129

Draft 15 Feb 86
Started working on again -- February 4, 1993 Reed!!

DYNAMIC RESPONSE

AND THE ESSENTIALS OF

INVASIVE BLOOD PRESSURE MONITORING

Edited by
Reed M. Gardner, PhD
Professor of Medical Informatics
LDS Hospital/University of Utah
Salt Lake City, Utah

Sections by

Alan H. Morris, MD
Associate Professor of Medicine
LDS Hospital/University of Utah
Salt Lake City, UT

Radene H. Chapman, RN, MS
Head Nurse, Respiratory Intensive Care Unit
Beth Israel Hospital/Harvard University
Boston, MA

Karen W. Hollingsworth, RN, MS
Cardiovascular Clinical Specialists
LDS Hospital
Salt Lake City, Utah

Prepared for Sorenson Research

TABLE OF CONTENTS

Draft of 8 Feb 86

Components Used in Invasive Pressure Monitoring Systems

Reed M. Gardner, PhD

Figure 1 is illustrative of the equipment used in acquiring direct measurements of blood pressure in the critically ill patient [1]. The function and potential limitation of each component in the system are discussed. Components numbered 1 through 7 must be sterile because they come in direct contact with the patient's circulatory system. These components are typically referred to as the "plumbing system". In most institutions they are disposable or single use items are used and are discarded after limited use (24-48 hours) because of the risks of contamination to the patient. Components 8 through 11 are used for processing and displaying pressure waveforms and derived parameters. A brief discussion of the function and limitation of each component follows.

1. Catheter

There are two primary purposes for insertion of the arterial and pulmonary artery catheters. The first is to provide access to the blood vessel for measurement of the intravascular pressures. The second equally important purpose, is to provide a site for drawing blood samples for use in blood gas analysis and other tests.

2. Stopcocks

Stopcocks are usually connected directly to the catheter or through 3 to 6 inches of pressure tubing and become a site for withdrawal of blood samples for blood gas and other tests. Modern disposable stopcocks cause minimal monitoring problems. They are made of clear plastic so air bubbles can be readily seen and easily removed and they have luer lock connections which prevents accidental disconnection.

When filling the plumbing system with fluid, care must be taken to make certain that all of the central switching cavities within the stopcock are filled with fluid so that no trapped air bubbles remain. Extreme care should be taken when handling the stopcocks and other ports to ensure that the patient is not contaminated during sample withdrawal or zeroing by touching the open ports.

3. Pressure Tubing

Pressure tubing is used to attach the catheter and stopcock to the flush device and transducer. For best pressure waveform reproduction, the tubing should be non-compliant (rigid or semi-rigid) pressure tubing and as short in length as possible. IV tubing is too soft and is not suitable for use as pressure tubing.

4. Stopcock

The #2 stopcock (See Figure 1) is usually put in place to allow disconnection of the flush device and transducer from the patient.

5. Continuous Flush Device

The continuous flush device (#5 in Figure 1) allows the system to be filled with fluid and also provides for a 1 to 3 ml-per-hour continuous flush of fluid through the catheter to prevent clotting. Techniques using the continuous flush device for verifying the "plumbing" system's dynamic response with the fast flush test are presented.

6. Transducer Dome

In recent years disposable diaphragm transducer domes (#6 in Figure 1) have become more available for use on pressure transducers. These disposable domes allow isolation of the transducer from the patient and thus permit rapid re-use of the transducer without re-sterilization. However, if not properly affixed on the transducer, diaphragm domes will cause poor coupling of the pressure wave to the pressure transducer and will result in a distorted waveform display.

7. Pressure Transducer

Pressure transducers come in a variety of sizes and shapes. The transducer is usually a resistive device (a Wheatstone Bridge) which converts the movement of its sensing diaphragm to an electric signal. Pressure pulses transmitted down the catheter-tubing system cause the sensing diaphragm to move. The resulting electrical signal is very small. Small signals from the transducer are amplified and processed by the bedside monitor.

