

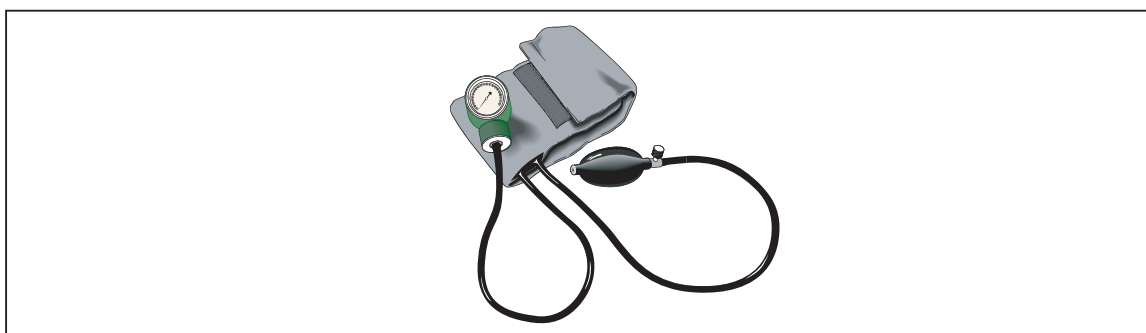
Blood Oxygen and Pulse Oximeters

Tutorial

Blood Pressure

Blood pressure readings provide valuable information about the condition of our bodies, indicating health or the lack of it. As the heart contracts (*systole*) and relaxes (*diastole*), the volume of freshly-oxygenated blood increases and decreases measurably within the artery walls. This action causes the artery walls to expand and contract in rhythm with the heart. The force of the blood exerted upon the artery walls is what is called *blood pressure*. Contraction produces the highest pressure, and relaxation the lowest.

A sphygmomanometer (shown in Figure 1) is one tool for measuring blood pressure. When our blood pressure is taken, it is measured at the brachial artery in the forearm in millimeters of mercury (mmHg). If our blood pressure reading is at or near 120 mmHg (*systolic*) over 80 mmHg (*diastolic*), we are considered to be in peak health, all else being normal.



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Figure 1. Sphygmomanometer

Gases in Blood

Blood pressure is not the whole story, however, since the exact concentration of gases such as carbon dioxide and especially oxygen in your blood cannot be determined by a simple blood pressure test.

To determine gas concentrations accurately, specifically saturated oxygen, a blood-gas sensing device must be used, and must be capable of detecting the wide range of nominal values for these gases. Gas concentrations in blood, specifically oxygen (O_2) and carbon dioxide (CO_2), can be expressed as milliliters of gas per liter of blood, and can be indicated by the partial pressure that the gases exert in your blood at a given temperature.

Pulse Oximeters

Because of their ease of use in many hospital- and critical-care situations, pulse oximeters have greatly increased in popularity since their introduction. Today, pulse oximeters are virtually required equipment in situations where the monitoring of arterial oxygen saturation (SpO_2) is essential, such as when anesthesia is in use, both during an operation and in post-operative recovery, intensive care, transport, and patient home care.

Pulse oximeters have proven to be capable and reliable, being highly accurate in measuring blood SaO_2 in the range of 80-100 %, while at the same time needing little, if any, calibration. No patient preparation is required before using the pulse oximeter; in addition, the devices are so simple to operate that specialized training is unnecessary.

How Pulse Oximeters Work

Pulse oximeters are defined as non-invasive, arterial, oxygen-saturation monitors which measure the ratio of two principal forms of hemoglobin in the blood: saturated arterial hemoglobin (also called *oxyhemoglobin*), HbO_2/SAT , to unsaturated (or *reduced*) hemoglobin, Hb .

The arterial oxygen saturation, SaO_2 , is defined as the ratio of the concentration of oxyhemoglobin (cHbO_2) to the concentration of $\text{HbO}_2 + \text{Hb}$ ($\text{cHbO}_2 + \text{cHb}$). Oxygen saturation is commonly expressed as a percentage and is calculated according to the formula in Figure 2.

$$\text{SaO}_2 = \frac{\text{cHbO}_2}{\text{cHbO}_2 + \text{cHb}} \times 100\%$$

Figure 2. Formula for Determining Saturated Oxygen Level

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Using this information, a correctly calibrated and operating pulse oximeter can accurately predict the level of oxygen in the blood, which in turn provides valuable data about the health of a patient, and in the case of anesthesia and post-operative recovery, the status of the patient.

