# Technical aspects of intravascular pressure monitoring during donor care

Many biological signals must be measured and interpreted accurately to titrate therapy properly during donor care. Although the technological aspects of intravascular pressure monitoring are usually delegated to bedside nursing colleagues, organ procurement coordinators should be familiar with those devices and methods. The equipment, supplies, and procedures used for arterial and central venous pressure monitoring are reviewed. Transducer leveling and zeroing plus maintenance of the hydraulic tubing system between the transducer and bedside monitor are especially important. These variables may greatly influence the accuracy of the displayed pressures and, therefore, must be considered during donor assessment as treatment is considered. (*Progress in Transplantation.* 2010;20:22-27)

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## Notice to CE enrollees:

A closed-book, multiple-choice examination after this article tests your ability to accomplish the following objectives:

1. Describe the physiologic processes that affect intravascular pressure monitoring
2. Discuss the importance of leveling the transducer with intravascular pressure monitoring systems
3. Identify possible causes of waveform dampening

The importance of intravascular pressure monitoring during donor care has been emphasized in other publications.[1,2] Similarly, authoritative groups have provided guidelines for individual parameters that are considered optimal for maintaining organ perfusion.[3-5] Aggressive evaluation and treatment of hemodynamic variables, titrated to specific goals, have also demonstrated that suboptimal organs can be improved and can perform well after implantation.[6] Organ procurement coordinators are, therefore, often responsible for directing donor care toward these important goals.

If therapy is to be titrated, the data acquired from ongoing monitoring must be accurate measurements of the donor's physiological condition. Reliable information is therefore a prerequisite for appropriate treatment. The responsibility for preparation, attachment, and maintenance of bedside monitoring equipment is usually delegated to the nurse assigned to the donor and other supportive hospital personnel, such as biomedical technicians. However, as advanced practice methods during organ procurement expand and the use of external donor care/organ recovery facilities[7] becomes more common, an understanding of the technology required for accurate hemodynamic monitoring may become more important for procurement coordinators.

Specific aspects of the system for monitoring intravascular pressure, transducer function, and variables that influence the accuracy of measurements are reviewed in the following discussion. Alternative methods commonly used during arterial pressure measurement (eg, oscillometric noninvasive techniques) and use of pulmonary artery data are discussed elsewhere.[2,8]

Information for this review was obtained from standard texts, the authors' files, and publications obtained from a directed search of the PubMed database from 1990 to 2008. Many of the citations referenced form the foundation upon which current routine practices are based.

## The Monitoring System

In general biomedical terms, the biological signal of interest, that is, an arterial or venous pressure waveform, is conveyed to a transducer, which converts the hydrostatic pressure within the intravascular compartment into a small electrical impulse. That impulse is increased by the amplifier within the bedside monitor and then displayed on the monitor screen. The first components of this process depend on the actions of bedside personnel and the last depends on biomedical management and preventive maintenance programs of the hospital.

## The Biological Signal

A biological signal may be any measurable quantity produced by the patient/donor (eg, electrocardiogram, electroencephalogram, blood pressure). This discussion is limited to the cardiovascular signals of arterial and venous pressure waveforms. These biological signals depend upon the physiological processes that produce them, for example, cardiac output, intravascular volume, friction of the blood against the wall of the blood vessel, elasticity of the vessel wall, choice of the artery or vein for pressure monitoring, and position of the catheter within the vessel.[8,9]

The arterial or venous pressure signals arrive at the intravascular catheter as complex waveforms created by the interaction between the heart and the arterial or venous walls. For example, throughout myocardial systole, a series of impulses occurs as systole proceeds through its building to lessening phases of myocardial contraction. These impulses move along the arterial vasculature, affecting the arterial/arteriolar walls, and ultimately reaching the tip of the catheter as a sequence of waveforms. Along this pathway, the impulses may encounter division (bifurcation) points in the artery, arterial plaques, or vessel irregularities that can absorb or deflect the forward-moving impulse. Likewise, these divisional or obstructing points may reflect the impulse back toward the heart as a "retrograde" waveform that has its own power and waveform characteristics. This reflection process is analogous to the ripple of a wave in a pool of water that hits the side of the pool or container and creates a wavefront that rebounds back against the incoming wavefront.

Depending on the characteristics and timing of the retrograde waveform, it may interfere with or augment the forward-moving primary arterial or venous wave.

