Pulmonary Fitness for Diving and Hyperbaric Exposure

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Pulmonary risks in diving

- Barotrauma (pressure lesions)
  - Pneumothorax
  - Pneumomediastinum
  - Arterial Gas Embolism
- Gas exchange O_2 – CO_2
  - Pulmonary oedema – hypoxemia
- Gas exchange inert gases
  - Decompression sickness

Acceptability of Risk

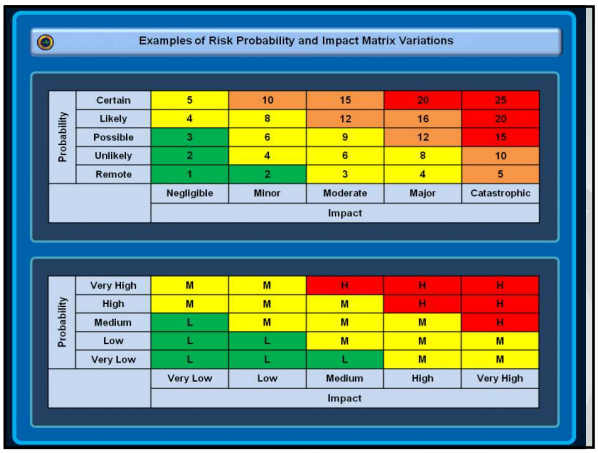
- Probability x Severity of consequences
- Appreciation of “acceptable risk” = variable
- Therefore, no definite guidelines (fitness to dive with pulmonary disease) exist

- Difference in risk evaluation according to diving activity (recreational diving vs. Sports diving vs hyperbaric work vs hyperbaric patients)

Examples of Risk Probability and Impact Scale Definitions

Rating	Score	Probability Definition	Frequency Definition
Very High	5	>95% chance of occurrence	It may occur every day
High	4	66% - 95% chance of occurrence	It may occur several times in a month
Medium	3	36% - 65% chance of occurrence	It may occur several times in a year
Low	2	5% - 35% chance of occurrence	It may occur once in 2 years
Very Low	1	<5% chance of occurrence	It may occur once in 5 or more years

Rating	Score	Impact Definition
Very High	5	Event resulting in patient death or permanent disability
High	4	Event resulting in increased length of stay, major treatment or intervention
Medium	3	Event resulting in additional monitoring, treatment or intervention
Low	2	Event resulting in minimal treatment or intervention
Very Low	1	Event resulting in negligible effects or no effects



Examples of "Fit to Dive" criteria

- *toutes les formes d'asthme,*
- *les pneumothorax et les «trappes à air» pulmonaires,*
- *les infections pulmonaires,*
- *toutes maladies, malformations ou opérations réduisant les échanges pulmonaires*

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Examples of "Fit to Dive" criteria

Contre-indications Absolues

- Insuffisance respiratoire
- Pneumopathie fibrosante
- Vascularite pulmonaire
- Pneumothorax spontané ou maladie bulleuse, même opéré
- Chirurgie pulmonaire
- Asthme

Contre-indications Relatives

- Pathologie infectieuse
- Pleurésie
- Traumatisme thoracique

Relative Risk Conditions

- History of Asthma or Reactive Airway Disease (RAD)*
- History of Exercise Induced Bronchospasm (EIB)*
- History of solid, cystic or cavitating lesion*
- Pneumothorax secondary to:
  - -Thoracic Surgery
  - -Trauma or Pleural Penetration*
  - -Previous Overinflation Injury*
- Obesity
- History of Immersion Pulmonary Edema Restrictive Disease*
- Interstitial lung disease: May increase the risk of pneumothorax

* Spirometry should be normal before and after exercise

Active Reactive Airway Disease, Active Asthma, Exercise Induced Bronchospasm, Chronic Obstructive Pulmonary Disease or history of same with abnormal PFTs or a positive exercise challenge are concerns for diving.

