Retinal Arterial Gaseous Embolisms Are A Non-Invasive, Real-Time Biomarker of Survivability Associated With A Rapid Decompression Emergency Scenario

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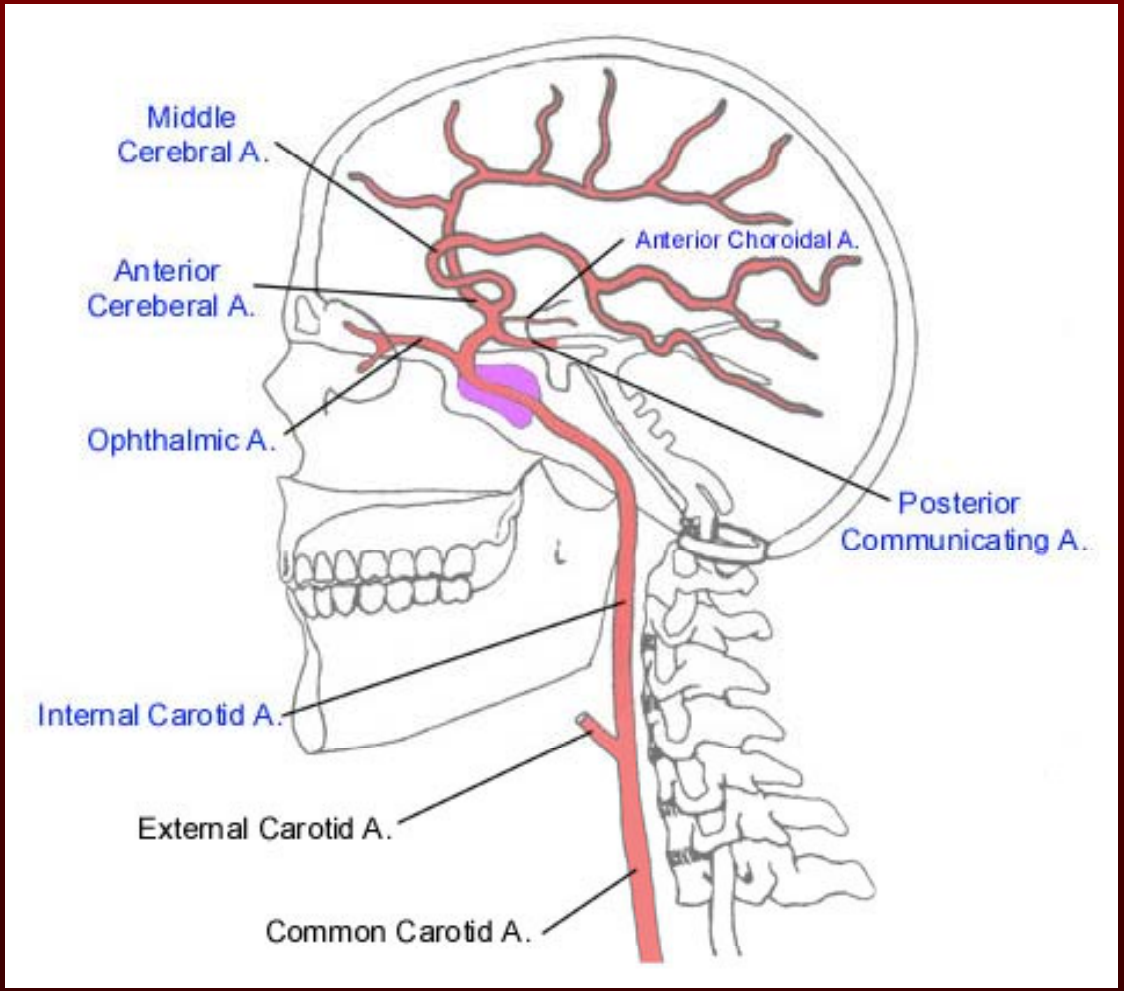
Background

Decompression Illness (DCI)

- Caused by the formation of bubbles in blood and tissue due to a sudden decrease in ambient pressure.
- Bubbles are typically formed in the venous circulation and venous gas emboli (VGE) can result.
- Arterial gas emboli (AGE) are also associated with DCI yet less frequently.
- Cardiopulmonary incapacitation, deleterious neurological sequelae, and even death can result.
- Thus, tools for detecting bubbles in the vasculature are important for the assessment of potential DCI and the need for immediate treatment.

