COPERNICUS DECOMPRESSION PROCEDURES
AN ANALYSIS OF PRACTICAL IMPLICATIONS OF A NEW ALGORITHM

Gutvik CR, Møllerløkken A, Brubakk AO

Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Trondheim, Norway

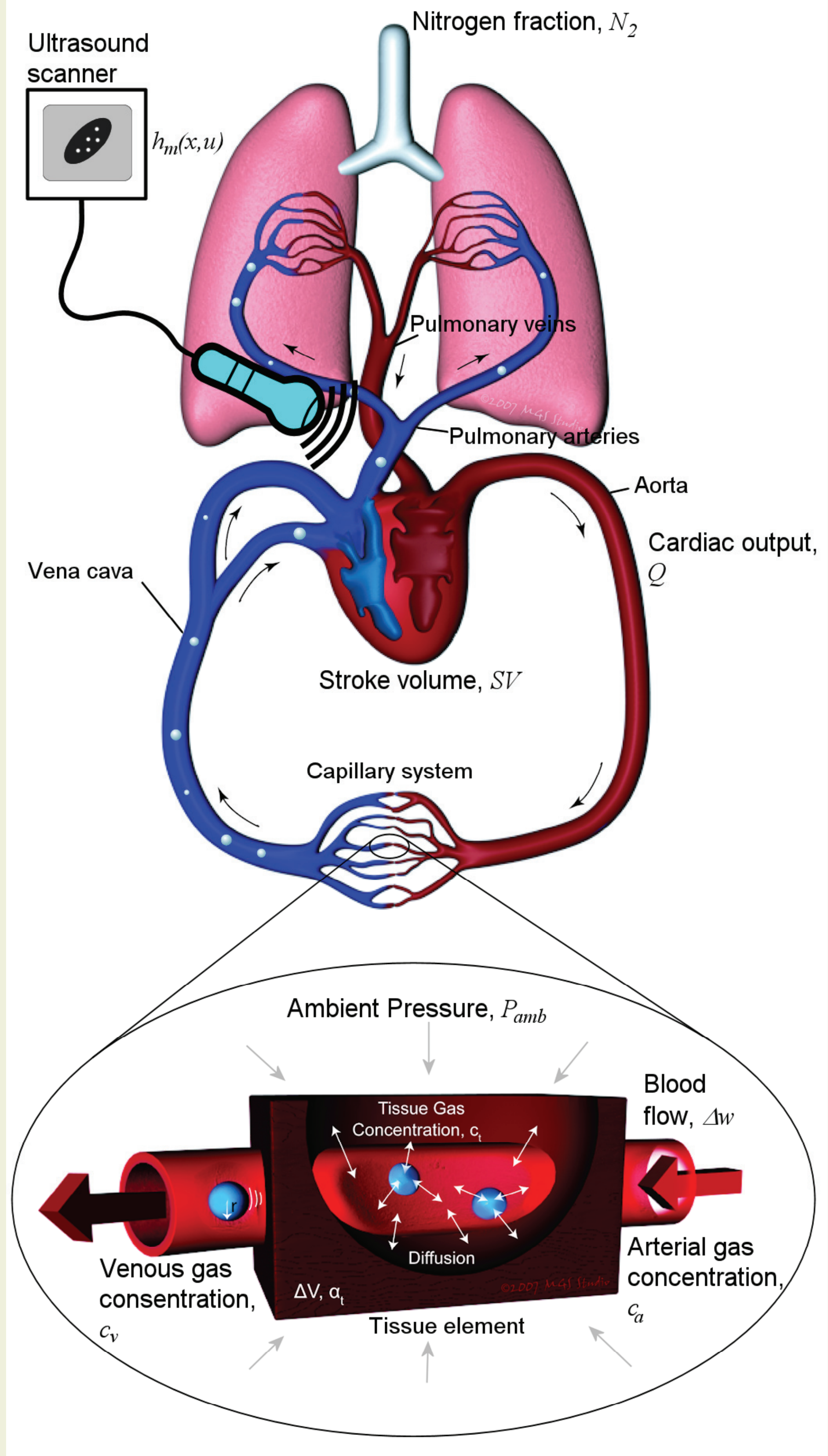
NTNU Norwegian University of Science and Technology