Several disposable pressure transducers have become available and they will likely come into more common use because they are smaller, more stable and more rugged than are the more expensive reusable transducers. Disposable pressure transducers already cost less than $15 and are expected to decrease in price; reusable transducers have better technical characteristics (such as stability of sensitivity and zero offset) as well as superior ability to take abuse caused by bumping and dropping, than do the current more expensive reusable devices.

Factors which should be considered when selecting a pressure transducer are listed below:

A. Ruggedness--withstand repeated clinical use/abuse.
B. Stability--"zero" and sensitivity stable with time and temperature.
C. Interchangeable--will they work with all your monitors?
D. Easy to set up-- are they easy to fill and use? consider the cost, inconvenience and problems of filling, coupling, and calibrating.
E. Cost--consider all cost factors such as setup time, repair, cleaning, sterilization, and disposable costs.

8. Amplifier System

For a transducer to provide sufficient output voltage to be displayed on oscilloscope or a strip chart recorder, an amplifier system is placed between the transducer and the display. Amplifiers usually increase the electrical signal 1000 times. The amplifier system may include low pass filters. These filters block out unwanted high frequency signals. Pressure amplifiers should have a flat frequency response from 0 (DC) to 50 Hz so that the patient's pressure waveform is not distorted. A DC response is needed because there is always steady (mean) pressure on which the pulse pressure is superimposed.

9. Oscilloscope

A calibrated oscilloscope is the best way to view blood pressure waveforms. The oscilloscope allows visualization of each pressure waveform and permits the determination of respirator variations, artifact, and distortion which may enter into the pressure signal. Although all pressure waveforms need not be displayed continuously and simultaneously, the ability to display each pressure quality as will be discussed below.

10. Digital Processing and Display

Digitally displayed results are available on most monitoring equipment. The digital displays present systolic, diastolic and mean pressure and in some cases give heart rate determined from the arterial pressure waveform. Digital displays provide a simple means of obtaining the qualitative results from pulse waveforms, but in most cases they have serious limitations.

11. Strip Chart Recorders

Strip chart recording devices are commonly, but not universally, available on pressure monitoring systems. It is highly recommended that strip chart recorders be available for documentation of pressure waveform changes, as well as for documentation of dynamic response characteristics. Recorders with appropriate sensitivities, and preferable a calibrated scale, should be used. Recorders are invaluable for measuring system dynamic responses, documenting aberrant rhythms, and especially for measuring pulmonary artery pressure where respiratory variations can cause large deviations leading to clinically important errors in pulmonary artery pressure reading.

February 8, 1986 Draft with Reed's editing

WHAT IS DYNAMIC RESPONSE

AND

WHY IS IT IMPORTANT IN PRESSURE MEASUREMENT?

Alan H. Morris, M.D.

The goal of all measurements of intravascular pressure is to provide rapid, precise, and accurate determination of the true pressure. The accuracy with which the system represents the true blood pressure is measured by the difference between the measured value and the "true" value. The precision with which the pressure is measured is indicated by the repeatability with which a known pressure can be measured and is frequently assessed by measures such as standard deviation, coefficient of variation or standard error of the mean. The time varying characteristics (dynamic response characteristics) of a pressure measuring system can be determined by the fast flush test. The fast flush test produces a rapid or "step change in pressure" which disturbs the measuring system. The response to a fast flush test can be used to predict the response of the pressure monitoring system to periodic waveforms such as arterial pressure waves [2,3,4].

