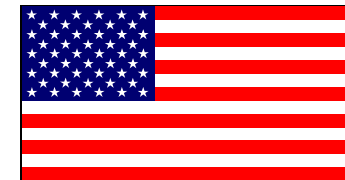




# Residual Oxygen Time Model after Dives to PO<sub>2</sub> = 1.3 atm



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Many mixed gas rebreathers operate at PO<sub>2</sub> = 1.3 atm.

Of concern: accumulation of pulmonary oxygen toxicity with multiple dives.

How long do pulmonary oxygen effects last after diving?  
How does one account for a recent dive when planning?

Despite many dives with PO<sub>2</sub> = 1.3 atm at Navy Experimental Diving Unit (NEDU) (Tables 1a and 1b) we can answer those questions directly in very few instances.

Modeling potentially can fill the gaps.

Table 1a. Resting Dives – PO<sub>2</sub> = 1.3 atm

3-hr	4-hr	6-hr	8-hr
# divers	# divers	# divers	# divers
At least 1 dive	At least 1 dive	At least 1 dive	1 dive
2-hr SI, then 16-hr SI	20-hr SI	28-hr SI	71
4 dives	At least 2 dives	At least 2 dives	
4-hr, then 16-hr SI	31	5 dives	
4 dives	At least 3 dives	42-hr SI	
6-hr, then 14-hr SI	28	At least 4 dives	
4 dives	At least 4 dives	6 dives	
	At least 5 dives		
	10 dives		
	44-hr SI		
	2 dives		
	18		

SI = surface interval

Table 1b.  
Dives with Exercise – PO<sub>2</sub> = 1.3 atm

3-hr	4-hr
# divers	# divers
At least 1 dive	At least 1 dive
21-hr SI	107
At least 2 dives	At least 2 dives
19	44
5 dives	5 dives
4-hr, then 16-hr SI	15-hr SI
14	14
At least 2 dives	2 dives
38	28
At least 4 dives	
18	

## Methods

Recovery of vital capacity after exposures to hyperbaric oxygen<sup>1-4</sup> can be expressed as an exponential function of time with time constant a function of either exposure PO<sub>2</sub><sup>5</sup> or exposure duration.<sup>6</sup>

As a function of exposure duration,

$$\Delta VC(t) = \Delta VC_0 \cdot e^{-[c + g/T_{dur}] \cdot t},$$

where  $\Delta VC$  is change in vital capacity from baseline,  $\Delta VC_0$  is that at the start of recovery,  $T_{dur}$  is the exposure duration,  $t$  is elapsed recovery time, and  $c$  and  $g$  are constants to be fitted.

Vital capacity changes measured during exposures to PO<sub>2</sub> between 1 atm and 1.5 atm<sup>1,3,4,7</sup> are linear in time for exposure durations < 500 min.<sup>8</sup>

$$\Delta VC_0 = a \cdot T_{dur}.$$

For any partial recovery, residual injury can be described as equivalent to that which would have occurred immediately following a shorter exposure time. We define residual oxygen time  $t_r$  as that equivalent exposure duration.

$$\Delta VC(t) = a \cdot t_r = a \cdot T_{dur} \cdot e^{-[c + g/T_{dur}] \cdot t_r},$$

where  $t_r$  is a function of both recovery time  $t$  and  $T_{dur}$ .

We assumed similar functional forms for all pulmonary injury at PO<sub>2</sub> = 1.3 atm and recovery at PO<sub>2</sub> = 0.21 atm and considered  $t_r$  at the end of a surface interval SI.

$$t_r = T_{dur} \cdot e^{-[c + g/T_{dur}] \cdot SI}$$

Values of  $t_r$  based on incidences of signs and symptoms were assigned to the dives of Tables 1a and b. For example, after four three-hour dives with SIs four hours then 16 hours, incidences were like those after two four-hour dives.

No recovery was considered until SI =  $T_{dur}$ . Iterative adjustment led to values  $c = 0.029 \text{ hr}^{-1}$  (standard error [SE] 0.020) and  $g = 0.41$  (SE 0.09), which were used to generate a table of residual oxygen times.

## Results

Table 2. Residual Oxygen Time (min)

Effective T <sub>dur</sub> (min)	Actual T <sub>dur</sub> + t <sub>r</sub> at the start of the dive	1	2	3	4	5	6	8	10	14	18
30	4										
60	6	9	2								
90	9	39	15	6	2	1					
120	12	120	43	22	11	5	1				
150	15	150	87	51	30	17	6	2			
180	18	180	180	93	60	39	16	7	1		
210	21	210	210	145	102	71	35	17	4	1	
240	24	240	240	240	153	113	62	34	10	3	
270	27	270	270	270	213	166	98	59	21	7	
300	30	300	300	300	300	227	144	92	37	15	

## Discussion

Residual time should be added to planned time to determine the effective duration of later dive.

Residual time is short if  $T_{dur}$  is short and long if  $T_{dur}$  is long. It is preferable to do short dives before long dives.

One must accept a risk of pulmonary toxicity and choose a maximum effective dive duration accordingly.

NEDU currently has chosen four hours. After a single four-hour dive with moderate exercise, 18% of divers (95% confidence interval 9–30%) experience symptoms, and 7% (2–17%) have short-term changes in pulmonary function.

## Conclusions

Modeling can be used to interpolate recovery times after dives of multiple durations.

The residual oxygen time concept can facilitate planning of dives with PO<sub>2</sub> = 1.3 atm.

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