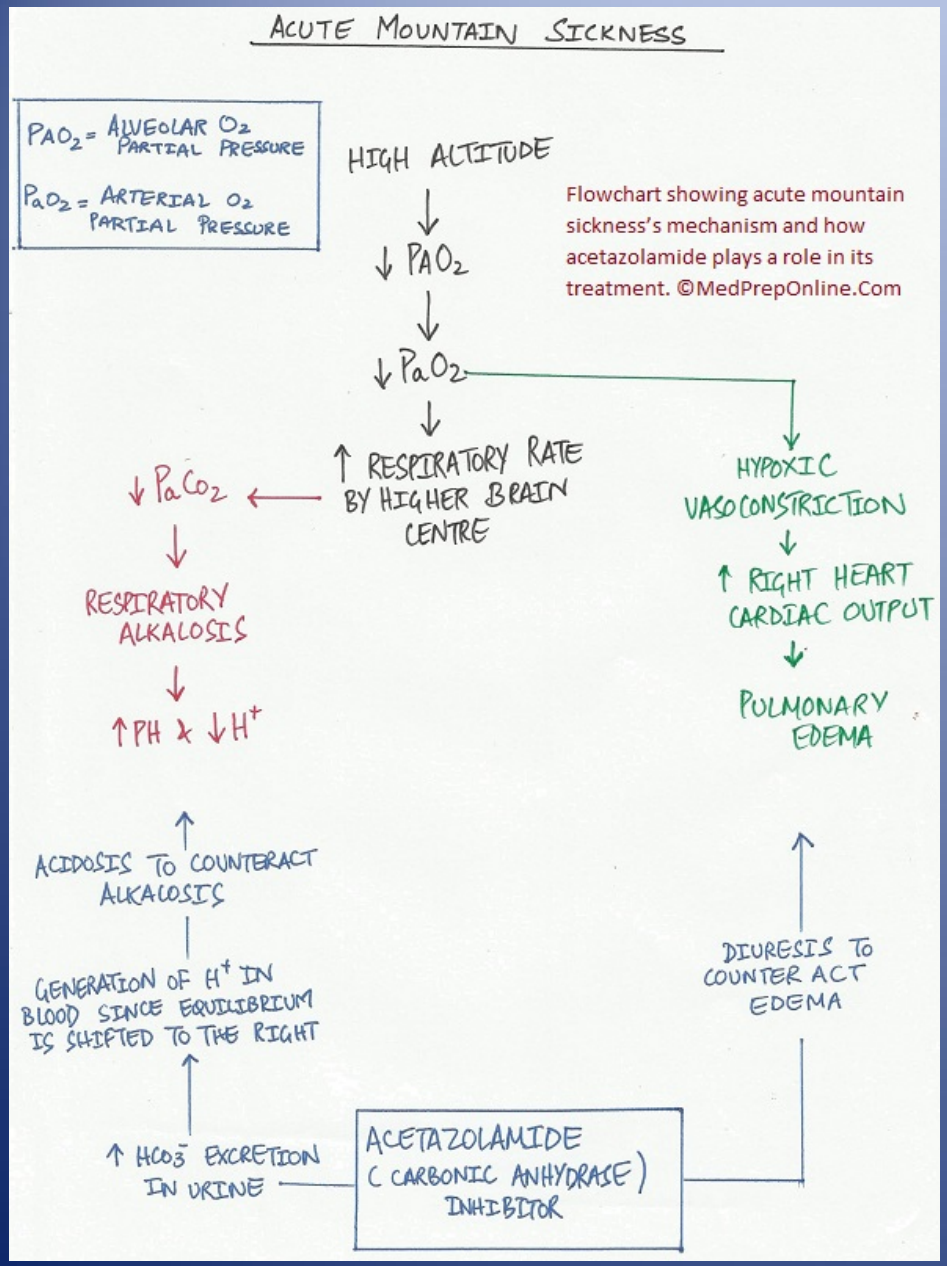
- Gamow Bag, CERTEC, Pac
- Manually inflated
- Pressurize to 105-220 mmHg above ambient
  - @ 1/3 descent
- Similar efficacy to O2
- 1 hour to effect

