





Oxygen First Aid in diving accidents : International Guidelines



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Context

- Oxygen administration is one of the important primary first aid measures in diver education
- Emphasis on
 - 100% oxygen
 - As soon as possible
 - For as long as possible until definitive care (recompression)
- Oxygen = pharmaceutical product
 - Difficulty obtaining and filling oxygen tanks
 - Commercial oxygen tanks / regulators not ideal for diving first aid
 - Oxygen administration = medical treatment, reserved for medical professionals



Evidence based medicine ?

- Physiologic rationale for Oxygen First Aid in diving accidents
 - Gas bubbles volume are (a) major cause of DCI
 - Vascular Gas Emboli are composed of inert (decompression) gases
 - 100% oxygen breathing →
 - Alveolar P_{N_2} close to zero : gradient for inert gas washout
 - Arterial P_{N_2} close to zero : tissue desaturation enhanced
 - Tissue P_{N_2} lower than P_{N_2} in gas bubble : gas bubble dissolves back into tissue
 - Oxygen window increased : inert gas transport to lungs increased



Evidence based medicine ?

- Physiologic rationale for Oxygen First Aid in diving accidents
- Consequences for first aid in diving accidents
 - 100% oxygen breathing needed
 - As soon as possible after the (suspected) diagnosis
 - As long as reasonably possible until definitive treatment (recompression treatment)


Evidence based medicine ?

- Physiologic rationale for Oxygen First Aid in diving accidents
- Consequences for first aid in diving accidents
 - 100% oxygen breathing needed
 - As soon as possible after the (suspected) diagnosis
 - As long as reasonably possible until definitive treatment (recompression treatment)
- Other first aid measures not to forget
 - Rehydration (vascular volume)
 - Position / manipulation / medication

Evidence based medicine ?

- Animal experiments
 - Paul Bert 1878
 - Hyldegaard et al. 1989, 1991, 1994, 2007
- Human studies
 - Altitude decompression sickness: 98.1% effectiveness of return to ground level and 2hrs GLO (ground-level oxygen) (Krause et al ASEM 2000)
 - Diving decompression sickness: FAO₂ (first aid with oxygen) (Longphre et al UHM 2007)
 - Improves the efficacy of first recompression treatment
 - Reduces need for multiple recompression treatments



Evidence based medicine ?

- Human studies: no randomised prospective studies
 - Retrospective studies
 - Parameters not well controlled (Concentration ? Time to start ? Duration ?)
 - Still – effects (NNT=6) if $FAO_2 < 4$ hours after start of symptoms (*Longphre et al UHM 2007*)

Evidence based medicine ?

- Human studies: no randomised prospective studies
- Are RCT possible in DCS ?
 - Only one RCT published !
 - Bennett et al. UHM 2003*: NSAID in musculoskeletal DCS
 - Adjunctive to classical accepted treatment of DCS (FAO_2 , recompression)
 - DCI is infrequent
 - Belgium: approx. 30-40 per year
 - Delay in symptom onset
 - Delay in diagnosis
 - Variability in efficacy of FAO_2 (nitrox, low-concentration masks...)

Evidence based medicine ?

- Human studies: no randomised prospective studies
- Are RCT possible in DCS ?
- Case files (*case reports not published*)
 - DAN Europe Emergency Telephone Hotline
 - Divers' personal experience
 - HBO centres' experience : recurrence of symptoms after cessation of oxygen administration

Common cases: cutis marmorata



Neurological symptoms and precordial (TTE) gas bubbles (VGE)

