Bulletin 1937; 35: 61-73

3* Fructus X. Treatment of serious decompression sickness. In *Treatment of serious decompression sickness and arterial gas embolism. 20th UMS Workshop*. Davis J. Ed. Bethesda, Maryland: Undersea Medical Society, 1979; 37-43

4 *The annual review of recreational scuba diving i njuries and deaths based on 1995 data*. Durham, North Carolina: Divers Alert Network (DAN), 1997

5 Marroni A. The Divers Alert Network in Europe. Risk evaluation and problem management in European recreational diving population. In *Handbook on Hyperbaric Medicine*. Oriani G, Marroni A and Wattel F. Eds. Berlin: Springer-Verlag, 1996; 265-276

6 Dutka AJ. Therapy for dysbaric central nervous system: adjuncts to recompression. In *Management of Diving Accidents.* Bennett PB and Moon RE. Eds. Bethesda, Maryland: Undersea and Hyperbaric Medical Society, 1990; 194-221

7 Seyer J. Pre-hospital treatment of decompression sickness in recreational divers. In *Handbook on Hyperbaric Medicine*. Oriani G, Marroni A and Wattel F. Eds. Berlin: Springer-Verlag, 1996; 187-191

8 Warner DS. Principles of resuscitation in CNS injury and future directions. In *Treatment of decompression illness. 45th UHMS Workshop.* Moon RE and Sheffield PJ. Eds. Kensington, Maryland: Undersea and Hyperbaric Medical Society, 1996; 374-388

9 Dutka AJ. Serious decompression injury: pharmacological aids to treatment. In *Treatment of decompression illness. 45th UHMS Workshop.* Moon RE and Sheffield PJ. Eds. Kensington, Maryland: Undersea and Hyperbaric Medical Society, 1996; 127-139

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OXYGEN ADMINISTRATION IN DIVING ACCIDENTS

David Komesaroff

Key Words

Accidents, equipment, first aid, oxygen, rescue.

Introduction

Oxygen administration in diving accidents has been well documented.[1] However the importance of duration of oxygen supply, humidification and temperature of inspired oxygen and pain relief has often been overlooked.

Basal (resting) physiological oxygen requirements of an adult are approximately 250 ml/min (3 ml/kg). Activity, body temperature and the presence of pain increase this. 2 l/min is about the maximum possible oxygen utilisation (measured in athletes following a 100 m sprint).

In demand valve resuscitators, high flow rates of oxygen are used to flush the exhaled carbon dioxide to the atmosphere. This has several disadvantages.

Approximately 10 l/min of oxygen are required.

The inhaled oxygen is dry and cold.

Sterilisation of equipment after use is inconvenient or impossible.

In closed circuit resuscitation systems less oxygen is used as expired carbon dioxide is removed by an absorbent, for example soda lime or baralyme.

Oxygen supply

A demand valve system requires a fresh gas flow in excess of 10 l/min. A demand valve system with manual triggering for the non-breathing patient (Manually Triggered Ventilator or MTV) will require more. C Size portable oxygen cylinders (2.84 l water volume) contain about 400 litres of oxygen, so a cylinder change is necessary about every 30 minutes. It is therefore essential to have available either multiple C size cylinders or a larger non-portable D (9.5 l water volume), containing about 1,600 l, or E (23.8 l water volume), containing about 2,200 l, size cylinder.

A closed circuit system (such as the OXI-dive1™) theoretically requires a fresh gas flow of about 0.25 l/min but in practice about 3 l/min is needed to achieve 100% inspired oxygen in a diving accident victim. A portable cylinder will last about 120-130 minutes. In experienced hands the closed circuit system requires only 1-2 l/min equating to approximately four hours supply of oxygen.

Humidification and warming of inspired gases

Diving accident victims require warming. With open circuit, high flow systems the administration of cold dry gases over long periods causes a loss of expired water vapour and a reduction of ciliary activity in the respiratory tract mucosa. In a closed circuit breathing system recirculation of the breathing gas retains humidity and heat.

Cross Infection

The National Health and Medical Research Council (NHMRC) in Australia have published infection control guidelines for breathing circuit apparatus.[1] Equipment used for the administration of oxygen must be renewed or sterilised before re-use on another patient.