AMS/HACE Prevention

- Preacclimatization
- **Acclimatization!!!**
  - Effects for AMS will last for > 1wk; 1-2d for HAPE
- **Acetazolamide**
  - Will not mask AMS
  - Appears 125 mg BID as effective as 250mg or 500mg QD
    - Journal of Travel Medicine 2012; Volume 19 (Issue 5): 298–307



Flowchart showing acute mountain sickness's mechanism and how acetazolamide plays a role in its treatment. ©MedPrepOnline.Com

Flowchart showing acute mountain sickness's mechanism and how acetazolamide plays a role in its treatment. ©MedPrepOnline.Com

http://www.medpreponline.com/2012/12/acute-mountain-sickness-and.html

Acetazolamide

- Sulfa allergy a concern
- Serious allergic reactions are rare
- Although at increased risk, individuals with Sulfa allergy are less likely to react to Diamox than PCN allergic patients
- Travelers with any allergic history should test their tolerance prior to departure
- References:
  - Strom BL et al. Absence of cross-reactivity between sulfonamide antibiotics and sulfonamide nonantibiotics. N Engl J Med. 2003; 349(17):1628-1635.
  - Editorial: Ray WA. N Engl J Med. 2003; 349(17):1592-1594.

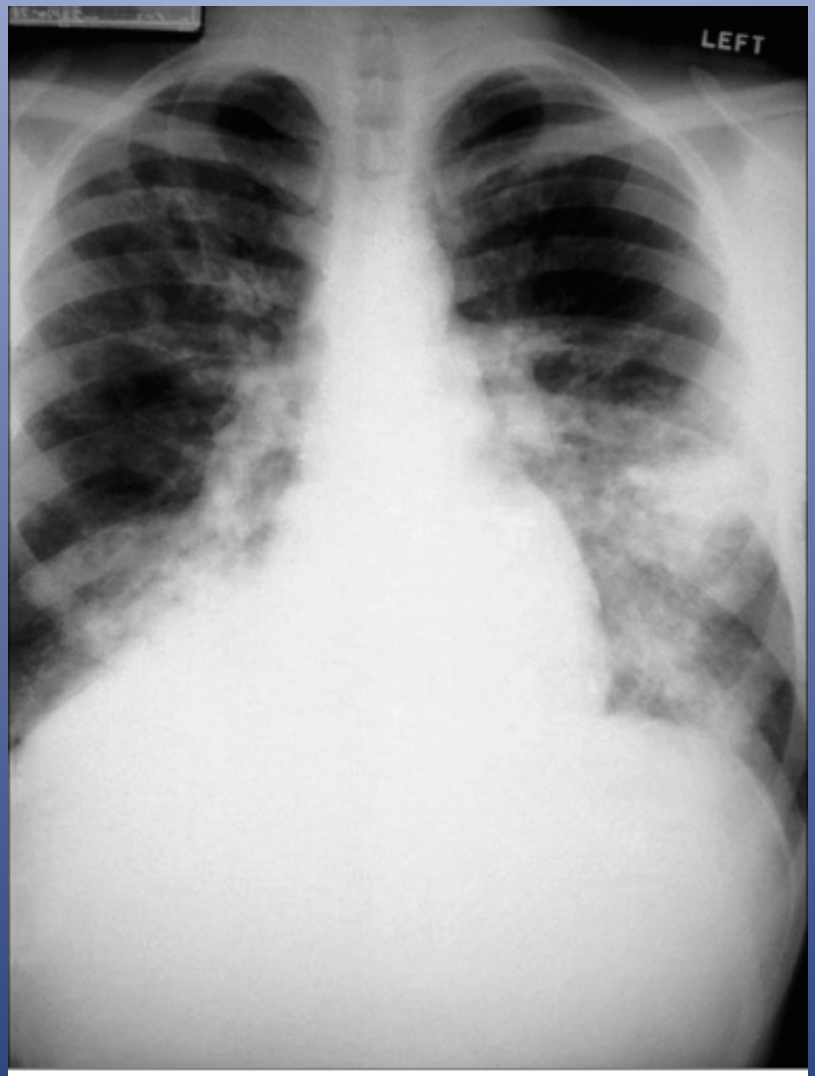
High Altitude Pulmonary Edema (HAPE)