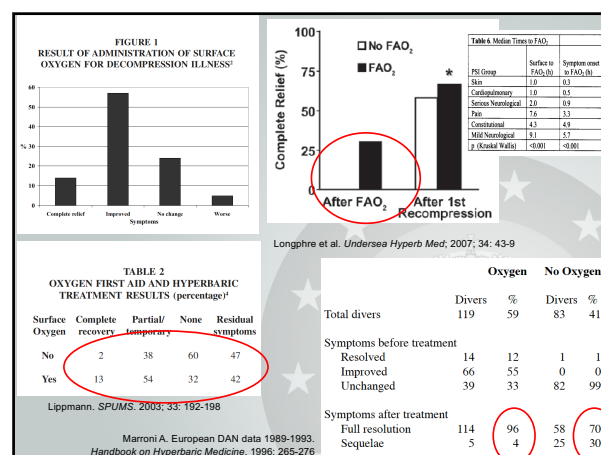
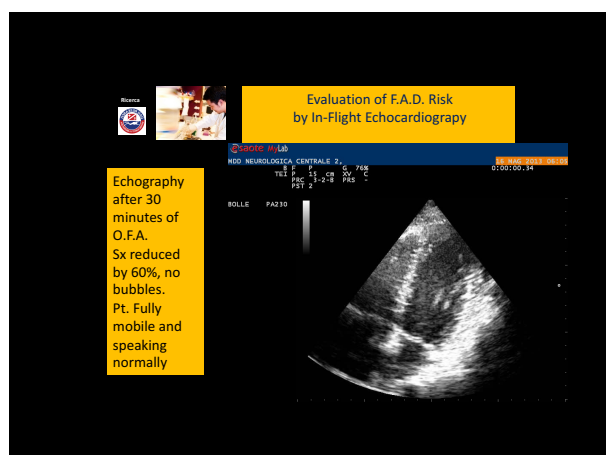
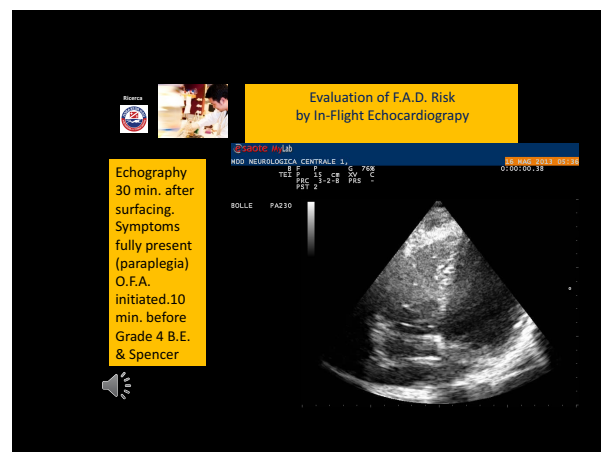


Oxygen effect on DCS

A Unique Case

The echography has been recorded on the Divemaster of the group of volunteer divers participating in the study.

A.B. developed sudden central nervous Sx, with extreme fatigue, dorsal pain, chest tightness, extreme muscular weakness of limbs R > L, inability to stand and articulate words, state of semi-consciousness, on surfacing from a 32 m – 44 min No-D Dive.



DEFENSE LA DEFENSE

ALERT DIVER ONLINE

Oxygen as Definitive Treatment

- If there is some suspicion by those present that DCS may be the culprit, it is recommended that divers be given FAO₂ while expert opinion is sought.

Despite the notorious difficulty in eliminating the diagnosis of DCS, experienced diving doctors can often clearly identify factors that make DCS [likely or] unlikely.

Under those circumstances, such an experienced physician may be comfortable prescribing simple measures with or without further oxygen. [...] Under these circumstances, FAO₂ could be considered definitive treatment for some conditions.

<http://www.alertdiver.com/396>

Mitchell SJ, Doolittle D, Wachholz CJ, Vann RD, eds. Management of mild or marginal decompression illness in remote locations: workshop proceedings. Durham, N.C.: Divers Alert Network, 2005

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DEFENSE LA DEFENSE

Evidence based medicine ?

- Human studies: no randomised prospective studies
- Are RCT possible in DCS ?
- Case files (case reports not published)
- Other diving diseases:
 - CAGE (Cerebral Arterial Gas Embolism): life-threatening
 - CPR, 100% Oxygen recognised as immediate therapeutic measures
 - IPE (Immersion Pulmonary Edema): life-threatening
 - Immediate oxygen administration (increase SaO₂)
 - Later: furosemide, Positive-Pressure respiration

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**Oxygen First Aid:
Guidelines from diving and
hyperbaric medicine societies**

- Undersea & Hyperbaric Medicine Society
- SPUMS
- European Committee for Hyperbaric Medicine
- Divers Alert Network International
- GTUEM - SUHMS
- DDRC
- DMAC
- Based on "Level C Evidence" : Consensus of Experts^{be}

