Is it prudent to correlate noninvasive blood pressure (NIBP) measurements with arterial blood pressure measurements? My understanding is that the accuracy of arterial blood pressure measurements is assessed by doing the square-wave test and leveling, not by correlating the arterial measurements with the NIBP values. However, I observe the practice of correlating with the NIBP values so often, it makes me wonder if I have misunderstood my previous training on arterial catheters.

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Many critically ill patients are monitored with continuous blood pressure measurements, which provide clinicians with the important measures of systolic blood pressure (reflecting the change of pressure in the artery related to ventricular stroke volume) and diastolic blood pressure (related to vascular tone), as well as the calculated mean arterial pressure and pulse pressure. The physiology of blood pressure monitoring is quite complex, and the meanings of the different values are often misunderstood. Although most providers use target end points for pressure monitoring and intervention, little evidence supports the use of a single blood pressure target. When measuring noninvasively, the points of measure are static, versus the invasive measures, which are dynamic (beat to beat). The complexity of variables requires a physiological appreciation of a constellation of signs and symptoms, not just the blood pressures or the mean pressure.¹

In 1896, the mercury sphygmomanometer was designed and then adopted and disseminated in part by Harvey Cushing. In 1905, Korotkoff developed methods for auscultating Korotkoff sounds, which were related primarily to diastolic pressures. The clinical techniques of direct measurement of blood pressure by intra-arterial cannula were initially developed in the 1930s but were not used effectively until the 1950s. These measurements were soon accepted as representing true systolic and diastolic pressures.² Since that time, a significant amount of research and engineering has produced a variety of invasive and alternative indirect methods of measuring blood pressure. Following a brief summary of the current methods of evaluating blood pressure, a simple overview of validation of invasive arterial blood pressure will simplify the comparisons.

Providers can indirectly monitor blood pressure by using a number of techniques, most of which describe the external pressure...
applied to block flow to an artery distal to the occlusion. These methods actually detect the effects of blood flow, not intra-arterial pressure. These differences in what is actually measured are the major points of discrepancy between direct and indirect measurements. Five methods are currently used for noninvasive monitoring of blood pressure: Doppler flow, infrasound, oscillometry, the volume clamp technique, and arterial tonometry.

**Doppler Flow**

Systems that operate on the Doppler principle take advantage of the change in frequency of an echo signal when there is movement between 2 objects. Doppler devices emit brief pulses of sound at a high frequency that are reflected back to the transducer. In an uncompressed artery, the small amount of motion of the artery wall does not cause a change in frequency of the reflected signal. The compressed artery exhibits a large amount of wall motion when flow first appears in the vessel distal to the inflated cuff, which changes the frequency of the signal, causing what is known as a Doppler shift. The first appearance of flow in the distal part of the artery represents systolic pressure. When the Doppler shift in the echo signal disappears, that represents diastolic pressure.

**Infrasound**

Infrasound devices use a microphone to detect low-frequency (20-30 Hz) sound waves associated with the oscillation of the arterial wall. These sounds are processed by a minicomputer, and the processed signals are usually displayed in digital form.

**Oscillometry**

Most automated NIBP devices are based on oscillometry. Oscillometric devices operate on the same principle as manual oscillometric measurements. The cuff senses pressure fluctuations caused by vessel wall oscillations in the presence of pulsatile blood flow. Maximum oscillation is seen at mean pressure, whereas wall movement greatly decreases below diastolic pressure. As with the other automated methods described, the signals produced by the system are processed electronically and displayed in numeric form. In oscillometry, variations in cuff pressure resulting from arterial pulsations during cuff deflation are sensed by the monitor and used to determine arterial blood pressure values. The pressure at which the peak amplitude of arterial pulsations occurs corresponds closely to directly measured mean arterial pressure, and values of systolic and diastolic pressure are derived from proprietary formulas that examine the rate of change of the pressure pulsations. Consequently, systolic and diastolic values obtained with this technique are less reliable than mean arterial pressure values.

