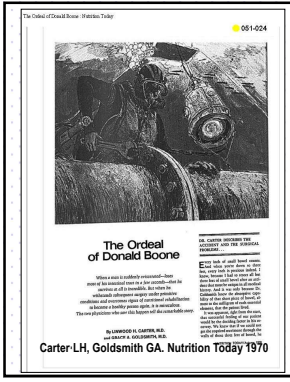
Medical Aspects of Non-Pulmonary Barotrauma

Dick Clarke, CHT

Medical Aspects of Non-Pulmonary Barotrauma

Primary Training in Hyperbaric Medicine

Columbia, South Carolina



The Ordeal of Donald Boone

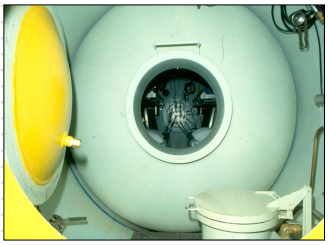
Carter·LH, Goldsmith GA. Nutrition Today 1970

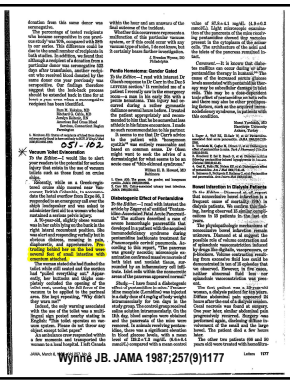
Multiday saturation dive

pipeline project

Support barge storage

TUP to/from 190'/58 m



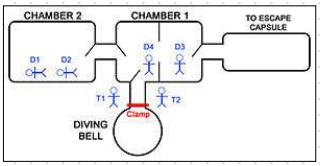


Wynne JB. JAMA 1987;257(9)1177

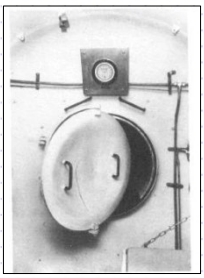
Explosive decompression from saturation storage complex

Multi-day saturation dive

4 divers stored at 260'/79 m



Communication lapse – *clamp holding bell to chamber complex catastrophically fails*



Giertsen JC, *et al.* 1988
Am J Forensic Med Path; 9(2)

An Explosive Decompression Accident

J. C. Giertsen, M.D., E. Sandstad, M.D., J. Morild, M.D., G. Berg, M.D., A. J. Bjørstad, M.D., and S. Eidsvik, M.D.

Significant for large amounts of fat clumps within arteries & veins, cardiac chambers, other organs

thought to have "dropped out of blood secondary to dramatic fall in pressure causing blood to boil off…" Armstrong's Line/Limit

Giertsen JC, *et al.* Am J Forensic Med Path 1988;9(2)

Potential barotrauma sites

External, middle & inner ear structures

Para-nasal spaces

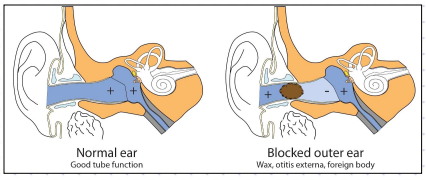
Teeth

Lungs…*discussed elsewhere*

Stomach - G.I. tract

Attached/implanted devices

External ear barotrauma



HBO pts…cerumen accumulation; cotton balls

Divers…bony ingrowth; ear plugs; neoprene hood

Pathology: gas contraction not compensated for by tissue collapse
bone & cartilage lining canal

Symptoms: mild to increasing pain, +/- bloody discharge

Examination: blood filled cutaneous blebs, +/- hemorrhage
TM bulging towards observer when visualized

Treatment: occlusion removal, pain control, 1.5-3% H2O2 irrigation

Prevention: ear examination pre-post exposure
prophylaxis for HBO pts eliminates risk

Middle ear barotrauma

Failure to equalize middle ear pressure, via Eustachian tube, commonly upon descent

may occur during ascent, particularly if compression problems encountered

Eustachian tube usually opens with gradient between middle ear & nasopharynx ~ 20 mmHg

