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On the statistical probability of contracting a decompression sickness after a single scuba dive on air within a no-decompression-limit

DOI:
10.13140/RG.2.2.17249.74084

Abstract:

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The P(DCS) is the statistical probability of contracting a decompression sickness, the NDL are the so-called „No Decompression Limits“, the time limits for dives where a direct ascent to the surface is still possible, i.e. without decompression stops.

Since there is variance in these NDLs from different agencies, we set out to analyze them with already published methods of assessing the P(DCS).

Thus the somewhat lengthy title could have been condensed to:

On the P(DCS) from a single air dive within NDL

The NDL from some recreational air dives from various training agencies are contrasted and analyzed with 3 published methods from the USN NEDU [1], [2] & [4].

Methods:

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The P(DCS) estimation is implemented according to [1], p. 8 & Table 2, p.11:

TABLE 2. PARAMETERS FOR THE STANDAIR MODEL

$$LOGIT = a + b \cdot (D - c) \cdot \left(\frac{1 - e^{\left(-d \cdot T^{f}\right)}}{TDT - g} \right)$$

LL = –669.144 (Null model, *LL* = –798.978, inc = 5.67%)

Parameter	Estimate	*ASE**	Param/*ASE*	Wald 95% Confidence Interval
a	-6.022169	0.277405	-21.7	-6.57 – -5.48
b	86.596315	18.887942	4.58	49.5 – 123.6
c	25.091718	2.038656	12.31	21.09 – 29.09
d	0.002929	0.000832	3.52	0.0013 – 0.0046
f	0.918547	0.041705	22.0	0.837 – 1.000
g	-170.304442	21.500126	-7.92	-212 – -128

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with ASE: asymptotic standard errors
LOGIT: logistic regression function
P(DCS) : probability of decompression sickness

$$Pdcs = \frac{1}{1+e^{(-LOGIT)}} \qquad (3)$$

$$LOGIT = a + b \cdot (D - c) \cdot \left(\frac{1 - e^{(-d \cdot T^{f})}}{TDT - g} \right) \qquad (4)$$

With D: bottom depth [fswg], T: bottom time [min], TDT: total decompression time [min]; a,b,c,d,f,g: the parameters according to Table 2, p.11.

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Whereas DIVE [3] uses metric units, the input of D has to be converted from m to fwsg, the TDT being as well a parameter for free input as TTS.

As well a very similar model, the so-called „Combination Model“ [2] is implemented by the same token. This model added 240 EAN / saturation dives to the calibration data set, thus the parameters are different ([2], p. 204):

Combination Model *LL* = -763.395, Null Model *LL* = -880.21, incidence = 5.94%

Parameter	Estimate	*ASE**	Param/*ASE*	Wald 95% Confidence Interval
a	-5.792136	0.234149	-24.8	-6.25 – -5.33
b	134.799017	15.251709	8.80	105 – 165
c	18.135384	1.477299	12.15	15.2 – 21.0
d	0.004029	0.000732	5.42	0.00256 – 0.0055
f	0.782505	0.024983	30.57	0.733 – 0.832
g	-284.304696	31.050956	-8.94	-345 – -223

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The 3rd. method implemented is the so-called „P-No-Stop Model“, a probabilistic model based on ca. 2.000 experimental no-stop dives on air / EAN [4].

The LOGIT regression function and the parameter set thus different from [1] & [2]; source [4], Table 3 on p. 14:

TABLE 3. PARAMETERS FOR THE P-NO-STOP MODEL

Equation 4: $$LOGIT = a + b \cdot D \cdot \left[\left(1 - e^{(-c \cdot T)}\right) + d \cdot \left(1 - e^{(-f \cdot T)}\right)\right]$$

Model = No-Stop, Equation 4, *LL* = –323.41 Null model, *LL* = –410.68, *inc* = 5.1%

Parameter	Estimate	ASE*	Param/ASE	95% Confidence Interval
a	–8.837279	0.382609	–23.10	–9.59 – –8.09
b	0.068630	0.008662	7.92	0.0516 – 0.0856
c	0.032453	0.005125	6.33	0.0224 – 0.0425
d	2.760433	0.379541	7.27	2.015 – 3.506
f	0.001651	0.000182	9.06	0.001293 – 0.002008