Many systems encountered in the body and most systems from which we obtain pressure measurements behave like--and can be modeled as if they were--second order systems [3,4]. A second order system has two energy storage elements. In the physiologic pressure measurement situation they are commonly mass (possesses the properties of inertia and momentum) and recoil elements (possessing springy or compliant properties). After the system is perturbed from its equilibrium position, energy transfer between these tow energy storage elements leads to a characteristic oscillation or "ringing" response (the natural response) which will be superimposed upon the forced response (the change impressed upon the system or object of interest) [2]. Some common examples of such systems include a car with poor shock absorbers (Figure 2) which after hitting a chuckhole bounces at its nominal frequency (Fn). Other examples include the "booming" of a low quality high fidelity system when certain low frequency notes are encountered; the oscillation and ringing of a tuning fork when struck; and the "sympathetic" vibration induced in the appropriate piano strings when the oscillation fork is brought to the piano string. Such systems tend to oscillate for a period of time determined by the freedom with which the system is allowed to move back and forth. A system which is very free to move back and forth will oscillate for an extended period of time and have a very long "settling time". A system in which movement is impeded (for example, a tuning fork placed into a glass of water or honey) will cease oscillating very quickly and have a short "setting time". When the system is unimpeded it will take a long time to cease oscillating. Figure 3 shows three other common objects exhibiting the response of a second order system. The "pan" balance has both mass and recoil and oscillates when displaced from its equilibrium position. The magnetic needle of the compass has mass and the recoil is provided by the interaction of the earth's gravitational field with the magnetic needle of the compass. The U-tube manometer has mass represented by the fluid contained within and a restoring pressure produced by the difference in heights between the two columns (h). Each of these systems will oscillate about a final equilibrium point after a sudden displacement from its equilibrium position.

A number of problems encountered in the clinical monitoring of blood pressure can interfere with the rapid, accurate and precise measurement of intravascular pressures [3,4]. These problems include:

1. A constant bias introduced by inaccurate static calibration due either to an improper zeroing or incorrect gain (amplitude) adjustment.
2. Artifacts caused by an unwanted but superimposed persistent signal which cannot be distinguished from the true pressure signal. For example whip artifact with pulmonary artery catheters.
3. The introduction of artifact in the same frequency range as the blood pressure signal. If high frequency noise is present it can usually be eliminated or significantly reduced by low pass filtering the signal.
4. Overestimation of the true systolic pressure as a result of distortion caused when underdamped pressure monitoring systems are used.
5. Underestimation of the true systolic pressure when overdampened pressure monitoring systems are use.
6. When the tip of the catheter has a clot in it or when the catheter tip rests against the wall of a vessel and prevents free fluid flow. The later condition is quite common when measuring pulmonary artery pressure.

These potential problems are common to all physiologic pressure measurements. In practice because of the large pressure measured, systemic arterial blood pressures are the easiest to measure. Eliminating these potential problems when measuring pulmonary vascular because of the lower pressures in the pulmonary circulation and because of the excessive noise introduced with the commonly used balloon-tipped flow directed catheter (Swan-Ganz). The catheter is relatively soft and passes through two heart valves which strike the catheter during valve closure with each heart beat. Although between the right atrial lumen and the pressure transducer, and the presence of a patent right atrial prot makes measuring the pressure straight formed. The measurements of the ??? wedge pressure Pra is not used ??? ??? ??? ??? ??? of a balloon and the catheter goes through the front and two of its valves.

The system commonly used for measuring physiologic pressures incorporate a catheter introduced into a vascular lumen, connecting tubing and a pressure transducer with a deformable diaphragm which is moved slightly by the changes in vascular pressure which results in small movements of fluid into and out of the catheter tip with each pressure pulse. It is axiomatic that rapid, accurate and precise measurements of intravascular pressure require a patent connection between the vascular lumen and the deformable element (diaphragm) of the pressure transducer. Free flow of fluid between the vascular lumen the pressure measuring system must be present to allow faithful pressure measurements. Years ago, the presence of free flow in a pressure measuring system was documented by observing the rapid and unimpeded descent of a saline manometer fluid column connected to the pressure measuring catheter [5]. In most clinical settings performing this procedure is no longer practical. However, two measures are presently available to test the patency of the pressure measuring system and establish that free flow is present. The first, and most practical, is the evaluation of the "dynamic response" of the pressure measuring system [6-9]. Using the fast flush test, the second is the ability to easily aspirate blood from the pressure measuring catheter [7-9].