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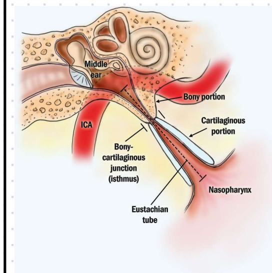
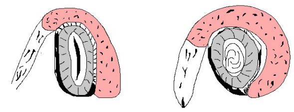




Valsalva vs Toynbee maneuver

051-128

UHM 2014, VOL. 41, NO. 5 – MIDDLE EAR BAROTRAUMA IN HBO_2

Middle ear barotrauma in hyperbaric oxygen therapy

Marvin Heyboer III, M.D. [1], Susan M. Wojcik, Ph.D. [1], William D. Grant, EDD [1], Patrick Chambers, BS [2], Shane Jennings, M.D. [1], Patrick Adcock, M.D. [3]

[1] Department of Emergency Medicine, Division of Hyperbaric Medicine, SUNY Upstate Medical University, Syracuse, New York USA
[2] SUNY Upstate Medical University, School of Medicine, Syracuse, New York USA
[3] Department of Emergency Medicine SUNY Upstate Medical University, Syracuse, New York USA

CORRESPONDING AUTHOR: Marvin Heyboer, M.D. – *heyboerm@upstate.edu*

Heyboer M, *et al.* UHM 2014;41(5)

Reviewed MEB incidence per compression rate

ROC 1.0 - 1.5 - 2.0 psi/min.

Tx. pressures 2.0 - 2.5 - 2.8 ATA

236 pts. 4,981 txs. single facility (monoplace)

UHM 2017, VOL. 44, NO. 2 – MIDDLE EAR BAROTRAUMA IN HBO_2: STAGED VS. LINEAR COMPRESSION

051-137

Incidence of middle ear barotrauma in staged versus linear chamber compression during hyperbaric oxygen therapy: a double blinded, randomized controlled trial

Andrew Wei Aun Ng, Reinhold Muller, John Orton

Anaesthesia – Armed Forces Hospital Lumut, RMN Base, Lumut, Perak 32100 Malaysia

CORRESPONDING AUTHOR: Andrew Ng – *dranwa@gmail.com*

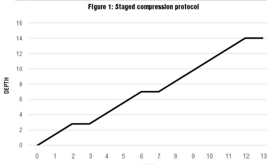
Ng A, *et al.* UHM 2017;44(2)

100 consecutive pts; first HBO tx

Single institution (multiplace)

Randomly assigned

Figure 1: Staged compression protocol



TIME (minutes)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
DEPTH (meters)	0	1.4	2.8	2.8	4.2	5.6	7	7	8.4	9.8	11.2	12.6	14	14

UHM 2021, VOL. 48 NO. 3 - EFFECT OF COMPRESSION TIME AND SLOPE CAUSING SYMPTOMS OF MEB

051-147

RESEARCH ARTICLE

The effect of total compression time and rate (slope) of compression on the incidence of symptomatic Eustachian tube dysfunction and middle ear barotrauma: a Phase II prospective study

Owen J. O'Neill [1,2,3]; David Dayya [1,2]; Lince Varughese [4]; Jo Anne Marker [1]; Lubiha Perez [1]; Michael Dayya [5]

[1] Department of Surgery, Division of Undersea and Hyperbaric Medicine, Phelps Hospital Northwell Health
[2] Department of Emergency Medicine, Division of Undersea and Hyperbaric Medicine, Upstate Medical University
[3] Department of Medicine, New York Medical College
[4] Department of Hyperbaric and Wound Medicine, Baylor, Scott & White Medical Center Rowlett
[5] Department of Engineering, University of Connecticut

CORRESPONDING AUTHOR: Owen J. O'Neill, MD - *OONeill@Northwell.edu*

O'Neil OJ, *et al.* UHM 2021;48(3)

