PHILIPS

IntelliVue

Patient Monitors

Noninvasive blood pressure principles

Application Note

Introduction

Oscillometry has become the preferred method for automated noninvasive blood pressure (NBP) monitoring in most clinical settings. It is increasingly used as an alternative to the invasive blood pressure measurement. Studies show that, especially in critical cases (arrhythmia, vasoconstriction, hypertension, shock), oscillometric devices are in general more accurate and consistent than devices using other noninvasive measuring techniques. However, the oscillometric measurement method does have its limitations.

This document describes the principles for measuring noninvasive blood pressure as well as the limitations of the oscillometric measurement method.

Principle of oscillometric blood pressure management

Oscillometric measurement devices measure the amplitude of pressure changes in the occluding cuff as the cuff deflates from a pressure above the systolic pressure. As the cuff pressure decreases, the pressure changes (pulsations) increase in amplitude. They reach a maximum, which approximates to the mean arterial pressure (MAP), and then diminish. The result is a characteristic oscillometric amplitude profile, or "oscillation envelope".

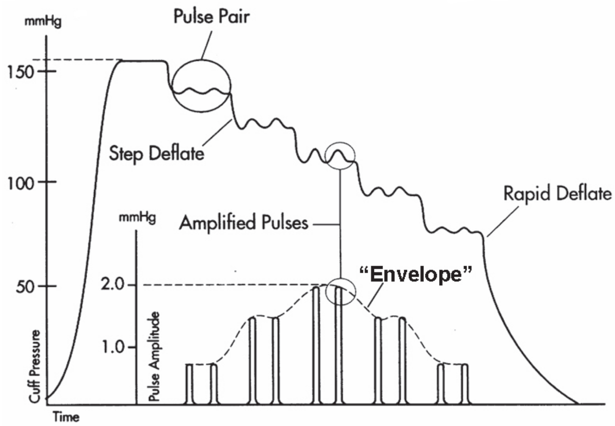

Figure 1: Oscillometric method

An algorithm analyzes the oscillation envelope and computes the systolic, mean, and diastolic pressures.

Key differences between oscillometric and auscultatory methods

Oscillometry ***calculates*** the systolic, mean, and diastolic pressure. With the auscultatory method, the clinician ***assesses*** the systolic and diastolic pressures by using a stethoscope. It is important to understand that in the auscultatory method, the systolic and diastolic points are well defined by the sudden appearance and disappearance of sounds. In the oscillometric method, they are more vaguely and empirically determined points on a continuously varying amplitude profile. This profile never goes fully to zero and can easily be distorted by artifact and physiological differences between patients. Usually, it is possible to find a maximum point on the envelope curve that approximately represents the mean arterial pressure displayed by the monitor. However, with a distorted or small oscillation envelope, it can become quite challenging to determine systolic and diastolic levels. In such cases, the algorithm as implemented in current Philips IntelliVue patient monitors provides only a mean pressure reading.

In practice, measuring blood pressure invasively will give different results from measuring it using the auscultatory method (Korotkoff sounds). For an oscillometric measurement device, to give pressure readings that statistically match either the invasive or the auscultatory results as closely as possible, a mechanism is needed to adjust the oscillometrically obtained pressures to the reference chosen by the clinician — invasive or auscultatory. This is done by correcting the oscillometrically obtained pressures with experimentally obtained coefficients.

Reference standards

There are two widely accepted reference standards that are used to validate the accuracy of NBP devices:

- Invasive reference standard
- Auscultatory reference standard

For details about the reference standards, see the Application Note *Clinical validation of NBP measurement accuracy*.

The challenge to derive systolic and diastolic blood pressures

In an ideal case for an oscillometric NBP measurement, you inflate the cuff pressure to slightly above the patient's "expected" systolic blood pressure, then deflate the cuff in a reasonable number of discrete steps. At each step, measure the oscillation amplitude of one pulse beat. An ideal, stable patient is one who is not moving during the entire measurement, has a heart rate of about 60 bpm and a normal blood pressure of about 120/80 mmHg. For this patient, you could derive an accurate envelope curve with about 10 pressure deflation steps, using step sizes of about 8 mmHg. With one pulse per step and pulses coming in every second, you would need about 10 seconds to assess the envelope in order to determine the patient's blood pressure. Allow another 20 seconds for cuff inflation, and you get a good systolic and diastolic blood pressure reading in about 30 seconds.