Background

The Retinal – Cerebral Connection

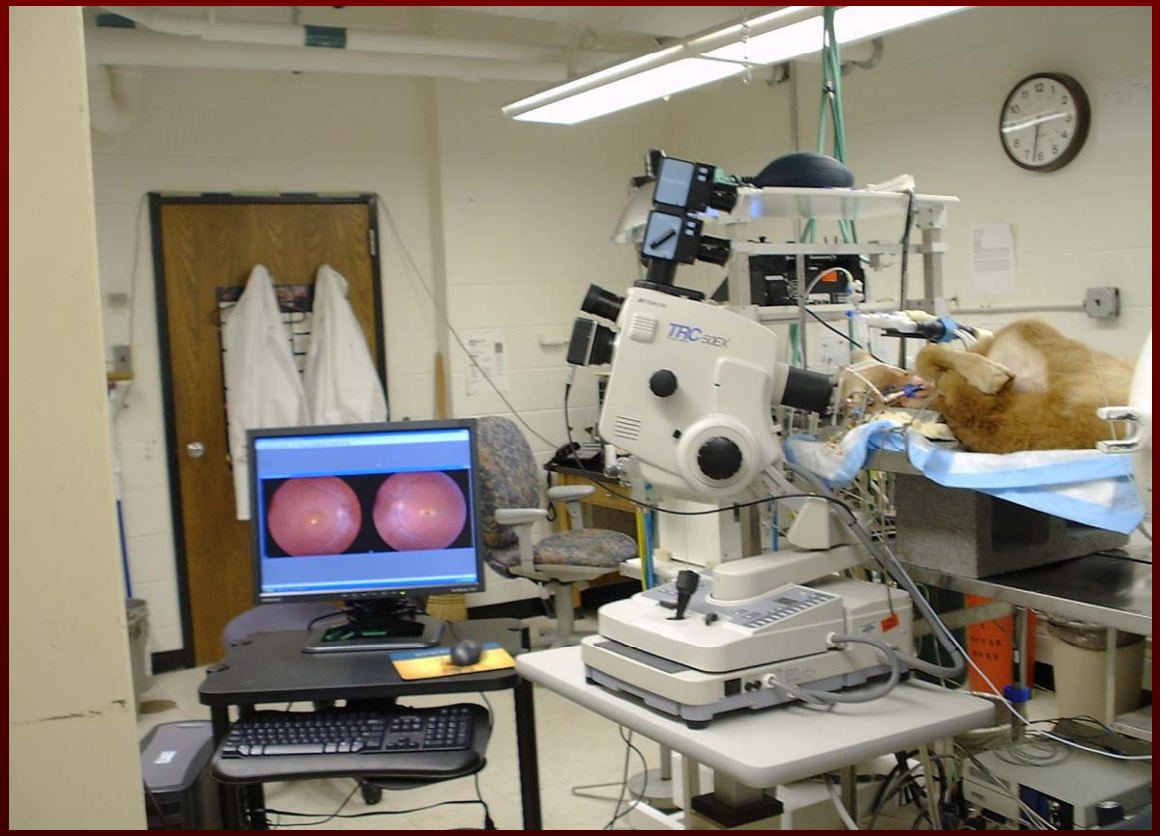


- Retinal circulation = non-invasive, visible window to the microcirculation of the brain.
- The internal carotid artery is the main supply line of blood to cerebral tissue.
- The ophthalmic artery, leading to the central retinal artery that feeds the retina, is the first branch of the internal carotid artery.
- Therefore, any embolic event affecting the circulation and tissue integrity of the retina, should parallel embolic events affecting the circulation of the cerebral tissue.