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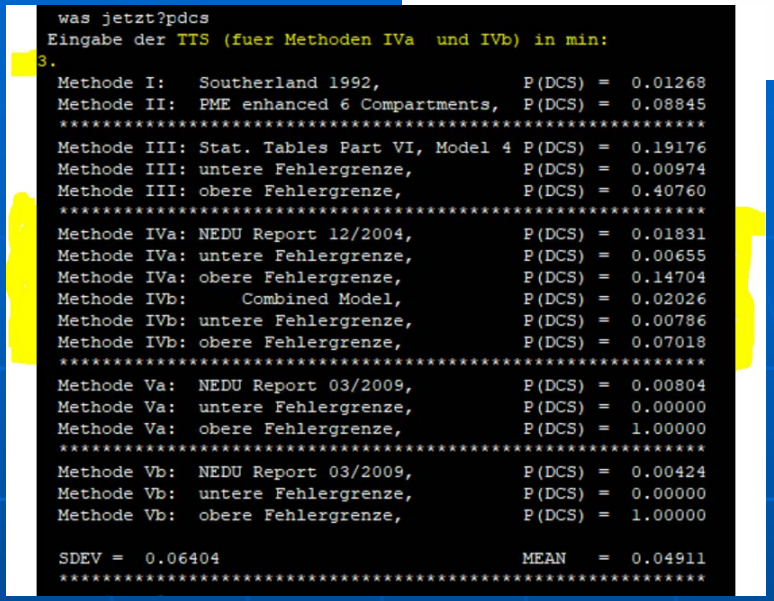
Sample outputs from DIVE [3]; Version 3_09 (pls. cf. next slides) for a single dive on air to 100 feet → 30.48 m, 17 min; TTS: 3 min as input for the P(DCS) dialogue [i.e.: bottom depth / ascent rate=30 m / 10 m / min]



DIVE [3]; Version 3_09 has implemented nine (9) published methods for the estimation of P(DCS); here, only 5 are showed in this screen shot.

For this presentation, we use only the methods designated here as: IVa & IVb (**yellow display**) from [1] and [2] because the calibration data sets fit to the scenario of a single air dive to a NDL and calculation of the P(DCS) at the end of the bottom time, i.e.: prior to ascent. The other methods are not relevant here.

Due to the ASE, we have the upper & lower error margins of these 2 methods calculated.

```
 was jetzt?pdcs
 Eingabe der TTS (fuer Methoden IVa  und IVb) in min:
3.
 Methode I:   Southerland 1992,              P(DCS) =  0.01268
 Methode II:  PME enhanced 6 Compartments,   P(DCS) =  0.08845
 ************************************************************
 Methode III: Stat. Tables Part VI, Model 4  P(DCS) =  0.19176
 Methode III: untere Fehlergrenze,           P(DCS) =  0.00974
 Methode III: obere Fehlergrenze,            P(DCS) =  0.40760
 ************************************************************
 Methode IVa: NEDU Report 12/2004,           P(DCS) =  0.01831
 Methode IVa: untere Fehlergrenze,           P(DCS) =  0.00655
 Methode IVa: obere Fehlergrenze,            P(DCS) =  0.14704
 Methode IVb:     Combined Model,            P(DCS) =  0.02026
 Methode IVb: untere Fehlergrenze,           P(DCS) =  0.00786
 Methode IVb: obere Fehlergrenze,            P(DCS) =  0.07018
 ************************************************************
 Methode Va:  NEDU Report 03/2009,           P(DCS) =  0.00804
 Methode Va:  untere Fehlergrenze,           P(DCS) =  0.00000
 Methode Va:  obere Fehlergrenze,            P(DCS) =  1.00000
 ************************************************************
 Methode Vb:  NEDU Report 03/2009,           P(DCS) =  0.00424
 Methode Vb:  untere Fehlergrenze,           P(DCS) =  0.00000
 Methode Vb:  obere Fehlergrenze,            P(DCS) =  1.00000

 SDEV =  0.06404                             MEAN   =  0.04911
 ************************************************************
```

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Sample output from the 3rd. method implemented,
the “P-No-Stop Model” [4],
for a dive on air to
bottom depth: 30.48 m, 20 min bottom time:

```
P-NO-STOP Model: NEDU TR 04-42,              P(DCS) =  0.02275
P-NO-STOP Model: untere Fehlergrenze,        P(DCS) =  0.00456
P-NO-STOP Model: obere Fehlergrenze,         P(DCS) =  0.12075
*************************************************************
```

Due to the ASE, we have the upper & lower error margins calculated.

