First aid normobaric oxygen for the treatment of recreational diving injuries.

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Submitted - 1/9/06 - Accepted - 8/25/06

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Longphre JM, Denoble PJ, Moon RE, Vann RD, Freiberger JJ. First aid normobaric oxygen for the treatment of recreational diving injuries. Undersea Hyperb Med 2007; 34(1):43-49. Introduction: First aid oxygen (FAO_2) has been widely used as an emergency treatment for diving injuries, but there are few studies supporting its efficacy. Methods: 2,231 sequential diving injury reports collected by the Divers Alert Network (DAN) Injury database from 1998 to 2003 were examined. Results: 47% (1,045) of cases received FAO_2. The median time to FAO_2 treatment after surfacing was four hours and after symptom onset was 2.2 hours. Persistent complete relief (14%) or improvement (51%) was seen with FAO_2 alone (65% overall response; n=330). After one recompression treatment 67% of FAO_2 patients reported complete relief compared to 58% of the no FAO_2 group (OR=1.5, 95% CI=1.2 -1.8). FAO_2 given at any time after surfacing significantly reduced the odds of multiple recompression treatments (OR=0.83, 0.70-0.98). When FAO_2 was given within 4 hours of surfacing, the OR decreased to 0.50 (0.36-0.69) yielding a number needed to treat of 6. Case severity affected urgency of FAO_2 treatment. Individuals with more prominent symptoms received prompt treatment. Cardiopulmonary, skin, and serious neurological symptoms had shorter delays to FAO_2 ($p<0.001$). Conclusions: FAO_2 increased recompression efficacy and decreased the number of recompression treatments required if given within four hours after surfacing.

INTRODUCTION

In 1878, Paul Bert was the first to report that oxygen resolved intravascular bubbles in decompressed animals(1). Shortly afterwards, Zuntz suggested that oxygen be combined with recompression(2), but this would not be put into widespread practice until after World War II. Oxygen is currently widely employed in the treatment of decompression disorders (3, 4). Although the use of surface oxygen is supported by animal experiments (5-8) there are few recent studies supporting its efficacy except for altitude DCS (9). To address this issue, the Diver's Alert Network (DAN) injury database was retrospectively queried for cases in which surface oxygen was provided as first aid for decompression illness (first aid oxygen, or FAO_2). These data were evaluated for symptom relief after recompression and for the total number of recompression treatments in divers who did and did not receive FAO_2.

METHODS

Record selection

Two-thousand, two-hundred and thirty-one sequential records from the Divers Alert Network (DAN) Injury Database that were collected using the Diving Injury Reporting Form (DIRF) from 1998 through 2003 were reviewed for data on oxygen-administration prior to recompression. FAO_2 administration status was determined for all cases from: (a) a completed answer to the yes or no question

on the DIRF about receiving FAO_2; (b) a record of FAO_2 flow rate, duration, or mode of administration; or (c) evidence from the textual narrative that FAO_2 had or had not been administered. The 66 cases that did not contain any of the above information were assumed not to have received FAO_2. All patients had been recompressed and while some may not have been diving related, none were excluded from the dataset because expert diagnosis of both DCS and AGE has been shown to take into account the response to treatment (10) and the elimination of ambiguous cases might have biased the analysis in favor of a beneficial effect for FAO_2. Once the cases were categorized, the dataset was analyzed to reveal how and when FAO_2 was administered to injured divers. It was then studied to determine the relationship between FAO_2 administration and outcome after treatment while accounting for possible confounding effects of timing of FAO_2 administration, the severity of the reported injury, and the age and gender of the diver. Unfortunately, there was no information about divers whose symptoms resolved after receiving FAO_2 and who did not report to a chamber for medical evaluation. There was also no information about symptom recovery prior to recompression for divers not receiving FAO_2. Thus, the data do not provide a complete picture of FAO_2 effectiveness.

Assignation of treatment groups based on the timing of FAO_2 administration

To the extent that they were available, the time intervals from surfacing and from symptom onset to FAO_2 were assessed. Although 47% (1045) of the patients received FAO_2, the time from surfacing to FAO_2 was recorded for only 365 and from symptom onset for only 362 individuals. In addition, the resolution of these times was poor because they were rounded to standard time points instead of given as exact observations. Thus, we used the median values as cut points to create surface to FAO_2 and symptom to FAO_2 groups for analysis. The number of recompression treatments and their clinical outcomes were compared across these groups.

Case severity classification

To investigate the effects of case severity on outcome, cases were categorized according to the Perceived Severity Index (PSI) that was introduced by DAN in the *2002 DAN Report on Diving Injuries, Fatalities and Project Dive Exploration* (11) and is summarized in Appendix 1. The PSI is based on an empirically derived hierarchy of symptoms associated with decompression illness in descending order of severity: serious neurological, cardiopulmonary, mild neurological, pain, lymphatic or skin, and constitutional or nonspecific. To control for the influence of presentation severity (10), comparisons of the effect of FAO_2 on clinical outcome were made without and with stratification by PSI.

