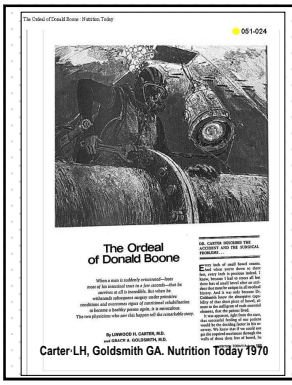
Medical Aspects of Non-Pulmonary Barotrauma

Primary Training in Hyperbaric Medicine

Columbia, South Carolina



The Ordeal of Donald Boone

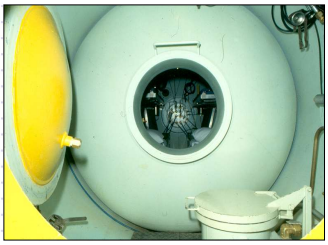
Carter·LH, Goldsmith GA. Nutrition Today 1970

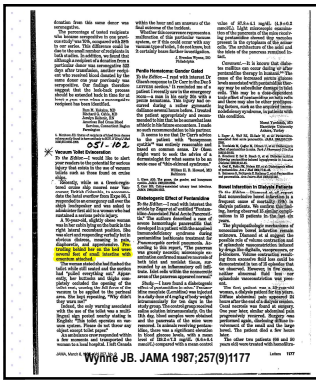
Multiday saturation dive

pipeline project

Support barge storage

TUP to/from 190'/58 m



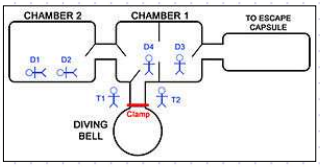


Wynne JB. JAMA 1987;257(9)1177

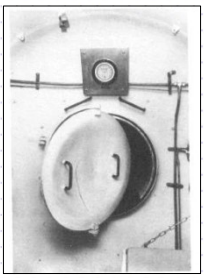
Explosive decompression from saturation storage complex

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)

051-039

An Explosive Decompression Accident

J. C. Giertsen, M.D., E. Sandstad, M.D., I. Morild, M.D., G. Berg, M.D., A. J. Bjørsdal, M.D., and S. Eidevik, 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

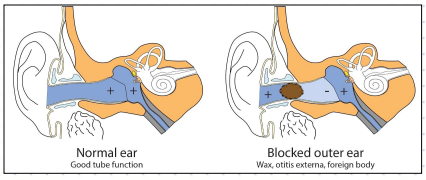
Teeth

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

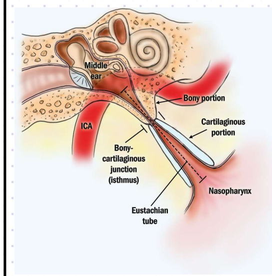
Prevention: ear examination pre-post exposure
prophylaxis for HBO pts eliminates risk

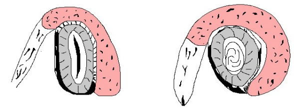
Middle ear barotrauma

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





Tube Closed   Tube Open

Valsalva vs Toynbee maneuver

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)

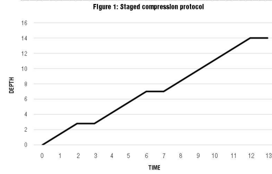
Ng A, *et al.* UHM 2017;44(2)

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

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

Phase II clinical trial; multiplace chamber

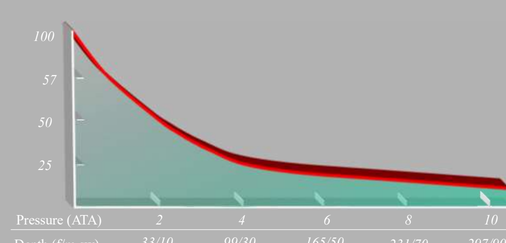
1,244 patient group exposures

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 prior to initial HBO_2. Oxymetazoline was discontinued after four days. Fluticasone was continued for the duration of HBO_2 therapy.

A total of 154 unique subjects underwent 5,683 HBO_2 treatments: 39 unique subjects in the FOT group underwent 1,501 HBO_2; 115 unique subjects in the nFOT (no oxymetazoline or fluticasone treatment) group underwent 4,182 HBO_2 treatments.