COPERNICUS

Introduction

Numerous of decompression algorithms exist to get divers safely back to surface after a dive without suffering from decompression sickness (DCS). Different algorithms can be characterized by conservatism, stop depth distribution and exposure scaling. We have previously presented a new dynamic, dual phase decompression model, called Copernicus [1], and validated it against human data of ultrasonic measurements of Venous Gas Emboli (VGE) [2]. VGE is recognized for being an objective and relevant stress predictor for DCS and has been hypothesized to improve the observability of the fundamental bubble dynamics within the Copernicus model. Later we have demonstrated how procedures can be calculated using numerical optimization. The present work intends to demonstrate practical implications of these improved model fundamentals.

Methods



The Copernicus model

Figure 1

Concept illustration derives into:

$$\dot{x} = f(x,u)$$
$$y = h_m(x,u)$$

where:

$$f(x,u) = \begin{bmatrix} \dfrac{\frac{D\alpha_b}{h}\left(x_{2i} - x_5 - \frac{2\gamma}{x_{2i-1}} + P_{meta} + c_s\frac{1}{x_{2i-1}^3}\right) - \frac{x_{2i-1}}{3}u_1}{x_5 + \frac{4\gamma}{3x_{2i-1}} - P_{meta}} \\ \varepsilon_{\tau,i}\frac{\alpha_b}{\alpha_{t,i}}\left(u_2 x_5 - x_{2i}\right)u_{2+i} + \dot{p}_{r,i}(x) \\ \vdots \\ u_1 \end{bmatrix}$$

$$h_m(x,u) = \frac{4\pi}{3}k_m\sum_i \delta_i r_i^3 V_i * \omega_i - V_0$$
$$x = \left[r_1\ p_{t,1}\ r_2\ p_{t,2}\ P_{amb}\right]^T$$
$$u = \left[\dot{P}_{amb}\ f_{N2}\ \omega_1\ \omega_2\right]^T$$

Simulation

Procedures from the Copernicus model were calculated using nonlinear optimization giving the fastest possible decompression with the constraint of VGE < III. The procedures were compared with VPM, RGBM and Bühlmann using V-Planner and GAP software. Implementation of Copernicus and simulation results of the profiles were carried out in Matlab. Various dive exposures and decompression regimes were compared including long/shallow vs deep/short, high exposures vs low exposures and enriched air nitrox (EAN) decompression.

Results

Exposure scaling

It has been previously shown that many decompression algorithms fail to get divers safely to the surface with air if the exposure increases enough [3], which is shown in fig. 2. Despite being designed to satisfy a "safe" stress level, the real risk increases more rapidly than what the traditional models cope with. A better model of bubble dynamics would require total decompression time to increase more rapidly with scaling exposure. A comparison between Copernicus and other modern models is demonstrated in fig. 3 and 4.

