

CONTROLLING DECOMPRESSION STRESS



Centre intégré de santé et de services sociaux de Québec
Appareilles
Québec



Neal W. Pollock, PhD
Université Laval, Québec, QC
Hôtel-Dieu de Lévis, Lévis, QC



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neal.pollock@kin.ulaval.ca
<https://www.facebook.com/neal.pollock.92>
<https://www.linkedin.com/in/neal-pollock-6185176a>



PERSPECTIVE

- ◆ Decompression guidance is well-intended, but imperfect
 - this should not be surprising
- ◆ Grounding - dosing of many (most) medications is imperfect
 - ie, need to adjust to achieve target titers and/or symptom response

OBJECTIVES

- ◆ We will discuss:
 - factors that can influence decompression safety
 - practical strategies to reduce decompression stress

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DIVE PROFILE CONTROL FLEXIBILITY

- ◆ Many occupational divers are required to comply with specific decompression limits and protocols
 - often table-based guidance
- ◆ Recreational divers typically have much more flexibility
 - in choice of table/algorithm
 - in choice of conservatism settings

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DIVE EXPOSURE CONTROL OPTIONS

- ◆ Topside controlled
 - diver buy-in relatively unimportant
- ◆ Diver controlled
 - diver buy-in essential

Commercial



Scientific



Recreational



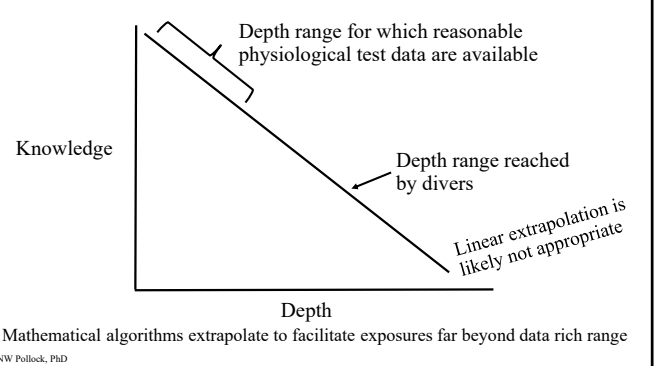
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DIVE COMPUTER-BASED DECOMPRESSION ALGORITHMS

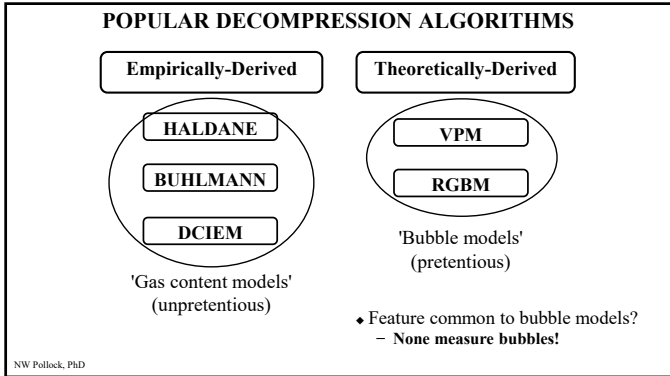
- ◆ Have allowed a seismic shift in dive planning
 - enabling complex dive profiles with minimal effort
- ◆ Many model variants, most with limited controlled human testing
 - thoughtful, cautious use is required
 - ◆ still very useful in providing first order approximation of risk



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DECOMPRESSION REALITIES



- ◆ Physiology is more than math
 - Models ≠ Reality
 - ◊ rely on many assumptions and limited measurement capability
- ◆ Dive computers do not get decompression sickness (DCS)
- ◆ Divers do get DCS
 - 0.3-35 cases per 10,000 dives
 - Dardeau et al. (2012)



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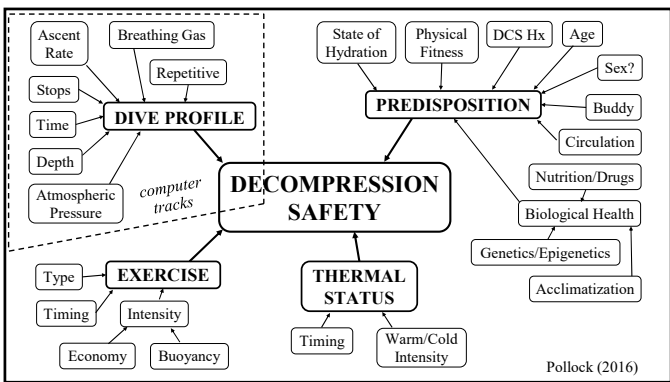
DCS - THE PERSONAL AFFRONT