In an analogous way to other mechanical system, the plumbing systems use for measurement of physiologic pressure contain two energy storage elements (Figure 4). The fluid column inside the catheter and tubing plumbing system has mass and therefore properties of inertia and momentum. The membrane of the pressure transducer is deformable although it moves only a few thousands of an inch with each pressure pulse and acts like a spring. If fluid is free to move rapidly in and out of the catheter tip to the transducer diaphragm, the dynamic response of the system might be satisfactory. If however, there is a clot at the catheter tip, the dynamic response of the system will be degraded. Figure 5 illustrates the responses of three pressure measuring systems, the lower panel revealing an underdamped response with prolonged oscillation, the middle panel revealing an almost ideal damping level with just a few oscillations and the upper panel indicating an overdamped system with no oscillations. In each of these three responses, the pressure was initially at a high level (on the left of the figure) and was suddenly dropped to a lower level.

The consequences of these problems can be critical to clinical decision making. Figure 6 illustrates the serious overestimation of systolic blood pressure which can occur when an underdamped system is utilized to measure a rapidly rising systolic blood pressure (one with a very fast systolic upstroke with a large Dp/dt). Such overshoot errors can be eliminated by systems with appropriate dynamic response (discussed in a later chapter). Figure 7 illustrates the danger when an apparently overdamped system is used to measure systemic blood pressure. Panel A through D all represent mean blood pressure obtained at 10:15 when blood could not be aspirated from a femoral artery catheter. Note that the mean blood pressure varied from 74 to 111 mm Hg within a mater of minutes although the patient was stable. The dynamic responses determined with the fast flush tests are inadequate in all of these panels. The dynamic response in panel E and F became adequate only after the catheter was withdrawn from the artery (0.5 and 5 cm respectively) with a mean blood pressure between 104 and 107 mm Hg. The reason for the difference in mean pressures is apparent upon inspection of Figure 8 where the arcom?? shows the point at which the continuous flush device (Intraflo) introduces the constant slow flow (3 ml/hr) through the catheter the plumbing system. If the dynamic response of the system is degraded because the catheter tip is plugged either with a clot or is burrowed into the intima of the vessel or is pressed against a vascular web (such as in the pulmonary circulation) when an important fraction of the 300 mm Hg may appear as a flow resistive pressure drop across the catheter tip. If this occurs, the pressure sensed by the transducer may vary ??? importantly from the patient's true pressure as illustrated in Figure 7.

Pressure measurement problems in the pulmonary circulation and particularly the pulmonary artery balloon occlusion or "wedge" (Pw) pressure are common. The 95% confidence interval for repeated measurements of Pw in stable patients is 4 mm Hg [8].

Wedge pressure differences of 4 mm Hg or more are therefore considered to be significant errors in our intensive care environment. A prospective study of 2,711 Pw measurements revealed that technical problems were present 30% of the time [7]. When Pw measurements were associated with technical problems there was a 33% chance of encountering a Pw error of 4 or more mm Hg whereas Pw measurements without technical problems were associated with only a 5% change of Pw error of 4 or more mm Hg [8]. Fast flush test dynamic response testing at the bedside allowed the prompt identification and correction of most (62%) of technical problems. Most of these technical problems are easily overlooked if not actively sought and most can be eliminated after they are identified [8].

Fast flush dynamic response testing has proved to be an excellent addition to the pressure measurement protocol in the ICU and has allowed rapid identification of the problem measurement. It has enabled those who use it to more appropriately direct the limited resources of the medical environment to the pressure measurement which is likely to generate an erroneous value (that measurement associated with technical problems) and has therefore been a valuable adjunct to pressure monitoring.

Draft 8 Feb 1986

How to Verify Dynamic Response Characteristics in the Clinical Setting

Radene Chapman and Karen Hollingsworth

Invasive hemodynamic pressure monitoring has become routine practice in the critical care setting. However, questions about the accuracy of the recorded pressure measurements remain. Intravascular pressure have the potential of being more accurate than clinically obtained auscultated pressures if several steps are taken to guarantee their validity.
First, the monitor and transducer must function properly and be used appropriately. Today's monitoring equipment is reliable but it must be serviced, calibrated and used as recommended by the manufacturer.
Second, zeroing must be done correctly with the transducer zeroed at the right-atrial level [1,10].
Third, the dynamic characteristics of the catheter-tubing-transducer system must be evaluated and optimized [11-14].

