Reconciliation of the Wienke RGBM & the Strauss GP Models for DCS

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Introduction

In 1989 Wienke described his Reduced Gradient Bubble Model (RGBM). It had widespread ramifications including:

<> Preventing the occurrence of decompression sickness

<> Explaining the cause of bubble formation

<>Modeling of algorithms for dive computers

<> Reducing ascents rates to 1 foot every 2 seconds

<> Executing a 3 minute "rest stop" at the 15 foot depth

With over 60 years of accumulated diving medicine experiences, we became aware of disordering events (see accompanying poster) that are precursors to undeserved decompression sickness (DCS). This evolved to generating our Gradient Perfusion (GP) model for DCS

This presentation reconciles the Wienke and our approaches to DCS and shows how each compliments the other in the prevention and management of DCS

Background

During the past 50 years it has been appreciated that off-gassing of the inert gas accumulated in the body tissues during decompression generated bubbles in the blood stream

In the majority of ascents (~9,997 of 10,000) the bubbles are carried to the lungs where they are harmlessly exhaled to the outside environment. These rightfully so are labeled "silent" bubbles

Multiple theories exist as to why bubbles form and include:

VPM (Varying Permeability Model) Yount (Hawaii)—Tiny bubble model
RGBM (Reduced gradient Bubble Model) Wienke (Los Alamos)—computer
BVM (Bubble-Volume Model) Thalmann (Duke)
BEM (Bubble Evolution Model) DCIEM (Toronto)—Doppler's
GDM (Gas-Dynamics Model) Flock/Van Liew (Buffalo)
TBDM (Tissue-bubble Dynamics Model) Gernhardt (Germany)

Deductions from the bubble formation theories

<>Two factors **Gradien**t for bubbles to nucleate & **Perfusio**n to off-gas determine whether or not DCS occurs

<>Clinical presentations of DCS are a function of in which tissues the bubbles forms

<>Explanations of why "undeserved" DCS occur can be due to **Overwhelming Gradients** and/or **Inadequate Perfusion**

Results & Observations

1. The soda bottle analogy explains many decompression science observations

Bubbles with shaking bottle

No bubbles with carefully removing cap

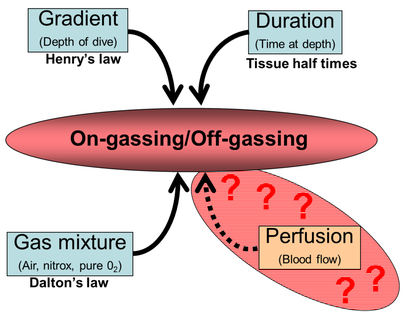
<>Body tissues, like the undisturbed soda bottle, can tolerate supersaturation of dissolved gases without bubble formation

<>When perturbed (i.e. a disturbance of motion, course, arrangement or state of equilibrium) bubbles form as in shaking the soda bottle; reasons include

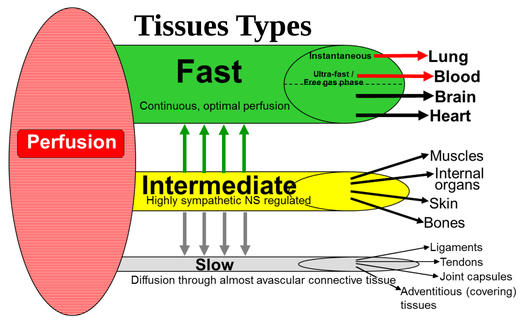
--Overwhelming gradients (i.e. reductions in ambient pressure
--Physical stresses such as shaking/vibrating the soda bottle
--Elevated temperatures—also enlarges bubbles (Charles Law)
--Chemical causes/catalysts—speeds reactions

<>Without a gradient (or uncapping the bottle) physical dissolved gas can not escape the liquid phase (i.e. body tissues)

2. Perfusion is the variable that makes decompression science imprecise



Gradient, Duration and Gas Mixture for on- and off-gassing can be precisely calculated



Perfusion varies with tissue type, metabolic demands and factors such as medications, water temperature, injuries & constriction of limb blood flow

To mitigate the perfusion dilemma, Wienke modified Haldane's tissue half time approach and realized ultra fast tissues (lung and blood) deserve special consideration using the label "free gas phase" for them

3. When **Perfusion is Inadequate** to off-gas the supersaturated inert gas in the tissues and/or the **Gradients are Too Great** autochthonous (in situ) bubbles form

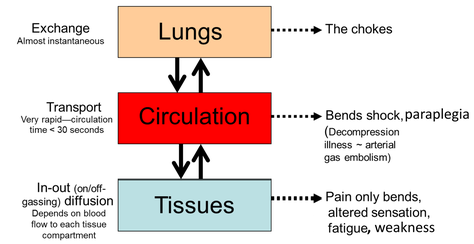
Our Gradient-Perfusion model provides a clinical approach to evaluation, management and return to diving for those incurring DCS

Conclusions

1. The Wienke and our (Strauss) models for inert gas dynamics in diving compliment each other
   <>Wienke's RGPM model is designed to prevent the occurrence of DCS
   <>Our GP model is designed to explain why DCS occurred, guide management and provide advice for return to diving

2. Wienke's model is based on theory; in about 50% of the cases of DCS, the divers do not violate their dive computer's information for safe bottom times, ascent rates or the three minute safety stop

3. The GP model accounts for the clinical presentations of DCS; the locations of the bubbles determine the symptoms. Extreme gradients generate symptoms in the ultra-fast tissues, inadequate perfusion is the source of bubbles in the intermediate and slow tissues



4. The GP model provides guidance for return to diving; If it is a gradient problem (e.g. omitted decompression and no residuals), it is usually a deserved DCS hit and it is safe to return to diving

   If it is a perfusion problem, careful consideration is required including cardiology and neurological consultations to make appropriate decisions about returning to diving

	Deserved	Undeserved
No Residuals	Yes (After 2 weeks; educate)	No*
Residuals (Especially neurological)	No (Possible dive with special precautions)	No

*If the bends victim is determined to dive again then 1) cardiology consult (bubble study), 2) neurology consult (brain and spinal cord MRI studies), 3) trial of recompression (60 feet for 60 minutes breathing air) and 4) instructions in conservative diving practices (nitrox; depth and time limitations, number of dives per day, etc.)

References

1. Strauss MB, IV Aksenov ***Diving Science***: Essential Physiology and Medicine for Divers, Human Kinetics, Champaign, IL, USA, May 2004, ISBN: 0736048308

2. Strauss, MB, SS Miller, Stresses in SCUBA and breath-hold diving, Part II: Physiological stresses, ***Wound Care & Hyperbaric Medicine***, 2014: 5(2):16-28. Available from : http://www.bestpub.com/periodicals-and-subscriptions/wchm.html

3. Wienke, BR, Tissue gas exchange models and decompression computations: A review, ***Undersea Biomed Res***, 1989; 16(1);53-89