- Incidence 0.01%-15%
- Genetic predisposition
  - Pulmonary artery hypertension
    - Exaggerated hypoxic pulmonary vasoconstriction
- Male
- Pre-existing medical conditions
  - Pulmonary HTN
  - Restricted pulmonary vascular bed
- Non-cardiogenic hydrostatic pulmonary edema

HAPE

- **Occurs 2-4 days after ascent**
- Worse at night
- Decreased exercise performance
- Dry cough
- Insidious onset that can quickly become fatal
  - Productive frothy cough
  - Severe Dyspnea
  - ↑HR and RR
  - Drowsiness and other CNS symptoms

HAPE



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HAPE Severity Classification

Hackett PH, Roach RC: *High-Altitude Medicine.* In: Auerbach PS (ed): Wilderness Medicine, 4th edition; Mosby, St. Louis, MO 2001; 2 - 43.

Grade	Symptoms	Signs	Chest X ray
1 Mild	Dyspnea on exertion Dry cough Fatigue while moving uphill	HR (rest) < 90 - 100 RR (rest) < 20 Dusky nail-beds or exertional desaturation +/- localized crackles	Minor exudate involving < 25% of one lung field
2 Moderate	Dyspnea, weakness, fatigue on level walking Raspy cough Headache, anorexia	HR 90-100 RR 16-30 Cyanotic nail-beds Crackles present + / - ataxia	Some infiltrate involving 50% of one lung or smaller area of both lungs
3 Severe	Dyspnea at rest Extreme weakness Orthopnea Productive cough	HR > 110 RR > 30 Facial and nail-bed cyanosis Bilateral crackles Blood tinged sputum Stupor or coma	Bilateral infiltrates > 50% of each lung

HAPE Treatment

- Descend if possible
- Oxygen
- **Nifedipine if descent is NOT possible**
- Hyperbaric treatment
  - 1 hour increments; 3-6 hours usually
- May need 3 days – 2 weeks for full recovery
  - Excellent prognosis with rapid recovery
  - May cautiously re-ascend after

HAPE Prevention

- Indicated if a history of repeated episodes
- Slower ascent
- Nifedipine
  - Use prophylactically or at the first signs
- Salmeterol
  - 50% reduction in susceptible persons

Other HAPE Prophylaxis

Table 1—*Pharmacologic Treatment Option for Altitude Illnesses, Not Including Recommendations of Ascent Rates, Descent Rescue*

Illness	Medication	Prevention	Treatment	Tested
AMS	Acetazolamide (oral)	125–250 mg bid	250 mg bid	Yes
	Dexamethasone (oral, IM, IV)	2 mg q6h or 4 mg bid	Same	Yes
HACE	Dexamethasone (oral, IM, IV)	Same as for AMS	8–10 mg initial dose then 4 mg q6h	Yes
HAPE	Nifedipine (oral)	20–30 mg extended release bid	10 mg sublingual initial dose, then 20–30 mg extended release bid	Yes
	Tadalafil (oral)	10 mg bid	Not tested for treatment	Yes
	Sildenafil (oral)	50 mg tid	Not tested for treatment	Yes
	Salmeterol (inhaled)	125 µg bid	Not tested for treatment	Yes

Schoene - *CHEST* 2008; 134:402–416

OTHER ALTITUDE RELATED CONDITIONS

Other Altitude-Related Conditions

- **'High Altitude Syncope'** – first 24 hours
  - No work-up needed unless recurs
- **Focal Neurologic Deficits**
  - Unmasked conditions that need evaluation
- **High-Altitude Retinal Hemorrhage (HARH)**
  - Altitude dependent 4%(4243m) to 50%(5360m)
  - Descend if symptomatic; Usually resolve completely within a few weeks.