Results (1):

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Bottom depth: 100 feet / 30.48 m	Bottom time [min]:	P(DCS) IV a:	P(DCS) IV b:	P(DCS) P-No-Stop Model:
Table / Agency				
USN 1957 (*)	**25**	**0.04155**	**0.03836**	**0.05402**
(**)	**20**	**0.02507**	**0.02596**	**0.02275**
DECO 2000 (***)	**15**	**0.01478**	**0.01705**	**0.00831**
- / -	**12**	**0.01064**	**0.01301**	**0.00422**

(*) used by nearly all agencies until the 90‘s
(**) used by: ZH-86, BSAC 88, SSI, PADI RDP, NAUI 2001
(***) DECO 2000 by Dr. Max Hahn, used by major D-A-CH agencies

Results (2):

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Bottom depth: 100 feet / 30.48 m Bottom time: 20 min	TTS = TDT [min]:	P(DCS) IV a:	P(DCS) IV b:	P(DCS) P-No-Stop Model:
Ascent Rate				
60 feet/min	**1.7**	**0.02552**	**0.02622**	**0.02275**
10 m / min	**3**	**0.02507**	**0.02596**	**0.02275**
5 m / min	**6**	**0.02411**	**0.02540**	**0.02275**
2.5 m / min	**12**	**0.02237**	**0.02435**	**0.02275**
1.25 m / min	**24**	**0.01953**	**0.02248**	**0.02275**

Discussion:

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(*) used by nearly all training agencies
until the 90‘s

(**) used by:
ZH-86: the Zuerich Air Table ZH-L16 A from A. A. Buehlmann
BSAC 88: British Sub-Aqua Club 1988 table by Hempleman et al.,
SSI: USN doppler-reduced NDL by Scuba Schools International, 1996
PADI RDP, the Recreational Dive Planner from Prof. Assoc of Diving Instructors
NAUI 2001, the RGBM table from National Assoc. of Underw. Instructors

(***) DECO 2000 by Dr. Max Hahn, used by major D-A-CH training agencies
[D: germany, A: austria, CH: switzerland]

All 3 methods / models suggest the following:

the reduction in ascent speed or increase in TTS decreases the P(DCS) only insignificantly, *whereas to reduce the P(DCS) significantly for this 30 m dive, an „NDL“ of ca. 11 → 12 min has to be applied.*

private remark:

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We would like to thank the USN NEDU, the Naval Experimental Diving Unit of the United States Navy!!!

For all their excellent reports: with superb clarity, outstanding quality in terms of documentation, diving technology and statistical wisdom!

Without these fine works, our world of modern diving would have been much more un-safe!

Sources / References:

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[1] H. D. Van Liew, E. T. Flynn (December 2004)
A SIMPLE PROBABILISTIC MODEL FOR ESTIMATING
THE RISK OF STANDARD AIR DIVES; USN NEDU TR 04-41 TA 01-07

[2] H. D. VAN LIEW, E. T. FLYNN (2005) A simple probabilistic model for standard air dives that is focused on total decompression time. UHM 2005, Vol. 32, No. 4, 199 - 213

[3] the SubMarineConsulting Group (1991) DIVE: a decompression suite; pls. cf. next slide

[4] H. D. Van Liew, E. T. Flynn (December 2004) PROBABILITY OF DECOMPRESSION SICKNESS.IN NO-STOP AIR DIVING, TA 01-07 NEDU TR 04-42

Bonus Material: Source for DIVE Version 3_09

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Download free of charge:

→ DIVE V 3_09
(https://www.divetable.info/DIVE_V3/index.htm)

→ and the german manual
https://www.divetable.info/DIVE_V3/DOXV3_0.pdf

The release train for
→ the english version (V3_04) is somewhat slower …
DIVE V 3_09 is not compatible with all older versions!

https://www.divetable.info/DIVE_V3/V3e/index.htm

Fine tuning of DIVE:

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Fine tuning could be done via the commands:

→ ascent rate („**AR**“)

→ ambient atmospheric pressure at start („**L**“)

→ the respiratory coefficient („**R**“)

→ the ambient (water)-temperature („**te**“)

→ the water density („**di**“)

→ Buehlmann Safety Factor („**B**“)

→ last stop depth („**LS**“)

And with: „**a**“ we recieve the complete decompression prognosis;
i.e.: the stop times in min per stage, modulo 3 m
and the **responsible leading compartment & the rounded up TTS** in min. The latest DIVE Version for beta testing is always staged there:

https://www.divetable.info/beta/index.htm

along with information on production date, size in bytes, new features and the checksums for verifying the download.

Handling of DIVE:

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The paradigm dive from above via
these commands,
the input of commands and
parameters are in the quotes: „ “

→ „d“ (simulation of a box profile with these parameters:)
→ „30.48“ (bottom depth)
→ „17.“ (bottom time)

→ the **P(DCS) dialogue** is invoked with: „**pdcs**“
→ pls. cf. slides #6 & 7

→ the methods IVa & IVb depend on the TDT / TTS, so this is an input parameter, the TTS (time-to-surface) = sum of all stop times + max. bottom depth / ascent rate

→ The „**P-NO-STOP Model**“ is started with: „**bpa**“ (for „Box Profile Air“)