Phase II clinical trial; multiplace chamber

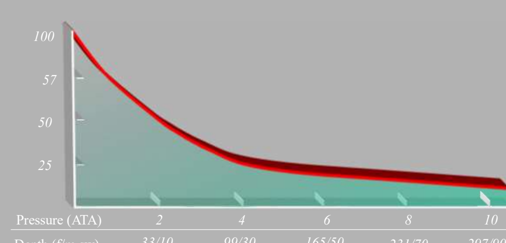
1,244 patient group exposures

all received each option/rotating basis

Compared four ROC to 2.36 ATA

15 min. non-linear
15 min linear
10 min. non-linear
10 min linear

Evaluated number compression holds



UHM 2021, VOL. 48 NO. 2 – OXYMETAZOLINE AND FLUTICASONE EFFECT ON EAR BAROTRAUMA

051-146

RESEARCH ARTICLE

Prevention of middle ear barotrauma with oxymetazoline/fluticasone treatment

Susan B. Millan, MD[1,2]; Catherine A. Hontz-Geisinger, BBA[2]; Benjamin J. Rooks, MS[2]; Derek B. Covington, MD[3]
[1] University of Florida, Department of Community Health and Family Medicine, Gainesville, Florida U.S.
[2] University of Florida, Wound Care and Hyperbaric Center, Gainesville, Florida U.S.
[3] University of Florida, Department of Anesthesiology, Gainesville, Florida U.S.
CORRESPONDING AUTHOR: Susan B. Millan – *sbmillan@ufl.edu*

ABSTRACT

Middle ear barotrauma (MEB) is a common complication of hyperbaric oxygen (HBO_2) therapy. It has been reported in more than 40% of HBO_2 treatments and can interrupt the sequence of HBO_2. MEB may lead to pain, tympanic membrane rupture, and even hearing loss.

The aim of this study was to determine if pretreatment with intranasal fluticasone and oxymetazoline affected the incidence of MEB.

We conducted a retrospective chart review of subjects undergoing HBO_2 at our institution between February 1, 2014, and May 31, 2019. Subjects in the fluticasone/oxymetazoline (FOT) treatment group used intranasal fluticasone 50 mcg two times per day and oxymetazoline 0.05% one spray two times per day beginning 48 hours …

INTRODUCTION

During hyperbaric oxygen (HBO_2) therapy people commonly manage tympanic middle and external ear pressure changes by using one of several pressure-equalizing techniques. These maneuvers may include the Valsalva maneuver, drinking water, moving the jaw, and stretching the Eustachian tube by moving the head with a side tilt [1]. When these techniques fail, middle ear barotrauma (MEB) may occur with continued increases in ambient pressure.

MEB, also known as otic barotrauma, middle ear squeeze, or barotitis media, occurs due to a persistent pressure gradient between the middle ear cavity and the external environment. If this pressure differential is not resolved spontaneously or with equalization maneuvers, …

Millian SB, *et al.* UHM 2021;48(2)

Retrospective chart review

115 pts - 5,683 txs without prophylaxis < 6/2017

39 pts -1,501 txs with prophylaxis > 6/2017

Primary outcome measure: incidence of MEB

pain perception

otologic exam per Teed scale

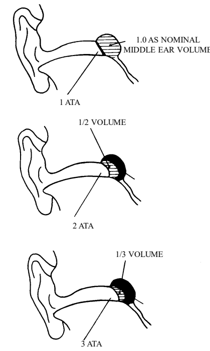
MEB incidence

overall: 16.2%

non-prophylaxis 16.5% N.S.

prophylaxis 15.4%

"…premedication…is not indicated for all pts…"



Pathology

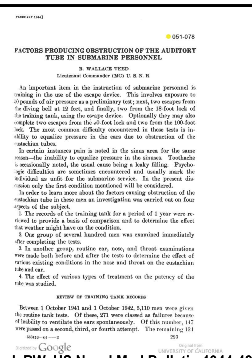
- Edema & hemorrhage
- Mucosal congestion
- Inward bulging of TM
- Perforation

Associated risk factors

- Upper respiratory infection
- Allergies
- Mucosal polyps
- Cigarette smoking
- 'Locking' phenomenon
- Radiotherapy

Symptoms

- Ear discomfort; increasing pain
- Pain resolution with in-chamber perforation
- Caloric stimulation with open water perforation
  - *~ disorientation, vertigo, panic*



FEBRUARY 1944]

051-078

FACTORS PRODUCING OBSTRUCTION OF THE AUDITORY TUBE IN SUBMARINE PERSONNEL

R. WALLACE TEED
Lieutenant Commander (MC) U. S. N. R.

An important item in the instruction of submarine personnel is training in the use of the escape device. This involves exposure to 50 pounds of air pressure as a preliminary test; next, two escapes from the diving bell at 12 feet, and finally, two from the 18-foot lock of the training tank, using the escape device. Optionally they may also complete two escapes from the 50-foot lock and two from the 100-foot lock. The most common difficulty encountered in these tests is inability to equalize pressure in the ears due to obstruction of the eustachian tubes.