Background

Retinal Angiography

- An ideal device for assessing the bubble load in the circulation should be a real time monitor that is sensitive, easy to use (requiring little training), and non-invasive.
- A fundus camera is a real-time, widely available, and relatively easy to use routine ophthalmologic tool.
- Non-invasive visualization of ocular structures including venous and arterial vasculature of the retina is easily carried out with fundus cameras.
- A fundus camera can be used to assess when bubbles form in the vasculature following the dive, location (arterial, venous, formed in situ), bubble size, dwell time, and rate of bubble flow through veins and arteries.



- Based on the retinal-cerebral connection, a correlation should exist between events observed in the retinal vasculature and outcome following rapid decompression scenario

Methods

Severe Cardiopulmonary DCI

- Dorset sheep (n=20, ~25 kg) were anesthetized, placed supine, and compressed (starting at 1 ATA) at 1 ATA/min to 2.0 ATA then 2 ATA/min to 7.0 ATA. Sheep remained at 7.0 ATA for 45 min then rapidly decompressed at 2 ATA/min to 1 ATA.
- Animals were observed for 60 min post chamber remaining fully anesthetized. Following the observation period, sheep were allowed to recover then returned to their flock for behavioral evaluation.
- In all non-survival situations, animals were humanely euthanized once physiological parameters indicated impending fatality.

Bubble Assessments

Retinal Angiography-

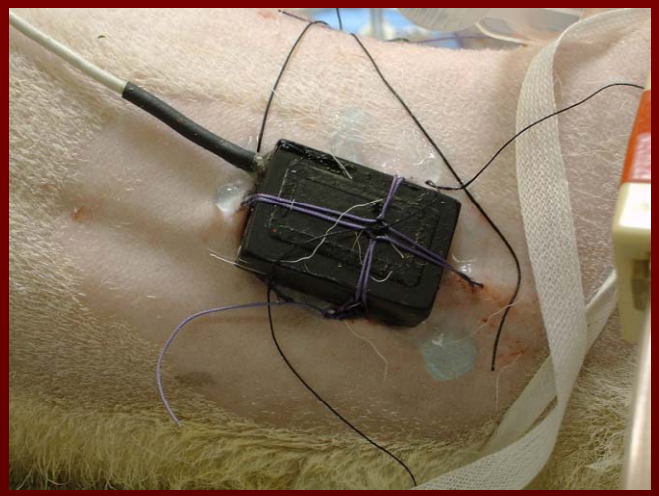
- Topcon TRC 50 EX fundus camera with Ophthalmic Imaging Systems' Winstation 5000 digital workstation.
- Within 5 min post chamber, the fundus camera was in place for continuous observation of the retinal vasculature in the sheep's right eye.

Methods

Bubble Assessments (cont.)

Emboli **D**etection **A**nd **C**lassification (EDAC)-

- Luna Innovations EDAC quantifier equipped with pulse echo ultrasound transducer.
- Within 2-3 min post chamber, the transducer was in place over the sheep left jugular vein for continuous monitoring of the venous circulation.