Other Altitude-Related Conditions

- **Peripheral Edema**
  - Females more at risk; Evaluate for AMS
  - Can use diuretics but caution with dehydration
- **High-altitude cough**
  - Altitude dependent; Cold/Arid
  - Paroxyxmal; Forceful; Purulent; Afebrile
  - Normal exercise tolerance and exam
  - Can have associated sore throat
  - Symptomatic treatment
- **UV Keratitis aka "Snow Blindness"**
  - Sunglasses!; Ointment; Analgesics : 24-48h to clear

Summary of Management

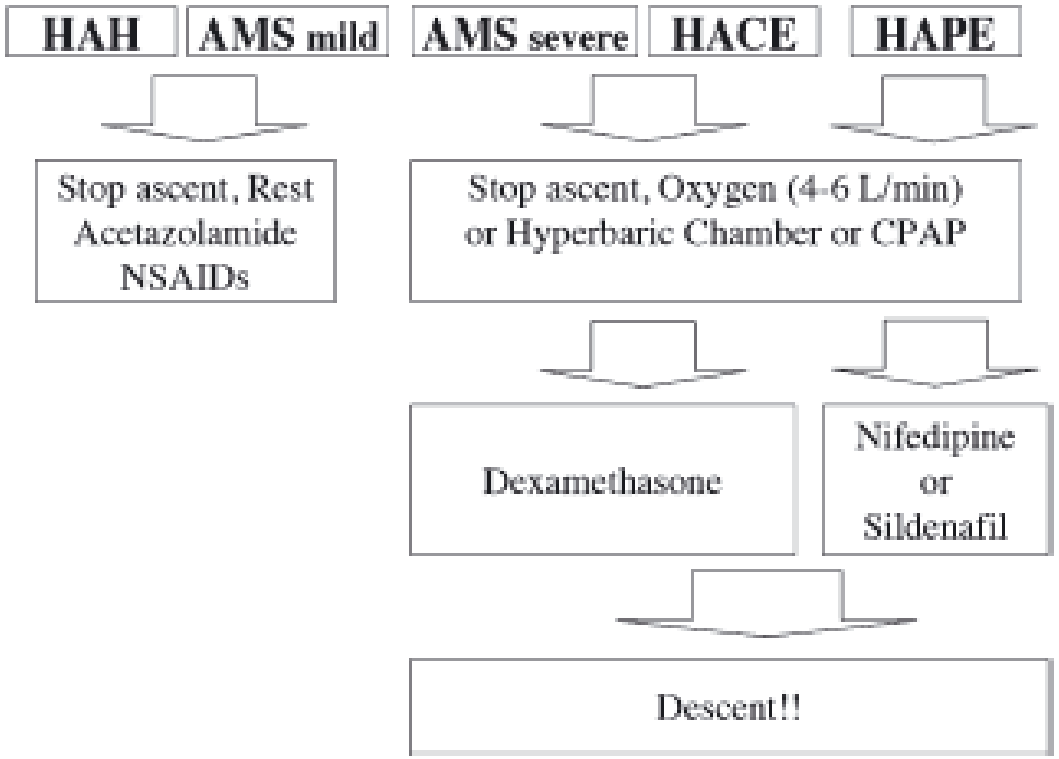

Figure 2 Overview on approved strategies of field treatment of high-altitude illnesses.

* Am J Respir Crit Care Med 2012; 185:192–198

Table 1 Medications for prevention and therapy of high-altitude illnesses.[51,55–82]

