Common Factors in Diving Fatalities

DAN America and DAN Europe Data

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Richard D. Vann, Ph.D.

Fatality Workshop, Durham April 8-10, 2010
Sources

• DAN Insured Members Claims 2000-2006
  – 187 dive-related deaths
• EDAN Insured Members Claims 1996-2008
  – 144 dive-related deaths
• DAN Fatality & Injury Database 1992-2003:
  – Most common causes of deaths; 947 cases in OC diving
  – Case control study: 165 fatal and 135 non-fatal AGE case
  – Diabetes mellitus: 37 cases vs. 938 non DM cases
Annual numbers of diving fatalities

USA & Canada
BSAC
Australia
EDAN, insured

Number of Deaths

Annual Number of Diving Fatalities

![Graph showing annual number of diving fatalities from 1970 to 2005 for USA & DAN. The number of deaths ranged from a high of 160 in the early 1980s to a low of about 60 in the late 1990s. The graph also indicates an increase in the number of deaths for the DAN category in recent years.]
Original articles

Scuba injury death rate among insured DAN members
Petar J Denoble, Neal W Pollock, Panchabi Vaithiyanathan, James L Caruso, Joel A Dovenbarger and Richard D Vann

• DAN diving accident insurance data, 2000-2006
• 1,141,367 insured member years
• 187 diving related deaths
• Sex, age, cause of death
Individual Risk Per Annum (IRPA)

• IRPA = Probability (individual is killed during one year of exposure)

• As safety performance measure:

  Observed number of fatalities
  IRPA = -----------------------------------------------
  Total number of person-years exposed
DAN Membership IRPA

187
IRPA = ------------------- = 163 * 10^{-6}
1,141,367

1 in 6000 or 0.016%
# Individual Risk Per Annum (IRPA)

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Annual risk</th>
<th>Annual risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recreational diving*</td>
<td>1 in 6,000</td>
<td>163 x 10^{-6}</td>
</tr>
<tr>
<td>Jogging</td>
<td>1 in 7,700</td>
<td>130 x 10^{-6}</td>
</tr>
<tr>
<td>Mining and quarrying</td>
<td>1 in 9,200</td>
<td>109 x 10^{-6}</td>
</tr>
<tr>
<td>Construction</td>
<td>1 in 17,000</td>
<td>59 x 10^{-6}</td>
</tr>
<tr>
<td>Agriculture, hunting</td>
<td>1 in 17,200</td>
<td>58 x 10^{-6}</td>
</tr>
<tr>
<td>Fatalities to self-employed</td>
<td>1 in 50,000</td>
<td>20 x 10^{-6}</td>
</tr>
<tr>
<td>Manufacturing industry</td>
<td>1 in 77,000</td>
<td>13 x 10^{-6}</td>
</tr>
<tr>
<td>Fatalities to employees</td>
<td>1 in 125,000</td>
<td>8 x 10^{-6}</td>
</tr>
<tr>
<td>Service industry</td>
<td>1 in 333,000</td>
<td>3 x 10^{-6}</td>
</tr>
</tbody>
</table>

Data from “Reducing risks, protecting people” (HSE 2001)
* DAN membership data
BSAC & DAN Fatality Rates