Demand valve oxygen systems are difficult to sterilise. As the separate components must be dismantled for cleaning, extreme care must be taken to ensure correct reassembly. In the OXI-dive™1, the breathing circuit components, including the KAB™ carbon dioxide absorber, can be autoclaved to ensure sterility. Alternatively it may be more convenient to use disposable components.

Inspired oxygen concentrations in the Oxi-dive™1

An investigation of respiratory rates, inspiratory and expiratory pressures, inspired oxygen concentrations and end tidal $PC0_2$ when using the Oxi-dive™1 was carried out. The Oxi-dive™1 is a closed circuit system which incorporates the KAB™ carbon dioxide absorber (available in autoclavable or disposable versions), a circle breathing system, oxygen cylinder, KDK™ Autovalve and self-sealing valve connections for attaching to an external oxygen supply. The tough plastic case housing the components is waterproof. The oxygen cylinder supplied with the Oxi-dive™1 is smaller than a C size cylinder (water volume 2.12 litres, contents about 320 litres). A C size cylinder is available on request fitted in a larger case.

Method

Two adult volunteers, Case 1(32 year old, 71kg male) and Case 2 (43 year old 90kg male) were the subjects. An OXI-dive™1 closed circuit resuscitator incorporating a KAB™ circular carbon dioxide absorber and a "Flexhose" twin hose breathing circuit (Figure 1) was used. The monitor port at the Y-piece was connected to a Datex Capnomac monitor after calibration against room air. A second line was connected to a pressure gauge (graduated -10 cm to +70 cm H_2O) to measure inspiratory and expiratory resistance in Case 1.

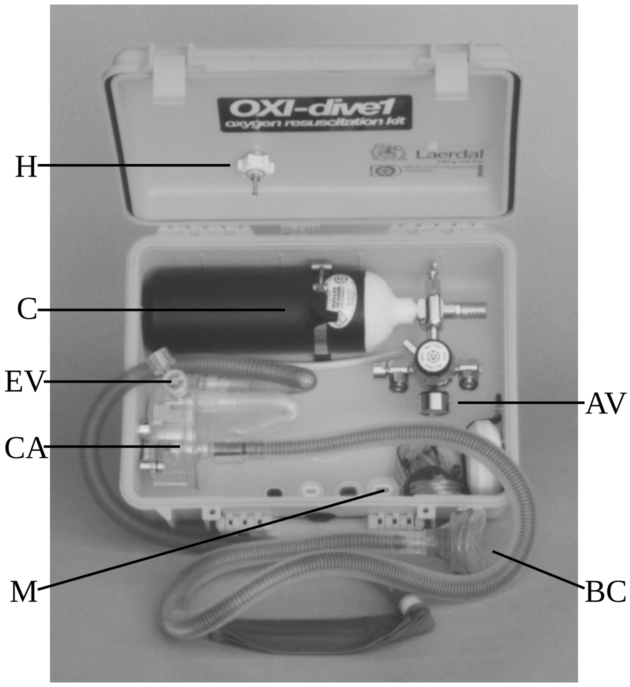

Figure 1. The OXI-dive™1 closed circuit oxygen resuscitator in its Pelican waterproof case. Individual items are the 8 l/min handwheel (H), oxygen cylinder (C), KDK™ AutoValve with 2 or 3 self seal outlets with a flow outlet at 11 o'clock (AV), KAB™ carbon dioxide absorber, shown empty of absorbent, (CA), the breathing circuit (hose in hose tubing) with a cushioned face mask and a breathing bag (BC), the adjustable pressure limiting exhause valve (EV) and storage for airways, a Hudson mask and a Laerdal pocket mask (M).

A size 5 disposable, cushion facemask (King Systems) was fitted to the patient port of the breathing circuit. The oxygen bypass (Flush) button was used to fill the breathing bag rapidly at the start of each set of tests. When the volunteers were connected to the circuit the adjustable pressure limiting (APL) valve was rotated (anti-clockwise) to the open position. The time, respiratory rate, end tidal PCO_2 and the inspired oxygen concentration (FiO_2) were recorded regularly. The inspiratory and expiratory pressures were recorded at random intervals. Four different flow rates were tested. These are described below

Results

High oxygen concentrations were obtained using all the settings tested. In all experiments inspiratory and expiratory pressures were acceptable. End tidal CO_2 levels were in the normal physiological range, showing that the absorbers were functioning correctly.