Equipment Issues

Frequency Response

The system used to monitor patients hemodynamic pressures have many sources of error. The components of the system for monitoring pressure were illustrated in Chapter 1, Figure 1.

Geddes states that good reproduction of the pressure waveform can usually be achieved if the overall system can respond uniformly at 10 times the cardiac frequency [15]. For example, if the heart rate is 120 per minute, the cardiac frequency is 2 per second (2 Hz) a uniform frequency response of at least 20 Hz is required for good waveform reproduction. As a consequence pressure monitoring systems perform no better than their poorest component. All system elements should have a frequency response greater that 20 Hz. Others have shown that the frequency response can be as low as 12 Hz if the system damping is adjusted [6].

Catheters

As shown in Chapter 2, catheters which are short and have large diameters provide the highest possible natural frequency. The catheter inserted should be as non-compliant as possible. Unfortunately, these requirements are not often achieved in the clinical situation. Catheters ??? are of the narrowest diameter possible to prevent thrombosis and they are often quite long (pulmonary artery catheters). Clinical monitoring catheters must also be somewhat compliant to facilitate passage and prevent trauma to the blood vessel wall. This makes the requirement for optimizing the remaining elements of the system even more crucial.

Tubing

Usually tubing and ??? are used to connect the ???. These components must be non-compliant since the frequency of oscillation (natural frequency) decreases as compliance increases. The volume displacement in the system is also an important consideration. As the volume displacement of the component increases, the natural frequency decreases. A system with the shortest and most non-compliant tubing with the least number of connections will produce the best system for recording accurate waveforms [Nancy].

Flush Device

Choosing a continuous flush device to be used in one of the most important decisions made in putting together a monitoring system. The flush device must have low volume displacement. In addition, it must have the capability to close quickly to generate a fast flush test. The fast flush test is used to measure the natural frequency and the damping coefficient of the system. Fast flush is done easily and conveniently at the bedside.

Dome and Transducer

The diaphragm is the deformable element of the pressure monitoring system which responds to changes in vascular pressure by movement forward and backward. This movement is usually sensed as change in electrical resistance in the transducer (Figure 9).

The electrical signal from the transducer is then amplified and displayed by the monitor oscilloscope.

The diaphragm dome and transducer must be properly coupled to obtain accurate pressures. It is crucial to accurate monitoring that no air be introduced between these two elements. Since air is easily compressible, air in the system will cause loss of movement energy in the fluid column affecting the pressure measurement and causing natural frequency to be decreased (damping) [1,6]. The diaphragm must come in close contact with the transducer or error will occur in pressure measurement. For instance, when 100 mm Hg pressure is applied it may give an output of only 90 mm Hg given an inaccurate pressure reading. Another consideration for the transducer is the amount of volume displacement. Different transducers vary from 0.01 to 0.2 microliters per 100 mm Hg. The smaller the volume displacement, the better the dynamic response [16].

Amplification and Display

Many existing amplifier systems have adequate frequency response for reproducing pressure waveforms. The frequency should convert the range from DC to 50 Hz. Many currently produced monitoring systems limit the frequency response to 12 Hz or less. This is done in an attempt to compensate for the overestimation of systolic pressure or might occur when a system is underdamped. This filtering of the pressure signal limits the ability to clinically measure and optimize the natural frequency of the system [16].

The type of display device used to present pressure waveforms may be an oscilloscope, a paper recorder or both. Most oscilloscope displays are capable of reproducing the actual patient pressure waveform and of the square wave test. Some paper recorders, especially those with thermal pen writers cannot reproduce the pressure waveform faithfully. If the frequency response is limited, the displayed pressure may be lower than actual because the highest frequency of the waveform will not be reproduced (Figure 10).

Clinically, it is important that the person responsible for measuring hemodynamic pressures, interpreting results and instituting therapeutic interventions know the equipment limitations. ??? erroneous data and subsequent ???? might have an understandable effect on the patient being treated. It has been demonstrated that improved accuracy of pressure measurement is possible if the system is optimized to provide high natural frequency that can be measured clinically at the patient's bedside.