Spectrophotometry

Pulse oximeters operate on the principle known as spectrophotometry, using wavelengths of light to determine the concentration of oxygen in the blood. Because we already know the wavelengths for the light absorption of blood hemoglobin, we can mathematically determine the arterial oxygen saturation in a patient's blood.

The light emitting diodes (LEDs) of a pulse oximeters shine two types of light—near infrared light (at 940 nanometers) and red light (at 660 nanometers)—wavelengths that pass through the skin and which are absorbed by both the oxyhemoglobin and the reduced hemoglobin. These light beams pass through the index finger of a patient to photo detectors on the opposite side of the pulse oximeter.

Figure 3 shows a typical pulse oximeter configuration, noting the location of the red and infrared LEDs.

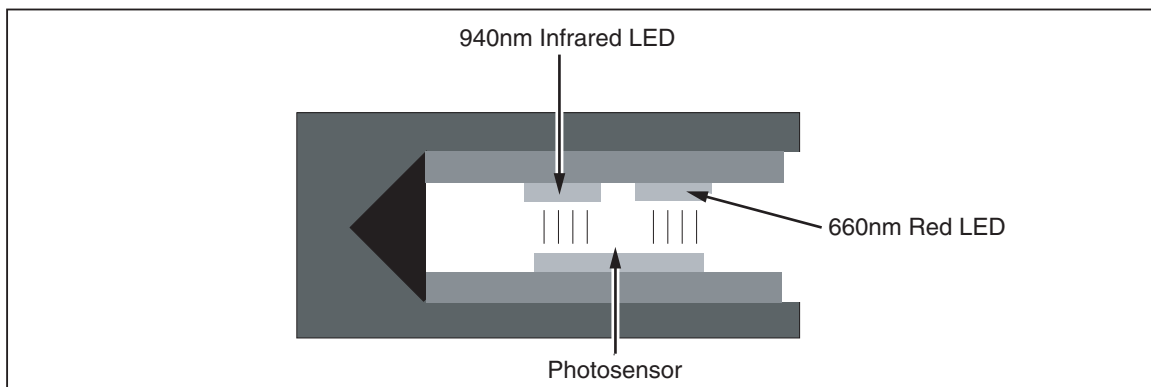


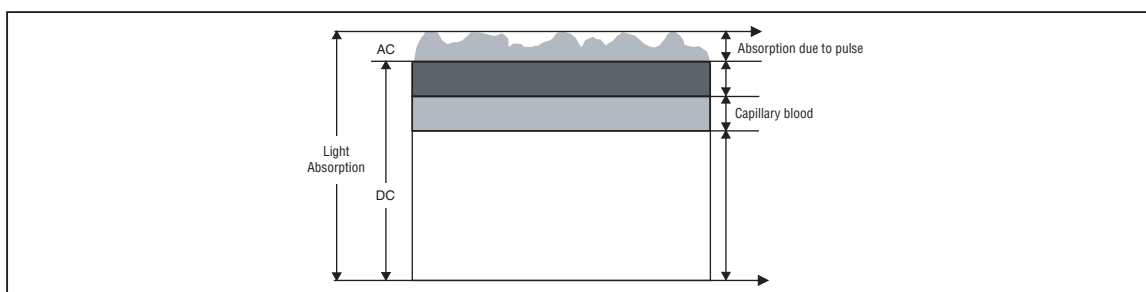
Figure 3. Diagram of Sample Finger Probe for a Typical Pulse Oximeter

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Using this dual light emitting and sensing technology, the pulse oximeter determines the amount of light absorbed by the blood and calculates the percent of oxygen saturation (SaO_2).

However, it is not quite that simple. Pulse oximeters must also calculate out the effect of absorption caused by the presence of venous and capillary blood and soft tissue in order to obtain the true SaO₂ value. To do so, pulse oximeters use a system that distinguishes between “ac” components (the pulsating arterial blood) and “dc” components (the *non*-pulsating components mentioned just above).

Figure 4 shows the different ac and dc components graphically.