Outcome classification

Clinical outcomes for FAO_2 treatment groups were compared before and after recompression therapy. Possible outcomes recorded in the DIRF were: complete relief of symptoms, improvement of symptoms, temporary improvement in symptoms, no change in symptoms, or worsening of symptoms. For some purposes, missing data compelled collapsing categories and dichotomizing the clinical outcomes into complete relief or not complete relief.

Mode and duration of administration

The mode and duration of FAO_2 administration were recorded in only 417 and 229 of the records, respectively. We elected to accept all reported instances of FAO_2

administration as having clinically adequate O_2 supplementation and duration with the understanding that inadequate FAO_2 would bias against finding a beneficial effect. If in this study population there were instances in which the O_2 administration was for a short period or at low inspired concentration the finding of a beneficial effect would suggest a more robust effect when FAO_2 is adequate.

Statistics

Observed versus expected frequencies of the possible outcomes were compared among the treatment groups using chi-square tests for independent proportions and logistic regression when controlling for other possible confounding factors. Median times to FAO_2 were compared by Kruskal-Wallis test. A p-value of 0.05 or less was considered statistically significant.

RESULTS

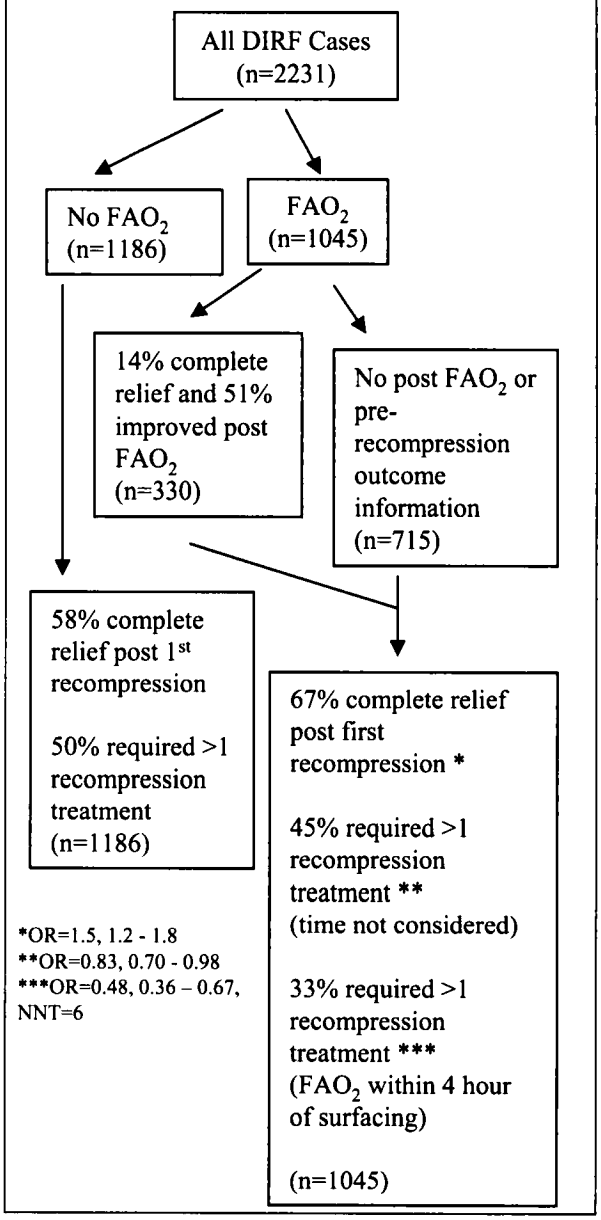
The dataset contained 2231 cases. A total of 1045 divers (47%) received FAO_2 at some point during the course of their illness.

Figure 1 summarizes the case breakdown by significant treatment groups and important outcome by significant treatment groups and important outcome findings.

Effect of FAO_2 on outcome in cases receiving recompression treatment

The effect of FAO_2 before recompression therapy on outcome after recompression was evaluated after the first recompression and at discharge after all recompressions. Following the first recompression, 67% of FAO_2 patients reported complete relief compared to 58% of the no FAO_2 group (OR=1.5, 95% CI = 1.2 to 1.8). This differential improvement was not seen at discharge.

Fig 1.



