Exercise-based cardiac rehabilitation for people with ventricular assist devices:

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Chronic Heart Failure (CHF): inability of the heart to generate sufficient cardiac output to meet the metabolic demands of the body.
Natural history of heart failure

What is a Left Ventricular Assist Device (VAD)?

Electromechanical pump implanted into the LV to augment cardiac output (CO).

- a. Heartmate II/III
- b. Heartware HVAD
LVAD implantation rates are increasing.

Number of patients implanted with VADs in the U.S

- Number of patients: 206, 345, 725, 944, 1451, 2506

Birks et al., 2011
LVADs are implanted as:
- Bridge to transplant (or eligibility)
- Bridge to recovery
- Destination therapy

LVAD implantation is associated with improved:
- Survival
- Quality of life (QoL)
- Exercise tolerance

Maybaum et al., 2007; Rogers et al., 2010
### Effects of LVAD implantation on aerobic capacity

<table>
<thead>
<tr>
<th></th>
<th>Pre-VAD (n = 46)</th>
<th>6 mths Post-VAD (n =30)</th>
<th>12 mths Post-VAD (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak VO$_2$, mL/kg/min</td>
<td>9.9±2.1</td>
<td>14.3±5.1</td>
<td>14.6±4.6</td>
</tr>
<tr>
<td>Percentage of predicted peak VO$_2$</td>
<td>32.3±7.4</td>
<td>41.4±12.7</td>
<td>42.0±15.0</td>
</tr>
<tr>
<td>VO$_2$ at AT mL/kg/min</td>
<td>8.2±1.1</td>
<td>9.9±2.6</td>
<td>10.3±2.2</td>
</tr>
</tbody>
</table>

- **Factors limiting aerobic capacity in LVADs**
  - right ventricular dysfunction
  - inability to increase cardiac output (CO) during exercise
  - peripheral maladaptations associated with HF(skeletal myopathy, endothelial dysfunction)

Structured rehabilitation
**Current exercise training trial**

- RCT of moderate intensity continuous exercise vs. high intensity interval training (HIIT).
- MICT - continuous aerobic exercise at 50 to 60% VO$_2$ reserve for 28 minutes
- HIIT - 4 sets of 4 minutes of aerobic exercise at 80 to 90% of VO$_2$ reserve, interspersed with 3 minutes of active recovery at 50 to 60% of VO$_2$ reserve
- Primary outcome measure: VO$_2$peak
Progressive resistance training
Buffing up for transplant
Physical activity energy expenditure

VAD: 19.7 ± 6 kJ/kg/d, vs. CHF: 11.6 ± 7 kJ/kg/d; p=0.01
## Physical activity duration at different intensities

<table>
<thead>
<tr>
<th>Physical activity intensity (METs)</th>
<th>VAD group (min/day)</th>
<th>CHF group (min/day)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary (&lt; 1.5)</td>
<td>1275 ± 99</td>
<td>1339 ± 75</td>
<td>0.048*</td>
</tr>
<tr>
<td>Light (1.5 - 3)</td>
<td>133 ± 43</td>
<td>89 ± 32</td>
<td>0.101</td>
</tr>
<tr>
<td>Moderate (3 - 6)</td>
<td>31 ± 22</td>
<td>12 ± 17</td>
<td>0.012*</td>
</tr>
</tbody>
</table>
Relationship between physical activity energy expenditure and peak VO$_2$ in VAD and CHF patients.

Correlation coefficient: $r_s = 0.523$, $p=0.01$
Restoring quality of life
Evaluating myocardial recovery

- Exercise right heart catheter study pre-LVAD explantation.
## Results

Metabolic and cardiovascular responses during peak CPET at 2400 rpm and 1800 rpm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2400 rpm</th>
<th>1800 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak $\dot{V}O_2$ (ml/kg/min)</td>
<td>23.2 (59% predicted)</td>
<td>22.8 (58% predicted)</td>
</tr>
<tr>
<td>$\dot{V}_E/\dot{V}CO_2$ slope</td>
<td>22.3</td>
<td>24</td>
</tr>
<tr>
<td>Duration (min)</td>
<td>16:00</td>
<td>16:40</td>
</tr>
<tr>
<td>HR max. (bpm)</td>
<td>144</td>
<td>148</td>
</tr>
<tr>
<td>BP max (mmHg)</td>
<td>145/85</td>
<td>145/80</td>
</tr>
<tr>
<td>Rating of exertion</td>
<td>very hard</td>
<td>very hard</td>
</tr>
</tbody>
</table>

LVAD Explantation
Patient assessments

Review at 3/12

- NYHA class I
- No hospital readmissions
- Return to work
- Preserved LV function
- Excellent exercise tolerance
- Completed City to Surf!!