R·S·T·C MEDICAL STATEMENT

Severe Risk Conditions

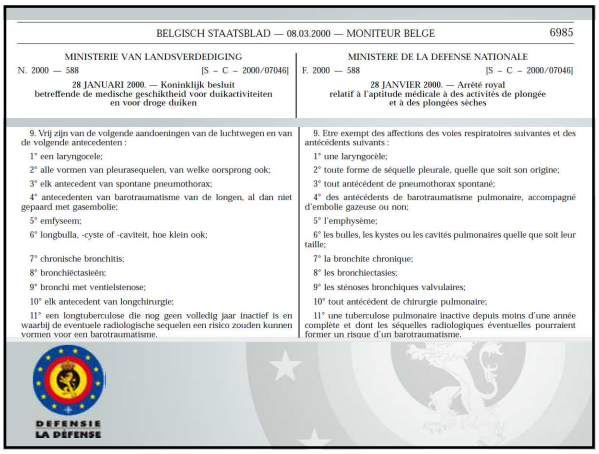
- **History of spontaneous pneumothorax.** Individuals who have experienced spontaneous pneumothorax should avoid diving, even after a surgical procedure designed to prevent recurrence (such as pleurodesis). Surgical procedures either do not correct the underlying lung abnormality (e.g.: pleurodesis, apical pleurectomy) or may not totally correct it (e.g.: resection of blebs or bullae).
- **Impaired exercise performance due to respiratory disease.**

HSE

The medical examination and assessment of commercial divers (MA1)

Condition	Candidate unfit to dive without need for further assessment	Candidate needs further assessment by respiratory physician with special interest in diving medicine	Additional guidance for specialists in secondary care
Acute respiratory disease such as pulmonary infection	All cases, until resolved with no sequelae		
Asthma	Requiring BTS Step 3 treatment and/or admitted to hospital with exacerbation in last 3 months; unstable asthma	Controlled on Step 1 or 2 of BTS guidelines – refer when diver is seen for the first time (initial medical) and consider re-referral if the condition subsequently changes (see paragraph 65)	Individuals with asthma should be found unfit to dive if they have wheeze precipitated by exercise, cold or emotion
Chronic obstructive pulmonary disease		All cases	
Cystic fibrosis	Pulmonary involvement	All other cases	
Tuberculosis	Active tuberculosis	After curative treatment, if lung function and chest radiography are normal	
Pulmonary fibrosis	Disease which reduces lung compliance and impairs gas transfer	All other cases	
Previous chest surgery; pneumomediastinum;		All cases	Candidate might be fit to dive if injury has healed and is associated with acceptable lung function and thoracic imaging
			Due to increased risk of barotrauma
		Resolved sarcoidosis	

HSE 2015



BELGISCH STAATSBLAD — 08.03.2000 — MONITEUR BELGE 6985

MINISTERIE VAN LANDSVERDEDIGING

N. 2000 — 588 [S − C − 2000/07046]

28 JANUARI 2000. — Koninklijk besluit betreffende de medische geschiktheid voor duikactiviteiten en voor droge duiken

9. Vrij zijn van de volgende aandoeningen van de luchtwegen en van de volgende antecedenten :

1° een laryngocele;

2° alle vormen van pleurasequelen, van welke oorsprong ook;

3° elk antecedent van spontane pneumothorax;

4° antecedenten van barotraumatisme van de longen, al dan niet gepaard met gasembolie;

5° emfyseem;

6° longbulla, -cyste of -caviteit, hoe klein ook;

7° chronische bronchitis;

8° bronchiëctasieën;

9° bronchi met ventielstenose;

10° elk antecedent van longchirurgie;

11° een longtuberculose die nog geen volledig jaar inactief is en waarbij de eventuele radiologische sequelen een risico zouden kunnen vormen voor een barotraumatisme.