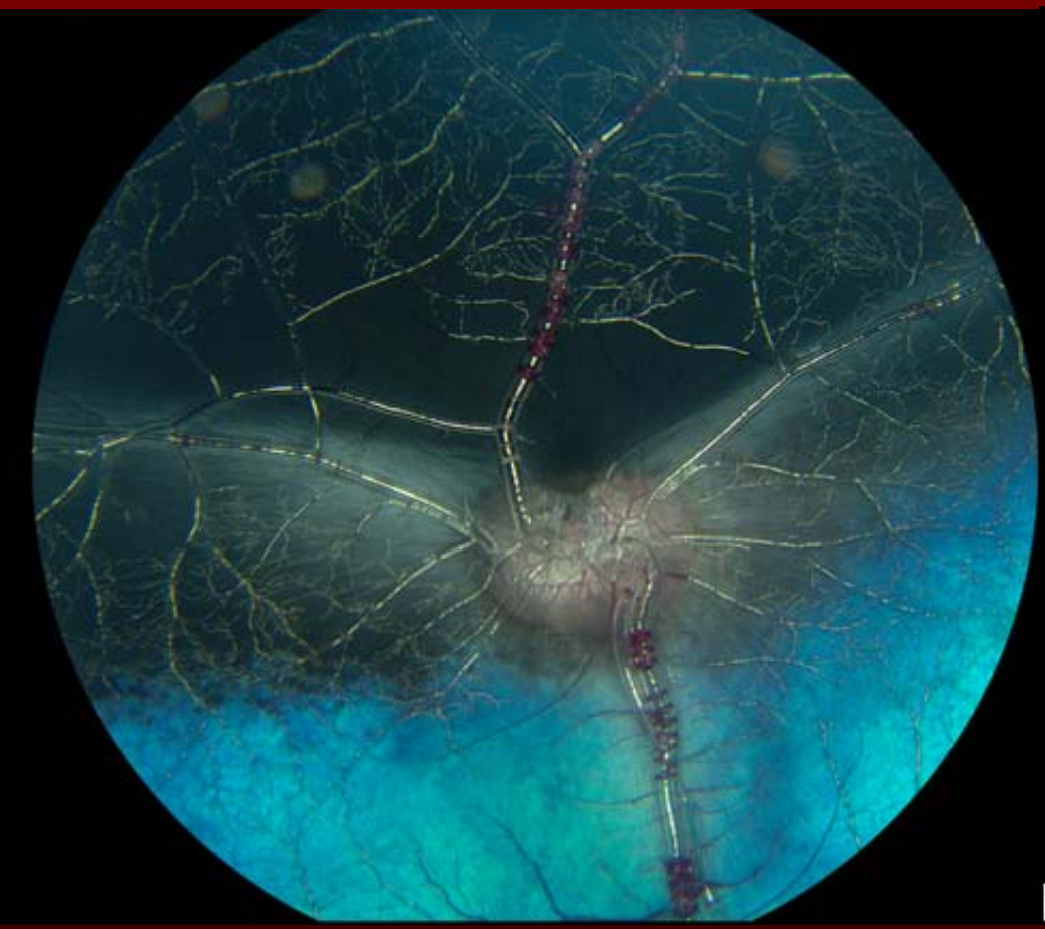


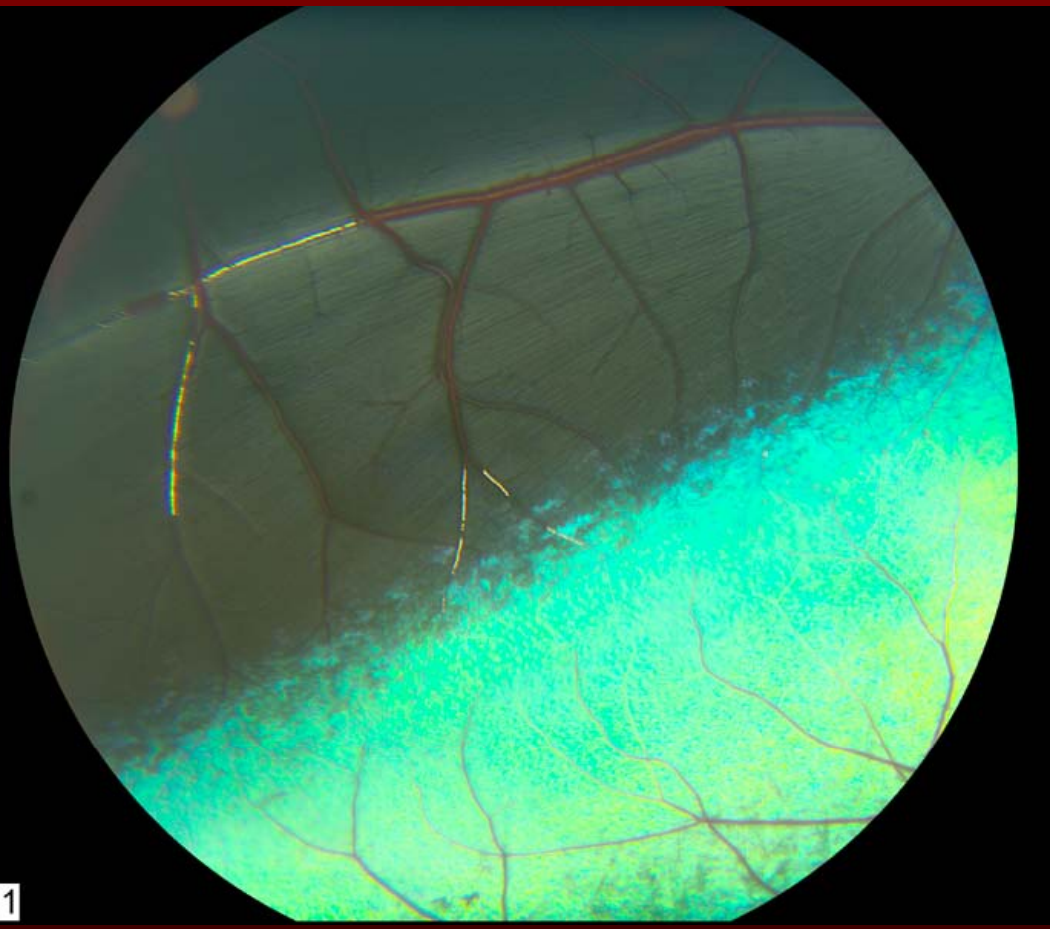
Behavioral Assessments

- Sheep were observed for 7 days post decompression with an infrared video monitoring system, housed with their social flock, given free access to food and water, and kept on a 12 hr light / 12 hr dark cycle.
- Control data was obtained by observing the sheep for one week prior to diving.
- When kept in a pen, sheep spend 100% of their time eating/drinking, standing around, or laying down and when standing, they spend most of their time eating. Thus, we report the amount of this total time the sheep spend laying down or eating
- Behavior is reported for the 12 hour light cycle.

