Pleth Variability Index (PVI)

Respiratory effect on plethysmographic waveform

The heart and lungs interact physiologically in a number of ways. The heart is positioned within the thoracic cage in such a way that its pumping action is directly influenced by relative changes in airway pressure, blood pressure and/or blood volume within the thorax.[1] The heart's normal pumping ability results from many factors including a balance between intrathoracic airway pressure and intravascular fluid volume. The changes in airway pressure within the thorax during normal respiration actually supplement or enhance normal cardiac pumping ability. For example, the increased negative intrathoracic pressure that occurs during normal inspiration increases venous return to the heart. This particularly supports venous return from the lower extremities.

As the relationship between blood volume and airway pressure becomes unbalanced, the resultant change in cardiac pumping ability can be seen as cyclical changes in pulse pressure/pulse volume occurring during the respiratory cycle. Khasnis[2] credits Lomar over 300 years ago with reporting the first recognition of this physiologic event as a decrease in pulse volume during inspiration in a patient with constrictive pericarditis. As the relationship between airway pressure and intravascular pressure or volume becomes more unbalanced, the impact on this respiratory variation in pulse pressure/pulse volume becomes more pronounced. Intrathoracic pressure changes have a direct effect on the way both the right and left sides of the heart fill and empty. These changes in the heart pumping capacity are reflected as cyclic changes in the systolic and diastolic blood pressures. Large cyclic changes in blood pressure associated with phases of respiration have been observed with continuous invasive recording of arterial blood pressure.

This cyclic pulse pressure/volume change results in changes in the peripheral perfusion. Photoplethysmography of peripheral perfusion can be displayed by pulse oximeters, with the photoplethysmographic (pleth) signal being derived from the infrared light absorption waveform. Changes in this infrared waveform have been shown to correlate well with local blood volume changes[3] and the beat to beat plethysmogram displayed on the pulse oximeter reflects beat to beat changes in local blood volume. While the pulse oximeter plethysmogram represents a volume change and the arterial line blood pressure tracing represents a pressure change, it has been demonstrated that cyclical shifts in the plethysmogram reflect similar cyclic changes in the blood pressure tracing and that these changes reflect changes in the intravascular volume status of patients.[4,5] As mentioned previously, these cyclic changes in blood pressure and pleth waveform can also be caused by changes in intrathoracic pressure relative to the intravascular volume. Asthma is one condition where intrathoracic pressures are greatly elevated compared to normal, resulting in pronounced cyclic changes. Steele demonstrated that cyclic changes in blood pressure and the pulse oximeter pleth waveform occur during airway obstruction,[6] and the magnitude of the cyclic waveform correlates with the severity of airway obstruction.

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Clinical Implications

In the case of severe asthma, the airway resistance increases the intrathoracic pressure during peak inspiration, resulting in a transient decrease in venous return and thereby causing a decrease in stroke volume output of the heart resulting in pulse pressure variation. In the case of hypovolemia, the pressure (or volume) within the vascular space is lower and is more greatly impacted even by relatively minor changes in airway pressure even during normal respiration thus resulting in cyclical changes in stroke volume output of the heart. This relationship inverts during mechanical ventilation as the airway pressure patterns invert; air is drawn in via negative pressure during spontaneous ventilation whereas it is pushed in via positive pressure during mechanical ventilation. So, mechanical ventilation may have a more pronounced impact on impeding venous return and increasing this cyclic variation.

These cyclic changes that occur due to alteration in physiology have been described by various terminologies: systolic pressure variability, pulse pressure variation, delta up/delta down and respiratory waveform variation.

Disease states or physiology that affects the relationship

Traditionally the presence of systolic pressure variability (SPV) has been noninvasively measured using a conventional blood pressure cuff or observation of arterial blood pressure from an arterial pressure line. These methods require great care in observing changes in blood pressure during normal respiration. An elevation in SPV may be a significant clinical sign in a variety of critical conditions (Table 1).