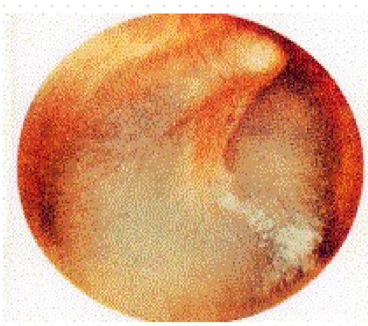
In certain instances pain is noted in the sinus area for the same reason—the inability to equalize pressure in the sinuses. Toothache is occasionally noted, the usual cause being a leaky filling. Psychologic difficulties are sometimes encountered and usually mark the individual as unfit for the submarine service. In the present dis- …

Teed, RW. US Naval Med Bulletin 1944;42

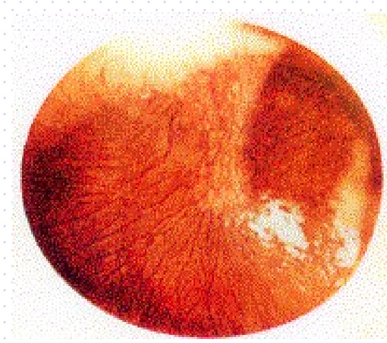
Teed (not TEED) Grade

- Grade 0 normal exam
- Grade 1 retraction/limited TM redness
- Grade 2 retraction/redness entire TM
- Grade 3 Grade 2 plus middle ear effusion
- Grade 4 gross hemotympanum
- Grade 5 perforation

Teed zero



Teed 1



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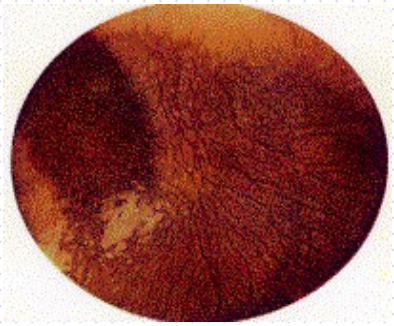

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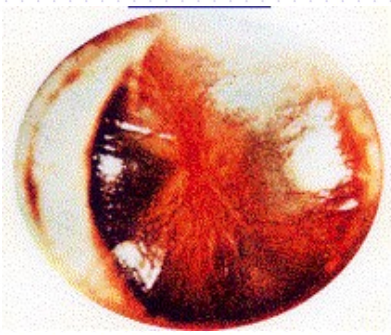
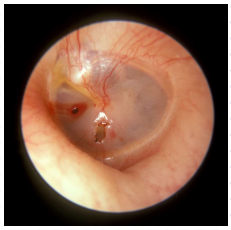
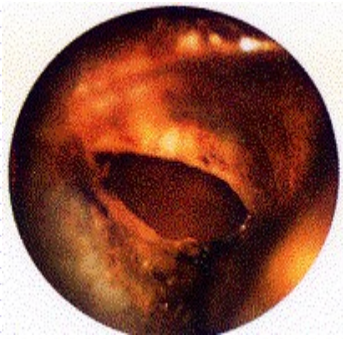


Teed 4

Teed 5





Management

No further pressure changes until resolution
~ elective indications/divers

Immediate prophylaxis for urgent HBO indications

Local and/or systemic decongestants

+/- Antibiotics (pre-existing infection/perforation in divers)

Audiometric exam, r/o hearing loss in severe cases

Prevention

Determination of ET patency
37% pts demonstrating effective auto-inflation per otoscopy developed MEB
Beuerlein M, et al. Laryngoscope 1998;107