MINISTERE DE LA DEFENSE NATIONALE

F. 2000 — 588 [S − C − 2000/07046]

28 JANVIER 2000. — Arrêté royal relatif à l'aptitude médicale à des activités de plongée et à des plongées sèches

9. Etre exempt des affections des voies respiratoires suivantes et des antécédents suivants :

1° une laryngocèle;

2° toute forme de séquelle pleurale, quelle que soit son origine;

3° tout antécédent de pneumothorax spontané;

4° des antécédents de barotraumatisme pulmonaire, accompagné d'embolie gazeuse ou non;

5° l'emphysème;

6° les bulles, les kystes ou les cavités pulmonaires quelle que soit leur taille;

7° la bronchite chronique;

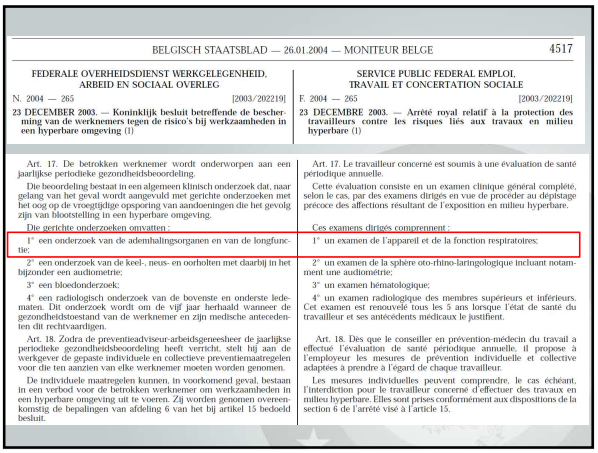
8° les bronchiectasies;

9° les sténoses bronchiques valvulaires;

10° tout antécédent de chirurgie pulmonaire;

11° une tuberculose pulmonaire inactive depuis moins d'une année complète et dont les séquelles radiologiques éventuelles pourraient former un risque d'un barotraumatisme.

DEFENSIE
LA DÉFENSE



BELGISCH STAATSBLAD — 26.01.2004 — MONITEUR BELGE 4517

FEDERALE OVERHEIDSDIENST WERKGELEGENHEID, ARBEID EN SOCIAAL OVERLEG

N. 2004 — 265 [2003/202219]

23 DECEMBER 2003. — Koninklijk besluit betreffende de bescherming van de werknemers tegen de risico's bij werkzaamheden in een hyperbare omgeving (1)

Art. 17. De betrokken werknemer wordt onderworpen aan een jaarlijkse periodieke gezondheidsbeoordeling.

De beoordeling bestaat in een algemeen klinisch onderzoek dat, naar gelang van het geval wordt aangevuld met gerichte onderzoeken met het oog op de vroegtijdige opsporing van aandoeningen die het gevolg zijn van blootstelling in een hyperbare omgeving.

Die gerichte onderzoeken omvatten :

1° een onderzoek van de ademhalingsorganen en van de longfunctie;

2° een onderzoek van de keel-, neus- en oorholten met daarbij in het bijzonder een audiometrie;

3° een bloedonderzoek;

4° een radiologisch onderzoek van de bovenste en onderste ledematen. Dit onderzoek wordt om de vijf jaar herhaald wanneer de gezondheidstoestand van de werknemer en zijn medische antecedenten dit rechtvaardigen.

Art. 18. Zodra de preventieadviseur-arbeidsgeneesheer de jaarlijkse periodieke gezondheidsbeoordeling heeft verricht, stelt hij aan de werkgever de gepaste individuele en collectieve preventiemaatregelen voor die ten aanzien van elke werknemer moeten worden genomen.

De individuele maatregelen kunnen, in voorkomend geval, bestaan in een verbod voor de betrokken werknemer om werkzaamheden in een hyperbare omgeving uit te voeren. Zij worden genomen overeenkomstig de bepalingen van afdeling 6 van het bij artikel 15 bedoeld besluit.