The incidence of MEB was 15.4% in the FOT group and 16.2% in the nFOT group. This was not a statistically significant difference (OR = 0.77; p = 0.636). Treatment pressure, age over 65 years, male sex, and BMI were not associated with a difference in MEB incidence.

In summary, pretreatment with intranasal oxymetazoline and fluticasone in patients undergoing HBO_2 did not significantly reduce MEB. More investigation with larger numbers of participants and prospective studies could further clarify this issue. ∎

KEYWORDS: hyperbaric medicine; hyperbaric oxygen therapy; nasal decongestants

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, patients can develop otalgia, tinnitus, tympanic membrane rupture, and, potentially, hearing loss [1].

MEB is one of the most common complications of HBO_2 and may occur in nearly 70% of treatments [2]. Fortunately, research demonstrates the vast majority of MEB is classified as minor on the commonly utilized Teed classification system for MEB [3-5].

Difficulty with pressure equalization often resolves with repeated trials of HBO_2 and patient education. Despite these efforts some patients are unable to equalize middle ear pressure and are at risk of developing MEB. For such patients a trial of intranasal fluticasone and oxymetazoline may facilitate middle ear pressure equalization. In the event of therapeutic failure, a tympanostomy tube may be placed to equalize the pressure during subsequent HBO_2 treatments.

In an effort to reduce middle ear barotrauma and hasten tympanostomy tube placement when necessary to continue HBO_2, our center instituted routine prophylactic treatment with intranasal fluticasone and oxymetazoline. As a corticosteroid, intranasal fluticasone acts

Copyright © 2021 Undersea & Hyperbaric Medical Society, Inc. 149

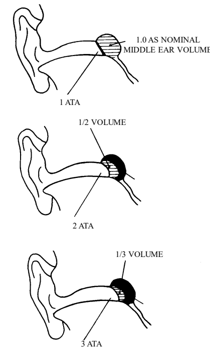
Millian SB, *et al.* UHM 2021;48(2)

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

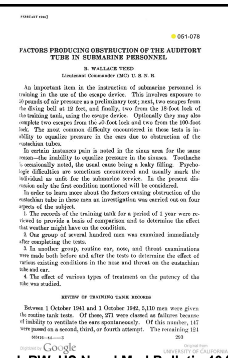
Perforation

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 discussion only the first condition mentioned will be considered.

In order to learn more about the factors causing obstruction of the eustachian tube in these men an investigation was carried out on four aspects of the subject.

1. The records of the training tank for a period of 1 year were reviewed to provide a basis of comparison and to determine the effect that weather might have on the condition.
2. One group of several hundred men was examined immediately after completing the tests.
3. In another group, routine ear, nose, and throat examinations were made both before and after the tests to determine the effect of various existing conditions in the nose and throat on the eustachian tube and ear.
4. The effect of various types of treatment on the patency of the tube was studied.

REVIEW OF TRAINING TANK RECORDS

Between 1 October 1941 and 1 October 1942, 5,110 men were given the routine tank tests. Of these, 271 were classed as failures because of inability to ventilate the ears spontaneously. Of this number, 147 were passed on a second, third, or fourth attempt. The remaining 124

563416—44——3 293

Digitized by Google
Original from UNIVERSITY OF CALIFORNIA

Teed, RW. US Naval Med Bulletin 1944;42

Teed (not TEED) Grade

Grade 0 normal exam

Grade 1 retraction/limited TM redness

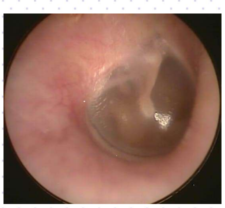
Grade 2 retraction/redness entire TM

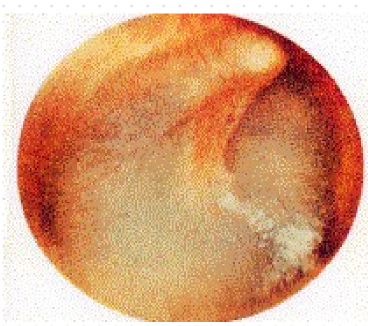
Grade 3 Grade 2 plus middle ear effusion

