Estimating DCS risk for Emergency Conditions

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The Issue

Basics

The risk of **Decompression sickness (DCS)** can be related to *how fast* a person returns from a high pressure exposure. (We mean to discuss DCS, not DCI)

DCS can usually be *prevented* by a "safe" controlled slow decompression.

BUT, in emergencies, the "safe" slow decompression may not be possible, and people may have to decompress by whatever schedule is actually possible..

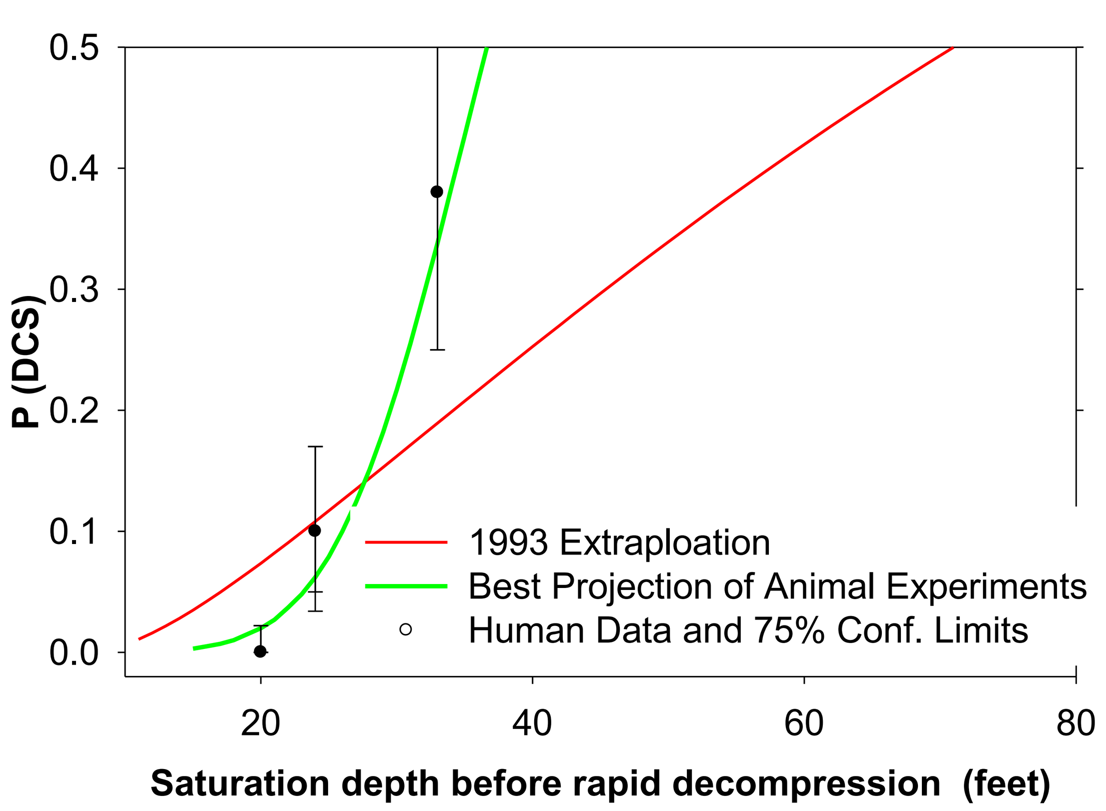
DCS population *incidence* can be *predicted*, in a defined regime. With an appropriate probabilistic decompression model (Individual DCS occurrence is still random).

A well known prediction model is known as USN93.

The 1993 model has been very useful in the range on Navy operational diving, when calibrated with data within that range. However, evidence has accumulated that it does not extrapolate well.

The best studied example of USN93 prediction failure is illustrated below

Failure of 1993 Model



Methods: the Dose-Response Problem

In a nutshell

We have substantial data and reasonable predictions near 5% DCS.

We have neither near 50% DCS.

Approach: Data

Choose N ~ 3,300 human trials, incidence 6% DCS, from database of controlled military trials performed during 1945-1995

Selection *bias for:* high risk, data "missed" by 1993 model, and data similar to applications in mind.
Selection *bias against:* types of military diving not similar to applications in mind.

Approach: Models

The commonly assumed mechanism of DCS is that inert gas loaded into tissue under high pressure will be supersaturated during and after decompression, thus allowing bubble formation and growth. The calculated supersaturation is equated to the argument in a hazard function.

$$p\,(DCS) = 1.0 - \exp\left(\int_0^{end\ of\ exposure} - r\ dt \right)$$

Where *r* is the instantaneous hazard or risk. For the **Old** 1993 model,

$$r = \left(\frac{Ptis - Pamb - Thr}{Pamb} \right) \ ; r \geq 0$$

Where P*tis* is the calculated tissue nitrogen partial pressure; P*amb* is the current ambient pressure; and *Thr* is a completely safe threshold (an estimated parameter).