SERVICE PUBLIC FEDERAL EMPLOI, TRAVAIL ET CONCERTATION SOCIALE

F. 2004 — 265 [2003/202219]

23 DECEMBRE 2003. — Arrêté royal relatif à la protection des travailleurs contre les risques liés aux travaux en milieu hyperbare (1)

Art. 17. Le travailleur concerné est soumis à une évaluation de santé périodique annuelle.

Cette évaluation consiste en un examen clinique général complété, selon le cas, par des examens dirigés en vue de procéder au dépistage précoce des affections résultant de l'exposition en milieu hyperbare.

Ces examens dirigés comprennent :

1° un examen de l'appareil et de la fonction respiratoires;

2° un examen de la sphère oto-rhino-laringologique incluant notamment une audiométrie;

3° un examen hématologique;

4° un examen radiologique des membres supérieurs et inférieurs. Cet examen est renouvelé tous les 5 ans lorsque l'état de santé du travailleur et ses antécédents médicaux le justifient.

Art. 18. Dès que le conseiller en prévention-médecin du travail a effectué l'évaluation de santé périodique annuelle, il propose à l'employeur les mesures de prévention individuelle et collective adaptées à prendre à l'égard de chaque travailleur.

Les mesures individuelles peuvent comprendre, le cas échéant, l'interdiction pour le travailleur concerné d'effectuer des travaux en milieu hyperbare. Elles sont prises conformément aux dispositions de la section 6 de l'arrêté visé à l'article 15.

Basis of most recommendations

BTS GUIDELINES

British Thoracic Society guidelines on respiratory aspects of fitness for diving

British Thoracic Society Fitness to Dive Group, a Subgroup of the British Thoracic Society Standards of Care Committee*

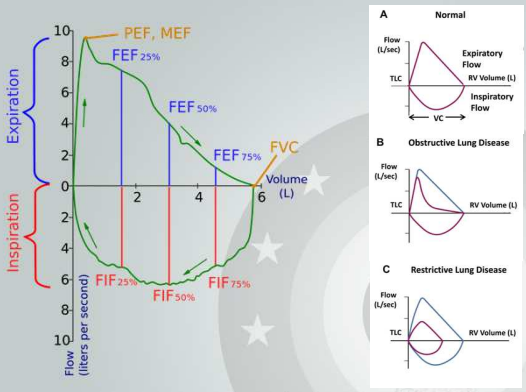
Thorax 2003;**58**:3–13

- Old ? But still valid & well balanced

Minimal requirements for divers

- Medical history
  - current respiratory symptoms
  - previous history of lung disease incl. childhood
  - previous trauma to the chest
  - previous episodes of pneumothorax
- Respiratory system clinical examination
- Lung function tests
  - FEV1, FVC, FEV1/FVC (Tiffeneau)
  - Flow-Volume Loop*
  - Provocation testing (exercise provocation) at slightest doubt !

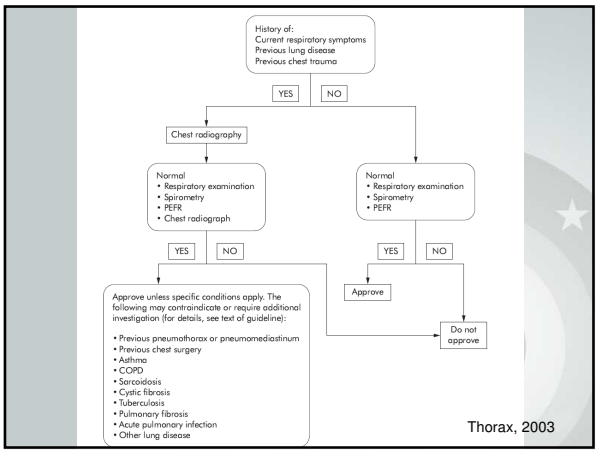
Tetzlaff K. et al. Risk factors for pulmonary barotrauma in divers. Chest 1997, 112:654-659



