A stress index to enhance DCS risk assessment for both air and mixed gas exposures

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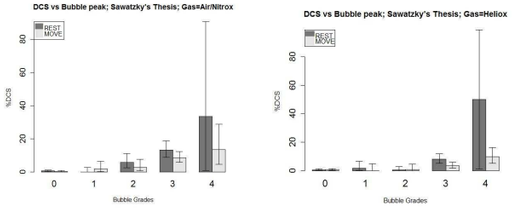
– Background and Objectives–

There are two common ways to assess decompression-induced physiological stress for dive exposures and associated decompression procedures :

- Detection of bubbles using Doppler ultrasound
  - DCIEM/DRDC approach [1]
  - Interest: method used extensively by DCIEM/DRDC Toronto Research Centre from the 80's to develop and validate decompression tables for the Royal Canadian Navy
  - Limitation: doesn't consider pressure profile/decompression profile to assess DCS risk



Dives	Number	Person Dives	Depth (msw)	BottomTime
Nitrox	354	1726	15-91	5-100 min
Heliox	252	1508	31-100	9-100 min
Total	606	3234	15-100	5-100 min

- Statistical predictive tools calibrated with a large diving profile/DCS database [2]
  - Interest: helps to verify the adequacy of the last version of the US Navy air decompression tables in terms of DCS risk target [3]
  - Limitation: doesn't consider inter / intra individual variability wrt DCS susceptibility

$$P_{DCS} = f(time, depth, model) = 1 - exp\int -rdt$$

$$P_{outcome} = {P_{DCS}}^{Y} * (1 - P_{DCS})^{1-Y} \text{ with Y=0 if NO DCS and Y=1 if DCS}$$

$$LL = \prod ln P_{outcome}$$

- Objectives : determination of a simple composite decompression stress index combining both approaches i.e. considering :
  - the dive profiles
  - the bubble grades detected at precordial level
- Such combination should lead to improved DCS risk assessment and predictability compared to indices based on bubble detection alone or profile consideration alone

– ROC curves –

- In statistics, a receiver operating characteristic (ROC) curve illustrates the performance of a binary classifier system as its discrimination threshold is varied
- ROC analysis can help to identify a relevant diagnostic test
- ROC analysis is increasingly used in many areas (ex: medicine)
- Accuracy is measured by the area under the ROC curve (AUC) :
  - .90-1 = excellent (A)
  - .80-.90 = good (B)
  - .70-.80 = fair (C) .60-.70 = poor (D)
  - .50-.60 = fail (F)

		Condition	
		Positive	Negative
Test outcome	Positive	True positive	False positive
	Negative	False negative	True negative
		Sensitivity=Σ True positive/ Σ Condition positive	Specificity=Σ True negative/ Σ Condition negative

– References –

1. Sawatzky KD. The relationship between intravascular Doppler-detected gas bubbles and decompression sickness after bounce diving in humans. MSc thesis, York University, Toronto; 1991
2. Weathersby PK, Homer LD, Flynn ET. On the likelihood of decompression sickness. J Appl Physiol 1984; 57: 815-825
3. Gerth WA, Doolette D. VVAL-18 and VVAL-18M Thalmann algorithm – Air decompression tables and procedures. Research Report 07-09. Panama City, FL: US NEDU; 2007
4. Temple DJ et al. The dive profiles and manifestations of decompression sickness case after air and nitrogen-oxygen dives. Report NMRC 99-02 (Vol. I and Vol. II). Bethesda, MD: Naval Medical Research Center; 1999
5. HanleyJA, McNeil. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. Radiology 1983; 148: 839-843

– Materials and Methods –

- Several decompression stress indices based on the inert gas load, Q, in the body and the total ascent time, TAT, were investigated for single air dives (no oxygen) and mixed gas exposures (with oxygen) merging two database

