Photoplethysmography: beyond the calculation of SpO2 and pulse rate

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I am NOT a “consultant” to industry
I am NOT a member of a “speaker bureau”
I do NOT receive funds from industry (research or otherwise)
A bit like a virgin...
• Full of virtue but have a hard time getting dates on Saturday night.
Who I am?

" MD with boards in Internal Medicine & Anesthesiology
" PhD in biochemistry with extensive training in data analysis
" Close to 20 years experience in pulse oximeter waveform research
" Chief of Ambulatory Surgery at Yale
Plethysmograph

How does it work?

Starting Point...

LED

LED

PD

Final Product...

A Volume Signal!

Photoelectric Plethysmograph

What is it?

"By-product of oxygen saturation determination"

"940 nm - Infrared"

"no calibration procedure"

Beer’s Law of Light

\[ A_{total} = E_1 C_1 L_1 + E_2 C_2 L_2 + \ldots E_n C_n L_n \]

- \( A_{total} \) = absorption at a given wavelength
- \( E_n \) = extinction coefficient (absorbency)
- \( C_n \) = concentration (need to know)
- \( L_n \) = path length

Plethysmographic Features

Method of Analysis

"Rhythm"

"Amplitude"

"Waveform Morphology"

"Advanced Techniques"
Rhythm Analysis

- Underutilized ability
  - used in combination with the EKG

- “Poor man’s” arterial line
  - compensatory pause
  - Sensitive to irregular heart rhythm
    - Atrial fib
    - PVCs, PACs

PVC's

Time (seconds)

Pleth

BP

EKG
Ventricular Tachycardia

Time (seconds)

Pleth
BP
ECG
Ventricular Fibrillation

Time (seconds)

Pleth

BP

EKG

Defib

Defib
Amplitude Analysis

- Need to turn off auto-gain
  - No calibration possible (yet)
- Vascular tone (site dependant)
  - Increased amplitude due to vasodilatation
    - Pharmacological – nitroprusside
    - Physiologic – warming, sedation
    - Anesthetic – regional blocks (spinal & epidural)
  - Decreased amplitude due to vasoconstriction
    - Pharmacological – phenylephrine, ephedrine
    - Physiologic – cold, surgical stress

Incision

BP (mm Hg)

Time (seconds)

Pleth

Incision
Nipride Effect

BP (mmHg) vs Time (seconds)

Pleth

Nipride started
Phenylephrine Effect

BP (mmHg)

Time (seconds)

Phenylephrine 160 mcg

Pleth
Phenylephrine effects on pulse oximetry waveform

56 y.o. female undergoing cervical discetomy.

Entire Pulse oximeter vs. A-line

Prior to Phenylephrine

Half-way point

Full Effect of Drug

Different Responses of Ear and Finger Pulse Oximeter Wave Form to Cold Pressor Test  
Anesth Analg 2001;92:1483-6

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Waveform Analysis

- Venous pulse\(^1\)
  - untapped source of information
  - \textit{Primary source of respiratory modulation}
  - \textit{Potential to calculate venous saturation}

- Time\(^2\) & Frequency\(^3\) domain analysis
  - Time domain > breaking waveform down to components
  - \textit{Blood pressure, cardiac output, SVR...}
  - Frequency domain > measure of respiratory modulations


Venous Pulse

e c t o p i c  p r e g n a n c y

Venous Pulse

Pleth

Venous Pulse (mmHg)

Time (secs)

Pleth

Pleth (arbitrary scale)

THE DETECTION OF PERIPHERAL VENOUS PULSATION USING THE PULSE OXIMETER AS A PLETHYSMOGRAPH

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Plethysmographic Sensors

Finger

EAR

Forehead
Effect of pressure on the sensor

Pressure dressing applied
Forehead & ear plethysmographic waveforms compared to classic arterial & CVP pressure tracings.

The clinical researcher can make a difference!

Time domain analysis of a photoplethysmographic (PPG) waveform from a patient with significant blood loss due to a surgical procedure.

The middle trace reflects changes in the mean of the PPG.

The bottom trace demonstrates fluctuations in the pulse amplitude of the PPG.
Twenty patients scheduled for CABG had their ear & finger oximeter and radial artery blood pressure waveforms collected.
The Fourier analysis of the same PPG waveform as the last slide.

The blue arrow corresponds to the modulation of the baseline (DC) component.

The red arrows to the modulation of the pulse amplitude (AC).

Oesophageal Pulse Oximeter

Pt 17: 5:10 - 6:40 mins : Spectrum (Amplitude Density) 9 x 8192 (400 Hz)

Venous modulation
Arterial modulation

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12 Nov 2007
St. Bartholomew's Hospital
Oesophageal & Brain PPGs!

City University
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THE USE OF JOINT TIME FREQUENCY ANALYSIS TO QUANTIFY THE EFFECT OF VENTILATION ON THE PULSE OXIMETER WAVEFORM

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Fig 2. Pleth after 300 cc EBL at High PAW

Fig 3. Fourier Transformation of fig 2. Major peaks due to cardiac pulse. Minor peaks due to respiration.

Fig 4. Detail of Fig 3. showing effect of ventilation on FT.

Fig 5. Joint Time Frequency Analysis showing how the same FT changes with time.
Functional hemodynamics

- answering fundamental questions

Based upon arterial pressure analysis

- index of fluid responsiveness

Photoplethysmograph

- mixture of arterial and venous signals
- impact of site (finger vs. ear)


Hypovolemia

Increased respiratory variability

72 y.o. female undergoing bilateral knee replacements. Note: no respiratory variability.

After 1500 cc blood loss, the BP has dropped. Both the Plethysmograph and BP show dramatic respiratory variability with positive pressure ventilation.
Pulse Oximeter Waveform Research

It takes a village…

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