Indirectly measured pressures vary depending on the size of the cuff used. Cuffs of inadequate width and length can provide falsely elevated measurements. Bladder width should equal 40% and bladder length at least 60% of the circumference of the extremity measured. When a cuff is slowly deflated and blood first begins to flow through the occluded artery, the artery’s walls begin to vibrate. This vibration can be detected as an oscillation in pressure and has served as the basis for the development of several automated devices for monitoring blood pressure. The disadvantages include the inability to measure diastolic pressure, poor correlation with directly measured pressures, and lack of utility in situations in which Riva-Rocci (auscultation) measurements are also unobtainable.

**Volume Clamp Technique**

The volume clamp method avoids the use of an arm cuff. A finger cuff is applied to the proximal or middle phalanx to keep the artery at a constant size. The pressure in the cuff is changed as necessary by a servocontrol unit strapped to the wrist. The feedback in this system is provided by a photoplethysmograph that estimates arterial size. The pressure needed to keep the artery at its unloaded volume can be used to estimate the intra-arterial pressure.

**Arterial Tonometry**

Arterial tonometry provides continuous noninvasive measurement of arterial pressure, including pressure waveforms. It slightly compresses the superficial wall of an artery (usually the radial artery). Pressure tracings obtained in this manner are similar to intra-arterial tracings. A generalized transfer
function can convert these tracings to an estimate of aortic pressure. This method has not yet achieved widespread clinical use.

In summary, automated non-invasive measurement of blood pressure is a major component of modern critical care monitoring. Oscillometric and Doppler-based devices are adequate for frequent blood pressure checks in patients without hemodynamic instability, in patient transport situations where arterial catheters cannot be easily used, and in patients with severe burns, in whom direct arterial pressure measurement would be associated with an unacceptably high risk of infection. Automated NIBP monitors have a role in following trends of pressure change; however, the averaging over time is the value-laden data, not the single measure, or its comparison to invasive arterial pressure. In general, such automated devices have significant limitations in patients with rapidly fluctuating blood pressures, and blood pressure values obtained with such devices may differ substantially from directly measured intra-arterial pressures.

Given these limitations, critical care practitioners should be wary of relying solely on NIBP measurements in patients with rapidly changing hemodynamics or in whom very exact measurements of blood pressure are important. It is vital to remember that regardless of the method by which blood pressure is measured, it is a poor surrogate for the true value of concern, that is, the stroke volume that forces itself (via cardiac ejection) into the resistant arteries. For most trials conducted in humans or animals, blood pressure measures obtained by using a wide variety of methods correlate poorly with invasive arterial pressure measurements, particularly in patients with edema, who are receiving vasoactive medications, or who have significant hypoperfusion.

In the clinical environment, monitoring of direct arterial pressure uses an underdamped catheter-transducer system. The arterial response to ventricular ejection is a frequency response, that is, the stroke volume bolus of blood goes into the artery, generating a vibration column that emits many responses (arterial wall oscillations) that are averaged into the systolic pressure. These frequencies transmit into the system, which transmits the frequencies through the fluid-filled tubing and transducer. Nowadays, monitors offer internal calibration, filtering of artifacts, and printouts of the display. The digital display shows an average of values over time and thus does not show beat-to-beat variability accurately. Beat-to-beat differences in amplitude can be measured precisely by freezing the monitor display with on-screen calibration, allowing assessment of the effect of ectopic beats on blood pressure, variations in pulse pressure or systolic pressure, and the severity of pulsus paradoxus.

Direct measurement of arterial blood pressure requires that the pressure waveform from the cannulated artery be reproduced accurately on the bedside monitor. The displayed pressure signal is markedly influenced by the measuring system, including the arterial catheter, extension tubing, stopcocks, flush devices, transducer, amplifier, and recorder.