TABLE 1

OXYGEN FLOW RATE 2 l/min FOR 2 MINUTES THEN 0.5 l/min

Time Minutes	Respiratory rate Case 1	Respiratory rate Case 2	Inspiratory pressure cm water Case 1	Expiratory pressure cm water Case 1	End tidal PCO_2 Case 1	End tidal PCO_2 Case 2	Inspired oxygen % Case 1	Inspired oxygen % Case 2
Flow rate 2 l/min								
0	14	13	-1.5	+2	40	40	21	21
0.5	12	12			41	38	78	56
1	11	11			38	39	80	65
2	11	10	-1.5	+2	37	37	80	76
Flow rate reduced to 0.5 l/min								
3	10	12			36	41	58	77
4	10	11			37	37	67	77
5	11	10			39	34	68	79
6	12	11	-2	+2.5	36	38	63	79
10	12	11			37	37	67	80

TABLE 2

OXYGEN FLOW RATE 2 l/min UNTIL F_IO_2 100% THEN 0.5 l/min

Time Minutes	Respiratory rate Case 1	Respiratory rate Case 2	Inspiratory pressure cm water Case 1	Expiratory pressure cm water Case 1	End tidal PCO2 Case 1	End tidal PCO2 Case 2	Inspired oxygen % Case 1	Inspired oxygen % Case 2
Fresh gas flow 2 l/min								
0	11	12	-1.5	+2	40	40	21	21
0.5	10	12	-1	+2	39	37	71	69
1	9	12			41	38	85	79
2	12	12			39	40	91	86
2.25	10	11			36	40	91	90
3	11	12			41	37	94	90
4	11	10			38	39	92	94
5	11	10			37	36	93	97
6	10	11	-2	+2.5	39	35	94	98
7	10	11			38	37	96	99
7.25	10	11			36	37	98	100
8	11	11	-1.5	+2	36	38	98	100
Fresh gas flow rate reduced to 0.5 l/min								
9	11	11			39	38	95	96
10	13	12			36	38	93	94
11	12	11			36	39	90	92
12	10	10			38	40	88	89
13	14	11			34	36	88	86
14	11	11			37	39	86	87
15	12	11			36	38	87	85

In the first experiment, the flowrate on the KDK Autovalve™ was set at 2 l/min for two minutes and then reduced to 0.5 l/min. After 10 minutes the inspired oxygen was only 67% in Case 1 and 80% in Case 2 (Table 1).

In the 2nd experiment the flowrate was set at 2 l/min until an inspired oxygen of 100% was achieved, which took 7 minutes and 25 seconds for Case 2. Case 1 had reached 98% after 8 minutes. Then the flowrate was reduced to 0.5

TABLE 3

OXYGEN FLOW RATE 8 l/min FOR 5 MINUTES THEN 2 l/min

Time Minutes	Respiratory rate Case 1	Respiratory rate Case 2	Inspiratory pressure cm water Case 1	Expiratory pressure cm water Case 1	End tidal PCO_2 Case 1	End tidal PCO_2 Case 2	Inspired oxygen % Case 1	Inspired oxygen % Case 2
Fresh gas flow 8 l/min								
0	11	12	-1.5	+2	41	40	21	21
0.5	13	11	-1	+2	37	38	90	100
1	12	10			40	38	100	100
2	10	13			39	39	100	100
2.25	13	10			36	37	100	100
3	11	13			37	39	100	100
4	13	11	-2	+2.5	37	38	100	100
5	12	11			37	37	100	100
Fresh gas flow rate reduced to 2 l/min								
10	11	11			40	38	97	98
11	12	11	-2	+2	37	39	97	96
12	12	10			38	40	94	94
13	10	10			38	38	95	96
14	11	10	-1.5	+2.5	38	39	94	96
15	11	10			38	38	95	94

l/min. The oxygen percentage dropped to 93% in Case 1 and 94% in Case 2 at 10 minutes and by 15 minutes it had dropped to 87% in Case 1 and 85% in Case 2 (Table 2).

In the 3rd experiment the flowrate was set at 8 l/min for five minutes and then reduced to 2 l/min. An inspired oxygen of 100% was achieved in 1 minute in both volunteers. However 5 minutes after reducing the flow rate to 2 l/min there was a steady drop in inspired oxygen and at 15 minutes it was 95% in Case 1 and 94% in Case 2 (Table 3).