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Figure 4. Diagram of Light Absorbers in Tissue

The pulse oximeter determines the ac component of absorberency at each wavelength and divides this by the corresponding dc (amplitude) component. This results in a "pulse-added" absorberency that is independent of the light intensity. The ratio (R) of these pulse-added absorberencies is calculated using the formula shown in Figure 5.

$$R = \frac{AC_{660}/DC_{660}}{AC_{940}/DC_{940}}$$

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Figure 5. AC/DC Infrared and Red Absorption Ratio

When the ratio of red-to-infrared absorberance equals 1.00, the saturation is approximately 81 %.

References

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- Clinical Pulse Oximetry*, Thomas L. Petty, MD, Anesthesiology, v. 70, no. 1, Jan. 1989.
- Oximetry/Blood Gas*, ---, Medical Electronics, Oct. 1989.
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Non-Invasive Blood Pressure Monitoring

Tutorial

Introduction

Manufacturers of NIBP monitors that use the oscillometric technique have performed clinical trials to determine the correlation between both auscultatory techniques and invasive (arterial line) methods of measuring blood pressure to the oscillometric technique. Various interpretations have emerged from these manufacturers with varying degrees of agreement. Because no regulatory agency has put forth a standard as to how pulse amplitudes should be interpreted to determine blood pressure, the accuracy and repeatability of these monitors is difficult to determine.

Because the Analyzer produces a stable live subject response to the cuff during the measurement cycle, it is possible to determine the repeatability and agreement of these monitors. The Analyzer produces the same response, independent of the inflate/deflate cycle or the algorithm used by the monitor; therefore, we offer the term Target Value as an approximation of the patient's actual blood pressure.

Absolute dynamic accuracy cannot be assigned to MAP, diastolic, and systolic target values at this time because no standard exists. Should any public standards emerge, the Analyzer can be programmed to implement them and test blood pressure monitor accuracy.

NIBP Monitoring

Blood pressure can be measured using a variety of techniques. They can be classified into two major categories. They are known as invasive and non-invasive. The invasive approach inserts a catheter into an artery of a test subject. The catheter may contain a pressure transducer at its tip or it may be fluid filled and couple the blood pressure thru the fluid to an external transducer. The change of fluid pressure (blood pressure) in the subject's artery is said to be measured invasively. This technique is also referred to as a direct measurement, because the parameter being measured is directly coupled to the transducer.

The non-invasive technique can be realized several ways. It usually involves the use of an inflatable cuff wrapped around the limb of a test subject. The cuff is inflated and deflated at a controlled rate and physical parameters are observed. The auscultatory and oscillometric techniques are well known non-invasive methods. These methods are indirect because they do not couple directly to the artery.

Auscultatory Technique (Not available in Fluke Biomedical Product Line)

The auscultatory technique is based on the sounds caused by the blood flow through the artery that is surrounded by the cuff. These sounds are known as Korotkoff (K) sounds. In manual blood pressure measurement these sounds are detected by a human observer using a stethoscope.

Automated blood pressure monitors use an audio transducer (microphone) to convert the K sounds into electric signals. The cuff is inflated to a point that occludes the artery. The pressure in the cuff is lowered. The cuff pressure at which the K sounds are first detected is the systolic pressure. The monitor continues to decrease the cuff pressure until the K sounds disappear. The cuff pressure at this point is called diastolic pressure.

Oscillometric Technique

The oscillometric technique does not use K sounds to determine blood pressure. The oscillometric technique monitors the changes in cuff pressure caused by the flow of blood thru the artery. The monitor inflates the cuff to a

pressure that occludes the artery. Even when the artery is occluded, the pumping of the heart against the artery can cause small pressure pulses in the cuff baseline pressure.

The monitor lowers cuff pressure at a controlled rate. As the cuff pressure goes down, blood starts to flow thru the artery. The increasing blood flow causes the amplitude of the pressure pulses in the cuff to increase. These pressure pulses continue to increase in amplitude with decreasing cuff pressure until they reach a maximum amplitude at which point they begin to decrease with decreasing cuff pressure. The cuff pressure at which the pulse amplitude is the greatest is known as Mean Arterial Pressure (MAP).

The manner in which the pulse amplitudes vary is often referred to as a pulse envelope. The envelope is an imaginary line that connects the peak of each pressure pulse and forms an outline. The shape of the envelope is observed by the monitor using a variety of techniques to determine the diastolic and systolic blood pressures.

Auscultatory vs. Oscillometric Techniques

The auscultatory response is based on the sounds heard with a microphone. The cuff is inflated to a pressure much higher than systole. As the cuff is deflated the observer (or automated monitor) listens for the onset of K sounds. The cuff pressure at which the K sounds are first detected is treated as systolic pressure.