For the **New** formulation,

$$r = \left(\frac{Ptis - Pamb - Thr}{Pamb} \right)^2 \ ; r \geq 0$$

Note that the whole term is squared.

There are also two different ways to calculate *Ptis*. Both have first order, exponential, uptake of nitrogen. One formulation has **Exp**onential elimination as well.

$Ptis = Ptis_0\ [\,1.0 - \exp(-k_1 t)\,]$

The rate constant k_1, is an estimated parameter. The second formulation has **Lin**ear release of gas (due, e.g. to bubble storage of gas)

$Ptis = Ptis_0 - k_2\, t$

where k_2 is controlled by another estimated parameter, but eventually merges with the same exponential curve $\exp(-k_1 t)$. The linear formulation serves to delay gas excretion and thus prolong the duration of finite hazard.

Three tissue compartments are used, with up to 4 parameters each.

Which Model Formulation is Best ?

For any model, the Goodness of Fit should be assesses by several methods.

In addition to Maximum likelihood, we use

- Ability to fit component data files
- Ability to fit various different types of dives
- Ability to fit all parts of the dose-response curve

There are 4 actual models after initial examination of many: combinations of
Old vs. **New** Hazard Term
Exponential vs. **Lin**ear gas elimination.

Overall statistical goodness of fit, the Log Likelihood (LL) function:

Best Found (12 parameters)	- 635.4
Old-Exp (8 parameters)	- 636.9
Old-Lin (8 parameters)	- 636.7
New-Exp (8 parameters)	- 639.2
New-Lin (8 parameters)	- 638.3

The Akaike Information Criterion (AIC) says that all but the first have appreciable information about the data (Note: NOT JUST the best model)

Goodness of Fit by Source Data (Chi-square, 16 df)
Data arose from 17-20 original studies

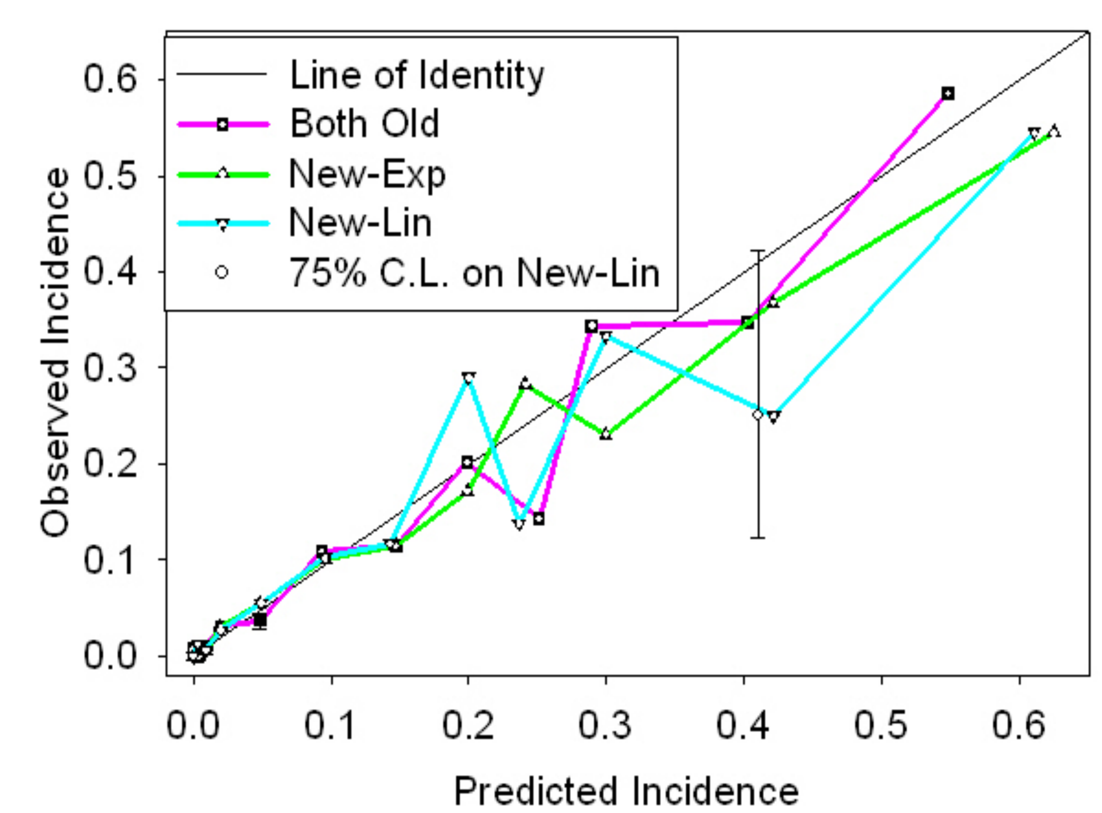
Chi-squares indicate probable miss of a source data file from 1992 diving trials, for both NEW models

Goodness of Fit by Exposure Type (Chi-square, 10 df)
Exposure type are shallow, intermediate, medium deep and deep depth; short, intermediate and long duration (for some depths).