Pulmonary requirements for divers

- Chest X-ray – in case of symptoms / history (required for professional divers)
- Chest HRCT: air-trapping, bullae

- Asthmatics
- Spontaneous pneumothorax
- Bullae / blebs



Asthmatics and diving

- Risk = bronchospasm during diving
  - Already present before diving
  - Induced by diving (breathing cold air, increased turbulent flow by effort and pressure, salt water spray inhalation)
- Decreased exercise capacity → exhaustion
- Air trapping → pulmonary barotrauma
- Bronchodilatators may increase pulmonary bubble passage → DCS
- Consequences = severe = unacceptable ?

Asthmatics do dive

- Divers Alert Network: no increased prevalence of asthmatics in DCS and PBT statistics
- Prevalence of asthma may be as high as 30% in general population
- Several (low quality studies) suggest that many asthmatics dive without (too much) problems

Mebane GY. The coincidence of asthma and morbidity or mortality in recreational scuba divers reported to DAN. UHMS 1996.
Farrell P et al. Diving practices of scuba divers with asthma. BMJ 1990; 300:166

Asthmatics can dive

- British Thoracic Society Guidelines 2003
  - Free of symptoms with/without medication
  - Normal spirometry (FEV1 >80%, FEV1/FVC >70%)
  - Negative exercise provocation test (8 minutes exercise 70-80% of max; breathing compressed air, <15% decrease of FEV1)
  - NO DIVING if
    - requiring medication <48hrs or
    - PEF decrease >10% from best value or
    - increased PEF variability >20% diurnal

Provocation testing

- Direct provocation tests (**histamine**, metacholine, hypertonic saline): may be positive in 10-12% of healthy population
- Of those, (only) approx. 20% will test positive on exercise provocation
- Pulmonary function tests should be APPROPRIATE for divers and COMPLETE

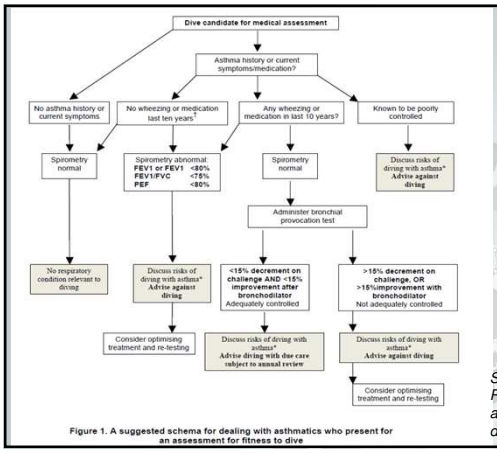


Figure 1. A suggested schema for dealing with asthmatics who present for an assessment for fitness to dive

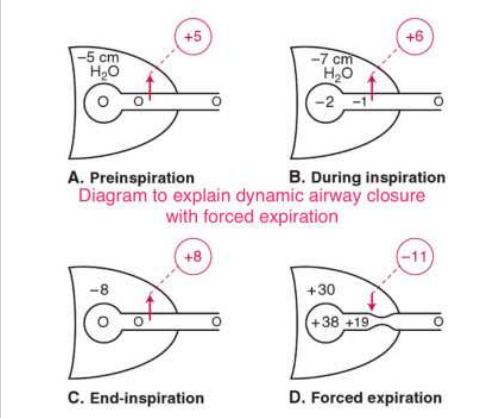
SPUMS 2010 Position paper asthma and diving