Effect of FAO_2 on the number recompression treatments prescribed

Without accounting for the timing of its administration, FAO_2 reduced the number of recompression treatments required before discharge. In our sample 45% of divers who received FAO_2 required more than one recompression treatment compared to 50% of those who did not receive FAO_2 (OR=0.83, 0.70-0.98). However, a much greater effect was

seen when divers who received FAO_2 within the first 4 hours after surfacing were compared with those not receiving FAO_2 (OR=0.49, 0.36-0.69). Only 33% of divers who received FAO_2 within 4 hours required more than one recompression treatment as compared to 50% of divers who did not receive FAO_2. This figure corresponds to a risk reduction in our dataset of 16.7 % and yields a number needed to treat (NNT) = 6, meaning that 6 divers need to be treated with FAO_2 to avoid one or more additional recompressions. Table 1 shows the percent of divers in each known time category of our database that required more than one recompression treatment. When the dataset was stratified by PSI, FAO_2 did not influence the number of treatments for the serious neurological or cardiopulmonary categories and time from symptom onset to FAO_2 was not predictive.

Table 1. Percent of divers in category requiring more than one recompression treatment	
Time of FAO_2 after surfacing from the dive	
≤ 4 h *	33%
>4 h	37%
No FAO_2	50%
* p <0.001 by Chi square when comparing FAO_2 at ≤ 4 h to No FAO_2	

Effect of FAO_2 on outcome prior to recompression treatment

Of the 2,231 recompressed divers in the dataset, there were 330 instances with data describing a treatment outcome prior to first recompression. Table 2 shows the reported response to FAO_2 treatment before recompression. Persistent complete relief or improvement was seen with FAO_2 in 65% of all cases treated. Because all divers in the dataset were recompressed, no controls received FAO_2 but were not recompressed, thus, the important question of the effectiveness of FAO_2 alone (without recompression) could not be answered.

Table 2. Outcome after FAO_2 alone	
Relief Level	Percent
Complete	14%
Improved	51%
Temporary	5%
No Change	26%
Got Worse	5%

Mode and duration of FAO_2 administration

The mode of oxygen delivery was recorded in 417 cases. Use of demand valve, pocket mask and non-rebreathers predominated. The duration of FAO_2 administration was available in 229 cases. The mean and median duration of FAO_2 were 132 and 93 minutes, respectively, but the O_2 flow rate and actual FIO_2 delivered were unknown. Table 3 describes the delivery modes recorded in the dataset.

Table 3. O_2 Delivery Mode		
Mode	Frequency	Percent
demand valve	87	20.9
pocket mask	128	30.7
non-rebreather	157	37.6
nasal cannula	30	7.2
Semi-closed circuit	12	2.9
built in breathing system	3	0.7
Total	417	100

Timing of FAO_2 in relation to symptom onset and surfacing

The timing of FAO_2 administration varied widely. Even though symptoms occurred most often within the first hour after the dive, the median time to FAO_2 was 2.2 hours after symptoms began (range 0 hours to 6.9 days) and 4 hours after the end of the dive (range 0 to 7 days). Table 4 describes the timing of FAO_2 in relation to symptom onset and surfacing.

Table 4. Time to FAO_2 administration		
Quartiles	Time (h) from surfacing to FAO_2 (n=365)	Time (h) from symptom onset to FAO_2 (n=362)
25%	1	0.25
50%	4	2.2
75%	18	11

Effect of perceived case severity on FAO_2 timing

The perceived severity of the case affected both the frequency and the timing of the administration of FAO_2. When the dataset was stratified by case severity (PSI), a significantly higher percentage ($p< 0.001$ chi square) of divers with severe symptoms (Cardiopulmonary or Serious Neurological) received FAO_2 compared to divers with less severe symptoms. Table 5 shows that divers reporting more severe symptoms were more often given FAO_2.

Table 5. PSI vs. Percent Received FAO_2		
PSI	Frequency	Percent of group that received FAO_2
Cardiopulmonary	64	68%
Serious Neurological	664	61%
Pain	457	42%
Skin	21	43%
Mild Neurological	982	40%
Constitutional	29	31%

The severity of the case also affected the urgency or timing of FAO_2 administration. With the exception of readily perceived skin findings, the median times to FAO_2 were shorter for the more serious symptoms as indicated by Table 6.

Table 6. Median Times to FAO_2		
PSI Group	Surface to FAO_2 (h)	Symptom onset to FAO_2 (h)
Skin	1.0	0.3
Cardiopulmonary	1.0	0.5
Serious Neurological	2.0	0.9
Pain	7.6	3.3
Constitutional	4.3	4.9
Mild Neurological	9.1	5.7
p (Kruskal Wallis)	<0.001	<0.001

Effect of timing of FAO_2, severity of presenting symptoms, age and gender on outcome

Although the data showed a beneficial effect for FAO_2 after the first recompression treatment, the time of surfacing to FAO_2 or symptom onset to FAO_2 were not significant predictors of complete relief or improvement when analyzed by logistic regression. The severity (PSI) was a nearly significant predictor ($p= 0.06$) as noted previously (10). This was confirmed by multi-factorial analysis of variance which suggested that severity tended to influence outcome after the first recompression ($p=0.06$) while time after surfacing did not. Neither age nor gender were significant predictors of outcome when time and PSI were controlled by logistic regression, but when analyzed alone, males had a 1.3 odds ratio (95% CI, 1.08-1.60) of complete relief compared to females and the effectiveness of FAO_2 decreased by 9% per decade (95% CI, 0.81-0.99).

