Physics & Physiology of Diving
Assessment Fitness to Dive
Rotorua June 2009

Andrew G Veale
Diving Fitness

- No-one is fit to dive!
Diving Fitness

- Everyone can be helped to dive!
Diving Fitness

- No-one is fit to dive!

- What is our role?
  - Assess the risks of diving in this individual
  - Advise methods by which these risks might be minimised
  - Assist the intending diver to reach an informed decision with regards to their risks
  - Assist the intending diver make a risk benefit choice
  - Monitor likely risks which change over time
  - Notify the coroner
  - Comfort the living
A Retrospective Analysis of Diving-related Deaths in New Zealand 2000-2006

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NZ Respiratory & Sleep Institute
Diving Fatalities

- Diving-related deaths are rare

- 5-10 deaths per year (5%) of the total number of drowning deaths in NZ

- 1980 to 2000 estimated scuba death rate 5.8 per 100,000 per year

(Davis, Warner & Ward – SPUMS 2002)
Diving Fatalities 2000-2006

- **40 SCUBA divers**
  - Mean age 39.6 years, range 21 to 69 years
  - 5 were female
  - 75% Caucasian, 17.5% Maori

- **16 breath-hold divers**
  - Mean age 42.9 years, range 18 to 78 years
  - All male
  - 53% Maori
SCUBA divers

- **Certification**
  - 31 certified
  - 6 of unknown certification
  - 3 never certified

- **Experience**
  - 21 (52.5%) were inexperienced (< 2 years)
SCUBA divers

- 11 solo divers
- 13 buddy separation
- At least 3 divers had run out of air
- 4 divers were over weighted
- Only 1 diver had released his weight belt
<table>
<thead>
<tr>
<th>AGE/SEX</th>
<th>MEDICAL CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>29M</td>
<td>Old Tb, pleural adhesions</td>
</tr>
<tr>
<td>58F</td>
<td>Unexplained syncope, chest pains</td>
</tr>
<tr>
<td>47M</td>
<td>Massive CVA; 2 years TIA’s, uncontrolled HT</td>
</tr>
<tr>
<td>68M</td>
<td>Coronary artery disease (CAD), DM type 2</td>
</tr>
<tr>
<td>34M</td>
<td>Myocarditis, cardiomegaly, CAD, BMI=33</td>
</tr>
<tr>
<td>69M</td>
<td>CAD</td>
</tr>
<tr>
<td>30M</td>
<td>Crohn’s disease – immunosuppressive meds</td>
</tr>
<tr>
<td>34M</td>
<td>Severe symptomatic CAD, pulmonary oedema</td>
</tr>
<tr>
<td>41M</td>
<td>CAD (no dive medical)</td>
</tr>
<tr>
<td>53F</td>
<td>Migraine meds (gastric rupture)</td>
</tr>
<tr>
<td>55M</td>
<td>Symptomatic CAD</td>
</tr>
<tr>
<td>53M</td>
<td>Pleural adhesions, PFO</td>
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</tbody>
</table>
Causes of Death

- Gas embolism – 9 deaths
- Adverse sea conditions
- CO poisoning – 1 death
- Head injury from boat
  - 2 deaths (1 breath hold)
- Trauma – hit by a whale tail
Introduction

- History
- Transition from air to water
- Diving Environment
- Physics of depth
- Physiology of Depth (Pressure)
- How Humans (try) and cope
- How Marine Mammals do
History

- Food (diving Ama)
- Salvage
- Construction (Caissons)
- Military
- Sport diving
- Scientific diving
Diving Ama
Bell diving – 1720
Auckland Harbour Bridge 1958
Military
Sport Diving
Environmental Factors

- **Self Contained Underwater Breathing Apparatus (SCUBA)**
  - Equipment heavy and awkward
  - Bottled gases (gas toxicities & contamination with CO, Diesel)
  - Runs out!!