Number of pulsations per step versus inflation time

Unfortunately the typical pulsation signals from real patients, under real clinical conditions, are never as ideal as described above.

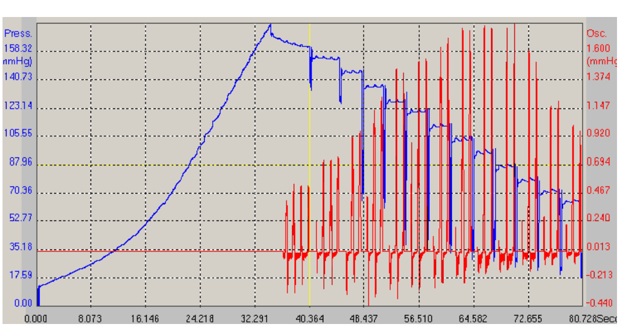

Figure 2: Cuff pressure and pulsation amplitudes

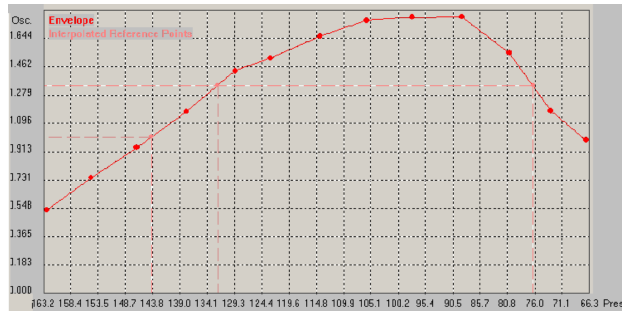

Figure 3: Ideal amplitude profile "envelope"

Figure 2 and Figure 3 show raw amplitudes and the resulting envelope taken from a real, straight forward, and easy-to-read oscillometric measurement with no obvious artifact. This gives very reliable systolic, diastolic, and mean blood pressure results. This example still comes close to the ideal picture. However, instead of one pulsation, at least two pulsations were measured for each deflation step, meaning that the measurement time has already more than doubled.

A meaningful envelope curve is the basis for a reliable NBP measurement. Since you can never be sure that any given pulsation was not caused by artifact, you need at least another pulsation to verify whether the first one was true or false. If the two measured pulsations deviate, you need at least a third one and sometimes even more.

The cuff inflation time is restricted in order to minimize patient discomfort, so you can allow only a certain number of pulsations per deflation step. Strong overlay of artifact occasionally makes it impossible to derive reliable pulsation amplitudes at one or even more deflation steps. The number of pulsations to be looked at for each individual deflation step, and over the entire deflation cycle, is therefore always a balance between an acceptable lack of reliable raw data and patient discomfort caused by extended cuff inflation times. With the standard NBP measurement, the minimum number of oscillations per deflation step is two.

Accelerated measurement

With the **Accelerated Msmt** configuration option, the minimum number of oscillations per deflation step is one. This allows a faster measurement result but requires that the patient keeps the limb in question still. In the accelerated measurement mode, no pulse can be derived.

Philips recommends the accelerated measurement for use when very few or no artifacts are expected, for example with sedated patients.

STAT measurement series

The STAT measurement series is a rapid series of NBP measurements over a five minute period. In STAT measurement mode, the algorithm looks at a single oscillation amplitude per deflation step, thus allowing the fastest possible assessment of a patient's blood pressure.

Only use this measurement series on supervised patients.

Artifact

If the envelope information during an NBP measurement was derived only from a few data points due to artifact during the deflation cycle, the algorithm can find the maximum point and the mean pressure, but reliable determination of the systolic and diastolic pressures is impossible.

Figure 4 shows how artifact oscillations can result in an envelope curve which has a clear maximum but difficult, or impossible to interpret slopes and fraction pressures. In this example, either the peak at A could be artifact or the two low amplitudes at B. Taking either A or B would result in significantly different systolic blood pressures. Given this uncertainty, the current Philips algorithm displays only a MAP reading.

