INTRAVENOUS PERFLUOROCARBON EMULSIONS INCREASE WHOLE-BODY OXYGENATION AFTER SEVERE DECOMPRESSION SICKNESS

Cameron Smith, Ph.D.[1,2,3], J. Travis Parsons, Ph.D.[1,3], Jiepei Zhu, M.D., Ph.D.[1,3], and Bruce Spiess, M.D.[1,3]

Department of Anesthesiology [1], Department of Physiology [2], VCURES [3]- Virginia Commonwealth University Reanimation Engineering Shock Center, School of Medicine, Virginia Commonwealth University, Richmond VA 23298-0695

Introduction

Decompression sickness (DCS) results from a sudden decrease in ambient pressure leading to super-saturation of tissues with inert gas and subsequent bubble formation[1]. Perfluorocarbons (PFC) are able to dissolve vast amounts of non-polar gases[2]. The administration of intravenous (I.V.) PFC emulsions reduce both morbidity and mortality associated with DCS[3], but the mechanism of this protective effect has not yet been demonstrated. The research described here was designed to investigate the effect of I.V. PFC emulsions administered acutely after surfacing on whole-body oxygenation in an ovine model of severe DCS.

Methods

Juvenile Dorper cross sheep of either sex weighing 18.5 ± 2.6 kg (n=31) were anaesthetized and instrumented for physiological monitoring, the administration of I.V. fluids and sampling of arterial and mixed venous blood. Animals were placed in a hyperbaric chamber and compressed to 6.0 atmospheres absolute for 30 minutes, then rapidly decompressed. Upon chamber exit animals were randomly assigned to receive 6cc/kg of either PFC or saline control over 5 minutes beginning immediately after chamber exit. Blood samples were drawn at 5, 10, 15, 30, 60, and 90 minutes to examine whole-body oxygenation.

The following formulae were used for the oxygenation calculations:

Arterial oxygen content:

$$C_aO_2 = (1.34 \times Hb \times S_aO_2) + [(0.0031 \times p_aO_2 \times \alpha) + (0.01997 \times p_aO_2 \times \beta)]$$

Mixed venous oxygen content:

$$C_vO_2 = (1.34 \times Hb \times S_vO_2) + [(0.0031 \times p_vO_2 \times \alpha) + (0.01997 \times p_vO_2 \times \beta)]$$

Oxygen delivery:

$$\dot{D}O_2 = \frac{[CO \times (C_aO_2 \times 10)]}{weight}$$

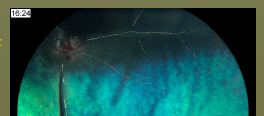
Oxygen consumption:

$$\dot{V}O_2 = \frac{CO \times [(C_aO_2 - C_vO_2) \times 10]}{weight}$$

Extraction ratio:

$$ER = \frac{\dot{V}O_2}{\dot{D}O_2}$$

Where C_aO_2 = arterial oxygen content in mL/dL
C_vO_2 = mixed venous oxygen content in mL/dL
Hb = hemoglobin concentration in mg/dL
S_aO_2 = arterial oxygen saturation fraction
S_vO_2 = mixed venous oxygen saturation fraction
P_aO_2 = arterial oxygen tension in mmHg
P_vO_2 = arterial oxygen tension in mmHg
$\dot{D}O_2$ = oxygen delivery in L/minute/kg body weight
$\dot{V}O_2$ = oxygen consumption in L/minute/kg body weight
ER = extraction ratio
CO = cardiac output in L/minute
0.0031 = oxygen solubility coefficient in plasma in mL/dL
0.01997 = oxygen solubility coefficient in PFC in mL/dL
α = blood fraction of circulation volume
β = PFC fraction of circulating volume



DCS was verified using retinal angiography and the Luna Innovations EDAC© system

Unless otherwise stated all data were analyzed using repeated-measures analysis of variance (ANOVA) with the following included as model effects: cardiac index, PFC administration. If the ANOVA was found to be significant post-hoc Least Squares Means Student's *t*-tests were applied to determine if PFC treatment and saline control groups were significantly different. Data are presented as Least Squares Means ± Standard Error. Differences were considered statistically significant with p-values of less than 0.05. All statistical calculations were performed using the statistical software JMP 8 from SAS Institute (Cary, NC).

Results

Figure 1

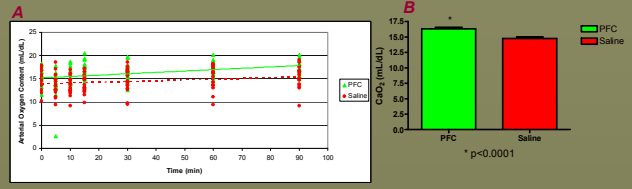


Figure 1 The effect of perfluorocarbon administration on arterial oxygen content.