Results

20 sheep dove for survival study, 6 presented with retinal bubbles





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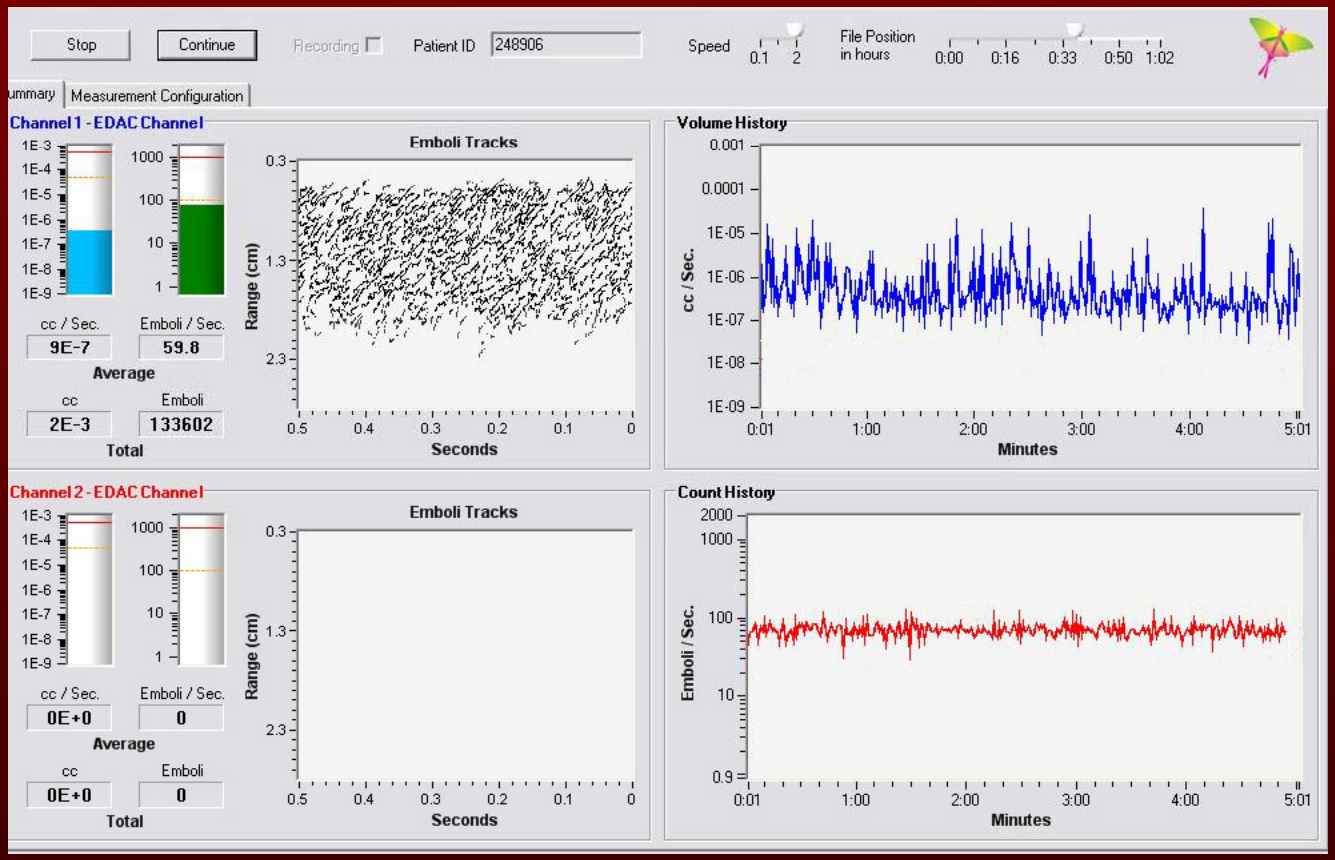
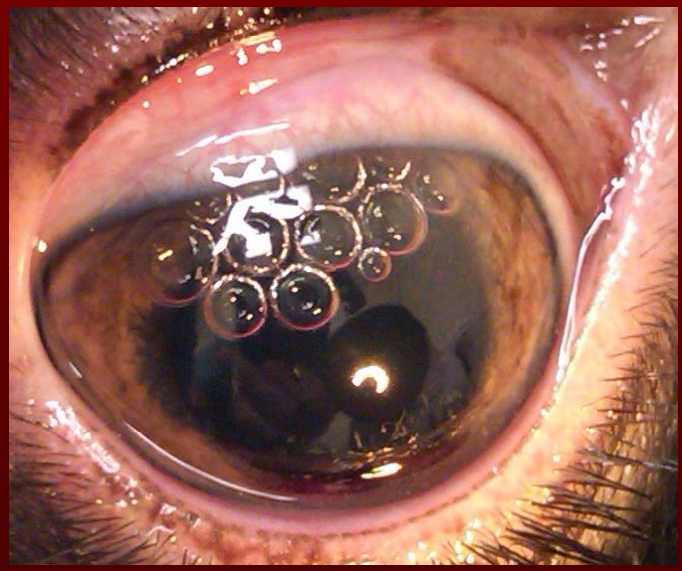
“Retinal blowout” 5 min post chamber

bubbles lodged in retinal artery





In honor of Sir Robert Boyle 1 sheep of 20 presented with anterior chamber bubbles that took 48 hours to resolve