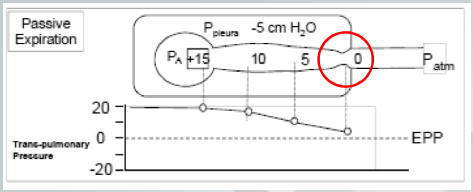
Spirometric abnormalities

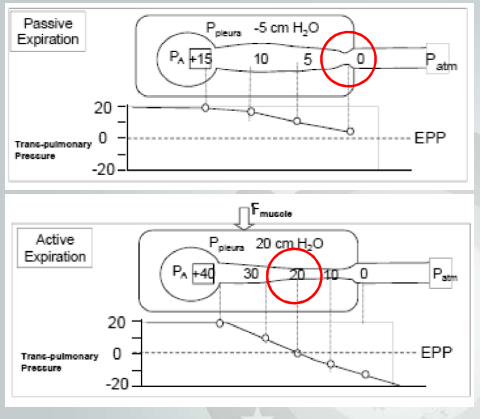
- Spirometric value tresholds vary according to source (BTS vs SPUMS vs…)
- Tiffeneau value: dependent on age, body size, race
- "Large lungs" – spirometry values > 120% of normal value
  - Van Hulst et al. 2011 : 6 cases of PBT in military divers
  - Subject selection or diving induced abnormality ?
  - All had also CT evidence of air trapping, bullae or blebs

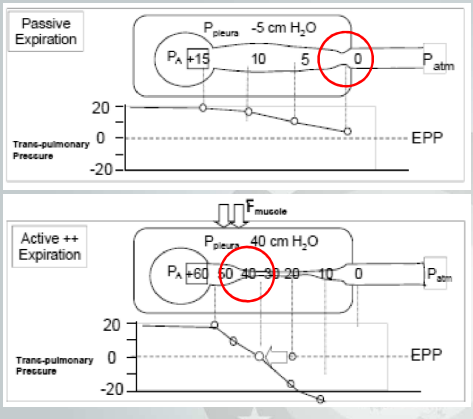
Spontaneous pneumothorax

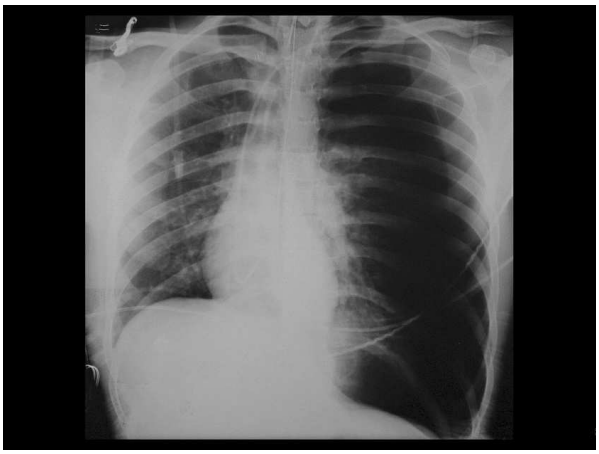
- Risk = pneumothorax while at depth
  - Spontaneous
  - Breathing against resistance
  - Equal Pressure Point shifting = hyperinflation
- Consequences:
  - Tension pneumothorax

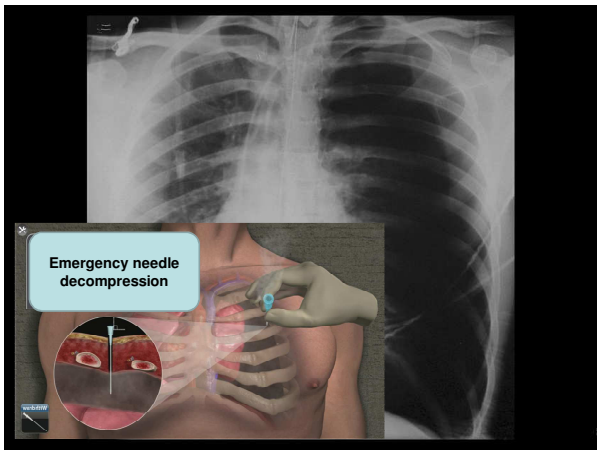












Spontaneous pneumothorax

- Recurrence rate, after initial drainage:
  - 35% → 54% total recurrence rate,
  - 25% of recurrences contra-lateral lung
  - 75% of recurrences within 2 years but even after 6-8 years (18%)
- Pleurodesis or not:
  - Simple drainage: 38.5% recurrence
  - Chemical pleurodesis: 26.5%
  - Surgical pleurodesis (pleurectomy): 0 – 0.5 %