y = -0.3456x + 704.87
R² = 0.1776 (p = 0.0016)
## Scuba injury death rates

<table>
<thead>
<tr>
<th>Group</th>
<th>Denominator</th>
<th>Time period</th>
<th>Rate (95%CI)</th>
<th>Rate (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>per 100,000</td>
<td>per 100,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>divers</td>
<td>dives</td>
</tr>
<tr>
<td>Cave Divers, GB</td>
<td>Measured</td>
<td>1957-1979</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>Cave Divers, GB</td>
<td>Measured</td>
<td>1980-2006</td>
<td>24.6</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>Estimated</td>
<td>1986</td>
<td>3.4 to 4.2</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>Estimated</td>
<td>1989</td>
<td>16.7</td>
<td>0.8 to 1.6</td>
</tr>
<tr>
<td>Orkney, Scotland</td>
<td>Measured</td>
<td>1999-2000</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Estimated</td>
<td>1989</td>
<td>34 (1 in 3000)</td>
<td>1.7 to 3.4</td>
</tr>
<tr>
<td>Victoria, Australia</td>
<td>Tank fill count</td>
<td>1992-1996</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Survey</td>
<td>2000-2006</td>
<td>3.57 (1 in 28,000)</td>
<td>0.57</td>
</tr>
<tr>
<td>BC, Canada</td>
<td>Tank fill count</td>
<td>1999-2000</td>
<td>2.04</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Tank fill count</td>
<td>(8.8-33.8)</td>
<td>1.0 to 2.4</td>
<td></td>
</tr>
<tr>
<td>BSAC</td>
<td>Measured</td>
<td>2000-2006</td>
<td>14.4</td>
<td>(10.5-19.7)</td>
</tr>
<tr>
<td>DAN Insured</td>
<td>Measured</td>
<td>2000-2006</td>
<td>16.4 (1 in 6000)</td>
<td>(14.2-18.9)</td>
</tr>
</tbody>
</table>

*estimated based on 25 dives/diver/year
Acceptable Risk

Activities with a fatality risk greater than $1 \cdot 10^{-3}$ deaths/year to the general public are generally not acceptable.

- Cars: $3 \cdot 10^{-3}$ deaths/person-year
- Falls: $1 \cdot 10^{-4}$ deaths/person-year
- Fires: $4 \cdot 10^{-5}$ deaths/person-year
- Drowning: $4 \cdot 10^{-5}$ deaths/person-year
- Firearms: $1 \cdot 10^{-5}$ deaths/person-year
- Poisoning: $1 \cdot 10^{-5}$ deaths/person-year
- Lightning: $8 \cdot 10^{-7}$ deaths/person-year

Scuba diving: $1.6 \cdot 10^{-4}$
Criteria for Acceptable Risk in the Netherlands

Diving $1.6 \times 10^{-4}$

*Figure 3* personal risk in Western countries, deduced from the statistics of causes of death and the number of participants per activity.

J.K. Vrijlinga, P.H.A.J.M. van Geldera & S.J. Ouwerkerka
Delft University of Technology
**ALARP**

- **As Low As Reasonable Practicable (ALARP)**

[Diagram]

- **Unacceptable region**
  - Tolerable only if risk reduction is impracticable or cost is grossly disproportionate to the improvement gained.

- **The ALARP**
  - 1/6,000

- **Broadly acceptable region**
  - 1/30,000

- **Negligible risk**
  - Negligible risk
Common causes of open-circuit recreational diving fatalities.

P. J. DENOBLE¹, J. L. CARUSO¹,²,³, G. de L. DEAR¹,², C. F. PIEPER⁴, and R. D. VANN¹,²

• 947 Open-Circuit Deaths from 1992-2003
  • 70% family interviews
  • 60% autopsy findings
  • 52% witness reports
  • <52% investigative reports
  • 28% equipment testing
  • 22% breathing gas analysis
Cause of Death
(DAN America, n=814)
Cause of Death
(EDAN, n=112)
Titanic Cause Map

Cause Mapping is a visual, systems-based approach that focuses on fundamental cause-and-effect relationships supported with evidence. The three basic steps of Cause Mapping are shown here.

### Basic Level

**Safety Impact**
- Loss of 1500 Lives
- Titanic Sank
- Ship Hit Iceberg

### More Detailed Analysis (zoom in)

**Vessel Impact**
- Lost entire ship
  - Titanic Sank
  - Water Filled Hull
  - Opening in Hull
  - Steel Plates Buckled on Hull

**Safety Impact**
- Loss of 1500 Lives
  - Solution: Add more lifeboats
  - Insufficient lifeboats
  - AND
  - Bulkheads Not Sealed