Patient-assessments
Acknowledgements:

- Advanced Heart Failure and Cardiac Transplant Service, FSH.
- Cardiovascular Rehabilitation team, FSH.
- The patients!
## Results

Haemodynamic and echo. responses at rest and during submaximal exercise* at 2400rpm and 1800rpm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rest 2400rpm</th>
<th>Rest 1800rpm</th>
<th>Exercise* 1800rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI (L/min/m²)</td>
<td>4.4</td>
<td>4.0</td>
<td>4.9</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>83</td>
<td>88</td>
<td>132</td>
</tr>
<tr>
<td>LVEDD (cm)</td>
<td>4.8</td>
<td>5.0</td>
<td>4.7</td>
</tr>
<tr>
<td>LVESD (cm)</td>
<td>3.5</td>
<td>3.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

* Submaximal exercise = 60% peak VO₂

No signs/symptoms of cardiac compromise at rest or during exercise with pump speed at 1800rpm.

Central haemodynamics of LVADs

RV function → Preload ← Heart rate

Contractility → Afterload

Native$_{CO}$ ← LVAD$_{flow}$ ← Total$_{CO}$

Speed
Assumptions

- Revisit Fick Equation

- Reducing LVAD speed creates resistance to flow (confirmed on echo at 2000rpm)
  \[\text{blood flow from the LV will take the path of least resistance via the aorta}\]

- Impaired skeletal muscle oxidative capacity is evident in HF (Drexler et al. Ann Rev. Med 1996;47:241)
  \[\text{LVAD patients unlikely to be able to compensate for reduced } O_2 \text{ delivery by increasing } O_2 \text{ utilisation}\]
Exercise training in LVAD recipients

- Supervised exercise, 3 x per week 6 weeks.
- 30 minutes treadmill walking
- 60% HRR

Within-group improvement of 10%, but no significant differences between groups.

Kerrigan et al., 2015.

* FIGURE 2 Peak VO$_2$ for Subjects in Both the CR and Usual Care Groups
Background

- LVAD implantation is associated with improved:
  - Survival
  - Quality of life (QoL)
  - Exercise tolerance

  Maybaum et al., 2007; Rogers et al., 2010

- Despite these improvements, physical impairment persists with:
  - Exercise capacity <50% of predicted values
  - Lagging behind heart-transplanted patients

  Kugler et al., 2011; Leibner et al., 2014; Dunlay et al., 2014
Studies that assessed the effects of exercise training in VADs recipients

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Study Design</th>
<th>Sample Size</th>
<th>Exercise Program</th>
<th>Change in $\dot{V}O_2$ in Training Patients</th>
<th>Change in Match $\dot{V}O_2$ in Control Patients</th>
<th>$P$ Between the 2 Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laoutaris et al$^{[1]}$ (2011)</td>
<td>RCT</td>
<td>15 (10 TG vs 5 CG)</td>
<td>Walk, moderate-intensity aerobic exercise using a bike or treadmill, and high-intensity inspiratory muscle training</td>
<td>Peak $\dot{V}O_2$, mean ± SD (mL·kg$^{-1}$·min$^{-1}$) increased from 16.8 ± 3.7 to 19.3 ± 4.5 ($P = .008$)</td>
<td>Peak $\dot{V}O_2$, mean ± SD (mL·kg$^{-1}$·min$^{-1}$) increased from 14.9 ± 4 to 14.8 ± 4.2 ($P = .5$)</td>
<td>.1</td>
</tr>
<tr>
<td>Kugler et al$^{[2]}$ (2012)</td>
<td>Nonrandomized intervention study</td>
<td>70 (34 intervention vs 36 control)</td>
<td>Patients were equipped with bicycle ergometer and tailored, home-based, smartcard-guided training program</td>
<td>$\dot{V}O_2_{\text{max}}$ (% pred) increased from 61 to 69 ($P = .05$)</td>
<td>$\dot{V}O_2_{\text{max}}$ (% pred) increased from 59 to 62 ($P = .21$)</td>
<td>.05</td>
</tr>
<tr>
<td>Hayes et al$^{[3]}$ (2012)</td>
<td>Prospective, RCT</td>
<td>14 (7 TG vs 7 CG)</td>
<td>Cycling, treadmill, and upper and lower limb strengthening exercises</td>
<td>Peak $\dot{V}O_2$, mean ± SD (mL·kg$^{-1}$·min$^{-1}$) increased from 10.5 ± 2.3 to 14.8 ± 4.9</td>
<td>Peak $\dot{V}O_2$, mean ± SD (mL·kg$^{-1}$·min$^{-1}$) increased from 12.4 ± 1.7 to 15.3 ± 4.4</td>
<td>.43</td>
</tr>
</tbody>
</table>

Abbreviations: CG, control group; IVAD, left ventricular assist device; RCT, randomized controlled trial; $\dot{V}O_2_{\text{max}}$, maximum oxygen uptake; TG, training group.

Alsara et al., 2014
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Types of LVADs

- **Pulsatile flow**
  - neumatically/electrically driven ‘ventricle’ that fill/empties mode.
  - CO during exercise increases as a function of preload and pump rate.
  - max. CO of >10 L/min

- **Continuous flow**
  - operate at a fix speed (HW – 2600rpm, HM II – 8600rpm)
  - flow influenced by pressure differential between inflow and outflow cannula.
  - CO of approximately 8.5L/min