In Figure 1, some smaller K sounds are shown to appear before the systolic point. In many cases there is a threshold point. The point at which the sounds jump from some very low level to a much larger level is more typical with live subjects. The K sound amplitude does not change much as the cuff continues to deflate until the point of diastole is reached. At this point, there is an abrupt drop in K sound amplitude.

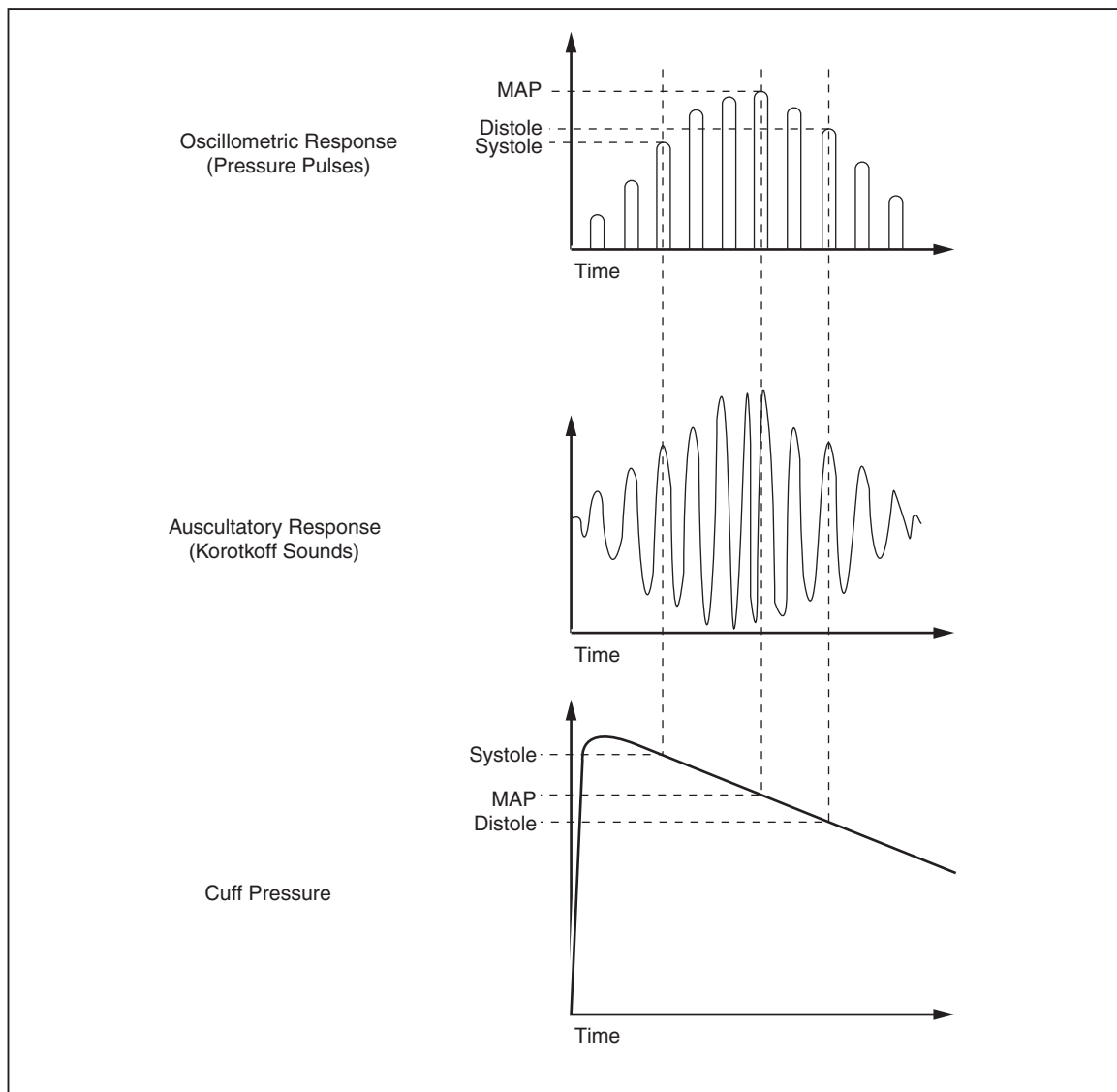


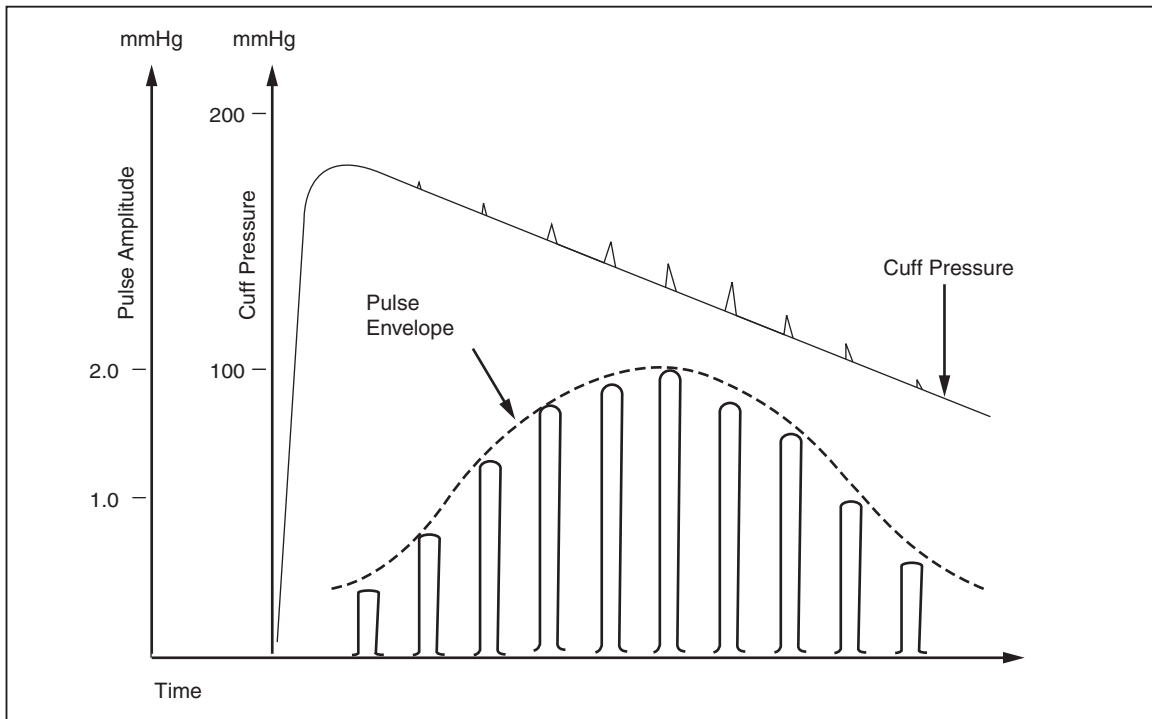
Figure 1. Auscultatory vs. Oscillometric Technique

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Also in Figure 1, the oscillometric pulse amplitudes are depicted as constantly changing. There is no point where the pulses abruptly change in amplitude, but there is a point where the pulse amplitude reaches a peak. It is generally agreed that the cuff pressure at peak pulse amplitude is the MAP, a value not easily identified using the auscultatory method.

Pulse Amplitude

The amplitude of the oscillometric pulses (hereafter referred to as pulses) is quite small when compared to the static pressure in the cuff. As shown in Figure 2, these pulses appear as very small spikes on the cuff pressure waveform. They are depicted in amplified form with the cuff pressure stripped off to reveal how the amplitude varies as a function of cuff pressure. The peak pulse amplitude is 2 mmHg at a cuff pressure of 115 mmHg in the example shown.



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Figure 2. Pulse Amplitude and Cuff Pressure vs. Time: Linear Deflate

In general, the peak pulse amplitude is 1-3 % of the cuff pressure at which it occurs. Therefore, the monitor must be able to strip off the large static cuff pressure to measure the individual pulse. Because the pulses are so small, it is possible for artifact conditions to obscure the pulse. Patient motion and respiration are common artifacts that the monitor must reject. When the cuff pressure is quite high the pulse amplitude is small. As the cuff deflates, the pulse amplitudes increase to a maximum and then decrease to a minimum.