A: Arterial oxygen content vs. time. Solid line represents PFC, dashed line represents saline. B: LS Means of saline- and PFC-treated groups. PFC significantly increased vs. the saline control (16.30±0.27 vs. 14.75±0.25 mL/dL, p<0.0001).

Figure 2

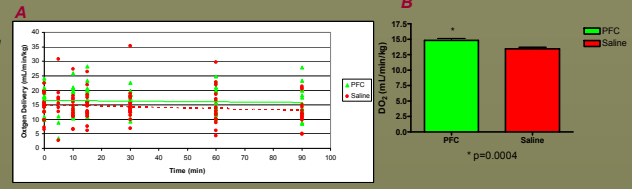


Figure 2 The effect of perfluorocarbon administration on oxygen delivery.

A: Oxygen delivery vs. time. Solid line represents PFC, dashed line represents saline. B: LS Means of the saline- and PFC-treated groups. PFC significantly increased vs. the saline control (14.83±0.28 vs. 13.44±0.25 mL/minute/kg, p=0.0004).

Figure 3

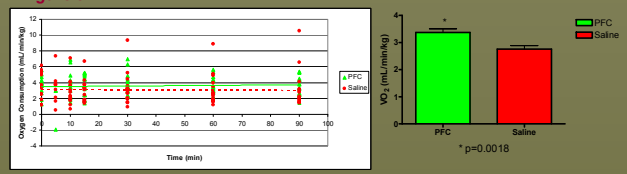


Figure 3 The effect of perfluorocarbon administration on oxygen consumption.

A: Oxygen consumption vs. time. Solid line represents PFC, dashed line represents saline. B: LS Means of saline- and PFC-treated groups. PFC significantly increased vs. the saline control (3.37 ± 0.14 vs. 2.76 ± 0.13 mL/minute/kg, p=0.0018).

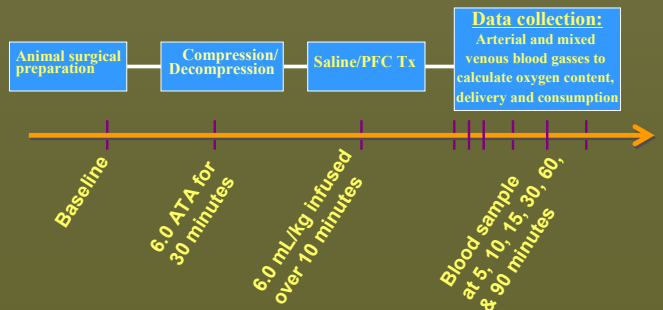
Table 1

Variable	PFC LS Mean	Saline LS Mean	p-value
C_aO_2	16.30 ± 0.27 mL/dL	14.75 ± 0.25 mL/dL	p<0.0001
C_TO_2	12.45 ± 0.26 mL/dL	11.74 ± 0.24 mL/dL	p=0.0558
$\dot{D}O_2$	14.83 ± 0.28 mL/minute/kg	13.44 ± 0.25 mL/minute/kg	p=0.0004
$\dot{V}O_2$	3.37 ± 0.14 mL/minute/kg	2.76 ± 0.13 mL/minute/kg	p=0.0018
ER	0.23 ± 0.012	0.21 ± 0.011	p=0.1869

Table 1 Table 1: The effect of perfluorocarbon administration on oxygenation variables.

The results of the LS means comparison of the results from the repeated-measures ANOVA on each of the examined variables. , , and were found to be significantly increased in the PFC-treated group compared to the saline control group.

Experimental timeline



Discussion and Conclusions

I.V. PFC administration results in an increase in C_aO_2, DO_2, and VO_2.

It is likely that PFC is able to carry oxygen to tissues receiving no erythrocyte flow.

PFC may act as a transport vessel for oxygen, ferrying it from erythrocytes to tissue.

Improved tissue oxygenation at a whole-body level is likely responsible for at least a portion of the beneficial effects offered by the I.V. administration of PFC emulsions after severe decompression sickness.

References

1. **DeGorordo A, Vallejo-Manzur F, Chanin K, Varon J.** Diving emergencies. *Resuscitation* 2003; 59:171-180
2. **O'Brien RN, Langlais AJ, Seufert WD.** Diffusion coefficients of respiratory gases in a perfluorocarbon liquid. *Science* 1982; 217:153-155
3. **Dromsky DM, Spiess BD, Fahlman A.** Treatment of decompression sickness in swine with intravenous perfluorocarbon emulsion. *Aviat Space Environ Med* 2004; 75:301-305

This study was supported from Office of Naval Research (N000140210399)