Dynamic Response Measurement

Proper zeroing, calibrating, and troubleshooting pressure monitoring systems are routine measurements. However, checking the dynamic characteristics of pressure monitoring systems using the fast flush are not. The fast flush test is easily done in the ??? and can be done routinely with pressure measurements in the clinical setting.

Fast Flush Testing

The dynamic response (frequency response and damping coefficient) can be measured from a recording of the pressure waveform during which 2 or 3 fast flushes are made. A fast flush is made by "snapping" the rubberized tail on the Intraflo. The Intraflo is routinely used to provide fast fluid flow through the catheter, cleaning it of blood, and to provide a continuous minimal flow of fluid through the catheter to maintain patency. When the valve is opened by pulling the tail, not only is fluid forced through the catheter, but the transducer and catheter system are exposed to the high pressure (potentially of the order of 300 mm Hg). When the tail is released, the pressure in the system suddenly drops as the fast fluid flow stops. This suddenly decrease in pressure, known as a square wave test, typically causes the catheter-tubing-transducer system to oscillate or "ring" and then return to the patients pressure (Figure 11 example A).

To evaluate the dynamic response test, a recording of the waveform with "flushes" should be made. Two measurements from the waveform need to be determined: 1) the natural frequency, or how fast the system oscillates, and 2) the damping coefficient, a measure how quickly it comes to rest. Timing of the "flush" is important so that the pressure waveform doesn't interfere with the dynamic response test (See Figure 11 example A).

The natural frequency is determined by measuring the period of one oscillation cycle (See Figure 12 example B).

The damping coefficient is determined by measuring the height, of any two successive peaks of the oscillation and then determining their ratio (See Figure 13 example C).

The damping coefficient can then be calculated or determined from an amplitude ration scale (See Figure 14 example D).

Optimal damping characteristics for catheter-tubing-transducer system have been determined (See Figure 15 example D).

If the natural frequency and damping coefficient fall within the wedge, the catheter-tubing-transducer system will accurately measure the intravascular pressure. Both natural frequency and damping coefficient should be within the adequate range. Notice that the higher the natural frequency, the wider the range of damping coefficient, which will produce adequate dynamic characteristics.

Common observations, such as "overshoot", catheter whip, damped waveform, fling, and artifact are the result of characteristics of fluid filled catheter systems. These can cause falsely high or low systolic and diastolic pressure measurement. Plotting the dynamic characteristics of such waveforms with these characteristics will result in either the damping coefficient, or the natural frequency falling outside the wedge plot. (See Figure 15).

It is important to recognize and measure the dynamic response capabilities of the catheter-tubing-transducer system you are using. The optimal damping coefficient and natural frequency should be identified initially for your standard catheter monitoring system. In most clinical settings, two or more pressure monitoring systems are used; one for arterial pressure monitoring, one for pulmonary arterial and wedge pressure monitoring. Other pressure monitoring systems are used for left atrial or intracranial pressure monitoring. the dynamic characteristics will vary for each type system used. Indeed for each system the characteristics depend on the filling and air bubble removal.

Some monitors have built in filters, which filter out the most of the signal frequencies above 12 Hz and prevent easy evaluation of the natural frequency and damping coefficient, because of the rapid settling of the catheter after using the fast flush test.

In bedside clinical practice, the dynamic response of the catheter system is most easily determined by categorizing only the natural frequency of the system.

Because of the wedge shape of the "adequate area" when plotting natural frequency and damping coefficient to determine the natural frequency is an acceptable guide for bedside evaluation of dynamic response. If the natural frequency is greater than 20 Hz, typically the dynamic response is adequate. Assuming zeroing and calibration are correct, the measurement is an accurate reflection of the intravascular pressure.

In most clinical settings, pressure waveforms are recorded at a display sweep speed to 25 mm/sec. Performing the fast flush test at this paper speed allows prompt assessment of the natural frequency. If one oscillation is completed within one small box (1 mm) on the record paper, the natural frequency is > 25 Hz. If the cycle takes two boxes (2 mm), the natural frequency is 12.5 Hz. **?? tapping the system ??*** Pressure measurements made with such systems can be relied on for accuracy. The lower the natural frequency, the greater the chance of a measurement error.