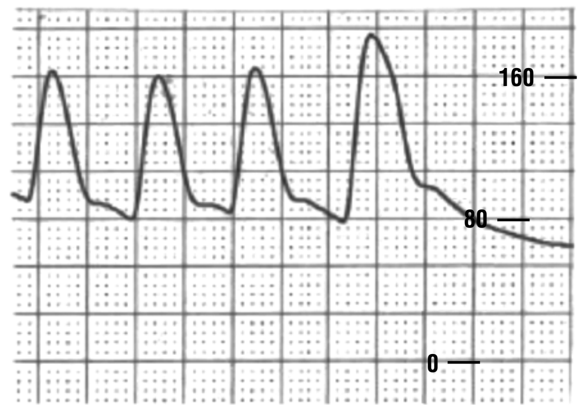


Figure 1 Normal arterial waveform.

The resultant composite waveform reaching the catheter tip may, therefore, be altered from its original configuration that left the heart. The complex interaction of forward and retrograde waveforms may be further analyzed but is beyond the scope of this discussion.[10]

Of clinical importance, however, is that although a single waveform appears on the bedside monitor (Figure 1), the potential intravascular interactions just noted may alter the appearance of the waveform and the accuracy of the measurement of the biological signal. Two examples of these changes are the overdampened and underdampened waveforms shown in Figure 2. These variations may occur when a retrograde waveform directly coincides (is synchronous with) with the forward-moving wavefront and the 2 augment each other, producing an "underdampened" configuration. Overdampening may also result from air bubbles within the tubing system, as discussed later. Conversely, when the 2 wavefronts are dyssynchronous, they may offset each other and result in an "overdampened" configuration. In both circumstances the "mean" arterial or venous pressure is not usually affected as much as the systolic pressure recording is affected. Therefore, mean or average vascular pressure is often used during titration of treatment.

## The Hydraulic Coupling System

The vascular catheter is joined to the transducer by silastic or plastic tubing filled with saline. The entire tubing system must be carefully purged to remove air, because air is easily compressed within the tubing and may greatly distort transmission of any pressure waveform. Additional tubing attached to a flushing device also is joined to the tubing system and continuously infuses saline (with or without heparin) retrograde through the catheter so as to keep it patent. The biological signal waveform must be faithfully transmitted through this hydraulic system without any change. Characteristics of the tubing system that are known to influence waveform conduction are shown in the

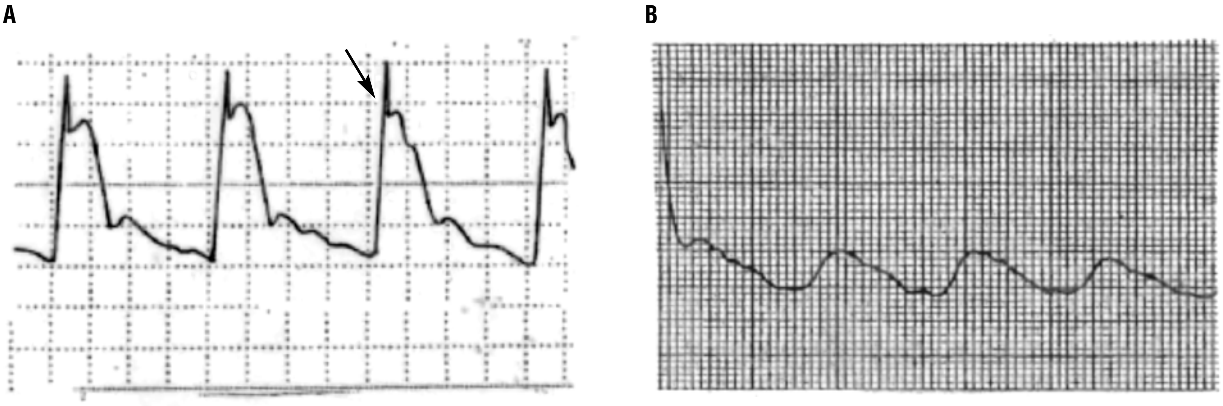


Figure 2 Abnormal arterial waveforms. A, Overdampened arterial waveform: the abnormal "spike" (arrow) is most likely due to synchronous overlap of forward-moving and retrograde wavefronts. B, Underdampened waveform: may be due to air bubbles in tubing system/transducer or other causes (see Table).

Table.[8] These factors contribute to a characteristic of the tubing system known as its frequency response. This feature identifies that the tubing may "resonate" or vibrate with or against the forward-moving (antegrade) wavefront. The resultant resonance may further amplify or dampen the wavefront and thereby alter the accuracy of the measurement reading.[8]

Most of the variables listed in the Table that could affect hydraulic coupling will have been considered by the hospital's biomedical department during purchase of the tubing systems. Therefore, they would not be modifiable factors during donor care, except for ensuring that no bubbles are present in the tubing or transducer, the length of tubing is as short as possible, and the tubing is not kinked.