Grade 4 gross hemotympanum

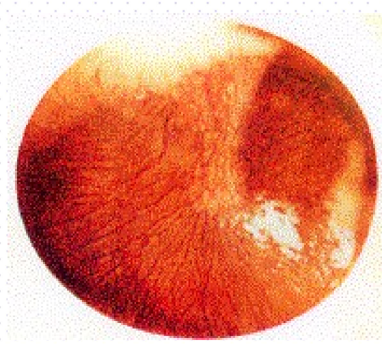
Grade 5 perforation

Teed zero

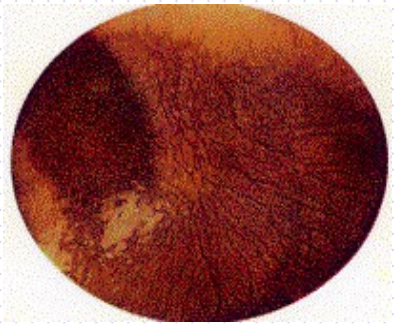




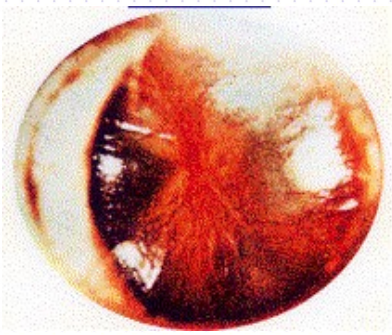
Teed 1



Teed 2

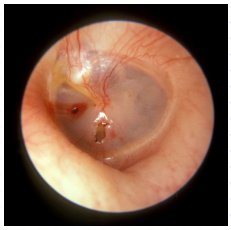


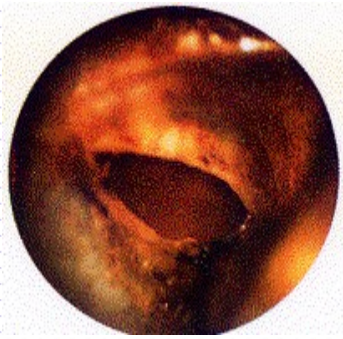
Teed 3



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

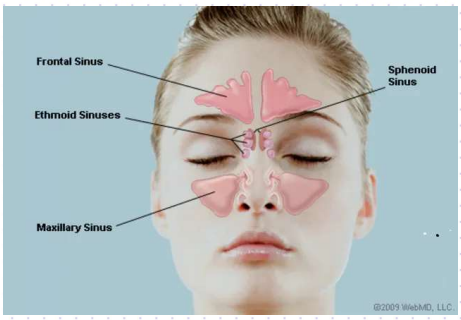
Slower initial compression(s)
associated with lower incidence; prompting those with hx H/N RT

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

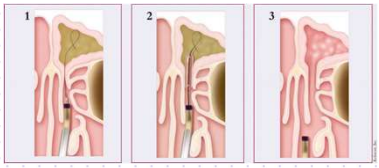


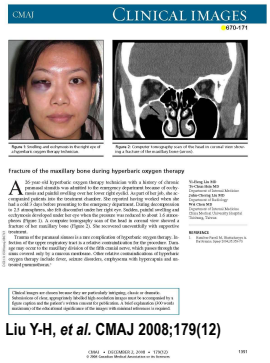
Risk factors

- 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)

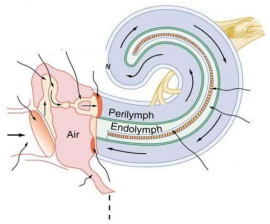
Presented to ED; 3-day hx painful swelling & ecchymosis

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

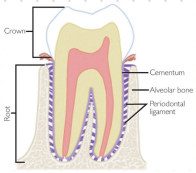
Dental barotrauma

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

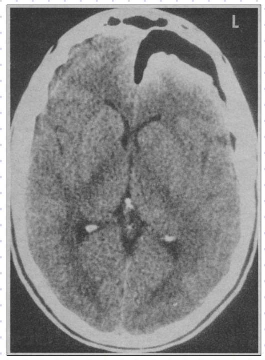
He contacted Divers Alert Network

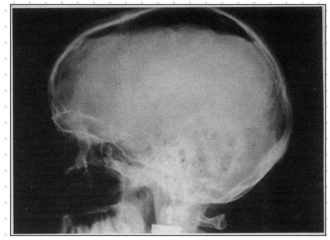
referred to a local hospital with experienced diving medicine team

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

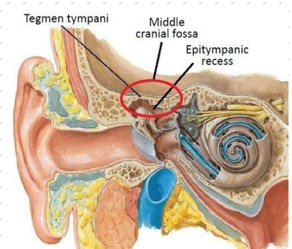
Discharged on day six with decreased L hearing

