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

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AND RESEARCH

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Heart Rate Variability: 
“Variation in heart rate for any reason.”

Breathing Induced Heart Rate Variability: 
“Variation in heart rate as a consequence of respiration.”

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.”
Respiratory Sinus Arrhythmia

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.
The Thoracic Cavity

The heart and lungs reside inside.
Pressure in the thoracic cavity varies with diaphragm position which can vary by up to 10 cm.
Boyle’s Law: Absolute pressure and volume of a gas are inversely proportional:

- As volume increases, pressure decreases
- As volume decreases, pressure increases

The Thoracic Cavity

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

However it can hold as much as ~900 ml and as little as ~200ml.

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

How much it holds is a function of thoracic pressure.

Thoracic pressure is a function of diaphragm position.

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

How much it holds is a function of thoracic pressure.

Thoracic pressure is a function of diaphragm position.

Pulmonary capillary bed
Pulmonary Blood Volume

Very complete exhalation

Very complete inhalation

200 ml

900 ml
What Does The Wave Look Like?

- Red = Blood
- Respiratory Component

As measured at the ear lobe
individual pulses
large slow wave is respiration induced
exhalation
inhalation
radial artery

Red = Blood
Red = Blood

inhalation

exhalation

inhalation

exhalation

inhalation

exhalation

Measured At The Medial Cubital Vein
Inhalation

Exhalation

Inhalation

Exhalation

Red = Blood

Measured At The Thumb
Temple
(Vicinity of Temporal Artery)

Red = Blood
Ear Lobe

the pulses (individual heart beats)

exhalation

Red = Blood
Blood Flow anatomy is simplified for purposes of illustration.

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?
And Heart Rate?

anatomy is simplified for purposes of illustration
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...
We see that changes in the blood wave lead changes in heart rate (at near resonance).
The End

Thank You!
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<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>
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<tr>
<td><strong>Diaphragmatic Movement</strong></td>
<td>1 cm (10%) Source: Pulmonary Physiology, p. 15</td>
<td>7.5 cm (75%) Estimated</td>
<td>10 cm (100%) Source: Pulmonary Physiology, p. 15</td>
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<tr>
<td><strong>Intrathoracic Pressure (Range)</strong></td>
<td>2.5 cmH₂O (8%) Source: Medical Physiology, p. 433</td>
<td>25 cmH₂O (75%) Estimated</td>
<td>33 cmH₂O (100%) 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) Source: Pulmonary Physiology, p. 55</td>
<td>3.4 L (75% of VC)</td>
<td>4.5 L (Vital Capacity) Source: Pulmonary Physiology, p. 55</td>
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<tr>
<td><strong>Respiratory Arterial Pressure Wave Magnitude</strong></td>
<td>2 mmHg (8%) Source: Medical Physiology, p. 193</td>
<td>20 mmHg (75%) Source: Medical Physiology, p. 193; Measured by Elliott</td>
<td>~27 mmHg (100%) Estimated</td>
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<tr>
<td><strong>Heart Rate Variability Amplitude</strong></td>
<td>5.3 beats (10%) (Source: Measured by Elliott)</td>
<td>40 beats (75%) (Source: Measured by Elliott)</td>
<td>~53 beats (100%) Measured by Elliott (60 beat HRVs have been witnessed by others)</td>
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