Table 1 *– A variety of conditions are associated with increased Systolic Pressure Variability.*[2]

Cardiac causes	Non-cardiac non-pulmonary causes	Pulmonary causes
Cardiogenic shock	Hypovolemia	Asthma
Cardiac tamponade	Septic Shock	Tension pneumothorax
Pericardial effusion	Anaphylactic shock	
Constrictive pericarditis	Diaphragmatic hernia	
Restrictive cardiomyopathy	Superior vena cava obstruction	
Pulmonary embolism	Extreme obesity	
Acute myocardial infarction		

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Methods of measurement:

From the discussion above, a reliable continuous non-invasive indicator of these cyclic changes would be clinically valuable. Although no way has been shown to quantify pressure from a pleth waveform, many clinicians currently observe the pulse oximeter's pleth waveform for cyclic changes in physiology. If the variability is increasing there is change in the intrathoracic/blood volume relationship. Unfortunately there is no consistency among the pulse oximeter manufacturers in the way they display the pleth waveform. Indeed there may be differences between various models from the same manufacturer. The ability to indicate changes in a numerical format which can then be trended is needed. Then even slight changes in physiology may be reliably followed.

Masimo has developed a measurement (Pleth Variability Index) to indicate cyclic changes in the pleth waveform due to alterations in physiology utilizing its Perfusion Index (PI) which is already available in its current pulse oximetry and pulse CO-Oximetry products.

Definition of Perfusion Index (PI)

Perfusion index is a measurement displayed on many pulse oximeters. It has been shown to be of value to gauge the severity of illness in newborns.[7,8] PI changes due to numerous factors such as epidural blocks,[9,10] pain stimulus,[11] sympathetic discharge, decreased peripheral perfusion,[12] etc. For the measurement of SpO_2 via pulse oximetry, red (R) and infrared (IR) lights are utilized. A constant amount of light (DC) from the signal of the pulse oximeter is absorbed by the skin, other tissues, and nonpulsatile blood, while a variable amount of light (AC) is absorbed by the pulsating arterial inflow. For the calculation of PI, the IR pulsatile signal is indexed against the non-pulsatile IR signal and expressed as a percentage (Equation 1). The IR signal is used because it is less affected by changes in arterial saturation than the R signal.

Equation 1

$$PI = \frac{AC}{DC} \times 100\ \%$$

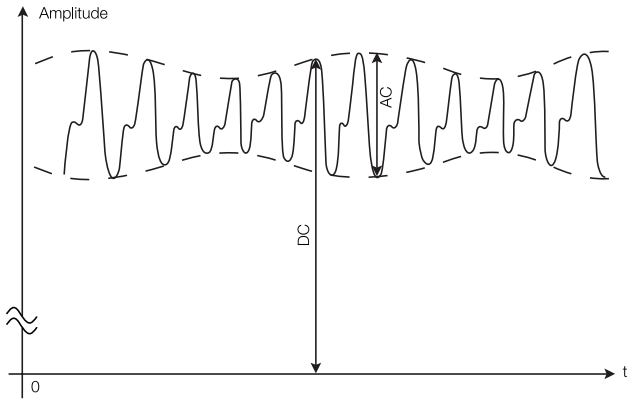

Figure 1. *Graphic representation of raw IR signal processed internally in the pulse oximeter. The AC component represents the changes in transmittance at the monitored site caused by the blood volume change during the cardiac cycle. The DC component is the transmittance due to pigmentation, tissue, bone, and non-pulsatile blood which occurs at the end of a cardiac cycle (diastole). NOTE: This internal IR signal customarily is inverted when displayed on the pulse oximeter due to clinicians' familiarity with the arterial pressure waveform.*

Definition of PVI

Pleth Variability Index (PVI) is a measure of the dynamic changes in the PI that occur during the respiratory cycle (Equation 2). The calculation is accomplished by measuring changes in PI over a time interval where one or more complete respiratory cycles have occurred.

Equation 2

$$PVI = \frac{PI_{Max} - PI_{Min}}{PI_{Max}} \times 100\ \%$$

PVI, therefore, is displayed as a percentage. The lower the number, the less variability there is in the PI over a respiratory cycle.

Potential clinical utility of PVI

PVI has the potential to provide useful information concerning changes in the balance between intrathoracic airway pressure and intravascular fluid volume. For example PVI may be used to monitor severity of asthma attacks and the response to appropriate therapy. Because PVI is a numeric value which indicates the cyclic changes in the plethysmographic waveform it may provide for easy trending of the patient's clinical condition. Trending of PVI may be useful in monitoring surgical patients, both intraoperatively and postoperatively, for appropriate hydration states. For example, a rising PVI may indicate developing hypovolemia. Trending of PVI may also be useful in monitoring patients with respiratory or cardiac failure, helping to evaluate the interrelationship between intrathoracic pressures and cardiac function. The ability to reflect this relationship continuously may become an integral part of the noninvasive monitoring of almost every hospitalized patient.

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