- ◆ Most decompression algorithms provide reasonable protection for modest dives – but when DCS does occur, divers typically look for something, anything to blame
 - ◊ other than themselves...
- ◆ Must appreciate that there are myriad influencing variables





Urine samples ranging in concentration; "dehydration" is often a scapegoat to explain away DCS

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Dehydration	Euhydration	Hyperhydration
<ul style="list-style-type: none"> ◆ Impaired circulation and gas exchange ◆ Increased fatigue and reduced performance ◆ Elevated risk of DCS 	<ul style="list-style-type: none"> ◆ Probably best for all risks ◆ Maintain fluid intake to ensure first morning void is pale to very pale yellow 	<ul style="list-style-type: none"> ◆ Increased elimination needs ◆ Elevated risk of IPE ◆ Risk of hyponatremia in extreme cases



Target color

Divers are advised to maintain a healthy fluid balance. Hazards are associated with dehydration (decompression sickness [DCS]) and hyperhydration (immersion pulmonary edema [IPE]).

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THERMAL STATUS AND DECOMPRESSION STRESS

- ◆ US NEDU immersion study (clamped water temperature)
 - two phases: descent/bottom and ascent/decompression
 - 37 m (120 fsw) for 30 min bottom (exercise at ~7.2 MET) / 87 min ascent
 - two temps: 'warm' = 36°C (97°F) and 'cold' (cool) = 27°C (80°F)
 - Gerth et al. (2007)

High Risk	<div style="border: 1px solid black; border-radius: 15px; padding: 5px; display: inline-block;">Warm / Cool</div>	maximum uptake / minimum elimination
30 min @ 22%	<div style="border: 1px solid black; border-radius: 15px; padding: 5px; display: inline-block;">Cool / Cool</div>	minimum uptake / minimum elimination
vs		60 min @ 22%
70 min @ 1%	<div style="border: 1px solid black; border-radius: 15px; padding: 5px; display: inline-block;">Warm / Warm</div>	maximum uptake / good elimination
70 min @ 17%		70 min @ 17%
Low Risk	<div style="border: 1px solid black; border-radius: 15px; padding: 5px; display: inline-block;">Cool / Warm</div>	minimum uptake / good elimination

Pollock (2024)

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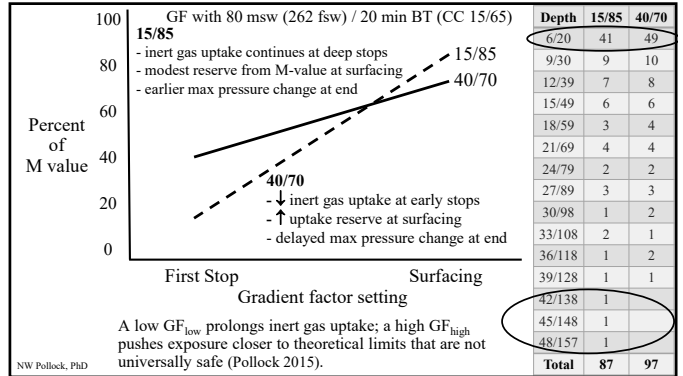
DIVE PROFILE CONTROL: GRADIENT FACTORS

- ◆ M-values (maximum allowable inert gas pressures) describe theoretical tissue limits of supersaturation for safe decompression
 - problem: both bubbles and DCS can develop below M-value
- ◆ GF limit the percentage of the M-value reached during ascent
 - constraining decompression profile
 - ◆ often applied to Buhlmann algorithm
 - described as two-step - eg, 40/70
 - ◆ GF_{low} - first stop depth called for if 0.4 M-value is reached
 - ◆ GF_{high} - ascent to surface regulated to stay within 0.7 M-value
 - Pollock (2015)



Images courtesy Shearwater Research

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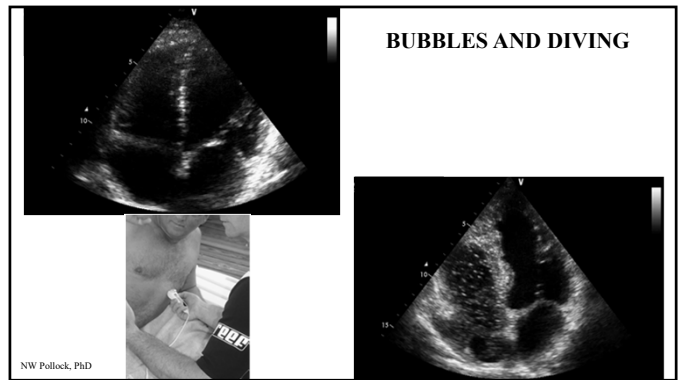


