Forward Looking Statement

This presentation contains forward-looking statements. All forward looking statements are management’s (Dave Rosa) present expectations of future events and are subject to a number of risks and uncertainties. Various factors (collecting more data) could cause actual results to differ materially from these statements...
Hemodynamics of C-Pulse: Kangaroos, Waves and Reflexes

www.sunshineheart.com
Simple Model of Cardiovascular System

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Principles of Counterpulsation

- Reduce Afterload
- Augment Diastolic Pressure → Increase Coronary Perfusion
- Secondary pulsatile heart
Counterpulsation Mechanism Based On Physiologic Hemodynamics of Wave Reflections

GOAL: Stabilize/reverse myocardial function and re-sensitize system to HF meds

Supports the failing heart – it is not a flow source. It optimizes hemodynamic conditions for ventricular ejection and myocardial perfusion.

GOAL: Stabilize/reverse myocardial function and re-sensitize system to HF meds
The Aorta

II. Peripheral Amplification of Pulse Wave

III. Summated Forward & Reflected Waves in the setting of a stiff aorta
Ascending Aorta: Key Predictor of Outcomes

Aortic Root Remodeling and Risk of Heart Failure in the Framingham Heart Study

Carolyn S. P. Lam, MBBS†‡, Philimon Gona, PhD†‡, Martin G. Larson, ScD§, Jayashri Aragam, MD¶, Douglas S. Lee, MD, PhD¶, Gary F. Mitchell, MD¶, Daniel Levy, MD¶,*, Susan Cheng, MD††, Emelia J. Benjamin, MD, ScM‡†, and Ramachandran S. Vasan, MD

Proximal aortic distensibility is an independent predictor of all-cause mortality and incident CV events: the MESA study.


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C-Pulse Design: Unique Placement on Ascending Aorta

- Proximal Aorta 70% of compliance in Arterial System

PROXIMITY TO AORTIC VALVE AND UNIDIRECTIONALITY AS PRIME FACTORS IN COUNTERPULSATION EFFECTIVENESS

S. Furman, R Whitman, J. Stewar, B. Parker, and M. McMullen

An aortic occlusive balloon of small volume distal to the volume displacing balloon projected virtually the total displacement toward the heart and increased arch and coronary blood flow.

C-Pulse Counterpulsation: Clinical Examples

Video 1

Video 2

Videos seen in presentation online courtesy of Dr. Daniel Bujnoch; Department of Cardiac Surgery, University of Erlangen, Germany
## Right Heart Catheterization 4-Months

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OFF</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate (bpm) (Paced)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>PA Pressure (Systolic/Diastolic) mmHg</td>
<td>62/25</td>
<td>51/19</td>
</tr>
<tr>
<td>CVP (mmHg)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>PCWP (mmHg)</td>
<td>19</td>
<td>8-10</td>
</tr>
<tr>
<td>Cardiac Output (L/min) Thermodilution</td>
<td>2.7</td>
<td>3.4</td>
</tr>
<tr>
<td>O₂ Saturation (%)</td>
<td>45.2</td>
<td>49.8</td>
</tr>
</tbody>
</table>

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Effects of Increased Load on Left Ventricle

- Wasted energy ($W_E$) and Tension-Time Index (TTI), Augmentation Index (Aix) are elevated in HF
- Key determinants of myocardial oxygen consumption
- Reduce stroke volume
- Increase wall stress
- Diastolic dysfunction

$$Aix = \frac{P_s - P_i}{P_s - P_d}$$
Pulsatile Load Increased in CHF


Milnor, WR. Arterial Afterload. In Busse; Arterial System 1978
Central Hemodynamics and C-Pulse

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Hemodynamic Effects of Unloading with C-Pulse

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Wall Stress and Shortening Velocity

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C-Pulse Reduces Wall Stress and Increases Shortening Velocity

Legend:
- Baseline
- 1:1

Graphs showing:
- (S) Wall Stress vs. VCFC (cycles/min)
- Mean Wall Stress Reduction

- Wall Stress (x10^3 dynes.cm⁻²)
- Baseline: 153
- 1:1 Counterpulsation: 99
- p=0.022

n = 6

Leggett et al. 112:1-26. 2005

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• The heart is especially **vulnerable** to ischemia, because its \(O_2\) extraction ratio is 65% (vs. average of 25% for rest of body)