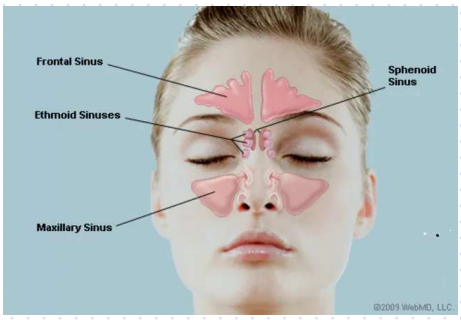
Slower initial compression(s)
associated with lower incidence; prompting those with hx H/N RT

Direct observation during all pressure changes
vs. missing those apparently struggling

Ventilation tubes for elective treatment indications
assures patency (remove cotton ball); avoids further MEB

Needle Myringotomy for urgent indications
48 - 72-hour patency; f/u ENT longer HBO courses

Sinus barotrauma

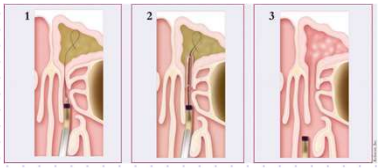


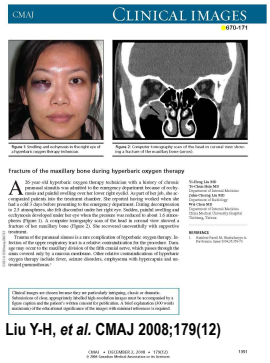
Risk factors

- Allergies
- Nasal polyps
- Mucosal congestion
- Inflammatory changes
- Blocked sinus ostium

Approach to management

- Decongestants
- Sinus x-rays, if persistent
- ENT referral
  drainage vs. ablation vs. osteoplasty




CMAJ CLINICAL IMAGES

Fracture of the maxillary bone during hyperbaric oxygen therapy

Liu Y-H, *et al.* CMAJ 2008;179(12)

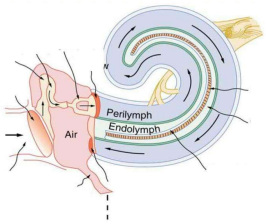
Presented to ED; 3-day hx painful swelling & ecchymosis

IA at 2.5 ATA; suffering head cold

Sinus pain on ascent at 1.6 ATA…*held several mins.*

Inner ear barotrauma

Permanently damaging complications may result in round/oval window fistula



Symptoms

- Ataxia & vertigo
- Tinnitus
- Disorientation
- High frequency hearing loss

Approach to management

- Prompt ENT referral
- *serial audiograms*
- *surgical repair as indicated*

Differential diagnosis

	IEB	IEDCS
Dizziness	yes	yes
Nausea	yes	yes
Vomiting	yes	yes
Hearing loss	yes	yes
Ataxia	yes	yes
Tinnitus	yes	yes

INNER EAR DECOMPRESSION SICKNESS COMBINED WITH A FISTULA OF THE ROUND WINDOW

CASE REPORT

Adkinson GH Meredith AP. Ann Oto Rhinol Laryn 1990;99

'Mixed' hearing loss

Ear squeeze > conductive loss

IEDCS > sensorineural loss

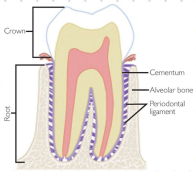
Dental barotrauma

Gas spaces may exist at roots of infected teeth/adjacent to incomplete fillings

soft tissue, or blood, will attempt to fill these spaces upon compression

Carious teeth with cavity involving thin cementum at risk

pressure imbalance across cementum may cause tooth to implode/explode



Case Report

Pneumocephalus as a Consequence of Barotrauma

Goldmann RW. JAMA 1986;255(22)