		DRDC (Pressure profile+DCS+Bubble grades)				*NMRC (Depth/BT/Ascent+DCS) [4]*			
	Gas	man*dives	DCS	DCS Type M	PDCS (CI95%)	man*dives	DCS	DCS Type M	PDCS (CI95%)
SINGLE DIVES (No Repet /No SD)	*AIR*	1041	29	3	2.8% [1.9-4.0]	1738	200	69	11.5% [10.1-13.1]
	AIR#OXYGEN	420	12	2	2.9% [1.6-4.9]	284	26	9	9.2% [6.3-13.1]
	HELIOX/TRIMIX #OXYGEN (@9m	3241	23	0	0.7% [0.5-1.1]	-	-	-	-
		4702	64			2022	226		

- The best index obtained was then applied to DRDC database only to estimate the usefulness of bubble detections to improve DCS predictability :

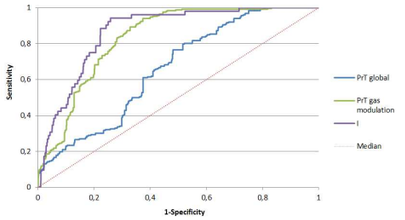
	DRDC database									
	Up to 1991 (Sawatzky)					Up to 2013				
Gas	man*dives	DCS	DCS Type 1	DCS Type 2	DCS Type M	man*dives	DCS	DCS Type 1	DCS Type 2	DCS Type M
AIR/NITROX	1726	41	32	7	2	2149	58	42	10	6
HELIOX	1508	32	32	0	0	5297	41	32	3	6
TRIMIX	-	-	-	-	-	1245	7	1	6	0
ALL GAS	3234	73	64	7	2	8691	106	75	19	12

➔ the bubble database was used to modulate the index according to the observed DCS risk ratio between bubble grades to obtain the best ROC curves for diagnosis [5]

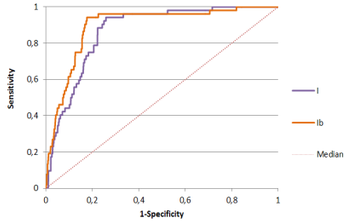
– Results –

Best decompression stress index determined :

➔ $I = \beta \frac{Q - Q^{*}}{TAT^{\alpha}}$ where $Q = P\sqrt{t}$, $Q^{*} = 12$, α=0.3 and β=1 for Air, β=0.8 for Air with O2 decompression and β=0.3 for Mixed Gas

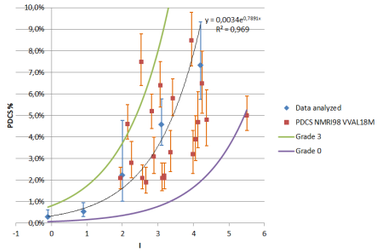


	P√t	P√t gas modulation	I
ROC AUC (CI95%)	0.654 (+/- 0.027)	0.816 (+/- 0.018)	0.851 (+/- 0.015)
ΔAUC z / p	-	z=9.67 ; p<0.001	z=2.94 ; p<0.005



	AIR	HELIOX/TRIMIX +OXY
Grade 0	I--->I_b=I-1,95	I--->I_b=I-0,5
Grade 1	I--->I_b=I+0,15	I--->I_b
Grade 2	I--->I_b=I+0,15	I--->I_b
Grade 3	I--->I_b=I+1,10	I--->I_b+0,3
Grade 4	I--->I_b=I+2,10	I--->I_b+1,8

	I	Ib
ROC AUC (CI95%)	0.867 (+/- 0.032)	0.895 (+/- 0.027)
ΔAUC z / p	-	z=2.14 ; p<0.05



PDCS NMRI98 predictions *vs* current PDCS=f(I) approach

– Conclusions & Perspectives –

- The combination of diving profile, the gas breathed and the bubble monitoring information improves the predictability of DCS risk.
- The ROC AUC are adequate for diagnostic purposes, with the index qualifying as "good" to "excellent" according to statistic standards
- A probabilistic model calibrated using both diving profile and bubble grade observations will consequently refine DCS risk predictability at group and individual levels