## The Transducer

Transduction is the process wherein one form of energy is converted to another. In this discussion, the mechanical force of the pulsed waveform (arterial or venous) is converted to an electrical (voltage) signal. An input current is carried from the bedside monitor to the transducer via a connecting cable. Within the transducer, a set of wires functions as a resistor for current flow within the transducer. As pressure is applied from the pulsed waveform against a sensing diaphragm or similar detector, the electrical resistance is changed in the transducer and flow of the input electrical current through the transducer is increased. The new output current from the transducer is returned to the amplifier in the bedside monitor. In this way, the biological signal of intravascular pressure has been changed to an electrical impulse.

The resistance changes within the transducer mimic the physiological pulse amplitude variations throughout the input of the physiological waveform and its conduction through the tubing to the transducer. The electrical impulse therefore varies as a reflection of the waveform changes during each cardiac cycle, and the configuration or shape of the biological signal, the pressure waveform, ideally is faithfully duplicated by the electrical signal.

Table Variables in hydraulic tubing systems that may cause inaccurate pressure measurements

| Variable | Explanation |
|---|---|
| • Air bubbles within the tubing/transducer | • Air bubbles are compressible and diminish the waveform and the transmitted pressure |
| • Length of tubing from the indwelling catheter to the transducer | • Tubing that is too long decreases waveform amplitude and accuracy |
| • Compliance (stiffness) of plastic tubing | • Tubing that is too soft "dampens" waveform |
| • Number of stopcocks or connections between catheter and transducer | • Too many stopcocks or connections reduces waveform amplitude and pressure accuracy |
| • Clot formation in the catheter or tubing | • Clots decrease pressure transmission |
| • Kinks in the tubing | • Kinks decrease waveform transmission |

### Transducer Leveling

Proper positioning of the transducer establishes a reference point for pressure monitoring.[11] The correct reference position for arterial and venous pressure monitoring requires that the top of the transducer be in the same plane as the right atrium. This location is customarily considered to be at the midaxillary line and is often called the "phlebostatic axis" (Figure 3). In some intensive care units, the transducer may be taped to the patient's chest in the correct position. However, most often the transducer is placed on a

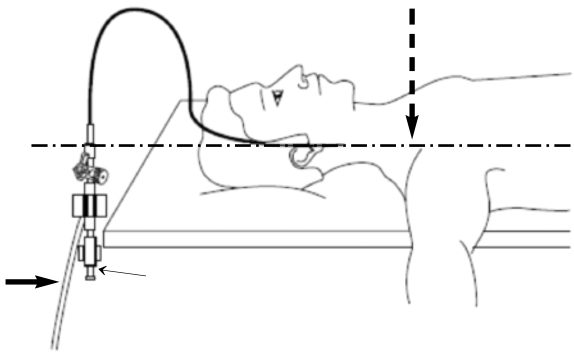

Figure 3 Schematic of intravascular monitoring assembly. An internal jugular venous catheter is attached to a transducer placed in the midaxillary level position ("phlebostatic axis") (dashed arrow and horizontal line). The transducer connects to the bedside monitor via an electronic cable (thick solid arrow) for conduction of a current to and from the transducer. A saline/heparin flush device is attached to the transducer/catheter (thin arrow).

free-standing pole at the bedside and its height adjusted so as to align it with the midaxillary line.

Positioning the transducer below the phlebostatic axis artificially raises the displayed pressure. Conversely, the pressure recording is falsely low if the transducer is above the midaxillary line. A measurement error of about 0.74 mm Hg occurs for each centimeter the transducer is from the proper "level" position.[12] Therefore, if the donor's head-of-bed or entire bed is raised or lowered, releveling the transducer to the midaxillary line is required.

### Transducer Zeroing and Calibration

This process is critical to transmitting the intravascular pressure accurately.[11] Its purpose is to establish atmospheric pressure as one reference for accurate pressure measurement. The transducer is "zeroed" to atmospheric pressure by adjusting (opening) the upper stopcock on the transducer so as to expose the transducer to bedside atmospheric pressure. After opening the stopcock on the transducer assembly, the nurse simply pushes the monitor's "zero" button and a reference signal is entered into the monitor. Modern monitors thereafter automatically initiate a second electronic calibration signal to establish a second reference point. After the stopcock is "closed" to allow the transducer to again be exposed to the biological pressure signal, the electrical current from the transducer is compared with the previously created zero and calibration scale, thereby generating the electronically equivalent value of the arterial/venous pressure.

### Signal Processing/Display

The output current created in the transducer and returned by the same electrical cable that carried the initial current to the transducer requires additional manipulation within the bedside monitor. The general term signal processing may include conversion of the direct-current output from the transducer to alternating current, amplification of the current received from the transducer, change to a digital signal, algorithms to "filter" out some variations in the signal due to artifacts, and calculation of mean values for some parameters. The "signal" is then displayed on the monitor as the respective waveform and/or numeric image.