In the 4th experiment the flowrate was set at 8 l/min for five minutes and then reduced to 3 l/min. The inspired oxygen for both subjects was 100% at 1 and at 5 minutes. At 10 minutes inspired oxygen was 99% in Case 1 and 98% in Case 2. At 15 minutes both subjects were breathing 99% oxygen. (Table 4 page 24)

Discussion

The basal oxygen requirement at rest is about 250 ml/min. However 0.5 l/min is the minimum recommended fresh gas flow of oxygen for closed circuit resuscitation systems. With low fresh gas flows the inspired oxygen only increases slowly with time because of mixing with expired gas, which has lower concentrations of oxygen (Table 1). This is accentuated in the presence of nitrogen loading which is common in diving accidents.

To maintain 100% inspired oxygen concentration, an initial fresh gas flow rate of 8 l/min of oxygen for five minutes and then reducing the flow to 3 l/min is recommended (Table 4).

To maintain inspired oxygen concentration over 90% an initial fresh gas flow rate of 8 l/min of oxygen for five minutes and then reducing to 2 l/min is required (Table 3).

How to use OXI-dive™1

1 Set the KDK Autovalve™ to an oxygen flow rate of 8 l/min.
2 Pre-fill the rebreathing bag with oxygen by occluding the patient port of the breathing circuit and depressing the oxygen bypass (Flush) button.
3 Attach the facemask to the breathing circuit and apply to the victim's face. The facemask is preferably held by the victim but can be assisted by the operator.
4 Open the exhaust (APL) valve.
5 After 5 minutes reduce the oxygen flow rate to 3 l/min.
6 Observe that the breathing bag regularly inflates and deflates. If the breathing bag tends to deflate, correct the application of the face mask to reduce leaks and/or increase the flow rate until the bag remains adequately inflated.
7 The oxygen bypass can be depressed at any setting to instantly refill the breathing bag.

TABLE 4

OXYGEN FLOW RATE 8 L/MIN FOR 5 MINUTES THEN 3 L/MIN

Time Minutes	Respiratory rate Case 1	Respiratory rate Case 2	Inspiratory pressure cm water Case 1	Expiratory pressure cm water Case 1	End Tidal PCO_2 Case 1	End Tidal PCO_2 Case 2	Inspired oxygen % Case 1	Inspired oxygen % Case 2
Flow rate 8 l/min								
0	14	14	-1.5	+2	41	40	21	21
0.5	13	13	-1	+2	39	38	90	100
1	13	13			40	38	100	100
2	12	11			39	37	100	100
2.25	11	12			37	39	100	100
3	11	13			39	38	100	100
4	10	11			37	39	100	100
5	11	10			38	36	100	100
Flow rate reduced to 3 l/min								
9	13	13			39	40	100	99
10	11	14			39	38	99	98
11	13	12			40	37	99	99
12	12	13			36	37	98	100
13	10	11			38	37	99	99
14	10	11			37	39	99	99
15	11	10			38	37	99	99

Important points when using Oxi-dive™1

If the patient is breathing, the exhaust (APL) valve must be remain in the open position (turned anti-clockwise). Excess gas in the breathing circuit is automatically vented.

If the patient stops breathing, close the APL valve (turn clockwise). The operator maintains the facemask in position and compresses the breathing bag intermittently approximately 14 times a minute. Excess gas in the breathing circuit is vented by briefly opening the ALP valve as required.

The oxygen bypass (Flush) rapidly inflates the re-breathing bag at the commencement of operation. It is also used for intermittent rapid filling if the breathing bag deflates.

To increase the rate of nitrogen or toxic gases (e.g. carbon monoxide) removal from the breathing circuit:

1 Remove the face mask from the patient's face every 5-10 minutes.
2 Empty the breathing bag.
3 Rapidly refill the breathing bag by depressing the oxygen bypass.
4 Re-apply the facemask and proceed as described above.

Other oxygen administration systems

Medical Developments Australia also produce three other oxygen resuscitation systems. All include accessories such as airways, pocket masks, etc. Venturi suction is available as an option.