Chi-square did not indicate a problem in missing exposure categories.

Goodness of Fit by Range of Predicted Outcome

Calibration Data Ordering



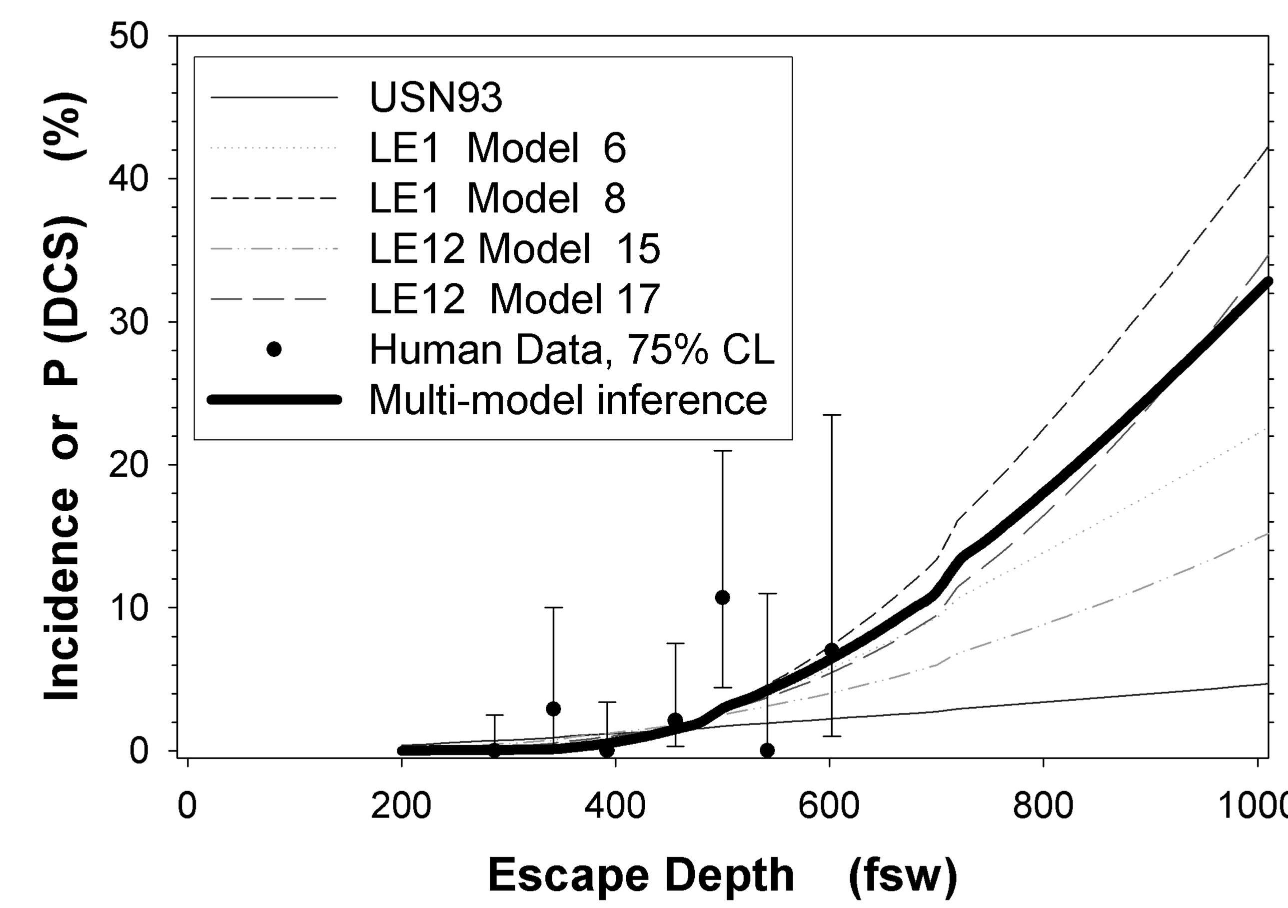
Multi-Model Inference

When more than one model fits data well, as in this case, choosing just the "best" model omits information contained in the other "almost-best" models. Maximum information for prediction is obtained by using a combined model obtained by adding the models weighted by AIC.

Burnham KP, DR Anderson. Model selection and multimodel inference: a practical theoretic-information approach. 2nd ed. New York: Springer. 2002.

Application 1 Submarine Escape

A submarine may become disabled but with many crew still alive. Many Navies have a system to allow individual escape and free ascent to the surface. The most common system "SEIE" has been tested to 600 feet deep.
How much deeper could it be used? DCS has long been considered to limit success.
Here are the current predictions:



Application 2 Pressurized Submarine Rescue

Many Navies offer the chance of rescue of survivors by specialized vehicles. During the time awaiting rescue, pressure rise in the disabled submarine is likely. Most rescue systems require crew to decompress to atmospheric for a period of time before getting therapeutic recompression.

What fraction of the survivors are likely to suffer DCS if the waiting interval is long? Here are the current predictions