Predicting Decompression Sickness Risk from H2 ives Using Conventional vs. Biochemical Decompression in Pigs

A. Fahlman, S.B. Kayar, P. Tikuisis, W.C. Lin and W.B. Whitman, Naval Med. Res. Center, Bethesda, MD 20889; Carleton Univ., Ottawa, ON, K1S 5B6; DCEM, Toronto, ON M3M 3B9 and Dept. Microbiology, Univ. of Georgia, Athens, GA 30602

Abstract:
Biomedical decompression, the facilitation of decompression by biochemically eliminating some inert gas stored in divers’ tissues, was demonstrated in pigs during simulated H2 dives (Fahlman et al., FASEB J, 13:A408, 1999). Data were compiled to create a model of decompression sickness (DCS) risk to determine gas kinetics during decompression. To simulate a H2 dive, pigs (n=98, 19.6±1.4 kg) were placed in a dry chamber and compressed to varying pressures (22.24, or 26 atm) for 2.5 or 3 h. Subjects were decompressed at different rates (0.45, 0.9, or 1.8 atm/min) to 11 atm, and observed for 1 h. The DCS incidence in control animals increased with time at pressure and with increasing decompression rate. Contrary to expectations, there was no correlation between DCS and pressure. Pigs receiving intestinal injections of the H2-metabolizing microbe, Methanobrevibacter smithii, had a DCS incidence that was half that of controls on a similar dive. From the complete data set, a probabilistic model will be created that will include parameters on risk assessment, gas kinetics, and H2 metabolism. This model will allow us to predict the advantage of biomedical decompression for H2 dives in general. (Support: ONR 603706N 0096 131 1703).

Introduction:
We have previously reported that H2 metabolizing microbes in the intestines of pigs significantly reduced the decompression sickness (DCS) incidence during simulated H2 dives in a pig model. Evidence suggests that pigs have a native gut flora of microbes that metabolize a sufficient amount of H2 in the tissues to reduce DCS incidence (Kayar et al., 1999, FASEB J, 13:A408). This microbial activity, which converts H2 to CH4, was enhanced by injecting cultures of Methanobrevibacter smithii, resulting in a significantly greater reduction in DCS incidence (Fahlman et al., 1999, FASEB J, 13:A408).

To further explore biomedical decompression in the pig, we have collected data from a variety of hyperbaric H2 exposures. Since the amount of gas breathed by a diver that becomes dissolved in the diver’s tissues is a function of the pressure of the gas and the duration of elevated pressure, the data set includes exposures of varying lengths of time and pressures. The data set also includes hyperbaric exposures of varying decompression rates. We will use these data to create a mathematical model that predicts the probability of DCS (PDCS) from any hyperbaric H2 exposure and activity of methanogens. H2 metabolism is hypothesized to reduce the net tissue gas burden before and during decompression, and therefore will decrease the PDCS for the dive. The model will be based on the hypothesis that the amount and rate of ambient pressure reduction during the decompression phase determines the outcome.

Materials and Methods:
Animals:
- Yorkshire pigs (Sus scrofa), castrated males, n=98, body mass range 17-23 kg

Groups:
1) Untreated controls (C)
2) Surgical controls (SC) - injected with 60 mL saline into caecum and large intestine
3) Treated animals (T) - injected with varying volumes (12-83 mL) and activities (200-2200 µmol CH4/min) of Methanobrevibacter smithii into the caecum and large intestine

Surgery performed under anesthesia, abdomen opened to allow access to caecum and large intestine.

Dive simulation:
- Chamber pressurized to 22, 24, or 26 bar (88-94%H2, 0.3-0.5 bar PO2) for 30, 120, 150, 180, or >1100 min.
- Decompression rate 0.45, 0.9, or 1.8 bar/min to 11 bar; animals observed for 1 h for DCS
- Enthusiast in chamber on confirmation of DCS or at end of hour.

Measurements:
- Chamber gases analyzed by gas chromatography for H2, O2, He, N2, and CH4
- CH4 output rate (µmol CH4/min) from the chamber was used as an indicator of the CH4 production rate from pigs.
- Severe symptoms of DCS included: walking difficulties, fore and/or hind limb paralysis, falling, convulsions.

Results:

Fig 1. CH4 Release Rate as a Function of Total Activity Injected in Animals at 24.1 atm

Fig 2. DCS Incidence in Control Animals with Variable Time at 24.1 atm

Fig 3. DCS Incidence vs Decompression Rate in Control Animals at 24.1 atm for 3 h

Fig 4. DCS Incidence in Control Animals as a Function of Total Ambient Pressure

Fig 5. Probability of DCS as a Function of Total Activity of Methanogens Injected

Conclusions:
1) Increasing time at elevated pressure and increasing decompression rate increased DCS incidence, suggesting that elevated tissue gas burden increases DCS risk.
2) Exposure to elevated pressures did not lead to increased DCS incidence, probably because the native H2 metabolizing microbes were removing some of the tissue H2, thus masking a pressure dependency.
3) Increasing activity injected decreased the DCS incidence, implying that H2 metabolism decreased the tissue gas burden.
4) We conclude that a model using time at elevated pressure, total ambient pressure, decompression rate, and H2 metabolism by methanogens would be a useful prediction tool for P(DCS) from any H2 dive.
Points of Contact:
NMRI-Principal Investigator
Dr. Susan Kayar,
E-mail: kayars@nmripo.nmri.nnmc.navy.mil
Phone:(301)295-5903
Research Assistant
Andreas Fahlman,
E-mail: fahlmana@nmripo.nmri.nnmc.navy.mil
Phone:(301)295-5867