OXI-dive™ 1A

Combined closed circuit and non-rebreathing demand valve system. It is the same as OXI-dive™1 with an manually triggered ventilator fitted with a self-store, coiled hose in the same case.

OXI-dive™2

Non re-breathing demand valve system. Consists of a manually triggered ventilator, oxygen cylinder, KDK™ regulator and self-sealing valve connections for attaching to an external oxygen supply. The tough plastic case housing the components is waterproof.

OXI-dive™3

As for OXI-dive™2 in a small compact case without the oxygen cylinder. Includes the PIBN adapter for connecting the KDK™ regulator to an external oxygen cylinder with a threaded fitting.

Conclusions

It is surprising that high flow non-rebreathing systems continue to be used in diving accidents. Conservation of oxygen, provision of warm, humidified gases and a clean breathing circuit for each patient are obvious advantages of closed circuit rebreathing systems.

The OXI-dive1™ closed circuit resuscitator achieves high inspired oxygen concentrations. An initial oxygen flow rate of 8 l/min for five minutes followed by 3 l/min provides 100% oxygen almost immediately and 99% indefinitely. A C size oxygen cylinder used at these rates with the OXI-dive1™ lasts for about 1.5-2 hours.

With an initial oxygen flow rate of 8 l/min for five minutes followed by 2 l/min the Inspired oxygen is 90+% after five minutes of 100%. A C size oxygen cylinder will last about 2.5-3 hours.

The duration of oxygen supply will be reduced if there is a poor seal with the facemask or if the facemask is removed for short periods.

Pain relief

In Australia methoxyflurane is now the most widely used agent for pre-hospital pain relief in ambulance services, defence, mining and ski areas. The efficiency of pain relief is at least equivalent to, and probably better than, the use of 50% nitrous oxide/oxygen (Entonox) in a demand valve system.[3,4] Entonox is, of course, contra-indicated in diving accidents as nitrous oxide is a more soluble gas than nitrogen so using Entonox after a dive will increase the diver's inert gas load and worsen any decompression illness present.

Methoxyflurane is administered using the hand held Penthrox™ Inhaler. 3-6 ml is carefully poured onto the base of the inhaler. The methoxyflurane then passes through circumferential openings into the polypropylene wick within the body. The mouthpiece can be fitted with a standard facemask or inserted directly into the patient's mouth. Inhalation provides pain relief for 25-55 minutes depending on whether 3 or 6 ml (the maximum recommended dose) is used. If higher concentrations of methoxyflurane vapour are required, the opening near the mouthpiece of the Penthrox™ Inhaler may be occluded with the index finger.

Oxygen can be connected to the nipple in the base. 3 l/min provides 35-40% and 8 l/min 50-60% inspired oxygen with the inhaled methoxyflurane vapour.

In 1987 Toomath published an article in the New Zealand Medical Journal[5] describing two patients who died following several weeks of intermittent administration of methoxyflurane for pain relief. The doses administered were approximately four times those approved by the Food and Drug Administration in the USA and ten times the dose recommended in Australia. As a result methoxyflurane was withdrawn from use in New Zealand. However an application is being made to re-register methoxyflurane for use in New Zealand.

References

1 Oxer H. Equipment for emergency. oxygen in diving accidents. *Scuba Diver* 1995; September/October: 67-69
2 National Health and Medical Research Council. *Infection control in the health care setting.* Canberra: Australian Government Publishing Service, 1996
3 Komesaroff D. Pre-hospital pain relief: Penthrane or Entonox? *Aust J Emerg Med* 1995; 2: 28-29
4 Tomlin PJ, Jones BC, Edwards R and Robin PE. Subjective and objective sensory responses to inhalation of nitrous oxide and methoxyflurane. *Brit J Anaesth* 1973; 45: 719
5 Toomath RJ and Morrison RB. Renal failure following methoxyflurane analgesia. *N Z Med J* 1987; 100 (836): 707-708

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IMMERSION HYPOTHERMIA

James Francis

Key Words

Accidents, first aid, thermal problems, treatment.

Introduction

I have a feeling that I was asked to do this because I hail from the "frozen north" although, looking around at some of the divers this week, hypothermia is not necessarily an exclusive problem for those north of the equator!

As we all know, the temperature of the body is determined by the balance between heat gained and heat lost. I am not going to address the thermal input side of the