26 yo diver underwent reported uneventful descent to 60'/18 m

During ascent, passing 20'/6 m, sudden onset sharp left ear pain

diver considered it reverse squeeze

continued ascending at slowed rate, increasing pain

Pain suddenly disappeared at surface; now severe left localized headache

Rested for several hrs dove again to 60'/18 m

headache improved at depth, returned with increased intensity upon surfacing

No related hx; no previous diving problems

No LOC or hemiplegia, nor other complaints suggestive of DCI

Normal affect/behavior

per wife

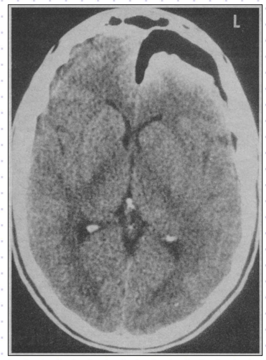
He contacted Divers Alert Network

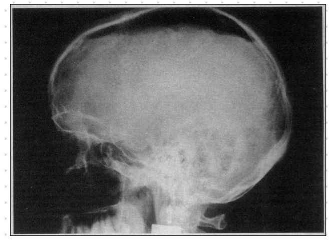
referred to a local hospital with experienced diving medicine team

CC: severe left sided headache, exacerbated by movement

Neuro intact; physical exam unremarkable except left ear bloody discharge /Teed III

No indication for recompression therapy





Admitted, antibiotic prophylaxis against meningitis

Analgesics

100% oxygen by NRB

Headache gradually resolved, remained afebrile

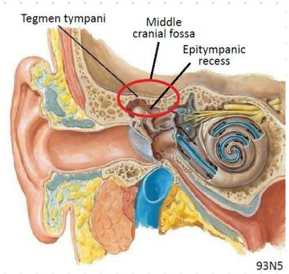
Discharged on day six with decreased L hearing

hearing normalized over ensuing 14 days

Declared permanently unfit for diving

Over-pressurized middle ear on ascent "reverse squeeze" fractured bony roof vs. existing defect

introduced air into mastoids > subdural space



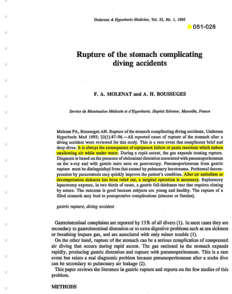
Gastrointestinal barotrauma

Potential problem of ascent as any residual gas expands

Common gas sources:

air swallowing on Valsalva; descending in head down position

+/- carbonated beverages



Rupture of the stomach complicating diving accidents

F. A. MOLENAT and A. H. BOUSSUGES

Molenat FA, Boussuges AH. UHM 1995;22:1

Causative Events

1. Panic
2. Panic
3. Panic/swallowing water
4. Panic/swallowing water
5. Panic/swallowing water
6. Equipment issue
7. Panic
8. Equipment failure/swallowing water
9. Near-drowning
10. Equipment failure
11. Panic
12. Equipment failure


Surg Today (2003) 33:299–301

Surgery Today
© Springer-Verlag 2003
051-099

Gastric Barotrauma in a Scuba Diver: Report of a Case

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[2] Hyperbaric Unit, Hull and East Yorkshire Hospitals, Lowfield Road, Anlaby, Hull HU10 7AZ, UK

Abstract
Stomach rupture can occur as a consequence of the expansion of compressed air during rapid ascent after diving. We present the case of a middle-aged woman who suffered a gastric tear from surfacing too quickly after diving, and discuss the diagnosis and management of such patients by reviewing previously reported similar events. Gastric barotrauma should be suspected in divers who complain of abdominal pain, even in the absence of frank signs of peritoneal irritation. Although pneumoperitoneum is always present in these patients, it can also occur as a consequence of pulmonary barotrauma, making gastroscopy or radiological contrast studies, or both, essential for a definitive diagnosis. Surgical repair represents the treatment of choice for an active full-thickness tear and, if associated with arterial gas embolism or decompression sickness, should ideally be performed in a center where a category I (intensive care-capable) hyperbaric unit is available.

Key words Stomach · Barotrauma · Diving · Surgery

Introduction

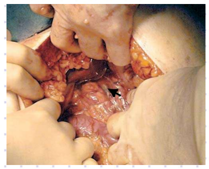
Gastric perforation caused by barotrauma is an unusual but potentially serious diving accident. A review of the literature revealed 13 cases of gastric barotrauma, only 7 of which were demonstrated and repaired surgically. Most cases are associated with decompression sickness or arterial gas embolism, or both, which, coupled with the common absence of local physical signs, could contribute to diagnostic delay. This report describes a case of gastric perforation in a scuba diver, and discusses the diagnostic and management options and priorities.