High-altitude illness	Medication	Prevention administration, dose	Therapy administration, dose	Side effects
Sleep disturbances	Acetazolamide	Oral: 125 mg once per night		Diuresis, malaise, paresthesias, nausea, and taste disturbances
	Temazepam	7.5–10 mg once per night	7.5–10 mg once per night	Drowsiness and dizziness
HAH	Acetaminophen	Oral: 1 g every 6 hours	Oral: 1 g every 6 hours	
	Ibuprofen	Oral: 400 mg every 8 hours	Oral: 400 mg every 8 hours	Gastrointestinal bleeding
AMS	Acetazolamide	Oral: 125 mg every 12 hours Pediatrics: 2.5 mg/kg every 12 hours	Oral: 250 mg every 12 hours Pediatrics: 2.5 mg/kg every 12 hours	Diuresis, malaise, paresthesias, nausea, and taste disturbances
	Dexamethasone	Oral: 2 mg every 6 hours or 4 mg every 12 hours	Oral, im, iv: 4 mg every 6 hours	Hyperglycemia and psychiatric alterations
	Theophylline	Oral: 250 mg SR version every 12 hours		Nausea, headache, and interaction with azithromycin
	Acetaminophen		Oral: 1 g every 6 hours	
	Ibuprofen		Oral: 400 mg every 8 hours	Gastrointestinal bleeding
HACE	Dexamethasone	Oral: 2 mg every 6 hours or 4 mg every 12 hours Pediatrics: should not be used for prophylaxis	Oral, im, iv: 8 mg once then 4 mg every 6 hours. Pediatrics: 0.15 mg/kg every 6 hours	Hyperglycemia and psychiatric alterations
HAPE	Nifedipine slow release	Oral: 30 mg SR version every 12 hours or 20 mg SR version every 8 hours	Oral: 30 mg SR version every 12 hours or 20 mg SR version every 8 hours	Dizziness, headache, and hypotension
	Dexamethasone	Oral: 2 mg every 6 hours or 4 mg every 12 hours		Hyperglycemia and psychiatric alterations
	Tadalafil	Oral: 10 mg every 12 hours		Dizziness, headache, and hypotension
	Sildenafil	Oral: 50 mg every 8 hours		Dizziness, headache, and hypotension
	Salmeterol	Inhaled: 125 µg every 12 hours		Tremor, tachycardia, and hypokalemia

Medication for prevention of AMS, HACE, and HAPE should be started approximately 12 hours before ascent.
HAH = high-altitude headache; AMS = acute mountain sickness; HACE = high-altitude cerebral edema; HAPE = high-altitude pulmonary edema; SR = sustained release; iv = intravenous; im = intramuscular.

* Am J Respir Crit Care Med 2012; 185:192–198

“CLIMBER’S LITTLE HELPER”

- “Several near deaths on the world’s highest peaks have shed light on a dangerous trend in mountaineering: rampant use of performance-enhancing drugs, particularly the powerful steroid dexamethasone.”

OUTSIDE MAGAZINE, APRIL 2013

COUNSEL YOUR PATIENTS ABOUT ILLICIT/UNREGULATED USE!!

Table 38.5 Advisability of ascent to high altitude (up to 3000 m)

Minimal risk	Some documented risk – consider medical monitoring, availability of oxygen	Substantial risk – ascent not advised
Children and elderly	Carotid surgery or irradiation	COPD, severe
Physically fit and unfit	Sleep-disordered breathing and apnea	Coronary artery disease, with poorly controlled angina
Obesity	COPD, moderate	CHF, uncompensated
Chronic obstructive pulmonary disease (COPD), mild	Cystic fibrosis	Congenital heart disease ASD, PDA, Down's syndrome
Asthma	Hypertension, poorly controlled	Pulmonary hypertension
Hypertension, controlled	Coronary artery disease, with stable angina	Pulmonary vascular abnormalities
Coronary artery bypass grafting, angioplasty, or stenting (without angina)	Arrhythmias, high-grade	Sickle cell anemia (with history of crises)
Anemia, stable	Congestive heart failure (CHF), compensated	Pregnancy, high-risk
Migraine	Sickle cell trait	
Seizure disorder, on medication	Cerebrovascular disorders	
Diabetes mellitus	Seizure disorder, not on medication	
LASIK, PRK	Radial keratotomy	
Oral contraceptives	Diabetic retinopathy	
Pregnancy, low-risk		
Psychiatric disorders		
Neoplastic diseases		
Inflammatory conditions		

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Table 38.4 Practical advice for travelers to altitude

Go slowly

- Avoid overexertion
- Avoid abrupt ascent to sleeping elevations over 3000 m
- Spend one to two nights at an intermediate elevation (2500–3000 m) before further ascent
- Above 3000 m, sleeping elevations should not increase by more than 300–400 m per night
- When topography or village locations dictate more rapid ascent, or after every 1000 m gained, spend a second night at the same elevation

Day hikes to higher elevations, with return to lower sleeping elevations help to improve acclimatization

Avoid alcohol consumption in the first 2 days at a new, higher elevation

Memorize the Golden Rules of Altitude

The Golden Rules of Altitude

- If you feel unwell at altitude, it is altitude illness until proven otherwise
- If you have symptoms of AMS, go no higher
- If your symptoms are worsening (or with HACE or HAPE), you must go down immediately