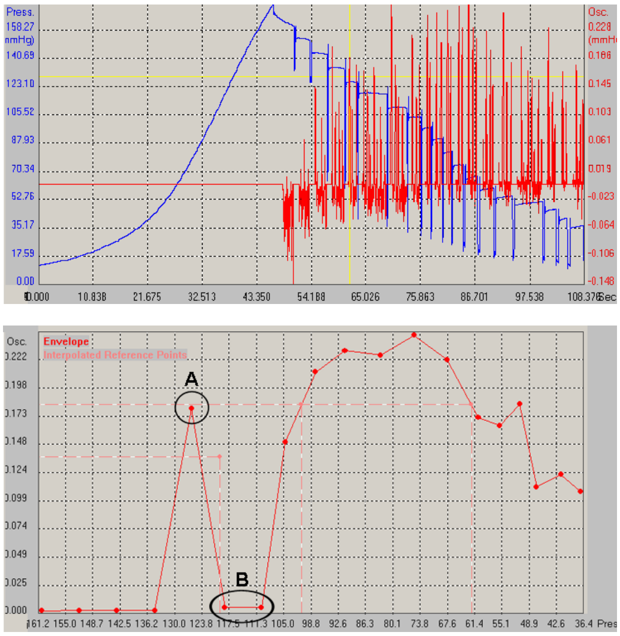

Figure 4: Oscillations with artifact and resulting envelope

Artifact suppression

The setting **Artifact Suppression** defines the level of artifact suppression for the NBP measurement. Artifact suppression only effects readings with artifact, for example from high patient activity, edema, or arrhythmia.

You can configure artifact suppression as **Standard** or **High**. The High configuration option uses a higher level of artifact suppression. This might decrease the number of potential questionable NBP readings, however, this might result in more NBP readings displayed with a question mark, and more conditions where no NBP measurement is possible.

Aged numerics

The setting **Aging Time** determines the time after which a numeric is aged. Depending on the presentation setting **Aged Numerics**, NBP numerics can be configured to be grayed out or to disappear from the screen after a set time. This avoids older numerics being misinterpreted as current data.

The aging time does not affect the lifetime of NBP numerics. The lifetime of NBP numerics is always 60 minutes. After this time, measured NBP values disappear from the monitor screen.

Low oscillation amplitudes

Oscillation amplitudes can sometimes be very small, for instance with obese patients or when cuffs are applied too loosely, or a combination of both. In such cases, oscillations can be more than 10 times smaller than normal oscillation amplitudes. An example is shown in Figure 6. Reliable determination of the maximum point on such a flat envelope curve is difficult. If, under such conditions, the accuracy of the measurement would be compromised, the Philips NBP algorithm displays a mean-only reading (see Figure 5).