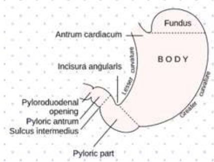
Case Report

A 45-year-old female amateur diver who was physically fit suffered a panic attack while scuba diving at a depth of approximately 30m, on an empty stomach. This triggered a rapid ascent with copious air swallowing. After surfacing she lost consciousness with apnea for less than 1 min, but recovered spontaneously. A presumptive diagnosis of arterial gas embolism was made and 4.75h of recompression oxygen therapy was given.

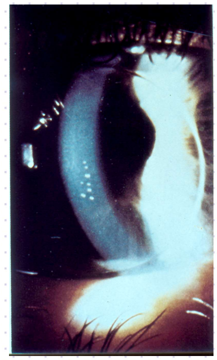
On leaving the chamber, the patient complained of generalized abdominal pain and was transported to the Accident and Emergency Department for further evaluation. On arrival she was tachypneic and tachycardic, but hemodynamically stable and apyrexial, with a Glasgow Coma Scale score of 14/15. Physical examination revealed diffuse abdominal distension and tenderness without guarding or rebound tenderness. An erect chest X-ray demonstrated a gross pneumoperitoneum with significant diaphragmatic ascension and normal lung fields, confirming the initial suspicion of visceral perforation. Because patients with arterial gas embolism can relapse, requiring further recompression therapy, the Royal Navy duty doctor who coordinated the initial management of the patient advised that the she be managed in a center specializing in hyperbaric therapy with appropriate surgical support. Accordingly, after passing a nasogastric tube and commencing intravenous cefuroxime and metronidazole, the patient was transferred overnight to the Hull and East Riding Hospital. Her general condition remained stable, but she became pyrexic, at 38.8°C. Intravenous ranitidine was administered on arrival, and urgent gastroscopy and radiological contrast studies with a water-soluble agent (100ml Gastrografin) were scheduled to identify the site

Reprint requests to: L.V. Titu
Received: March 18, 2002 / Accepted: September 3, 2002





Titu LV, *et al*. Surgery Today 2003;33



Diver wearing hard contact lens

Decompressed from simulated 30 min air dive 150'/45m

Slit lamp observation of bubbles between hard contact lens & cornea
first noticed enroute to 30'/9m stop

Corneal epithelial edema evident

Simon DR. Bradley ME
JAMA 1980;244(11):1213-1214

Facial soft tissue barotrauma

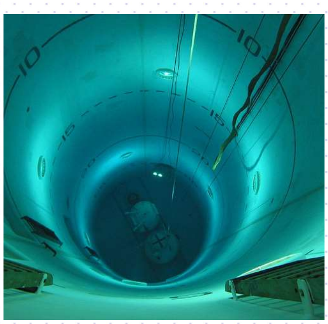
48 yo novice diver overly tightened face mask strap

On descent passing 15'/5 m lost vision bilaterally

Panic ascent, recovered into dive boat

Profound facial swelling, eyes swollen shut

Treated with ice packs & reassurance



Exceedingly rapid compressions possible/necessary

Pressure *			Elapsed Time (sec.)
ATA	FSW	MSW	
2	33	10	4
4	99	30	8
8	231	70	12
16	528	160	16

** ambient pressure doubled every 4 seconds…decompression at 14-18 fps/4-5 mps*

~ results in an 'acceptable' incidence of DCS up to 545'/165 m (17.5ATA)

Morbidity associated with submarine escape trials

Depth (fsw/msw)	100/30	300/100	400/120	500/150	600/180
No. Escapers	44	26	23	20	2
Ear Barotrauma	2	2	1		
TM Perforation		1	2	3	1
Sinus Barotrauma		1			
Dental Barotrauma			1		
Thoracic Squeeze		2			1
Stomach Rupture				1	
Vasovagal Episode				1	
DCS				1	1
Acute Stress Reaction					1
Near Syncope			1		

Haydon JR Fox MJ, 1987
Inst. Naval Med UK # 8/88