Edwards FloTrac Sensor & Edwards Vigileo Monitor

Measuring Continuous Cardiac Output with the FloTrac Sensor and Vigileo Monitor
Topics

• System Configuration

• Physiological Principles
  – Pulse pressure relationship with stroke volume

• Calculating Arterial Pressure-Based Cardiac Output (APCO)
  – Assessing pulse pressure
  – Assessing patient specific effects of vascular tone

• Measuring CO Without a Manual Method of Calibration
The Vigileo monitor by Edwards Lifesciences supports both the FloTrac Sensor for continuous cardiac output and the PreSep central venous catheter for continuous central venous oximetry (ScvO2)
The Vigileo monitor continuously displays and updates Continuous Cardiac Output, Cardiac Index, Stroke Volume, Stroke Volume Index, Systemic Vascular Resistance*, Systemic Vascular Resistance Index*, and Stroke Volume Variation every 20 seconds when used with the FloTrac sensor. DO2 and DO2I are also available for intermittent calculation.** These parameters help guide the clinician in optimizing stroke volume through precision guided management of preload, afterload, and contractility.

Vascular tone = vessel compliance and resistance

The Vigileo monitor then helps identify the adequacy of cardiac output by monitoring central venous (ScvO2) or mixed venous (SvO2) oxygen saturation when used with Edwards venous oximetry technologies.

* These parameters require the CVP value to be slaved from bedside monitor for continuous monitoring. SVR/SVRI can also be assessed on the Derived Value Calculator for intermittent calculations using either slaved or manually entered MAP, CVP, and CO values.

**These parameters require the SpO2 and PaO2 values to be manually entered. If CO is being continuously monitored, the calculator will default to the existing CO value. Otherwise, the user may override the continuous value to manually enter CO.
The specially designed FloTrac sensor provides the high fidelity arterial pressure signal required by the Vigileo monitor to calculate the stroke volume.

The Vigileo monitor uses the patient’s arterial pressure waveform to continuously measure cardiac output. With inputs of height, weight, age and gender, patient-specific vascular compliance is determined.

The FloTrac sensor measures the variations of the arterial pressure which is proportional to stroke volume. Vascular compliance and changes in vascular resistance are internally compensated for.

Cardiac output is displayed on a continuous basis by multiplying the pulse rate and calculated stroke volume as determined from the pressure waveform.

The FloTrac sensor is easily setup and calibrated at the bedside using the familiar skills used in pressure monitoring.
How does the FloTrac system’s APCO algorithm work?

(Arterial Pressure-based Cardiac Output)
The measurement algorithm starts with the premise that stroke volume is proportional to pulse pressure.

We see from these references that the pulse pressure is simply the difference between systolic and diastolic pressure and that an increase in stroke volume will be shown by an increase in pulse pressure.

We also see that compliance will have an effect on pulse pressure. That is the greater the compliance for any given SV, the lesser the pulse pressure.
Cardiac Output is calculated by multiplying Heart Rate times Stroke Volume.

The APCO algorithm uses Pulse Rate calculated from the arterial pressure signal.

Stroke Volume is calculated by multiplying the standard deviation of the arterial pressure “sd(AP)” signal against $\chi$.
The calculation of pulse pressure and its proportionality to SV:

$sd(\text{AP})$
Trending Stroke Volume

- Arterial pressure is sampled at 100 Hz
- Changes in stroke volume will result in corresponding changes in the pulse pressure
- A robust “whole waveform” measure of the pulse pressure is achieved by taking the standard deviation of the sampled points of each beat
- $\text{sd(AP)} \propto \text{Pulse Pressure} \propto \text{Stroke Volume}$
- SV estimates are calculated every 20 sec

Arterial pressure is sampled at 100 times per second (100 Hz). Each sample is a pressure data point measured in mm Hg.

This data is analyzed and updated every 20 seconds, utilizing the 2000 data points (20 sec x 100 Hz) collected.

The standard deviation ($\text{sd(AP)}$) of these data points is proportional to the pulse pressure, which is proportional to the stroke volume.

This method is robust in its assessment of pulse pressure because it looks at the whole waveform.