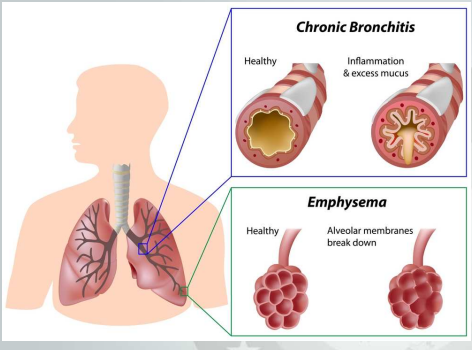
Recommendations BTS 2003

- Spontaneous pneumothorax = contra-indication to all diving
- UNLESS
  - Treated with BILATERAL surgical pleurectomy
  - AND associated with normal lung function (Flow-Volume Loop) and thoracic HRCT scan
- For recreational divers ???
  - Federation guidelines differ – mostly: NO

Pulmonary Bullae - Blebs

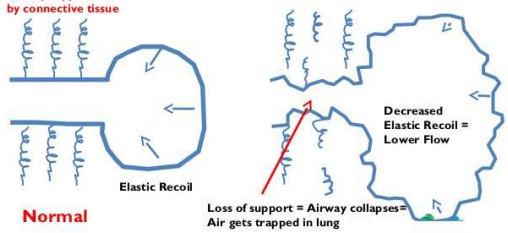
- Risk = overinflation upon ascent
  - Pneumothorax
  - Pneumomediastinum
  - Arterial Gas Embolism
- Risk factors:
  - Congenital
  - Infectious
  - SMOKING

Bullae - Blebs



Emphysema Predominant

-This results in a loss of the elastic recoil of the lungs on expiration
-This also results in loss of tethering or support of the most distal portions of the airway leading to collapse on expiration



Diagnosis of bullae = HRCT

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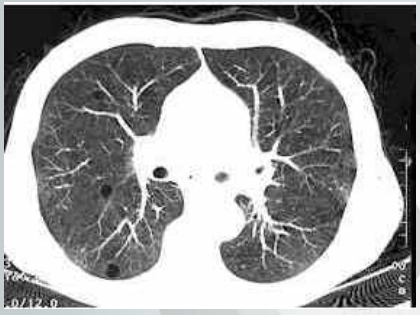
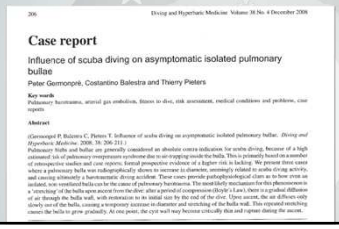


Discussion point

- "Isolated" bullae → no risk ?
- "Thick-walled" → no risk ?
- Note: Evidence for increasing size of bullae with diving (years)

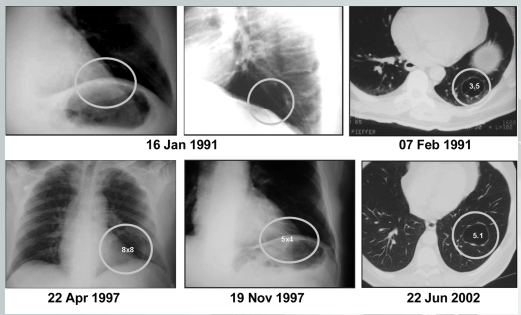


Case report

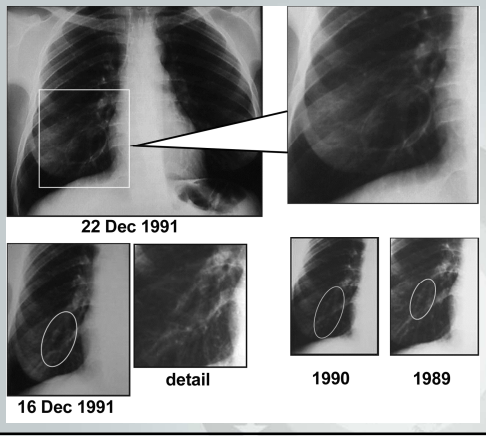
Influence of scuba diving on asymptomatic isolated pulmonary bullae