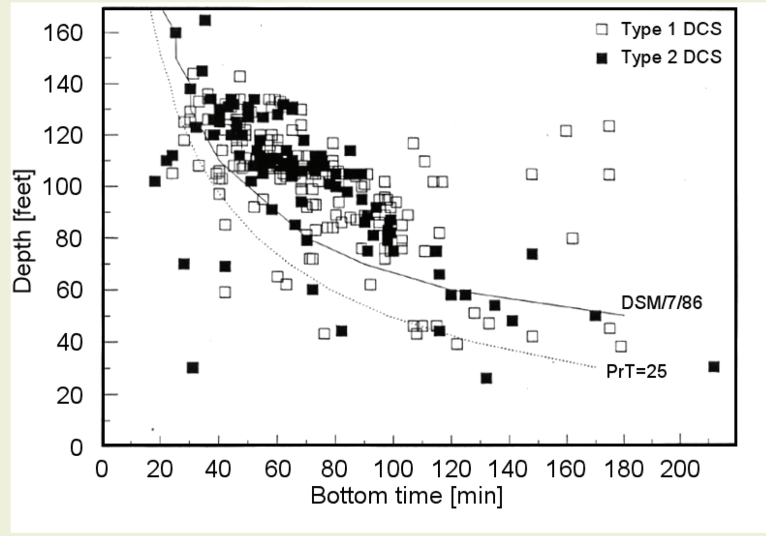


Figure 2: Most of the DCS incidents happen on exposures where PrT>25

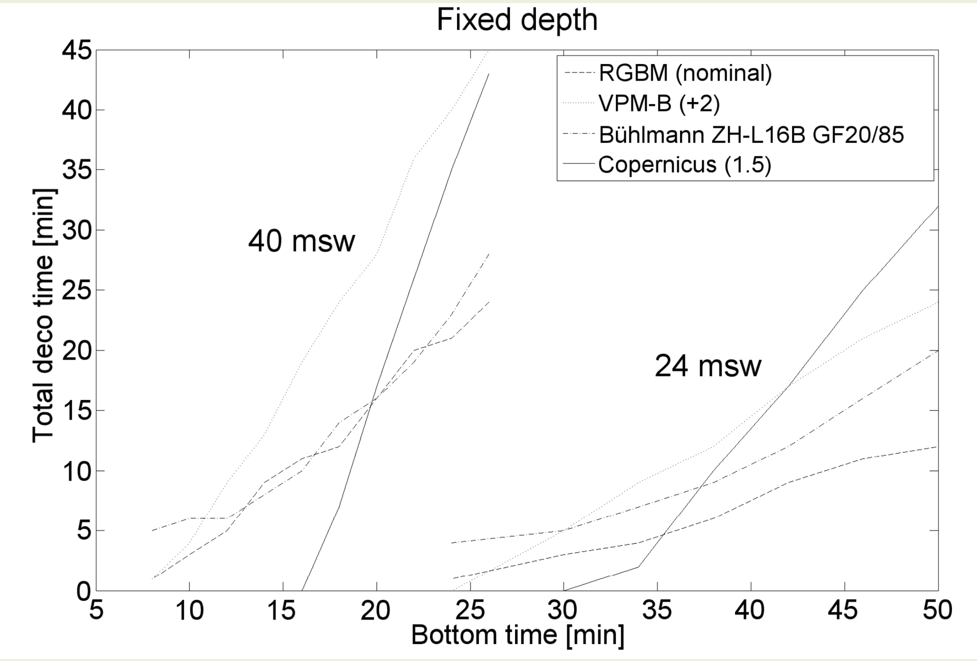


Figure 3: Total decompression time scaling with increased bottom time for a given dive depth