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DIVE PROFILE CONTROL - SURFACE GRADIENT FACTOR

- ◆ SurfaceGF (SurfGF)
 - shows what GF would result from instant surfacing (the "what if" risk)
 - ◆ indicator of the accumulated decompression burden/risk
- ◆ GF_{low/high} and SurfGF are often unknown or not well understood by divers

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GAS PHASE (BUBBLES)

- ◆ A consequence of significant decompression
 - biologically promoted and potentially problematic

EFFECT CONTINUUM



- ◆ Greatest utility is as an indicator of decompression stress
 - but must not overstate
 - ◆ bubbles ≠ DCS

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LIMITATIONS OF BUBBLE DATA

- ◆ Selective monitoring windows
 - accessible: precordium, major vessels
 - inaccessible: most tissues
- ◆ Intermittent monitoring
 - at best 1-2 min out of 15-20 min
 - at best when continued for a minimum of 2 h post-dive
- ◆ Restricted capture zone
 - eg, 2-dimensional capture of 3-dimensional zone
- ◆ Variable sensitivity of monitoring devices/settings
 - eg, power, gain, and frame rate all matter
- ◆ Variable technician skill
 - research quality training is time-consuming

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DOPPLER BUBBLE DETECTOR



TechnoScientific Doppler bubble monitor

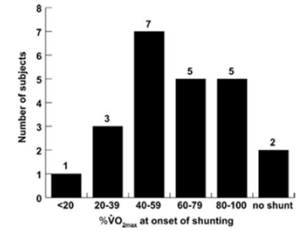


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SYSTEMIC ARTERIALIZATION OF BUBBLES

- ◆ Substantial bubble presence increases likelihood
 - decompression stress
 - pulmonary barotrauma (PBT)
- ◆ Two primary pathways for right-to-left heart passage
 - patent foramen ovale (PFO)
 - lung shunt
 - ◆ increases with exercise
 - Eldridge et al. (2004)

Histograms showing distribution of exercise intensity (%VO_{2max}) at the onset of shunting (n=23)
 • Eldridge et al. (2004)



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ENSURING HIGH QUALITY LITERATURE

- ◆ Requires effort by investigators and publishing teams
 - investigators must employ appropriate methods throughout effort
 - peer reviewers and editors must ensure reasonable methodological standard is met to justify publication

Diving and Hyperbaric Medicine Volume 46 No. 1 March 2016

Consensus Development Conference

Consensus guidelines for the use of ultrasound for diving research
 Andreas Møllerløkken, S Lesley Blogg, David J Doolette, Ronald Y Nishi and Neal W Pollock

- ◆ Report from 2025 consensus workshop coming....

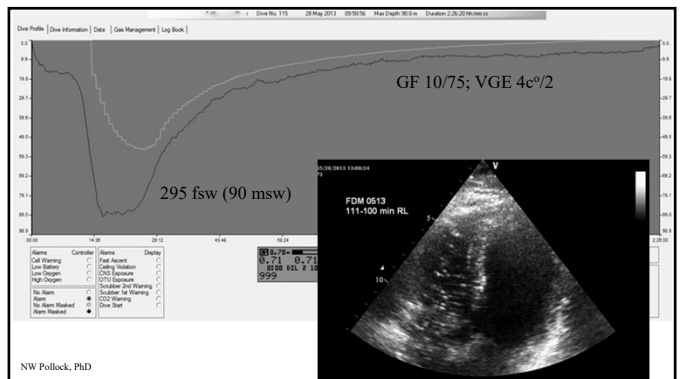
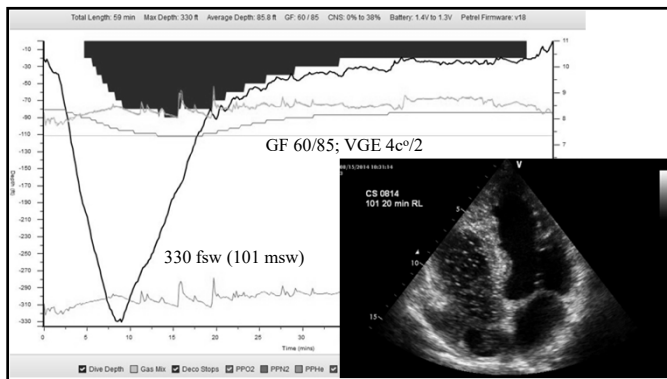
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TWO-DIMENSIONAL ECHOCARDIOGRAPHIC IMAGING