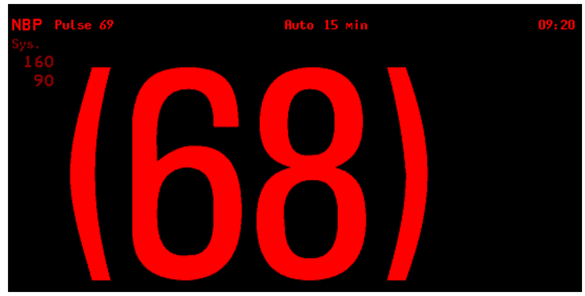

Figure 5: Mean-only reading

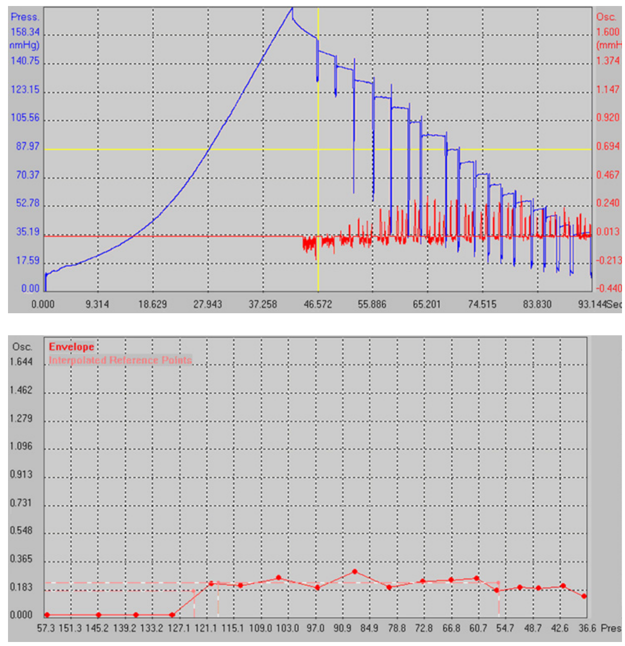

Figure 6: Small oscillation amplitudes cause very flat envelop curves

Design and material of cuff and tubing

The internal pneumatic system (that is, the combination of hardware such as pump, valves, and tubing) in an oscillometric device are uniquely designed to match each other's mechanical and pneumatic intrinsic characteristics in conjunction with the external pneumatic component, the cuff, tube, and inflating/deflating cuff bladder. Geometry, size, and elasticity of the cuff, bladder, as well as design and material of the tubing contribute to the performance of the overall system. All components are an inseparable part of the empirical calibration and system validation. Use of non-validated, third-party cuffs and supplies can inherently affect the measurement performance of an NBP device. Figure 7 shows a worst case oscillation profile that is impossible to interpret.

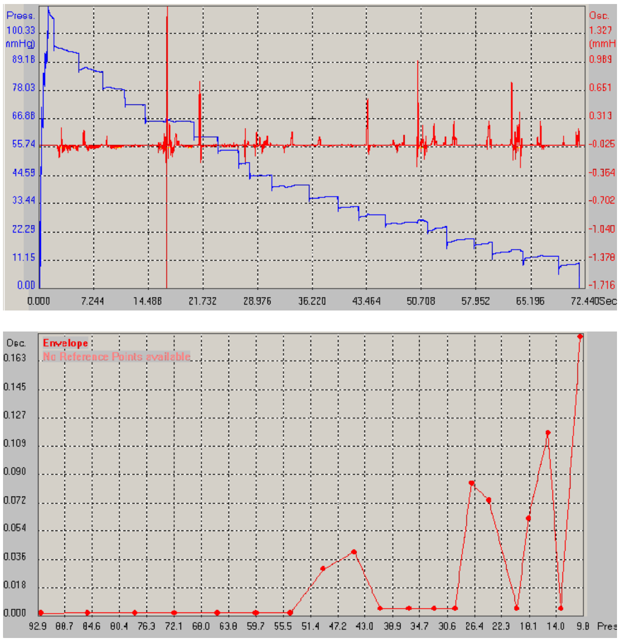

Figure 7: Impossible to interpret oscillation pattern resulting from artifact, weak signals, and use of wrong cuffs

Cuff size

It is essential that the cuff size is appropriate for the patient: undersized cuffs may give pressure readings that are too high, whereas oversized cuffs give pressure readings that are too low.

Conclusion

The oscillometric method is the standard in today's state-of-the-art automatic NBP devices for use in hospital settings. Yet it has its limitations. Despite these limitations, the method is known to be easy to apply, generally giving more reproducible results than the auscultatory method on most patients, even in poor clinical conditions. Occasionally, however, the limitations of this relatively indirect measurement method do not allow derivation of a complete set of readings for systolic, diastolic, and mean blood pressures. In many of these suboptimal measurement conditions, it is possible to measure the maximum elevation of the oscillometric amplitude envelope resulting in at least a mean blood pressure reading. There are clinical conditions, where there is not too much that can be done to prevent this from happening.

However, use of approved and correct sized cuffs according to instructions in the devices' labeling, and a tight, but not over-tight application of the cuff to the patient's limb, all help to reduce the number of mean-only readings as well as the occurrence of questionable or unsuccessful measurements.

In situations when the patient's condition is changing rapidly, causing mean-only readings, try using STAT mode as an alternative.

Frequently Asked Questions

When is it best to use the auscultatory instead of the invasive reference method?

The invasive reference method is recommended if the NBP measurement replaces or is compared to to an invasive ABP measurement. The auscultatory reference method is recommended whenever the NBP measurement replaces or is compared to manual auscultatory measurements.

In general, Philips recommends to use the same reference in all care areas (OR, PACU, ICU, and so on) between which adult and pediatric patients are moved.

When should I use high artifact suppression?

High artifact suppression might be useful if you expect a significant level of artifacts, for example in post-anesthesia care units. However, more measurements might fail and need to be repeated to meet the higher criteria on signal quality.

What is the difference between accelerated measurement and STAT mode?

The STAT mode is a rapid series of NBP measurements over a five minute period. The STAT measurement series always uses the minimum number of one oscillation per deflation step.