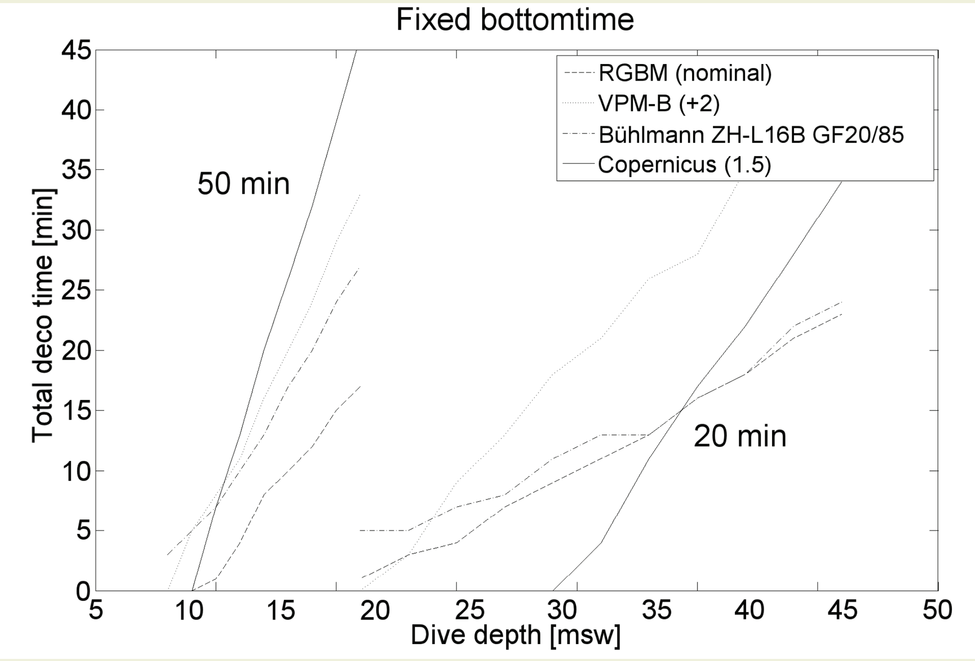


Figure 4: Total decompression time scaling with increased dive depth for a given bottom time