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



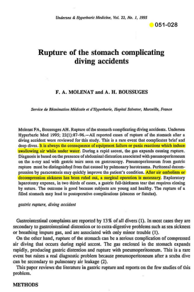
Gastrointestinal barotrauma

Potential problem of ascent as any residual gas expands

Common gas sources:

air swallowing on Valsalva; descending in head down position

+/- carbonated beverages



Undersea & Hyperbaric Medicine, Vol. 22, No. 1, 1995

051-028

Rupture of the stomach complicating diving accidents

F. A. MOLENAT and A. H. BOUSSUGES

Service de Réanimation Médicale et d'Hyperbarie, Hopital Salvator, Marseille, France

Molenat FA, Boussuges AH. Rupture of the stomach complicating diving accidents. Undersea Hyperbaric Med 1995; 22(1):87–96.—All reported cases of rupture of the stomach after a diving accident were reviewed for this study. This is a rare event that complicates brief and deep dives. It is always the consequence of equipment failure or panic reactions which induce swallowing air while under water. During a rapid ascent, the gas expands causing rupture. Diagnosis is based on the presence of abdominal distention associated with pneumoperitoneum on the x-ray and with gastric tears seen on gastroscopy. Pneumoperitoneum from gastric rupture must be distinguished from that caused by pulmonary barotrauma. Peritoneal decompression by paracentesis may quickly improve the patient's condition. After air embolism or decompression sickness has been ruled out, a surgical operation is necessary. Exploratory laparotomy exposes, in two thirds of cases, a gastric full-thickness tear that requires closing by suture. The outcome is good because subjects are young and healthy. The rupture of a filled stomach may lead to postoperative complications (abscess or fistulas).

gastric rupture, diving accident

Gastrointestinal complaints are reported by 13% of all divers (1). In most cases they are secondary to gastrointestinal distention or to extra-digestive problems such as sea sickness or breathing impure gas, and are associated with only minor trouble (1).

On the other hand, rupture of the stomach can be a serious complication of compressed air diving that occurs during rapid ascent. The gas enclosed in the stomach expands rapidly, producing gastric distention and rupture with pneumoperitoneum. This is a rare event but raises a real diagnostic problem because pneumoperitoneum after a scuba dive can be secondary to pulmonary air leakage (2).

This paper reviews the literature in gastric rupture and reports on the few studies of this problem.

METHODS

An extensive review of the literature showed that only 12 cases of gastric rupture after a diving accident have been reported since 1969 (3–13). Four other authors reported

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

Liviu V. Titu[1], Gerard Laden[2], Gerard M. Purdy[2], and Kevin R. Wedgwood[1]

[1] Academic Surgical Unit, Castle Hill Hospital, Castle Road, Cottingham, North Humberside HU16 5JQ, UK
[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.

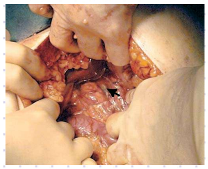
Case Report

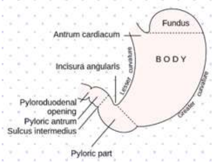
A 45-year-old female amateur diver who was physically fit suffered a panic attack while scuba diving at a depth of approximately 30m, on an empty stomach. This triggered a rapid ascent with copious air swallowing. After surfacing she lost consciousness with apnea for less than 1min, but recovered spontaneously.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

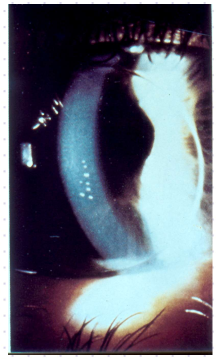
On leaving the chamber, the patient complained of generalized abdominal pain and was transported to the Accident and Emergency Department for further evaluation. On arrival she was tachypneic and tachycardic, but hemodynamically stable and apyrexial, with a Glasgow Coma Scale score of 14/15. Physical 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

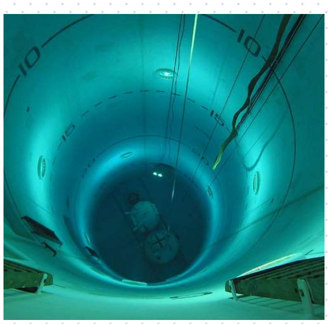
48 yo novice diver overly tightened face mask strap

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