EXPERT'S OPINION

**Diving physiopathology:
the end of certainties? Food for thought**

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ABSTRACT

Our understanding of decompression physiopathology has slowly improved during this last decade and some uncertainties have disappeared. A better understanding of anatomy and functional aspects of patent foramen ovale (PFO) have slowly resulted in a more liberal approach toward the medical fitness to dive for those bearing a PFO. Circulating vascular gas emboli (VGE) are considered the key actors in development of decompression sickness and can be considered as markers of decompression stress indicating induction of pathophysiological processes not necessarily leading to occurrence of disease symptoms. During the last decade, it has appeared possible to influence post-dive VGE by a so-called "preconditioning" as a pre-dive desaturation, exercise or some pharmacological agents. In the text we have deeply examined all the scientific evidence about this complicated but challenging theme. Finally, the role of the "normobaric oxygen paradox" has been clarified and it is not surprising that it could be involved in neuroprotection and cardioprotection. However, the best level of inspired oxygen and the exact time frame to achieve optimal effect is still not known. The aim of this paper was to reflect upon the most actual uncertainties and distill out of them a coherent, balanced advice towards the researchers involved in gas-bubbles-related pathologies.

(Cite this article as: Balestra C, Germonpre P, Rocco M, Biancofiore G, Kot J. Diving physiopathology: the end of certainties? Food for thought. *Minerva Anestesiologica* 2019;85(10):1128-37. DOI: 10.23736/S0575-9395.19.13618-8)

KEY WORDS: Diving, Decompression sickness, Physiopathology.

**UNDERSEA & HYPERBARIC
MEDICAL SOCIETY**
Raising the quality of practice one member at a time

UHMS Best Practice Guidelines
Prevention and Treatment of Decompression
Sickness and Arterial Gas Embolism

28 April 2011

5. Pre-Recompression
Oxygen
15 L/M with reservoir mask or demand valve
Patient in supine position (not head down)
Continuous monitoring
Air transport
As low as safely possible
Preferably lower than 1000 ft
Pressurize aircraft cabin to 1 ATA if possible
Consider Emergency Evacuation Hyperbaric Stretcher
Recompress even if signs/symptoms resolve prior to recompression

UHM 2018, VOL. 45, NO. 3 – CONSENSUS GUIDELINE: PRE-HOSPITAL DCI MANAGEMENT

**Consensus guideline: Pre-hospital management of decompression illness:
expert review of key principles and controversies**

Simon J. Mitchell¹, Michael H. Bennett², Phillip Bryson³, Frank K. Butler⁴,
David J. Doolette⁵, James R. Holm⁶, Jacek Kot⁷, Pierre Lafere⁸

2. FIRST AID PROCEDURES

A. Normobaric oxygen (surface oxygen administered as close to 100% as possible) is beneficial in the treatment of DCI. Normobaric oxygen should be administered as soon as possible after onset of symptoms.

B. Training of divers in oxygen administration is highly recommended.

C. A system capable of administering a high percentage of inspired oxygen (close to 100%) and an oxygen supply sufficient to cover the duration of the most plausible evacuation scenario is highly recommended for all diving activities.

In situations where oxygen supplies are limited, and where patient oxygenation may be compromised (such as when drowning and DCI coexist) consideration should be given to planning use of available oxygen to ensure that some oxygen supplementation can be maintained until further supplies can be obtained.

Observational human studies [13,14]
In vivo studies of bubble and symptom resolution [15–21]

**European Committee for
Hyperbaric Medicine 1998**

a) Strongly recommended (type 1 recommendation) :

- normobaric oxygen

The administration of normobaric oxygen allows for the treatment of hypoxemia and favours the elimination of inert gas bubbles. Oxygen should be administered with an oro-nasal mask with reservoir bag, at a minimal flow rate of 15 l/min, with CPAP mask circuit using either a free flow regulator or a demand valve, in such a way to obtain a FIO₂ close to 1.

In case of respiratory distress, shock or coma, the patient should be intubated and ventilated with a FIO₂ = 1 and setting the ventilator to avoid pressure and volume trauma. Normobaric oxygen should be continued until hyperbaric recompression is started (with a maximum of 6 hours when the FIO₂ is 1).