Acknowledgement

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Enriched Air Nitrox

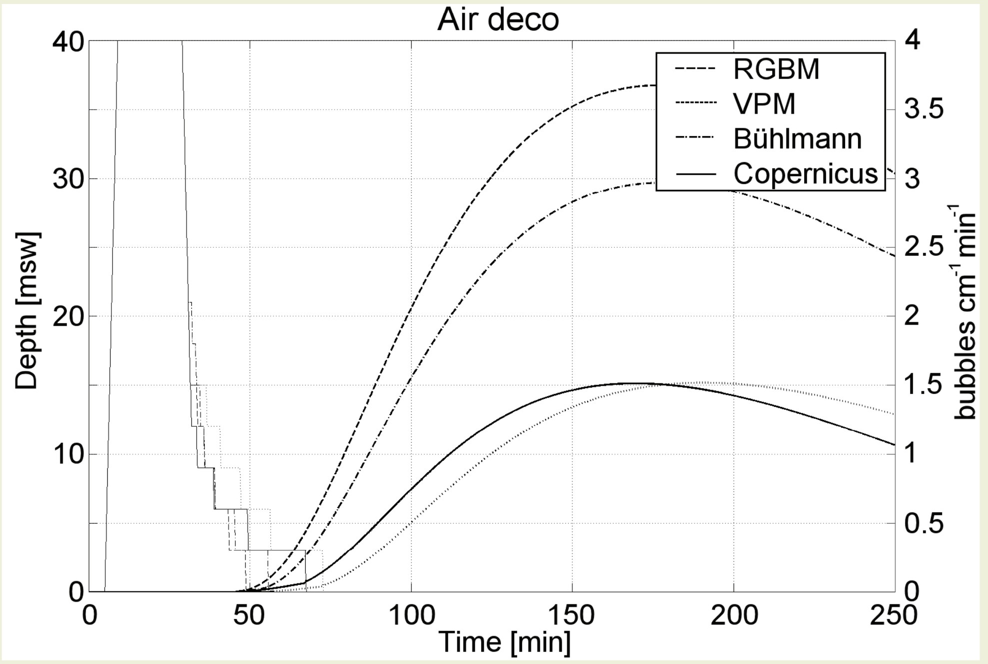

Figure 5: Simulation of 40 msw / 24 min doing air deco

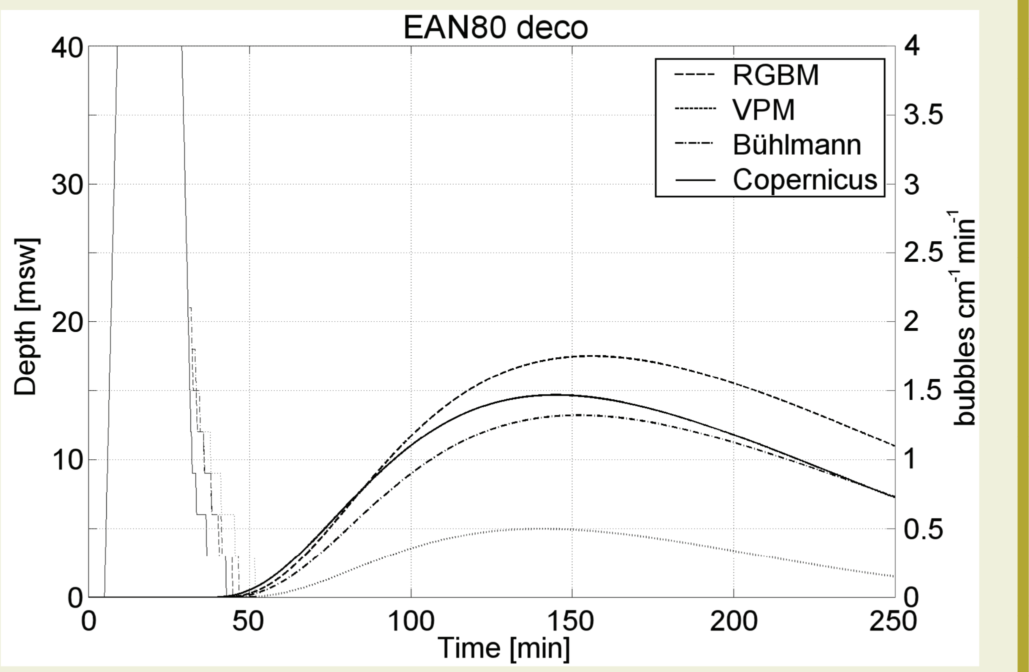

Figure 6: Simulation of 40 msw / 24 min doing EAN80 nitrox deco at the 9, 6 and 3 msw stop