Observation and evaluation of the pressure waveforms at the bedside are as vital as the ECG tracing evaluation. Often, obvious problems can be identified and corrected. Evaluation of the "flush" is vital, as problems in the catheter-transducer system, which can cause erroneous measurements, yet are not obvious, can be identified and corrected.

In addition to the dynamic response characteristics of the catheter,, the flush test identifies free fluid flow in the catheter system. Free flow can be impaired by blood banking up in the system, a clot at the catheter tip, the catheter tip against a vessel wall or there can be a kink in the catheter or connecting tubing. Without free fluid flow in the system, pressure measurement errors will occur. To assess free fluid flow from the flush test, the waveform should oscillate freely, once or twice, then return directly into the pressure waveform and not "peg" or "stick" on the top or the bottom of the paper before going into the pressure waveform (See Figure 17).

The "flush test" should be made on initial system setup, after blood withdrawal, with every recorded measurement, during troubleshooting and at periodic intervals such as every shift when zeroing and calibrating are done, to document the continued ability of the pressure monitoring system to accurately reflect intravascular pressure. Visualization of the flush can be made from the monitoring screen for coarse, quick system evaluation by the experienced observer [7,8].

How to Make Accurate Hemodynamic Pressure Measurements

1. Know how to operate your monitoring equipment.

2. Set up the monitor and transducer appropriately.

   A. Couple membrane dome (if used) to transducer with fluid ???.

   B. Remove according to manufacturer's specifications all air bubbles.

   C. Use as little tubing and system connections as possible.

   D. Use only high quality pressure tubing.

   E. Calibrate transducer against know values or use ???.

3. Zero transducer to mid-chest level.

4. Perform "fast flush" test.

   A. Evaluate flush for dynamic response of system.

   B. Evaluate flush for free flow of catheter system.

   C. Correct problems to obtain adequate flush.

      1. Remove air bubbles

      2. Tighten loose connections

      3. Remove excessive lengths of tubing

      4. Reattach dome

      5. Flush blood through catheter

      6. Aspirate clot

      7. Reposition catheter

      8. Attach Accudynamic

5. When measuring PA, PW, and RA pressure, evaluate flush of each pressure measurement separately.

6. Know the characteristics of a normal pressure waveform.

GLOSSARY

Accudynamic:
: A mechanical device to adjust the damping of a pressure monitoring system.

Accuracy:
: The quality of freedom from mistake or error, that is of conformity to truth.

Artifact:
: A medical term used to describe electrical noise. Errors in test results, graph or written record.

Bias:
: A constant error whether due to equipment or setup conditions. For example a bias in a pressure monitoring system could result from not properly "zeroing" the transducer system.

Catheter Whip:
: Artifact caused by the catheter being "whipped" by the movement in the atrium and ventricle or by being "banged" by the heart valve.

Catheter:
: A plastic tube used to connect a fluid filled pressure monitoring system to the patient's blood stream. For a pulmonary artery catheter the tube is long (usually 100 cm) for the arterial pressure the catheter may be as short as 5 cm or as long as 100 cm.

Compliance:
: A property of materials which is the reciprocal of stiffness.

Continuous Flush Device:
: A device used in pressure monitoring to deliver a small amount of fluid flow to keep the catheter free of blood. Intraflo is an example of such a device.

Correctorr:
: A mechanical device used to adjust the damping of a pressure monitoring system.

Damping Coefficient:
: A characteristic of a second-order system such as a pressure monitoring system which relates to how quickly it comes to rest after being disturbed.

Diaphragm:
: The deformable membrane of a pressure transducer which separates the fluid column from the sensing element.

Distortion:
: An undesired change in waveform.

Disposable Dome:
: A plastic dome which is attached to the transducer. Usually has a thin plastic membrane between the fluid column attached to the plastic and the transducer sensing diaphragm.

Dynamic Response:
: A measure of the time varying characteristics of a pressure monitoring system> Usually characterized by a natural frequency and damping coefficient.

Equilibrium:

A method of balance between two opposing forces.

Fast Flush Test:

A method to test the dynamic characteristics of a pressure monitoring system.