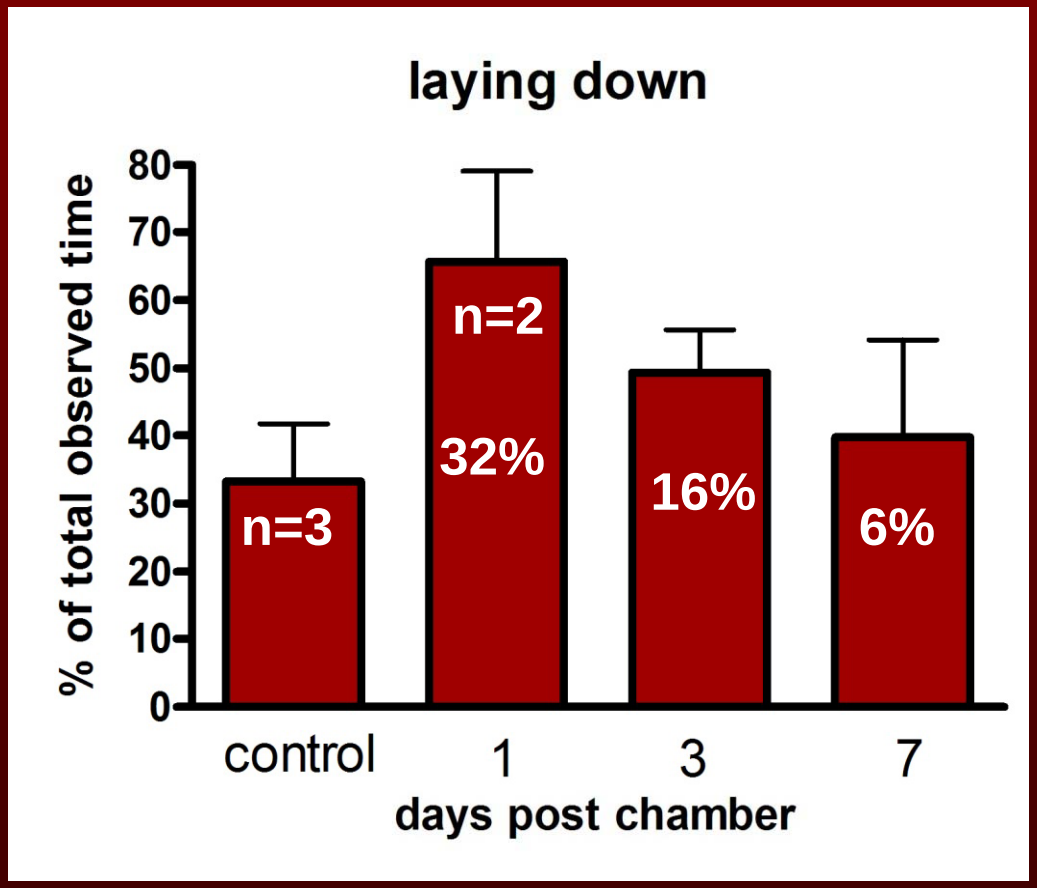
EDAC revealing significant bubble load in jugular vein