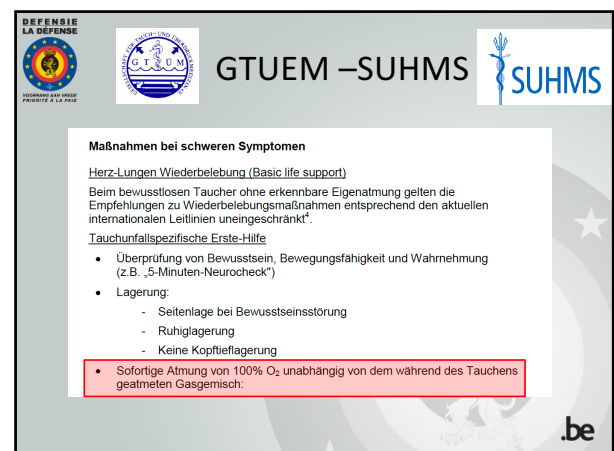
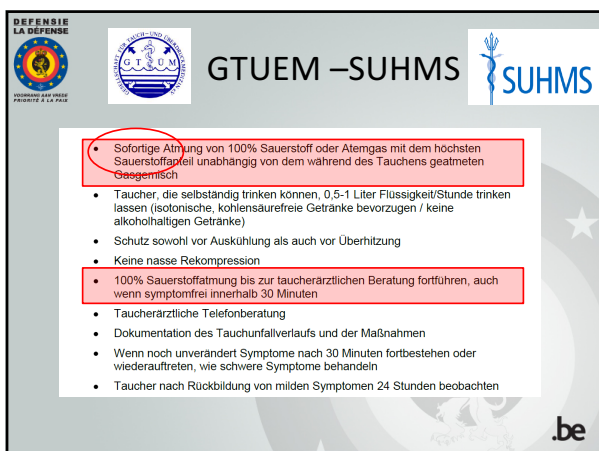
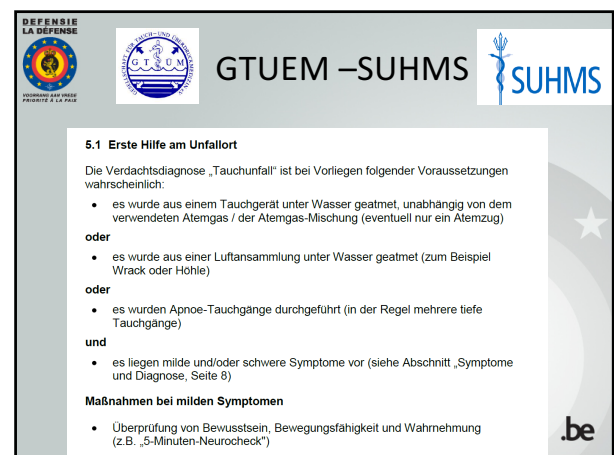
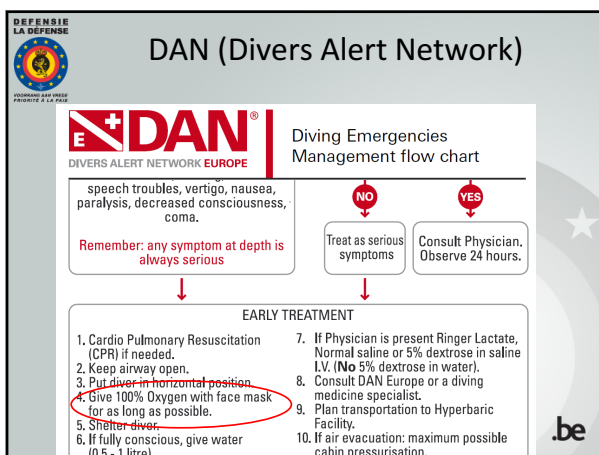
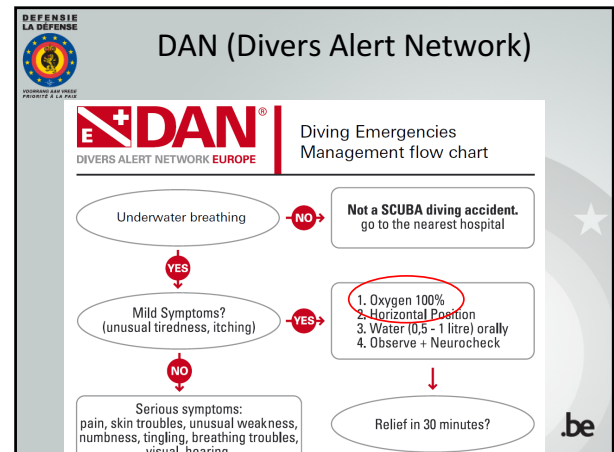
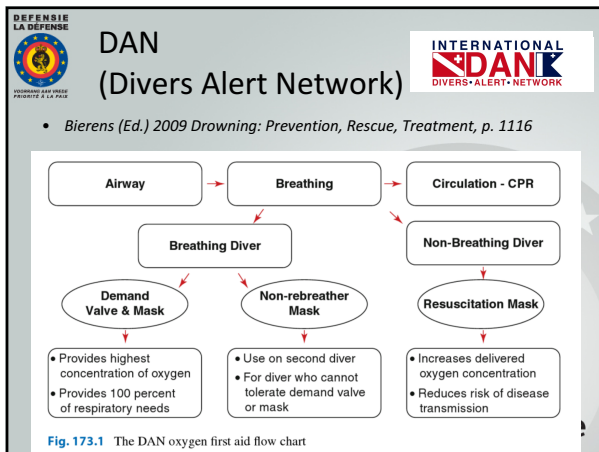
www.echm.org