Peter Germonpré, Costantino Balestra and Thierry Pieters

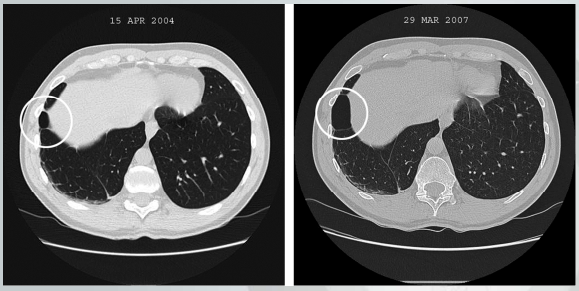
Case report



16 Jan 1991 and 07 Feb 1991: Presence of bulla in left lower lung. No symptoms. Continued diving for 6 years.
27 Apr 1997: Immediately after diving and symptoms of cerebral arterial air embolism.
19 Nov 1997: After 6 months - reduction of bulla volume.
29 Jun 2002: Stable volume after 5 years (no diving).

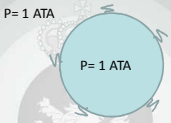


Case report: residual air space after pleurodesis



Proposed mechanism

- Descent (Boyle's Law) :
  - Bulla volume decreases
  - Relative underpressure (elasticity limit of bulla wall)



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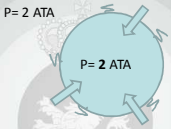

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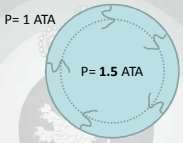
  - Relative overpressure in bulla
  - Gradual return to normal volume



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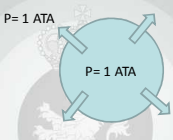

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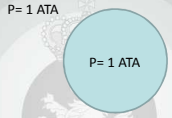
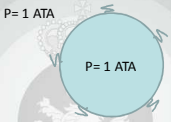
  - Gradual return to normal volume



Proposed mechanism

- Descent (Boyle's Law) :
  - Bulla volume decreases
  - Relative underpressure (elasticity limit of bulla wall)
- Isopression :
  - Diffusion of inert gas into bulla
  - Equipressure after variable amount of time (30+ minutes ?)
- Ascent (Boyle's Law) :
  - Bulla volume increases
  - Bulla wall stretches
  - Relative overpressure in bulla
  - Gradual return to normal volume
- Cyclic !
- At one point, bulla wall "overstretches" during / after ascent → Pulmonary Barotrauma



Evaluation of asymptomatic, isolated, pulmonary bulla: HRCT, PFT !

- Location ? Apical vs. juxtapleural vs intrapulmonary
- Size ? > 1cm
- Other pulmonary abnormalities (pleural adhesions, air-trapping), Flow Volume Loop ?
- Clinical history ?
  - Pneumothorax
  - Pulmonary barotrauma
  - Smoking, asthma
- Diving history (years, dives)
- In case of doubt, repeat CT scan after x months diving ?

Pulmonary symptoms after diving ?

- **Recognise & treat as a possible emergency !**
- Contact hyperbaric / diving medicine specialist
  - 24/24 Hotline for diving emergencies
  - Toll-free number (Belgium)
  - Telephone advice only
  - Referral to HBO centre in case of need

DEFENSIE
LA DÉFENSE

Pulmonary Fitness for Diving and Hyperbaric Exposure

09 Dec 2017 – Military Hospital Brussels

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