Note: Thanks to Dr David Shlim who originally popularized *The Golden Rules of Altitude*

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Table 38.1	Online information resources on altitude illness
International Society for Mountain Medicine: www.ismmed.org Detailed practical information on altitude illness available for both physicians and non-physicians. Includes diagnostic criteria for AMS, HACE, and HAPE, as well as AMS scoring tools for adults and children. An 'ask the experts' section is available for difficult cases.	
The High Altitude Medicine Guide: www.high-altitude-medicine.com Information on altitude illness and other health issues for travelers and their physicians. Has a practical tutorial on field hyperbaric treatment, and comparisons of the various portable hyperbaric bags.	
EMedicine: www.emedicine.com/emerg/environmental.htm Written in a brief, easy-to-review format; targeted at physicians. The cerebral and pulmonary syndromes of altitude illness are covered in separate 'chapters'.	
Web MD: www.webmd.com Has separate consumer and physician sections, and extensive medical info for consumers. Online chat rooms cover various topics including altitude illness and travel medicine.	
ICAR-MEDCOM: www.mountainmedicine.org/mmed/icarmedcom/papers.html A collection of articles on medical management of mountaineering emergencies, including a suggested alpine medical kit. Presented by the International Commission for Mountain Emergency Medicine.	
Wilderness Medical Society: www.wms.org Complete archives of Wilderness and Environmental Medicine and the prior *Journal of Wilderness Medicine*. Archives are open, but the current issue is only accessible to subscribers and WMS members.	
Bibliography of High Altitude Medicine: annie.cv.nrao.edu/habibqbe.htm A searchable bibliography of important work in high altitude medicine.	

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EXTRA
Slides

Case

- **CC: Extreme fatigue**
- **HPI: This 39 yo male on patrol was carried down from 4800 m with complaints of a cough and extreme fatigue with exercise. He was noted to have gurgling respirations during the night. He denied dyspnea at rest, and had had no orthopnea. He had a fever of 40 C the morning of presentation, along with a moderate headache which partially responded to aspirin and/or descent. He seemed confused on arising at altitude, according to his buddy. He attempted to walk down but was able to walk only 1/2 km before needing to be carried due to fatigue and gross ataxia.**

- **PMH: no prior AMS, HACE or HAPE. Resides at sea-level, and is a marathon runner**
- **Meds: Amoxicillin, 2 doses for presumed pneumonia. Aspirin for fever and headache.**

Case

- **Ascent History:**
  - **Trekked in from a very gradual 7-9 day ascent.**
  - **x 1 night 3440 m**
  - **x 1 night 4080 m**
  - **X 1 night 4750 m**
  - **ascended to 5500 m on a day hike**
  - **x 1 night 4690 m**
  - **crossed pass 5420 m**
  - **Last night 4840 m**
- **Exam: Thin, shivering man.**
  - **HR 110, BP 120/80, RR 30, SaO2 58% ("normal" is 82-86% at 4250 m)**
  - **Cardiac: tachycardic, otherwise normal**
  - **Lungs: Right Middle Lobe crackles and some right-sided intercostal retractions noted.**
  - **Neuro: stepped off line on tandem-gait testing.**
- **AMS scores:**

– HA	1
– Fatigue/weak	3
– Sleep	1
– Mental Status	2
– Ataxia	2
– TOTAL SX	9

Case

- **Dx: HAPE**
  HACE
- **Tx:**
  - **Nifedipine 10 mg chew, plus 10 mg swallow. → SaO2 rose to 66% after nifedipine treatment.**
  - **Dexamethasone 8 mg po stat.**
  - **The patient was well enough to descend without additional treatment, though the Gamow bag was offered to the patient if he felt too fatigued to walk to Pangboche**
- **Plan:**
  - **Nifedipine 20 mg po q 6 hours.**
  - **Dexamethasone 4 mg po q 6 hours.**
  - **Immediate descent.**
- **DISCUSSION**
  - **Classic physically fit man**
  - **Rapid ascent**
  - **HAPE→ HACE**
  - **Classic denial "I cannot have altitude sickness, I am a marathon runner!"**
  - **Exertion and subsequent fatigue, classic of HAPE**