24 Diving and Hyperbaric Medicine Volume 47 No. 1 March 2017

Consensus Conference
Tenth European Consensus Conference on Hyperbaric Medicine:
recommendations for accepted and non-accepted clinical indications
and practice of hyperbaric oxygen treatment
Daniel Mathieu, Alessandro Marroni and Jacek Kot

Decompression illness (DCI)

- We recommend HBOT in the treatment of DCI (Type 1 recommendation, Level C evidence).
- We recommend 100% normobaric oxygen first aid (Type 1 recommendation, Level C evidence).
- We recommend intravenous fluid resuscitation with non-glucose containing crystalloid solutions (Type 1 recommendation, Level C evidence).



GTUEM –SUHMS

- Bei ausreichender Eigenatmung unabhängig vom Bewusstseinszustand Atmung von 100% O₂ über dicht abschließende Maske / Atemregler (auf Dichtsitz der Maske achten) mit:
 - Demand-Ventil oder
 - Kreislauf-System mit Absorber für Kohlendioxid
 - gegebenenfalls über Konstantdosierung (mindestens 15 Liter/Minute) mit Reservoirbeutel, wenn keine besseren Systeme zur Verfügung stehen.
- Bei unzureichender Eigenatmung Masken-Beatmung mit 100% O₂-Zufuhr über:
 - Beatmungsbeutel mit 100% O₂ Demand-Ventil oder
 - Beatmungsbeutel mit O₂-Reservoir und O₂-Konstantdosierung (mindestens 15 Liter/Minute) oder
 - Kreislauf-System mit CO₂-Absorber.

First Aid:
Recovery position, Maintain airway, Administer 100% O₂ regardless of sats

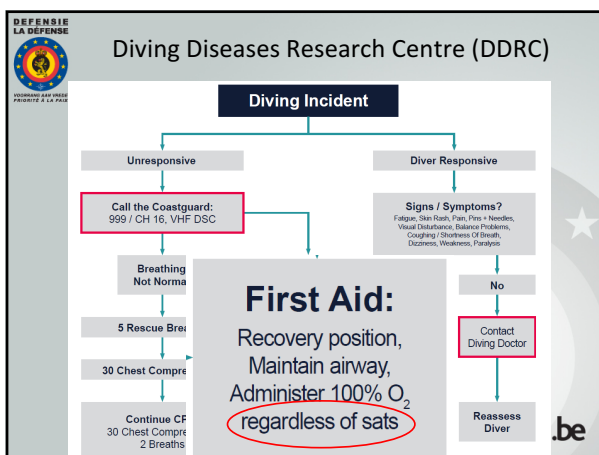
GTUEM –SUHMS

5.2 Primärversorgung durch medizinisches Fachpersonal

Herz-Lungen-Wiederbelebung (Basic + advanced life support)
Wiederbelebensmaßnahmen sind entsprechend den aktuellen internationalen Leitlinien durchzuführen.
Ertrinkungsunfälle können Folge eines Tauchunfalls sein und müssen in einem solchen Fall spezifisch behandelt werden.

Tauchunfallspezifische Maßnahmen bei schweren Symptomen

- Lagerung:
 - Lagerung nach notfallmedizinischen Standards
 - Ruhiglagerung
- Atmung von 100% O₂ (schnellstmöglicher Beginn, unabhängig von dem während des Tauchens geatmeten Gasgemisch) mit:
 - Atemregler oder
 - Demand-Ventil oder
 - Masken-CPAP (Risiko bei V.a. Pneumothorax beachten) oder
 - Kreislauf-System mit Absorber für CO₂.