The accelerated measurement also reduces the minimum number of oscillations per deflation step to one. Contrary to the STAT mode, the accelerated measurement applies to the Auto, Manual, and Sequence modes.

Can I use a non-Philips cuff with the Philips IntelliVue patient monitors?

Philips cannot make any claims about the performance with third-party cuffs. Our NBP accessories and the NBP algorithm have only been validated with the Philips cuffs.

What do I do if there is a leak in the tubing or cuff?

The pneumatic system must not leak. A leak in the pneumatic system might lead to an extended measurement time and could result in inaccurate readings. In case of a large leak, the NBP pump tries to reinflate the cuff during an ongoing measurement. This might happen several times and strongly indicates a possible leak. If you notice or suspect a leak, use new tubings and cuffs. Alternatively, and if the issue persists, contact your biomedical department or your Philips representative.

Can I use an NBP simulator to check the measurement accuracy?

No, you cannot use an NBP simulator to check the measurement accuracy. You can use an NBP simulator only to test the overall functionality of the NBP measurement. This is because multiple factors can influence the NBP measurement. These factors cannot be reflected by an NBP simulator:

- Interaction between a patient's arm and cuff.
- Manufacturers of NBP monitors may use different algorithms. These algorithms may vary based on the monitor's patient categories and software version.
- You can configure IntelliVue patient monitors to use different references (auscultatory or invasive).

What happens if the NBP algorithm cannot derive a reading?

If the NBP algorithm is not able to derive a reading, the algorithm will automatically initiate one or two additional measurements shortly after the first. If the additional measurements fail again, the monitor displays question marks and an INOP which informs about the unsuccessful measurement.

What can I do if the monitor displays implausible or no readings?

Check if one or more of the measurement limitations listed in the *Instructions for Use* of the monitor apply.

What is an early systolic value?

The NBP algorithm calculates an early systolic value during an ongoing measurement. This value is based on the previous measurement and gives a first estimate. Artifacts and changed patient conditions can impact the early systolic value. Because of this, there is no early systolic value for the first NBP measurement.

If the **Artifact Suppression** setting is set to **High**, no early systolic value will be shown.

Can I change the interval between the columns on the Vital Signs trend?

Yes, you can have the NBP measurement determine the interval between the columns on the Vital Signs trend. To configure this, you can select **Main Setup** > **Trends** > **Setup VitalSigns** > **Column** > **NBP**. This displays the trends with one column for each NBP measurement. Only the times and respective vital signs of an NBP measurement are displayed.

Why is the NBP value on the monitor different from the mean NBP value in my charting system?

The mean NBP value on the monitor is a measured value. The algorithm analyzes the oscillation envelope and computes the systolic, diastolic, and mean pressures. Some charting systems estimate the mean pressure by a rule of thumb, for example:

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MAP = (2 × diastolic + systolic) / 3
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Such rules of thumb are less accurate because they do not consider the influence of the pulse shape and heart rates. Use the values of these charting systems with caution.

Why do I need to discharge patients at the monitor?

Discharging patients at the monitor resets the NBP algorithm and removes any stored values.

Why would I select Stop All?

Stop All will stop all NBP measurements when in Sequence, Auto, or STAT measurement mode. This setting will also reset the NBP algorithm. This might help if the NBP algorithm searches for cuff pressure oscillation in the wrong cuff pressure range because of an error in the previous reading.

Make sure to restart Sequence, Auto, or STAT measurement mode if you select Stop All to reset the NBP algorithm.

Why is it important to select the correct patient category?

Different patient safety limits are applied to neonatal, pediatric, and adult patients. These limits include the maximum cuff pressure and the duration of the cuff inflation. In addition, the monitor uses different algorithms based on the patient category to calculate systolic, mean, and diastolic pressures.

Can I apply the cuff over cloth?

No, cloth between the cuff and the patient's arm dampens the signal. This can compromise the accuracy and availability of the NBP measurements.

What are best practices to obtain a reliable NBP reading?

The AACN Practice Alert includes information about obtaining accurate NBP measurements in adults. This includes considerations regarding the cuff placement, the positioning of the patient, the cuff size, and patient safety. For detailed information, see "AACN Practice Alert: Obtaining Accurate Noninvasive Blood Pressure Measurements in Adults", Journal of Critical Care Nurses, Vol. 36, No. 3, June 2016.

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