The “Thoracic Pump” Impetus for the Respiratory Arterial Pressure Wave and Breathing Induced Heart Rate Variability

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The Thoracic Pump

Breathing Induced Heart Rate Variability:

“Variation in heart rate as a consequence of respiration.”

Heart Rate Variability:

“Variation in heart rate for any reason.”

We also know this as “Respiratory Sinus Arrhythmia” or “RSA”.
The phenomenon of RSA:

“Heart rate tends to increase with inhalation and decrease with exhalation in a sinusoidal fashion.”
Why?

- For nearly 100 years the answer has been that heart rate changes in response to changes in blood flow and pressure as a consequence of respiration.

- This understanding is fundamentally sound. But we don’t know much about it.

- Most of our understanding regarding respiration has to do with “air” and “gas exchange”, not blood.

- So, let’s look at blood flow and pressure as a function of respiration.
The Thoracic Cavity

A **sealed** chamber bounded on 3 sides by the rib cage and the diaphragm at the bottom.

Reprinted with permission.
radiograph of chest
© rvelde, Fotolia.com
The Thoracic Cavity

The heart and lungs reside inside.

Heart and lungs reprinted with permission: menschliche organe © Sebastian Kaulitzki Fotolia.com
Pressure in the thoracic cavity varies with diaphragm position which can vary by up to 10 cm.
Boyle’s Law: The absolute pressure and volume of a gas are inversely proportional:

- As volume increases, pressure decreases
- As volume decreases, pressure increases
The thoracic cavity anatomy is simplified for purposes of illustration.

Pulmonary circulation holds ~450 ml of blood at atmospheric pressure. (Diaphragm is in a neutral position.)

However, it can hold as much as ~900 ml and as little as ~200 ml. How much it holds is a function of thoracic pressure.

The pulmonary circulation has a compliance equal to that of the entire arterial tree.

Thoracic pressure is a function of diaphragm position.
Pulmonary Blood Volume

Very complete exhalation

Very complete inhalation
What Does The Wave Look Like?

Red = Blood

• thoracic pump + vascular action + heart beat

• heart beat

Respiratory Component

As measured at the ear lobe
Individual pulses

Large slow wave is respiration induced

Exhalation

Inhalation

Radial artery

Red = Blood

Measured at the radial artery
Measured At The Medial Cubital Vein

Red = Blood

Exhalation

Inhalation

Exhalation

Inhalation
Inhalation
Exhalation
Inhalation
Exhalation
Inhalation

Red = Blood

Measured At The Thumb
the pulses (individual heart beats)

exhalation

inhalation

Red = Blood
Blood Flow

So, if we observe blood flow in the Vena Cava during respiration what will we see?

And, if we observe blood flow in the Aorta during respiration what will we see?

anatomy is simplified for purposes of illustration
And Heart Rate?

anatomy is simplified for purposes of illustration

And heart rate...
During inhalation?
During exhalation?
Heart Rate

Why?

The simple answer....

1. When this much blood (the extreme case) flows into the aorta all at once, if heart rate did not decrease, blood pressure would rise too much.

2. When the lungs are storing this much blood, if heart rate did not increase, blood pressure would fall too much.
This supports the theory that “breathing induced HRV” is an outcome of autonomic nervous system regulation of blood flow and pressure.

[Consistent with the prevailing understanding of Respiratory Sinus Arrhythmia.]

If this is so, we can expect to see that changes in blood flow and pressure precede changes in heart rate....

And if we look, this is what we see...
If We Look...

We see that changes in the blood wave lead changes in heart rate (at near resonance).
The End
Thank You!
A 10X Relationship?

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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</thead>
<tbody>
<tr>
<td><strong>Physiologic Phenomenon</strong></td>
<td>Typical &quot;Shallow&quot; Breathing (10% of VC)</td>
<td>Deep Synchronous Breathing (75% of VC)</td>
<td>Vital Capacity (4.5L) (75% of total lung capacity)</td>
</tr>
<tr>
<td><strong>Diaphragmatic Movement (Range)</strong></td>
<td>1 cm (10%)</td>
<td>7.5 cm (75%)</td>
<td>10 cm (100%)</td>
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<tr>
<td></td>
<td>Source: Pulmonary Physiology, p. 15</td>
<td>Estimated</td>
<td>Estimated (Can be much higher during forced inspiration)</td>
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<tr>
<td><strong>Intrapleural Pressure (Range)</strong></td>
<td>2.5 cmH₂O (8%)</td>
<td>25 cmH₂O (75%)</td>
<td>33 cmH₂O (100%)</td>
</tr>
<tr>
<td></td>
<td>(-5 to -7.5 mmH₂O)</td>
<td>Estimated</td>
<td>Estimated (Can be much higher during forced inspiration)</td>
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<tr>
<td><strong>Inspiratory/Expiratory Volume</strong></td>
<td>.5 L (Tidal volume of typical adult -11% of VC)</td>
<td>3.4 L (75% of VC)</td>
<td>4.5 L (Vital Capacity)</td>
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<td></td>
<td>Source: Pulmonary Physiology, p. 55</td>
<td></td>
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<tr>
<td><strong>Respiratory Arterial Pressure Wave Magnitude</strong></td>
<td>2 mmHg (8%)</td>
<td>20 mmHg (75%)</td>
<td>~27 mmHg (100%)</td>
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<tr>
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<td>Source: Medical Physiology, p. 193</td>
<td>Source: Medical Physiology, p. 193; Measured by Elliott</td>
<td>Estimated</td>
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<tr>
<td><strong>Heart Rate Variability Amplitude</strong></td>
<td>5.3 beats (10%)</td>
<td>40 beats (75%)</td>
<td>~53 beats (100%)</td>
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<tr>
<td></td>
<td>(Source: Measured by Elliott)</td>
<td>Source: Measured by Elliott</td>
<td>Measured by Elliott (60 beat HRVs have been witnessed by others)</td>
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