Zeroing and leveling are common procedures for most providers, but the importance of the dynamic response to fluid flush is not generally well understood or used to test the accuracy of the system. The length, width, and compliance of the tubing all affect the system’s response to change. Small-bore catheters are preferable because they minimize the mass of fluid that can oscillate and amplify the pressure. The compliance of the system (the change in volume of the tubing and the transducer for a given change in pressure) should be low. In addition, bubbles in the tubing can affect measurements in 2 ways. Large amounts of air in the measurement system damp the system response and cause the system to underestimate the pressure. Large amounts of air are usually easily detectable. Small air bubbles cause an increase in the compliance of the system and can markedly amplify the reported pressure.

**Testing the Accuracy of the Monitoring System**

**Zero Reference**

When pressure measurements seem inaccurate or differ markedly from indirect measurements, the system’s accuracy can be checked quickly. The most likely source of error is improper zeroing of the
system, which can be caused either by a change in the patient’s position or by zero drift. Opening the transducer stopcock to air and aligning the transducer with the midaxillary line should confirm that the monitor displays zero (a transducer that is below the zero reference line will result in falsely high measurements and vice versa). The monitor should be zeroed whenever the patient’s position changes, when blood pressure changes significantly, and routinely every 6 to 8 hours because of zero drift. Disposable pressure transducers are standardized and do not require calibration. If zero referencing is correct, a fast-flush test can be done to assess the system’s dynamic response.

**Square-Wave Test**

Two major factors affect the validity of pressures measured: resonant frequency response, the vibration of the fluid column in response to a change in the system (eg, flush), and the damping coefficient, evaluating the end of the vibrations.

Overdamped tracings are usually caused by problems that are correctable, such as air bubbles, kinks in tubing, clots, overly compliant tubing, loose connections, a deflated pressure bag, or anatomical factors that affect the catheter. An underdamped tracing results in systolic overshoot and can be due to excessive tubing length or patient-related factors such as increased inotropic or chronotropic state, as the vessel wall is more rigid and oscillates at a higher level. Many monitors can be adjusted to filter out frequencies above a certain limit, which can eliminate frequencies in the input signal that are causing ringing, although elimination of important frequencies will result in inaccurate measurements.

Although other techniques can be used, the easiest way to test the damping coefficient and resonant frequency of a monitoring system is by doing a fast-flush test (also known as a square-wave test). This test is performed at the bedside by briefly opening and closing the continuous flush device, producing a square-wave displacement on the monitor followed by a return to baseline, usually after a few smaller oscillations. Visual inspection is usually sufficient to ensure a proper frequency response. An optimal fast-flush test causes an undershoot followed by a small overshoot, then settles back into the patient’s waveform (Figure 1). When air is present in the tubing, a clot is on the tip of the catheter, or the catheter is not properly positioned, the waveform will

![Figure 1](http://ccn.aacnjournals.org/)  
Crisp systole, dicrotic notch, and diastole. When flush test is applied, 2 oscillations follow before return to baseline.
appear more rounded and less defined. When the square-wave flush is applied, no resonance is seen (Figure 2). Finally, when the system is underdamped, the tubing is too long, or the catheter is the wrong size, multiple oscillations are apparent after the square-wave test is applied (Figure 3).

Dynamic response validation by fast-flush test should be performed frequently: at least every 8 hours, with every significant change in the patient’s hemodynamic status, after each opening of the system (zeroing, blood sampling, tubing change), and whenever the waveform appears damped.

Components of the monitoring system are designed to optimize the frequency response of the entire system. The 18- and 20-gauge catheters used to gain vascular access are not a major source of distortion but can become kinked or occluded by thrombus, resulting in overdamping of the system. Standard, noncompliant tubing is provided with most disposable transducer kits and should be as short as possible to minimize signal amplification (overdamping). Air bubbles in the tubing and connecting stopcocks are a notorious source of overdamping of the tracing and can be cleared by flushing through a stopcock.