Expand to as much detail as necessary.
Root Cause Analysis of Diving Deaths

Trigger
First identified cause in the chain

Harmful Agent/Action
Immediate cause of disabling injury

Disabling Injury
Incapacitates or kills diver

Cause of Death (COD)
Final cause of death as specified by Coroner

Example 1
Out of Air
Emergency Ascent
Air Embolism
Drowned

Example 2
Entangled
Out of Air
Asypxhia
Drowned
## Root Causes

<table>
<thead>
<tr>
<th>Causes</th>
<th>Frequency</th>
<th>Role</th>
<th>Disabling Agent</th>
<th>Trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complication of a pre-existing disease</td>
<td>389</td>
<td></td>
<td>169</td>
<td>24</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>293</td>
<td></td>
<td>43</td>
<td>18</td>
</tr>
<tr>
<td>Emergency ascent</td>
<td>289</td>
<td></td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>Water movements</td>
<td>217</td>
<td></td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Gas supply problem</td>
<td>199</td>
<td></td>
<td>62</td>
<td>145</td>
</tr>
<tr>
<td>Equipment problem</td>
<td>109</td>
<td></td>
<td>6</td>
<td>56</td>
</tr>
<tr>
<td>Entrapment/Entanglement</td>
<td>75</td>
<td></td>
<td>61</td>
<td>68</td>
</tr>
<tr>
<td>Injury</td>
<td>40</td>
<td></td>
<td>38</td>
<td>26</td>
</tr>
<tr>
<td>Wrong gas</td>
<td>14</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Lost/separated</td>
<td>13</td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>N/A</td>
<td>574</td>
<td></td>
<td>381</td>
</tr>
</tbody>
</table>
Triggers (n=346)

- Insufficient air: 41%
- Entrapment: 60%
- Equipment trouble: 50%
- Rough water: 20%
- Trauma: 0%
- Bouyancy: 0%
- Inappropriate gas: 0%

Cumulative Frequency
Disabling Agents (n=332)

- Emergency ascent: 60%
- Insufficient air: 80%
- Buoyancy problem: 94%
- Inappropriate gas: 98%
- Equipment problem: 100%
Disabling Injuries (n=590)

Frequency of Disabling Injury

- Asphyxia: 33%
- Cardiac Incident: 62%
- 88% Cumulative
- Trauma: 93%
- DCS: 96%
- LOC: 98%
- Inappropriate Gas: 100%

Cumulative Disabling Injury
## Triggers by Disabling Injury

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Asphyxia</th>
<th>AGE</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient gas</td>
<td>32%</td>
<td>63%</td>
<td></td>
</tr>
<tr>
<td>Entrapment</td>
<td>40%</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>Equipment trouble</td>
<td>15%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>Rough water</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Disabling Agent by Disabling Injury

<table>
<thead>
<tr>
<th>Disabling Agent</th>
<th>Asphyxia</th>
<th>AGE</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency ascent</td>
<td>13%</td>
<td>97%</td>
<td></td>
</tr>
<tr>
<td>Insufficient gas</td>
<td>62%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buoyancy trouble</td>
<td>17%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough water</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Odds Ratios for Root Causes & Intrinsic Factors

<table>
<thead>
<tr>
<th></th>
<th>Asphyxia</th>
<th>AGE</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrapment</td>
<td>≥30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency ascent</td>
<td></td>
<td>≥30</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular Disease</td>
<td></td>
<td></td>
<td>≥30</td>
</tr>
<tr>
<td>Insufficient gas</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age &gt; 40 years</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Equipment trouble</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough water</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth &lt; 80 fsw</td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Cardiac Incidents (n=156)

- Body Mass Index
  - Cardiac incidents: 30.5 kg/m²
  - AGE: 28.7
  - Asphyxia: 27.8

- 60% of victims of cardiac incidents noted dyspnea, fatigue, distress, chest pain, or felt ill

- 56% had autopsy reports & usually evidence of CVD but not myocardial damage
Case Control Study: Risk Factors for Fatal & Non-Fatal AGE, 2005