Diving Medical Advisory Committee (DMAC)

3 Levels of First Aid Training

Title	Training Aim
Initial Diver Training also called 'Diving First Aid'	To assess and establish the needs of a diving casualty including first aid at work, knowledge of diving physiology and diving related illness, administration of oxygen and assisting in the treatment of diving illness.
First Aid at Work Oxygen administration	To deal safely and effectively with injuries or illness at work. To safely administer pure oxygen or oxygen enriched breathing gas mixtures to a diving casualty.
Diver Medic	To administer advanced first-aid and life support skills in the management of diving casualties including treatment while at pressure and during saturation diving operations.

<http://www.dmac-diving.org/guidance/DMAC11.pdf>

Diving Medical Advisory Committee (DMAC)

Initial Diver Training (minimum 40 hours)

- First aid at work
- Barotrauma of middle and inner ear, paranasal sinuses, the lung (pneumothorax, pneumomediastinum, subcutaneous emphysema and arterial gas embolism)
- Near drowning
- Carbon dioxide retention
- Oxygen toxicity
- Vomiting underwater
- Underwater blast injury
- Oxygen administration
- Decompression illness – pathophysiology, clinical features including examination and management
- Nitrogen narcosis
- Carbon monoxide poisoning
- Anoxia/hypoxia
- Hypothermia

Additional for mixed gas diver training

- High pressure nervous syndrome and compression arthralgia

<http://www.dmac-diving.org/guidance/DMAC11.pdf>


Diving Medical Advisory Committee (DMAC)

Initial Diver Training (minimum 40 hours)

First Aid at Work (minimum 24 hours)

- Communication and allocation of responsibility in emergency
- Resuscitation
- Management of unconscious patient
- Treating shock
- Treating and controlling bleeding
- Treating injuries to bones, muscles and joints
- Treating eye injuries and conducting eyewash
- Treating minor injuries
- First aid management of poisoning, gas and fume exposure
- Moving injured people
- Recognising illness
- Treating burns and scalds
- Personal hygiene
- Cross infection in treatment of wounds
- Use of first aid kit material
- Simple record keeping

<http://www.dmac-diving.org/guidance/DMAC11.pdf>



Diving Medical Advisory Committee (DMAC)

Initial Diver Training (minimum 40 hours)


First Aid at Work (minimum 24 hours)

Oxygen Administration (minimum 4 hours)

- Knowledge and recognition of illness which benefit from administration of pure oxygen or oxygen enriched breathing mixtures
- Understanding of the benefits of providing pure oxygen or oxygen enriched breathing mixtures
- Understanding of the potential hazards of working with pure oxygen or oxygen enriched breathing mixtures
- Demonstration of the safe administration of pure oxygen or oxygen enriched breathing mixtures from an administration kit to a breathing and non-breathing casualty
- The safe assembly/disassembly of an oxygen administration kit

<http://www.dmac-diving.org/guidance/DMAC11.pdf>

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Diving Medical Advisory Committee (DMAC)

4 All Divers


All divers should be trained in the first aid management of those common illnesses and injuries to which they may be exposed. This training should include the use of common items of first aid equipment including oxygen administration systems. In most situations this will form a part of basic diver training.

5 Supervisors

Diving supervisors and life support supervisors should have received training in diving first aid as part of their early training. As a result they should be familiar with the first aid equipment provided at the dive site and with the required response to medical emergencies. They should be familiar with and competent in the prevention, recognition and management of diving related illness and particularly with the contractors specific procedures e.g. for the treatment of decompression illness. In most circumstances responsibility for the provision of first aid will be delegated to a designated first aider in which case it is not a requirement for the supervisor to hold a valid first aid qualification.

<http://www.dmac-diving.org/guidance/DMAC11.pdf>


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Summary of recommendations

- Every case of (suspected) DCI (DCS – CAGE)
- Give 100% oxygen (highest possible concentration)
- As soon as possible (minutes)
- Until definitive treatment given or expert medical advice obtained
- With adequate equipment (delivery of high-flow O₂)
- After adequate training
 - Recognising suspected DCI
 - Safely administering O₂
- Rapid consultation w/ Diving Medicine Specialist

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Risks of giving First Aid with Oxygen to diving accidents

- Incorrect diagnosis
 - Spinal DCS → lumbar disc hernia
 - Cerebral DCS → acute cerebrovascular accident (CVA)
 - Pulmonary DCS → pulmonary embolism
 - Pulmonary DCS → immersion pulmonary edema
 - Systemic DCS → shock of unknown origin
- Structural risks
 - Fire, explosion
 - Delay to definitive care (in case of good clinical response to FAO₂)

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“Oxygen Provider” training

- Divers Alert Network
 - Pioneer Oxygen Provider
 - Internationally recognised courses
 - Adopted by many dive organisations
- Belgian Diving Federations
 - Diver Education according to EN
 - Level of First Aid skills depending on Diver Certification



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NELOS - LIFRAS

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MINISTÈRE DES VIEUX
PROTÈGE À LA PAIX

Legal for recreational divers ?