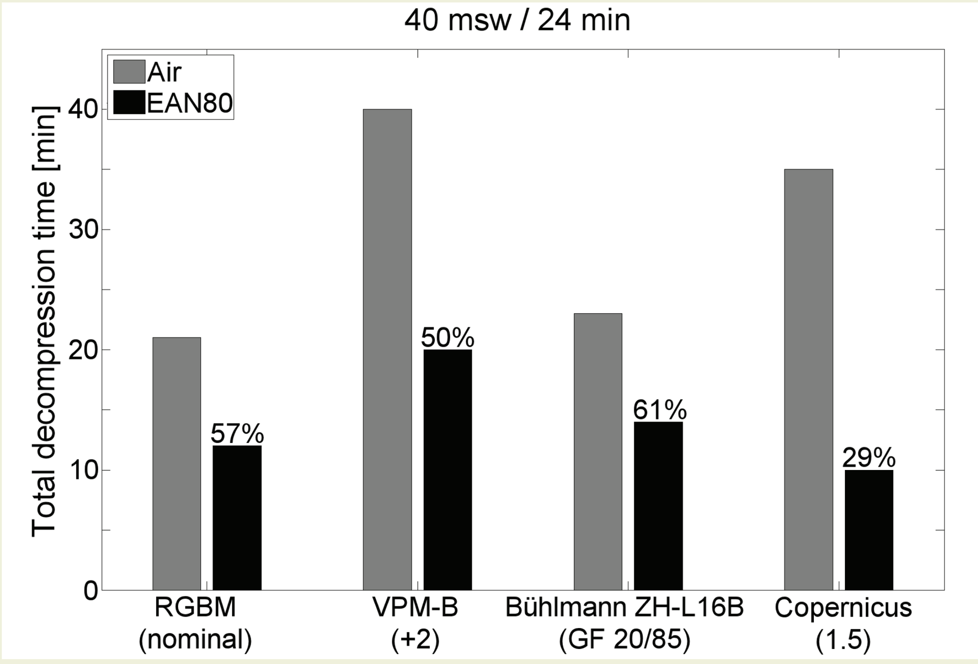

Figure 7: Effect of EAN on calculated deco time, deep / short

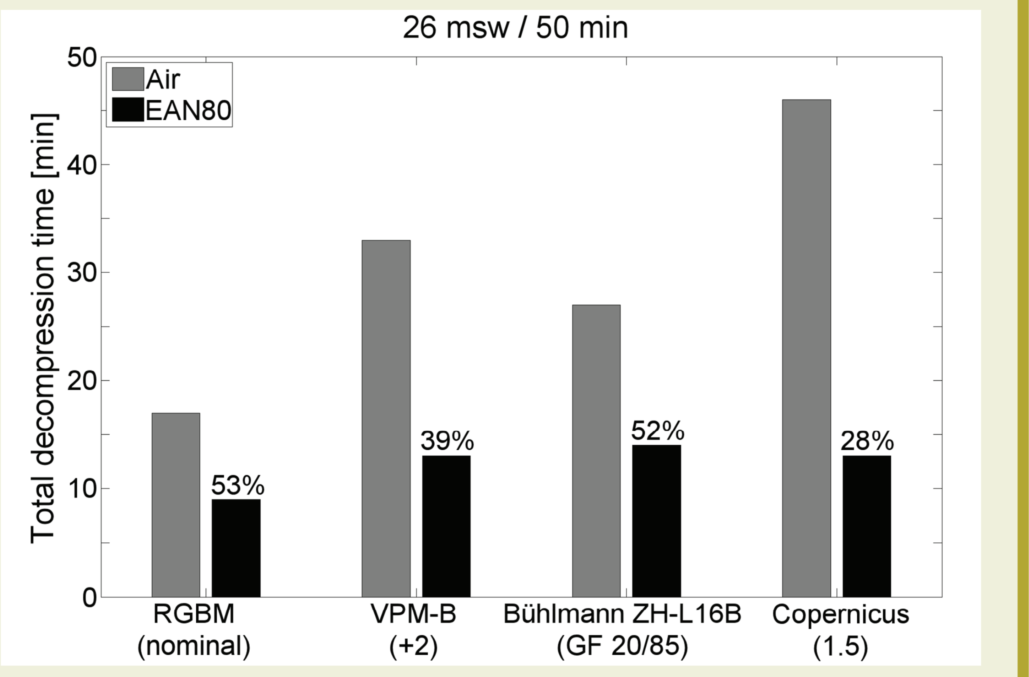

Figure 8: Effect of EAN on calculated deco time, long / shallow

Conclusions

There is no straight forward answer whether Copernicus is "more or less conservative" than other models, In order to keep VGE at a consistent level, the deviations are dependent on type of exposure. The most apparent difference is significantly more deco time on long and/or deep air dives. These types of dives are preferred with EAN deco gas, which clearly is demonstrated by Copernicus. We suggest that with a quantitative model like Copernicus, a more consistent risk suppression can be achieved.

References

[1] C. R. Gutvik and A. O. Brubakk, "A Dynamic 2-Phase Model for Vascular Bubble Formation During Decompression of Divers", *IEEE Trans Biomed Eng*, vol 55, pp 885-89, 2009

[2] C. R. Gutvik , R. G. Dunford, Z. Dujic and A. O. Brubakk, "Parameter Estimation of the Copernicus Decompression Model Using Non-Linear Optimization", *Medical & Biological Engineering & Computing*, In Press, 2010

[3] T. G. Shields, P. M. Duff, S.E. Wilcock and R. Giles, "Decompression Sickness From Commercial Offshore Air-Diving Operations On the UK Continental Shelf During 1982 To 1988", in *Advances in Underwater Technology and Offshore Engineering*, The Society for Underwater Technology, November 1989