Cuff Deflation

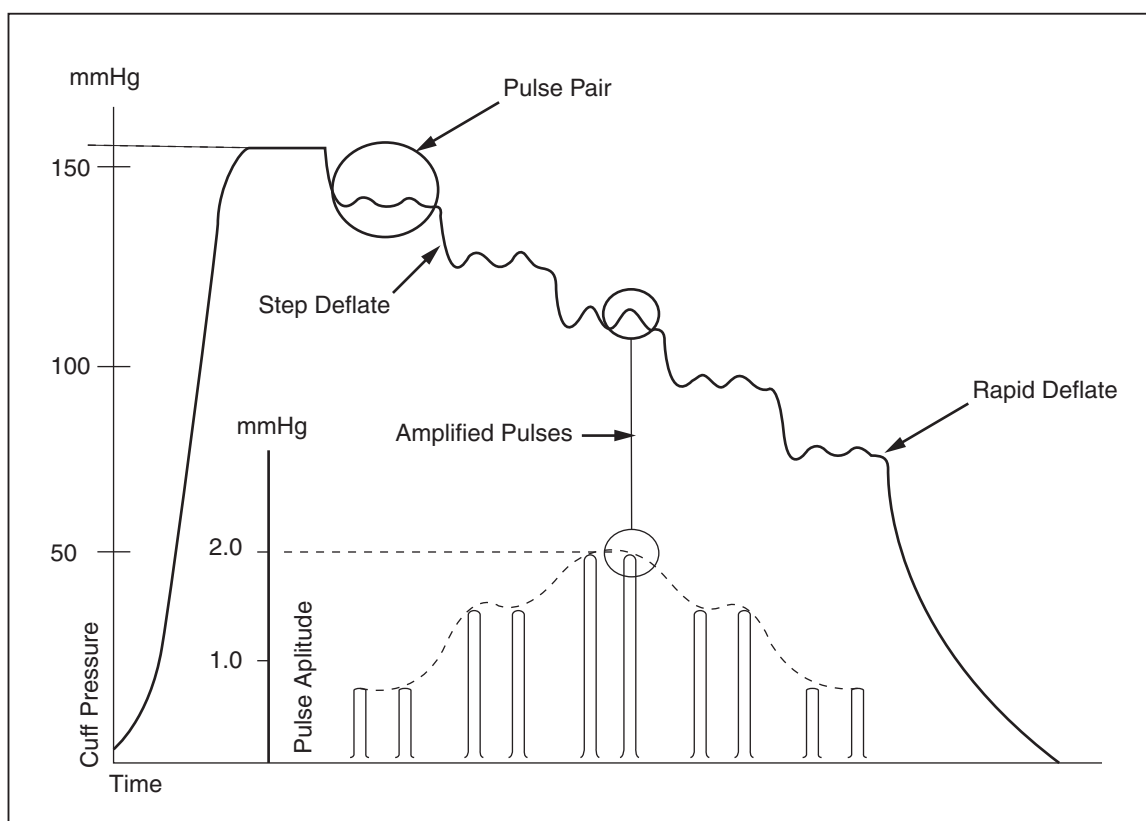
The linear deflate method is also known as continuous bleed. This is the method a nurse typically uses when measuring blood pressure manually. If the deflate is slow, accuracy is improved.

For example, if the bleed rate is 1 mmHg/sec and the heart rate is 60 BPM, the cuff pressure changes 1 mmHg per heart beat. Therefore, the error due to change in cuff pressure is limited to 1 mmHg. If the bleed rate is 10 mmHg/sec, then the cuff pressure changes 10 mmHg per heartbeat, and the potential error due to change in cuff pressure is 10 mmHg. This error is in addition to the error of the method being used to determine blood pressure. The tradeoff is accuracy versus patient discomfort.

Note

If someone taking a subject's blood pressure deflates the cuff faster than 3 mmHg/sec, an appreciable error in the ability to measure blood pressure may be introduced. For example, if the cuff is inflated to 180 mmHg and then deflated to 60 mmHg, it should take 40 seconds at a deflation rate of 3 mmHg/second.

Automated monitors employ algorithms to interpret the measurement points to minimize error due to rapid deflate. A typical deflate method used by automated monitors is known as a step or stepwise deflate, as shown in Figure 3.