Variations in the way the monitored parameter can be displayed are extensive. The display can be compared on a variety of electronic scales for convenience of interpretation. For example, when a pulmonary artery catheter is inserted,[13] the monitor display of the amplified venous waveform is adjusted to show the venous waveform transition through the heart, using a scale from 0 to 60 mm Hg to enlarge the waveform changes, while other monitoring scales can be used for routine observations. Other features of the monitor's display programs may include "freezing" or stopping the waveform's progression across the screen to allow closer inspection, memory functions, transport of the signal to other remote monitors, trending of variables over time, connection to a paper recording device, and alarm features to detect deviations from set parameters.

## Clinical Application

As noted earlier, bedside nurses are usually assigned responsibility for implementing and maintaining the equipment and supplies for vascular monitoring. This responsibility, however, may be given to procurement personnel if the number of hospital-independent organ recovery facilities increases.[7]

Collaborative practice between the bedside nurse and the procurement coordinator also should allow discussion during the assessment of variations in intravascular pressures. For example, an important part of the diagnosis of hypotension or hypertension includes surveillance of the monitoring system to exclude any measurement errors that might produce false (inaccurate) central venous, pulmonary artery, or arterial pressure readings. Thus, inspection of the transducer's position relative to the midaxillary line, rezeroing the transducer, or searching for air bubbles in the tubing system may reveal the reason for new hypotension displayed on the bedside monitor and prevent addition of potentially harmful vasoactive drugs. This type of collaboration, when offered constructively, should be welcomed as supportive of everyone's goal of providing the best organs to the recipient.

**Financial Disclosures**

None reported.

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## CE Test

**Test ID 4000-138: Technical aspects of intravascular pressure monitoring during donor care.**

**Learning objectives:** 1. Describe the physiologic processes that affect intravascular pressure monitoring 2. Discuss the importance of leveling the transducer with intravascular pressure monitoring systems 3. Identify possible causes of waveform dampening

**1. The intravascular pressure that is converted to obtain a biological signal is which of the following?**

a. Orthostatic pressure
b. Hydrostatic pressure
c. Oncotic pressure
d. Phlebostatic pressure

**2. Which of the following physiological process(es) directly influence(s) arterial or venous pressure monitoring?**

a. Cardiac output
b. Intravascular volume
c. Elasticity of the vessel wall
d. All of the above

**3. The characteristics of the vessel chosen for catheter placement can alter the appearance and accuracy of the waveform.**

a. True
b. False

**4. The entire tubing system of the monitoring device must be carefully purged to remove air because of which of the following?**

a. Air is easily compressed and diminishes the amplitude of the waveform.
b. Air is easily compressed and increases the amplitude of the waveform.
c. Air is not easily compresses and diminishes the amplitude of the waveform.
d. None of the above

**5. The nonmodifiable factors that affect the frequency response of the hydraulic tubing system are which of the following? (Select all that apply.)**

a. Air bubbles in the tubing
b. Kinks in the tubing system
c. Compliance of the tubing system
d. Clot formation in the catheter or tubing system

**6. The correct reference point of the transducer for arterial or venous pressure monitoring…**

a. …requires the transducer to be in the same plane as the right atrium.
b. …is called the phlebostatic axis.
c. …is customarily considered to be the mid-axillary line.
d. All of the above

**7. Releveling the transducer to the phlebostatic axis is required after any change in the donor's position or the level of the bed because of which of the following?**

a. A measurement error of 0.74 mm Hg occurs for each centimeter the transducer is not at the proper level.
b. The pressure recording is accurately elevated or decreased.
c. It is not necessary to relevel the transducer after a change in the donor's position or level of the bed.
d. None of the above

**8. The processes involving the transducer to ensure accurate transmission of the intravascular pressure include which of the following?**

a. Leveling the transducer to the mid-Clavicular line
b. Zeroing/Calibrating the transducer to atmospheric pressure
c. Adding additional stop cocks
d. Purging the tubing of all air bubbles

**9. The purpose of transducer calibration/zeroing is which of the following?**

a. To establish atmospheric pressure as one reference for accurate pressure measurement
b. To initiate a second reference point
c. For pressure adjustment
d. None of the above

**10. During donor care the arterial waveform is observed to be underdampened; the possible causes include which of the following?**

a. There is a clot in the catheter or a kink in the tubing.
b. The level of the bed/donor is lower than the level the transducer.
c. The patient has become acutely hypotensive and needs resuscitation.
d. All of the above

**Test answers:** Mark only one box for your answer to each question. You may photocopy this form.

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