Despite technical problems, direct arterial pressure measurement offers several advantages. Arterial catheters actually measure the end-on pressure propagated by the arterial pulse. In contrast, indirect methods report the external pressure necessary either to obstruct flow or to maintain a constant transmural vessel pressure. Arterial catheters can also detect pressures at which Korotkoff sounds are either absent or inaccurate. Arterial catheters provide a continuous measurement, with heartbeat-to-heartbeat blood pressures.

**Problems With Comparing Noninvasive and Invasive Pressure Monitoring**

Indirect methods of measuring blood pressure estimate the arterial pressure by reporting the external pressure necessary to either obstruct flow or maintain a constant transmural vessel size. A recently published meta-analysis of 28 studies involving 919 patients concluded that inaccuracy and imprecision of continuous noninvasive arterial pressure monitoring devices are larger than what was defined as acceptable. This may have implications...
for clinical situations where continuous noninvasive arterial pressure is being used for patient care decisions.

Direct arterial catheters measure the end-on pressure propagated by the arterial pulse with every beat. They are not measuring the same end points as indirect methods measure. Rigorous validation of the accuracy of the monitoring system can be done with the square-wave flush test, but that does not ensure the value of the blood pressure measurements, just the accuracy of the system.11

Direct arterial pressure measurement offers several advantages in many but not all patients. Although an invasive catheter is required, the reported risk of complications is low. Arterial catheters provide a heartbeat-to-heartbeat measurement, can detect pressures at which Korotkoff sounds are either absent or inaccurate, and do not require repeated inflation and deflation of a cuff. Regardless of the method used, the mean arterial pressure should generally be the value used for decision making in most critically ill patients, because it is the most stable (least affected) measurement (calculation) across all methods of blood pressure monitoring.

So to answer the first question, “Is it prudent to correlate NIBP measurements with arterial blood pressure measurements?” No. Most noninvasive methods provide an average calculation for systolic and diastolic blood pressures, based on a measured mean pressure. Compare the mean pressures and consider the tested and zeroed invasive arterial pressure to be the true measure whether you like the numbers or not. These 2 types of measurements evaluate something quite different: direct pressure monitors beat-to-beat pressure pulse, whereas the commonly used noninvasive methods measure peak oscillations related to blood flow. Especially in patients treated with vasopressors, inotropic agents, and vasodilators, these measurements may differ significantly.

The second question was, “My understanding is that the accuracy of arterial blood pressure measurements is assessed by doing the square-wave test and leveling, not by correlating the arterial measurements with the NIBP values. However, I observe the practice of correlating with the NIBP values so often, it makes me wonder if I have misunderstood my previous training on arterial catheters.”

Leveling and square-wave testing provide an evaluation of the system and validation of system acceptability. Neither test validates the patient’s arterial pressure, but the tests validate the integrity of

Figure 3  Spiked systole with a lower diastole should alert the provider to a possible underdamping issue. Underdamping usually occurs when the tubing is too long or the catheter is the wrong size. The problem is usually not physiologic. Reduce the tubing length and stabilize or replace the catheter. Observe that the mean pressure remains constant between oscillated and invasive.
the monitoring system that measures the pressure. If zeroing is performed and the square-wave test is passed, you can rest assured that the direct pressure is being monitored correctly. When invasive arterial pressure monitor is zero referenced, leveled, and passes the frequency response test, then the invasive pressure is what should be monitored. At the very best, correlation can be made between noninvasive and invasive measurements at the mean pressure measure only.

Remember that the primary role of the circulation is to provide tissues with dissolved and bound oxygen as well as other energy substrates, so it is always best to correlate pressure readings with indicators of tissue perfusion, no matter what method(s) you choose for monitoring. Recommendations for pressure targets must take into consideration the site and method of measurement as well as the true value of blood pressure versus oxygen adequacy. Trends in blood pressure and the relationship to metabolic measures are the most important measures in today’s critical care environment. CCN

Financial Disclosures
None reported.

References