- EN24803 (2007 – 2014): Recreational diving services - Requirements for recreational scuba diving service providers

4.3 Emergency equipment and procedures

4.3.1 Emergency equipment

For all locations where diving activities take place the service provider shall ensure the availability of:

- a first aid kit suitable for the planned diving activities,
- **an emergency oxygen unit with a capacity of delivering at least 15 l/min of pure oxygen for at least 20 min.**
- a communication system suitable for alerting emergency services.

4.3.2 Emergency procedures

At each dive site where diving activities take place a documented emergency plan comprising at least the following information shall be available:

- procedures for casualty recovery, resuscitation and evacuation,
- **use of the emergency oxygen supply.**
- information (including contact details) about the nearest medical resources (including data about the availability of a hyperbaric recompression chamber).

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MINISTÈRE DES VIEUX
PROTÈGE À LA PAIX

Legal for recreational divers ?

- NOB (Nederlandse Onderwatersport Bond)

Zuurstof
Een slachtoffer van een duikongeval 100% zuurstof toedienen, is erkende eerste hulp bij duikongevallen en kan ernstiger schade voorkomen. **Zuurstoftoediening is geen voorbehouden medische handeling in de zin van de wet BIG.** Zuurstoftoediening mag een hyperbare zuurstofbehandeling niet vervangen.

Omdat bij een decompressieongeval vaak beide duikers van een buddy-paar betrokken zijn, wordt aangeraden een zuurstofkoffer zodanig in te richten dat men in staat is twee duikers gelijktijdig zuurstof toe te dienen. Aanbevolen wordt de voorraad zuurstof af te stemmen op de te overbruggen tijd tot hulpverlening ter plaatse is. Bij duiken op Nederlands grondgebied kan ervan uit worden gegaan dat een ambulance veelal binnen een kwartier ter plaatse kan zijn. Bij duiken op de Noordzee of op ruime binnenwateren is deze tijd aanzienlijk langer.

Wet BIG: Wet op de Beroepen in de Individuele Gezondheidszorg

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IS IT LEGAL?

However ...

Belgian EMS Law – based on International Resuscitation Guidelines

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Resuscitation Guidelines (AHA)

Administration of oxygen is not considered a standard first aid skill.

AHA 2015 recommendation

This recommendation suffers one major exception, which is the relief of decompression sickness.

AHA 2015 recommendation

Singletary EM et al. Part 15: first aid: 2015 American Heart Association and American Red Cross Guidelines Update for First Aid. Circulation. 2015;132(suppl 2):S574–S589

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Resuscitation Guidelines (ERC)

In 2015, we focus on adults and children who exhibit signs and symptoms of shortness of breath, difficulty breathing, or hypoxemia in the out-of-hospital setting.

Treatment recommendation
No recommendation; the confidence in effect estimate is so low that the task force thinks a recommendation to change current practice is too speculative.

Values, preferences, and task force insights
In this review, the administration of supplementary oxygen was found to be of some benefit in the following specific circumstances:

- Advanced cancer patients who exhibit symptoms or signs of shortness of breath (dyspnea) and signs of hypoxia
- **Individuals with decompression injury**

The use of supplementary oxygen should be limited to individuals with specific training in oxygen administration.

David A. Zideman et al. Part 9: First aid - 2015 International Consensus on First Aid Science with Treatment Recommendations. Resuscitation 95 (2015) e225–e261

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Question

- In view of the medical specificity of the (diving accident) situation
 - Oxygen not (only) for ensuring adequate oxygen transport
 - But also (mainly) for curative action on inert gas bubbles
 - With extreme emergency (minutes)
- Should divers with adequate training
 - In recognising the emergency situation
 - In safely administering oxygen
- Be allowed to give O₂ before medical first aid arrives ?
 - (And insist that high-flow O₂ is continued by EMS !)

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