• What factors influence the risk of death?
  – Demographic
  – Experience
  – Medical history
  – Dive profile
  – Dive conditions
  – Dive problems
Odds Ratio (OR) of non-fatal AGE for divers with buoyancy trouble

\[
\text{OR} = \frac{7/(127-7)}{69/(10,928-69)} = \frac{0.06}{0.0064} = 9.2
\]
AGE Findings

• ~12% of all injuries were fatal
• ~6% of non-fatal injuries were AGE
• Over half of all AGE were fatal
• Sex, CVD, diabetes & asthma not AGE risk factors
• Greater AGE risk for divers in 1st year of certification & on 1st dive of day
AGE Findings

• AGE risk decreases with experience
• Dive problems appear strong risk factors although diagnostic bias is a problem
  – Rapid ascent, gas supply, buoyancy
• Factors associated with AGE death
  – Higher risk: obesity, increasing age, use of helium, increasing maximum depth
  – Lower risk: healthy BMI
Pulmonary Barotrauma in Divers During Emergency Free Ascent Training: Review of 124 Cases
Pierre Lafèrè, Peter Germonpré, and Costantino Balestra

- Risk of PBT during training dives 100-400 x
- During ascent training dives 500-1500x
- Most Belgian sport diver federations have modified their ascent training protocols since 2006
  - Since then, no cases of PBT related to ascent training

Diabetes & Fatalities

• Review DAN Fatality Database 1992-2004

• Total 975 fatalities
  – 938 Non-DM (96.2%)
  – 37 with DM (3.8%)

• Variables: divers characteristic, accident scenario, disabling conditions

• Age and dive depth tested with t-test for independent samples

• Contrasts tested with Chi squared analysis
  • Significance accepted at p<0.05
## Adverse Events Preceding Deaths

<table>
<thead>
<tr>
<th>Condition</th>
<th>% of Decedents</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM</td>
<td>Non-DM</td>
</tr>
<tr>
<td>Cardiac</td>
<td>40.5</td>
<td>15.9</td>
</tr>
<tr>
<td>Unknown</td>
<td>27.0</td>
<td>37.8</td>
</tr>
<tr>
<td>AGE</td>
<td>10.8</td>
<td>17.9</td>
</tr>
<tr>
<td>Drowning</td>
<td>10.8</td>
<td>20.5</td>
</tr>
<tr>
<td>Unexplained LOC*</td>
<td>10.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Trauma</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>DCS</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>Wrong gas</td>
<td>0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*loss of consciousness
Mean Age
DAN Members and Fatalities

\[ y = 0.702x + 38.47 \]
\[ R^2 = 0.838 \]

\[ y = 0.3287x + 36.53 \]
\[ R^2 = 0.7475 \]
EDAN Insured Members
200,000 insured years, 141 deaths

Age | RR | 63,000 Females | 137,000 Males
--- | --- | --- | ---
<20 | | | 0.2-10 (NS)
20-29 | | | 0.6-12 (NS)
30-39 | RR 1.9-9.9 | | RR 0.6-3.6 (NS)
40-49 | | | 1.9-9.9
50-59 | | | 0.6-3.6
60+ | RR 0.2-10 (NS) | | 0.6-12 (NS)
### Age & Cause Specific Relative Risk

<table>
<thead>
<tr>
<th>Disabling Injury</th>
<th>&lt;50 years n=788,489</th>
<th>≥50 years n=352,878</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac</td>
<td>5*</td>
<td>29</td>
<td>12.9</td>
</tr>
<tr>
<td>AGE</td>
<td>8</td>
<td>14</td>
<td>3.9</td>
</tr>
<tr>
<td>Asphyxia</td>
<td>15</td>
<td>17</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>50</strong></td>
<td><strong>79</strong></td>
<td><strong>3.5</strong></td>
</tr>
</tbody>
</table>

* Number of deaths
Conclusions

• Death while diving by insured DAN members occurs at a rate of 1 in 6000 divers per year.

• Most common causes are gas supply problems, emergency ascent, cardiac health issues, entrapment/entanglement, and buoyancy issues.

• Risk of death while diving increases with age.