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Figure 3. Cuff Pressure and Pulse Amplitude vs. Time: Commercial Monitor

The cuff is inflated to a pressure much greater than systole and deflated in discrete steps. Typical step deflate size is from 4 to 10 mmHg depending on the monitor and cuff size being used. After the deflate, the monitor measures some number of pulses before deflating again. The number of pulses gathered depends on the monitor software and the algorithm used. In a stat mode, it is common to gather only one pulse per step. In normal mode, it is common to gather pulses until at least two pulses are within some tolerance of each other in amplitude for artifact rejection.

When a monitor step deflates in large steps, it must interpolate the shape of the pulse envelope. The larger the step size the larger the potential for error when interpolating. If the step size is small, the potential for error is reduced.

Much effort has been spent by manufacturers to maximize step size and minimize error with varying degrees of success.

With the introduction of the Analyzer, it is now possible to compare normal mode to stat mode and observe the repeatability of the monitor as a function of step size and pulse pair matching. The end of the measurement cycle is defined as the point at which diastolic pressure has been determined. At this time the cuff is rapidly deflated to further minimize patient discomfort.

BP Determination

The manner in which oscillometric pulses vary as a function of cuff pressure is open to interpretation. Height-based and slope-based algorithms are used to determine blood pressure based on pulse amplitudes. Figure 4 shows the same pulse envelope interpreted by these two different methods.

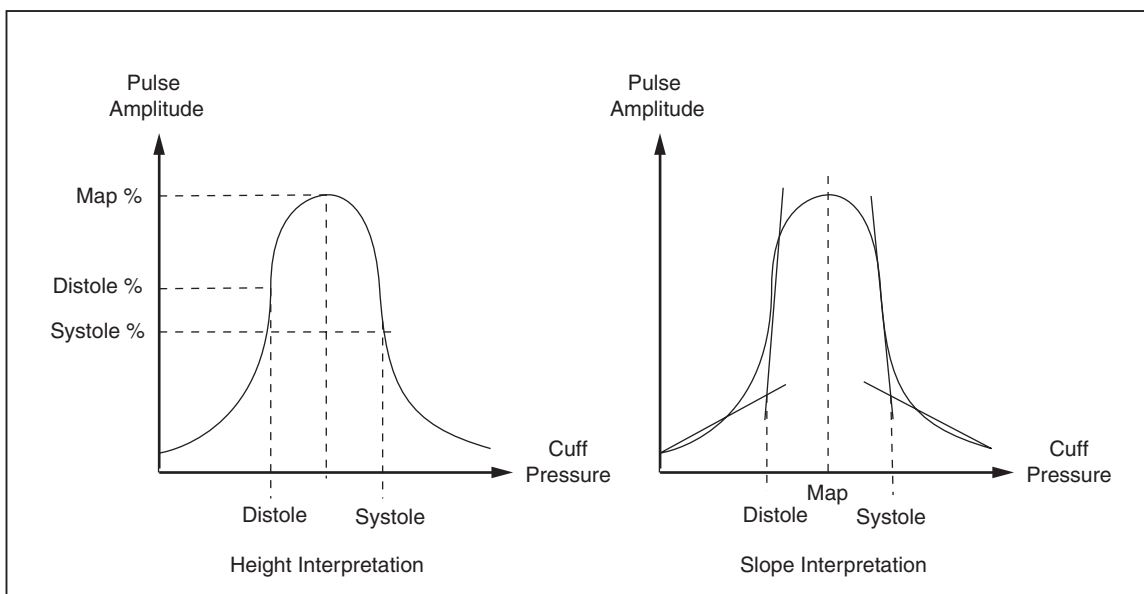


Figure 4. Height/Slope Interpretations for Determining BP from Pulse Amplitude Data

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Height Method

The peak pulse amplitude is treated as MAP and normalized to a value of 100 %. The cuff pressure at MAP is the MAP pressure. Systole and diastole are fixed percentages based on MAP. The cuff pressure under diastole is the diastolic pressure and the cuff pressure under systole is the systolic pressure.

There is no standard to suggest what the percentages for systole and diastole should be or even that they should be fixed percentages. Manufacturers using height-based algorithms have performed their own clinical trials and drawn their own conclusions about what the percentages should be and whether they are fixed as a function of MAP pressure.

Slope Method

There are many methods employed to determine how many slopes should be drawn and what conclusions can be made about their intersection. As shown in Figure 4, the cuff pressure under the intersection of the slopes is treated as the systolic and diastolic pressures. There is no standard for slope algorithms, just as there is no standard for height algorithms.