$\text{sd(AP)} = \text{a measure of variance}$

The Stroke Volume is averaged and displayed every 20 seconds.

The user has the capability to choose between a 20 second calculation or 5 minute moving average option.
This graphic shows the relationship between varying arterial pulse pressure and stroke volume in the presence of a constant vasculature.

The sd(AP) is simply a statistical tool used in the algorithm for quantitatively assessing the magnitude of pulse pressure, correlated with an estimated stroke volume.

Since we know that an individual's vasculature is not constant, an assessment of vascular tone must also be included in the calculation as it will affect the relationship between pulse pressure and stroke volume.
Including the effect of vascular tone in the calculation of flow:
There is a direct relationship (i.e., the shape of the trend shown above) between arterial pressure and large vessel compliance as it relates to a human's age or gender. That is, a male will typically have a more compliant aorta than a female of the same age, and a younger person will have a more compliant aorta than an elderly person. This relationship was quantified and mathematically modeled by Langewouters.

Through development of the algorithm, it has also been found that there is a relationship between aortic compliance and BSA. For example, a larger person (higher BSA) will typically have more compliant vessels than a smaller person (lower BSA).

As part of the assessment for vascular tone, estimates of aortic compliance based on the above principles are important but not all encompassing. Therefore, in addition to Langewouter’s mathematical model, further waveform analysis is conducted by the algorithm to take into account patient specific, real time effects of vascular tone on the waveform.
The aortic compliance function (i.e., age, gender, BSA function) within $X$ helps to provide a “ballpark estimate” of the patient’s likely vascular tone. Further analysis of the waveform shape is also a significant factor to providing vascular tone estimates essential to the SV calculation. This method allows for reliable calculation of key flow parameters without manual calibration.

$X$ (pronounced “khi”) = a symbol for dynamic polynomial functions, a function that continuously adjusts to multiple changing variables

Depending upon the state of the patient’s vasculature, the arterial waveform will take a shape that can be characterized mathematically. The statistical tools used, in addition to the aforementioned standard deviation, are the mean, skewness and kurtosis. Mean, clinically known as MAP, can provide an indication of the increase or decrease in resistance. Skewness, or symmetry of the data, is also often associated with the stiffness of the patient’s vasculature. Kurtosis, a measure of how peaked or flat the data distribution is, provides an indication of the nature of vasculature as well. For example, larger vessels will typically have a “flat” distribution as compared to peripheral vasculature.

**Skewness:** The angle or slope exhibited on the rise of the waveform.

**Kurtosis:** How flat and wide the waveform is

If the shape changes, the mathematical calculation will change, providing a patient-specific, real time assessment of shifts in vascular tone. The greater the magnitude increase in tone, as calculated as a decrease in $X$, the lesser the weight pulse pressure estimates (i.e., sd(AP)) will have in the SV calculation.
Requires NO Manual Calibration

- Other continuous monitoring technologies require calibration to accommodate for the effects of independent variables associated with changing vascular tone.
- The APCO algorithm compensates for the continuously changing effects of vascular tone via analysis of waveform characteristics directly correlated with vascular tone.

Continuous, patient-specific monitoring without manual calibration

In building the algorithm, comparisons were made between known stroke volume with a given PP comparable (i.e., sd(AP)). Furthermore, statistical correlations were found that provided a mathematical model for providing a quantitative assessment of vascular tone effects on SV. The foundations for these correlations are: the known SVs corresponding PP comparables, continuous arterial pressure data, and the patients’ age, gender, and BSA.

By utilizing these empirical data relationships established during development of the algorithm, the system is able to correlate pressure calculations with stroke volume without requiring a manual process of calibration (e.g., thermodilution, lithium dilution washout curve) and remains accurate when changes in tone occur.

Other pulse contour or pulse power based technologies require a dilution washout curve to provide a calibration constant, compensating for these algorithms’ inability to independently assess the ever-changing effects of vascular tone on SV.
The FloTrac sensor enables clinicians to monitor critically ill patients with parameters traditionally only available through more invasive means.
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Helping patients is our life’s work, and

life is now