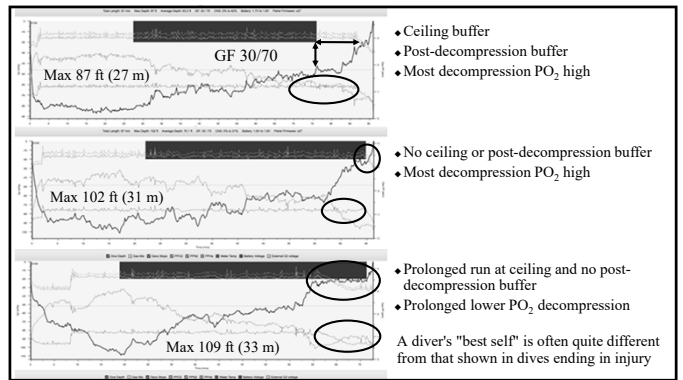
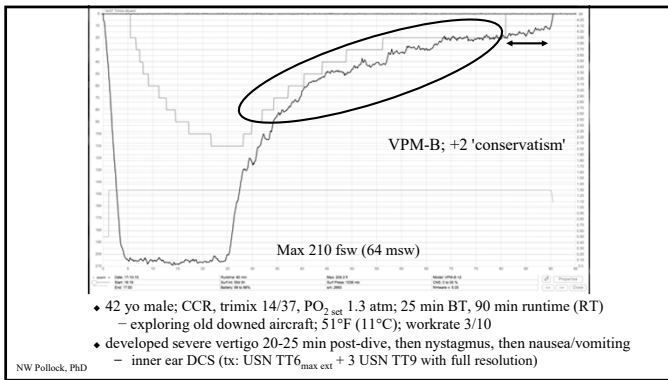
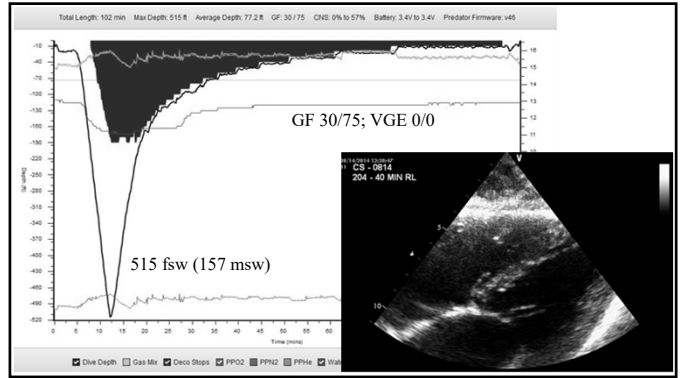
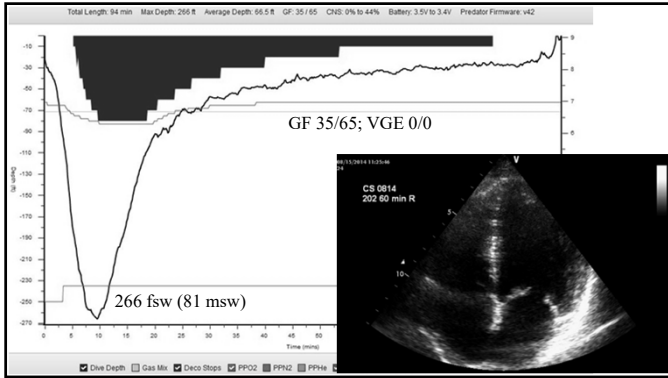


◆ GE Vivid q, Philips Lumify, GE Vscan Air

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STRATEGIES FOR DECOMPRESSION CONSERVATISM

- Use nitrox to limit N₂ exposure
 - but below nitrox table limits
- Plan multi-level dive profiles
 - progressively longer shallow times
- Build in algorithm conservatism
 - best using gradient factors (GF)
- Monitor and manage GF_{surf}
 - be mindful of maximal exposure
 - attain lowest level feasible before surfacing from shallowest stops
- Add extra shallow stop time
 - with both safety and obligatory stops
- Include surface debrief/rest time
 - to further delay post-dive exercise

Greatest value in 13-33 msw (43-110 fsw) depth range

Employ as a standard where feasible

Controlling both peak and end-dive risk

Cheap insurance; especially when post-surfacing effort cannot be avoided

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SUMMARY

- Deco stress represents a dynamic integration of factors
 - diver actions can dramatically alter level of risk
- Smart use of decompression algorithms can manage risk
- Ultrasound technology can provide a useful tool to evaluate relative risk of decompression exposures

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