- Wet
- Cold
- Unstable
- Distant from help
- Specialist help
Transitions

- Thermal
- Noise
- Light
- Density of the medium
Temperature

- Non-immersion 28°C
- Submersion
  - 15°C
  - 20°C
  - 35°C

Subject J.R.

Breath-Holding Time (sec) vs. Breath-Hold Number

Combined Heat Transfer Coefficient (W m⁻² °C⁻¹)

- Air: 2
- Still water: 44
- Stirred water: 64
- Swimming 0.5 m/s: 400

NZ Respiratory & Sleep Institute
Physics

- **Pressure (1 Bar, 2 ATA, 10msw, 33fsw, 34ffw)**
  - Boyle's Law: \( P \times V = K \)
  - If pressure doubles volume must halve

- **Solubility**
  - Henry's Law: \( Q = k \times P_{gas} \)
    - If pressure doubles then dissolved gas doubles (over a time)
    - Diffusion into tissue depends on solubility in that tissue and perfusion

- **Gas Density**
  - If pressure doubles gas density doubles
  - Gas movement will become turbulent rather than laminar

- **Pascal's Principle**
  - Pressure is transmitted through incompressible liquid
Immersion

- Gravity reversed
- Dead space
- FVC decreased
- Compliance reduced
- 30% increased CO
- Bradycardia
- Vasoconstriction increased SVR and BP
- Diuresis
Hypertension
### Boyles Law

<table>
<thead>
<tr>
<th>Depth Meters</th>
<th>ATA</th>
<th>Volume</th>
<th>Volume</th>
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<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>1/2</td>
<td>500</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>1/3</td>
<td>333</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
<td>1/4</td>
<td>250</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>1/5</td>
<td>200</td>
</tr>
</tbody>
</table>
The Ear

- Ear squeeze
- Tympanic membrane
- Middle ear
- Round window
- Labyrinth
The Lung - free diving

- Compresses with depth to RV
- Becomes stiffer and less compliant
- Engorges with blood
- Fills with fluid
Exercise

- **Hardwork**
  - due to fluid density
  - Equipment
  - Poor technique
  - Poor training

- **Work of breathing**
  - Regulator resistance
  - Increased deadspace (increased Vd/Vt)
  - Decreased chest wall compliance due to wetsuit
  - Increased gas density
  - Increased turbulent flow
  - Decreased compliance (blood and fluid)
Swimming Work

![Graph showing the relationship between oxygen consumption (ml/kg/ml) and speed (knots). The graph indicates an increase in oxygen consumption as speed increases.]
Diver technique
The Lung - SCUBA

- Increased density increases WOB
- VCO2 increases as VO2 increases
- Increased resistance (equipment and wetsuit)
- The reduction in FRC may increase CV
- MVV falls
- VE CO2 falls
- Reduced response to rising CO2
- Different time constants
- Differential compliance
Barotrauma
Decreased ventilation with increased depth
Case 1

- 38 year old experienced diver instructor
  - Mitral regurgitation due to MVPS
  - Past history of hayfever and asthma
Case 2

- 30 year old experienced scientific diver
  - Past hayfever and asthma
Case 4

- 33 year old intending diver
- with past hyperthyroidism
Case 5

- 55 year old intending diver
  - Well
Case 6

- 55 year old diver
- CAVG 4 mths ago
Case 7

- 40 year old intending diver
  - Hypertension
Case 8

- 25 year old intending diver
  - Doing a course with 3 flatmates
  - Last to submerge
  - First to ascend
  - Ascends with half the air of others in his group
Summary 1

- Will the condition increase risk of a diving related injury
- Will treatment of the condition increase diving injury risk
- Could diving make an existing condition worse
- Is the consequence of the medical condition serious
- Could the condition make diagnosis retrieval/treatment of a diving injury more difficult
Summary II

- GP best to determine normality
- Diving trained doctor best to determine diving relevance of a condition
- Specialist best to evaluate severity and correctability of a medical condition
- Individual is best to determine if the risk is worth it