• Because the heart is near maximal \(O_2\) extraction more \(O_2\) during increased demand, primarily accomplished by **increasing blood flow**

• Myocardial wall stress best correlate of \(MVO_2\)
Boost Diastolic Pressure: Reservoir for Coronaries to Fill

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C-Pulse Effect on Coronary Hemodynamics in Normal Swine

Coronary Flow (mL/min)

**OFF**

**C-Pulse**

Backward waves from descending less efficiently propagated to aortic root

Mynard et al. J. Hypert. 33:2015

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Wave Intensity Analysis of Coronary Flow: Reservoir for Coronary Suction from the Aorta

Davies et al. Circ. 113:1768. 2006
Cardiac Function in OPTIONS HF

**Ejection Fraction**

- **Baseline (N=11)**
- **Month 6 (N=8)**

**End Systolic Volume**

- **Baseline (N=11)**
- **Month 6 (N=8)**
Feasibility Study: Improved Filling Pressures and Diastolic Function

Sunshine Heart data on file

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Rat Heart

Courtesy of: Dr. Frits Meijler

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Counterpulsation Timed to Most Sensitive Phases of Cardiac Cycle for Baroreceptor Stimulation

Peterson, LH. Circ. 21:1960
Large Unloading Effects Partly Due to Neural Reflexes from the Aortic Arch?

American Journal of Physiology
Vol. 221, No. 3, September 1971. Printed in U.S.A.

Direct and reflex vascular effects of intra-aortic balloon counterpulsation in dogs

C-Pulse balloon placement even more optimal location to activate reflexes
Sympathetic Outflow from the Brain

It is axiomatic that the heart can pump as much blood as it receives.

Carl Wiggers

REGULATION OF CARDIAC OUTPUT

Arthur C. Guyton, M.D.
Jackson, Mississippi

Most physicians are surprised to learn that the heart has relatively little effect on the normal regulation of cardiac output, but all the physician has to do is to look at his patients, and he will see...


NEJM:277. 1967

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Systemic Effects of Sympathetic Activation

Black, HR. Braunwald’s Hypertension; 2012.

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Technique to Measure Sympathetic Nerve Activity

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Individual and mean muscle sympathetic nerve activity (MSNA) burst frequencies in healthy controls and patients with pulsatile and nonpulsatile left ventricular assist devices in the supine position and during upright tilt.

Markham D W et al. Circ Heart Fail. 2013;6:293-299
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LVADs Do Not Normalize Circulation or Regulation of Cardiac Output

Brasard et al. Circ. Heart. Fail. 4:554. 2011

Cornwell et al. ISHLT 2015

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Arterial Baroreceptor Denervation and Volume Management

<table>
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<tr>
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<th>Control MAP 103.9±5.8</th>
<th>SAD MAP 104.7±6.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD of AP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mmHg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAD ( - )</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>( + )</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>SD of LAP</td>
<td>(mmHg)</td>
<td></td>
</tr>
<tr>
<td>SAD ( - )</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>( + )</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Period of high LAP ( &gt;18mmHg )</td>
<td>(sec)</td>
<td></td>
</tr>
<tr>
<td>SAD ( - )</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>( + )</td>
<td>1500</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1: Sinoaortic denervation (SAD) induces the increase of SD in AP and LAP, and the elevation of LAP. Funakoshi K et al. J.Card. Fail. 20(1); 2014

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C-Pulse and Volume Management

C-Pulse Therapy Patient with Cardiomems

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C-Pulse Effects on Renal Blood Flow

Normal Swine

Renal Artery Flow (mL/min)

Time

Diastolic Augmentation

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Baroreceptor Stimulation Effects on Renal Artery Flow

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C-Pulse Therapy Goal

**Supports the failing heart – it is not a flow source. It optimizes hemodynamic conditions for ventricular ejection and myocardial perfusion.**

**GOAL:** Stabilize myocardial function and circulatory homeostasis and re-sensitize system to HF meds
Pressure-dimension Loops Before (Control) and After Milrinone (Mil)

Increase in Cardiac Output only at expense of increases MVO2

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Thank you!

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