DISCUSSION

This study, based on outcomes obtained from the DAN Diving Injury Database, supports the current practice of using FAO_2 in the emergent treatment of recreational diving injuries. It shows that after the first

recompression, more divers in the FAO_2 group recovered completely than in the group not receiving FAO_2 and that this effect was independent of the time of FAO_2 administration after surfacing or symptom onset. The study also shows that FAO_2 decreased the odds of a diver requiring more than one recompression treatment and that this effect was stronger in divers who received FAO_2 within 4 hours of surfacing from the dive. FAO_2 within 4 hours of surfacing (compared to no FAO_2) decreased the total number of hyperbaric treatments required with a NNT = 6 similar to Bennett's finding of NNT = 5 for a decrease in treatments with Tenoxicam as adjunctive therapy (12). The absence of an effect of FAO_2 on final outcome was similar to Bennett's observation for Tenoxicam, and both studies are consistent with the observation that the natural history of mild DCI symptoms is for eventual recovery although refractory cases sometimes occur (12).

Both complete relief after the first recompression and multiple recompressions were independent of gender when severity and time were controlled statistically and although age was a significant negative predictor for both outcomes, the effect was small. The study also showed that 65% of divers who received FAO_2 prior to recompression obtained either complete relief or improvement in symptoms although the significance of this observation is impossible to determine because there was no control group of divers who received FAO_2 but were not recompressed.

Finally, this study casts light on how, when, and to whom FAO_2 is generally administered. Most FAO_2 recipients utilized the free-flowing non-rebreather mask which does not supply 100% FIO_2. Only 20.9% utilized the more efficient demand valve, which can supply 100% FIO_2. Given that the inspired oxygen fraction and duration of application may have been less than optimal in more than 50% of the injured divers, wider dissemination of devices that can deliver higher concentrations for longer times and better education regarding its effectiveness would appear necessary. Fifty percent of injured divers had at least a 2.2 hour delay until the administration of FAO_2. This was surprising, given the early onset of most symptoms and perceived widespread availability of oxygen at dive sites. It is also interesting that divers who received FAO_2 were more likely to be those with obvious clinical presentations, such as cardiopulmonary symptoms, serious neurological symptoms, and skin manifestations.

This study has several limitations. First, while DAN has collected diving injury data since 1986, the database was not designed to analyze the efficacy of FAO_2, and there were many cases with missing data in important fields. These omissions did not allow us to control for oxygen flow-rate, mode of oxygen delivery, or duration of FAO_2 administration. In addition, because only divers who were treated with recompression were included in our database, we were unable to evaluate effect of FAO_2 alone. Another criticism concerns the decision to contrast the cases that received FAO_2 within less than 4 hours of surfacing with the others. However, considering the wide range of time points recorded in our dataset, the median value seemed to be the most representative cut point. Higher quality data are clearly needed to answer questions concerning optimal FAO_2 timing, dose, method of administration, and the efficacy of FAO_2 without recompression.

Hitherto, the use of first aid surface oxygen for injured divers has been largely based upon a credible, but assumed, rationale. The outcome data from this study provide epidemiological support for its routine use for decompression illness.

Appendix I - Perceived Severity Index

Perceived Severity Index (PSI)	Reported Signs or Symptoms
1. Serious Neurological	bladder or bowel dysfunction
	coordination, ataxia or gait
	Consciousness
	hearing, tinnitus
	mental status, dysphasia, memory, mood, orientation, personality
	Reflexes
	weakness, hemiparesis, motor weakness, paraplegia, other paresis
	Vision
2. Cardiopulmonary	cardiovascular, arrhythmias, palpitations
	pulmonary, cough, hemoptysis, shortness of breath, respiratory distress, voice change
3. Mild Neurological	paresthesia, numbness, numbness & tingling, tingling, sensation, twitching
4. Pain	pain, ache, cramps, discomfort, joint pain, pressure, sharp pain, spasm, stiffness
5. Lymphatic / Skin	lymphatic, swelling
	Skin, burning or skin, itching, marbling, rash
6. Constitutional / Non-Specific	dizziness, dizziness / vertigo
	Fatigue
	Headache
	nausea, nausea & vomiting, vomiting
	chills, diaphoresis, heaviness, heavy load, lightheadedness, malaise, restlessness
	Vertigo

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