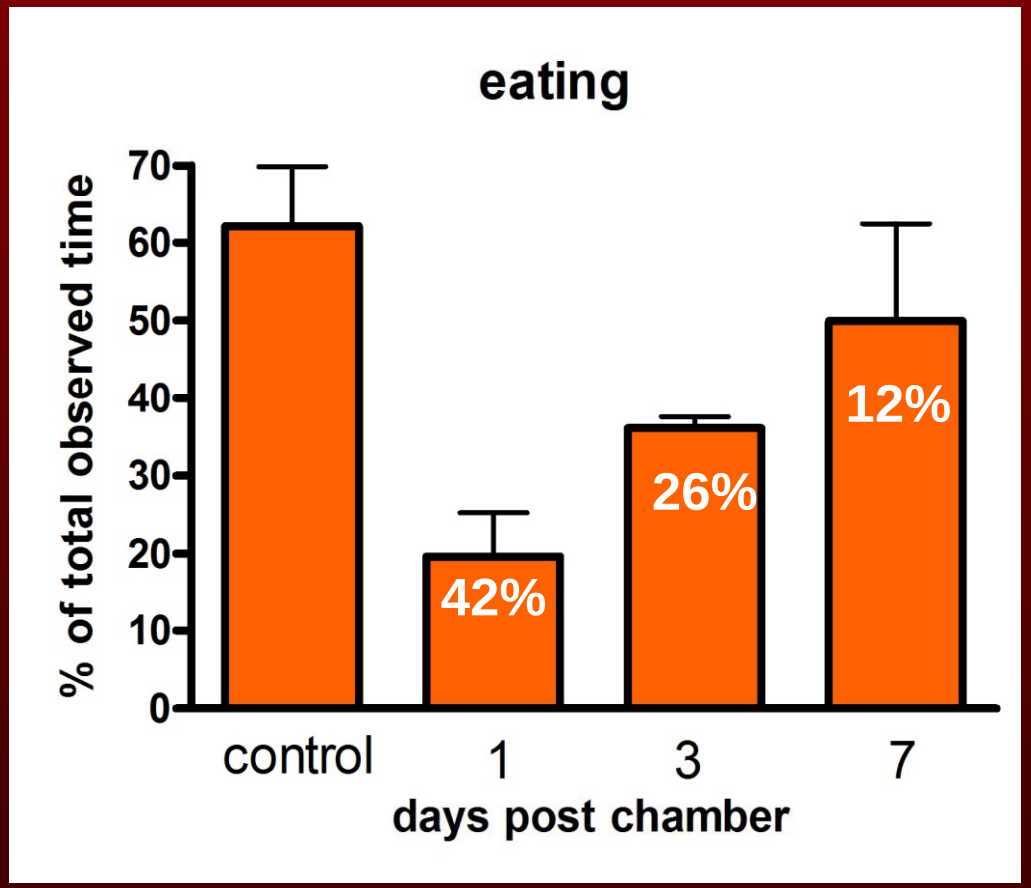
Results

Emboli Detection and Classification (EDAC)

	Bubble lodge time retinal angiography	Emboli / sec 5	10	15	30	45	60	Total emboli count	
Sheep 1	blowout	5.3	3.1	2.5				1,766 (TOD)	Dead within 20 min
Sheep 2	blowout	18.4	9.7	6.0				6,095 (TOD)	Dead within 18 min
Sheep 3	blowout	267	193	198				183,439 (TOD)	Dead within 15 min
Sheep 4	10 min	240	275	258	235	163	125	451,752	Dead within 3 hrs
Sheep 5	20 min	59	102	124	134	124	106	353,560	Dead within 4 hrs
Sheep 6	Bubbles did not lodge	0	4.6	12.8	21	29	24.7	83,300	survive

Results


laying down
% of total observed time
80
70
60
50
40
30
20
10
0
n=3
n=2
32%
16%
6%
control
1
3
7
days post chamber


eating
% of total observed time
70
60
50
40
30
20
10
0
42%
26%
12%
control
1
3
7
days post chamber

Conclusions

- 100% mortality revealed in sheep with retinal arterial gaseous embolisms.
- Retinal angiography may prove to be an invaluable, real-time, non-invasive, objective tool for triaging patients needing immediate treatment in a mass DCI (DISSUB) scenario.
- EDAC data suggest that animals with retinal blowout had compromised systemic blood circulation likely untreatable with either traditional recompression/decompression or non-recompression therapies (PFC).

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