Filter:

A device that passes certain electrical signals frequencies or a frequency range while preventing passage of others.

Fling:

To move suddenly such as what the tip of a pulmonary artery catheter might do when it is "bumped" by the pulmonic valves and right ventricle.

Flush:

A sudden and rapid flow of fluid which results from opening the "fast flush" valve of the Intraflo.

Frequency Response: **?? Fix for nurses

The frequency-dependent relation, in both gain and phase difference, between steady-state sinusoidal input and output.

Hertz:

Abbreviated Hz. The technical term used to indicate cycles per second. For example, 1 hertz is equivalent to 1 cycle per second.

High Frequency Noises:

Noise which is of high frequency. **redundant**

Inertia:

The tendency of matter to remain at rest if at rest, or if moving, to keep moving in the same direction.

Intraflo:

A device which permits continuous flushing of a catheter-transducer monitoring system and also provides dynamic testing capability by using the "fast flush" test.

Low Pass Filter:

A filter which allows low frequency to "pass" while attenuating high frequencies.

Membrane Dome: ?? leave out

A thin plastic membrane between the fluid column in a pressure monitoring system used to isolate the patient from the pressure transducer. Usually associated with a disposable dome.

Momentum:

The quantity of motion of a moving object, equal to the product of its mass and its velocity.

Natural Frequency:

For a second-order system such as a pressure monitoring system without damping, the frequency of free oscillations in hertz (cycles per second).

Noise:

Unwanted disturbances superimposed upon a useful signal, that tent to obscure its information content.

Oscillate:

To swing or move regularly back and forth.

Oscillations:

The act of oscillating. A regular motion between maximum and minimum values.

Over Damped:

A second-order system which when perturbed does not oscillate.

Overshoot:

The amount of over travel of the indicator beyond its final steady deflection when a new constant value of the measured quality is suddenly applied to the instrument. For pressure monitoring systems the overestimation of systolic pressure caused by an underdamped plumbing system.

Patent:

The state of being open and unobstructed.

Periodic Wave:

A sinusoidal wave the most typical example. A patient with a fixed heart rate also generates a period pressure waveform.

Plumbing:

For pressure monitoring systems usually the plumbing is considered the catheter, stopcocks, tubing, continuous flush device and the transducer.

Precision:

A measure of the repeatability of the results.

Pressure Transducer:

A device which converts the pressure signal to an electrical signal for amplification and display.

Recoil Element:

For example, a spring.

Ring:

Like a bell. Mechanical systems are said to "ring" at their natural frequencies.

Second Order System:

A mathematical model of a spring, mass and dashpot system. Pressure transducer, tubing and catheter systems are second order systems.

Settling Time:

Time it takes the system to settle after being disturbed.

Spring:

A mechanical element which by being stretched stores mechanical energy.

Square Wave Response:

A specific type of test signal used to test mechanical and electrical systems.

Square Wave Test:

The type of test done on pressure monitoring plumbing systems by using the fast flush test.

Step Pressure Change:

Part of the square wave test used to test the mechanical and electrical systems.

Stopcock:

Usually a plastic element used to switch fluid paths in a pressure monitoring system.

Tubing:

Plastic tubing used to interconnect catheter and transducer in a typical pressure monitoring system.

Under Damped:

A characteristic of a second-order system such as a pressure monitoring system which has a damping coefficient of less that 1.0. Such systems "ring" at near their natural frequency.

Volume Displacement:

The measure of how a transducer or other element of a pressure monitoring system displaces with application of pressure.

Zeroing:

The process the pressure monitoring user goes through to compensate for transducer offset and hydrostatic effects.

Draft 8 Feb 1986

References

1. Gardner RM, Hollingsworth KW. Optimizing ECG and Pressure Monitoring. Crit Care Med 1986; 14:651-658.
2. Fry DL. Physiologic recording by modern instruments with particular reference to pressure recording. Physiol Rev 1960; 40:752-788.
3. Blesser WB. A system approach to biomedicine. McGraw-Hill, New York, 1969.
4. Cobbold RSC. Transducers for biomedical measurements: Principles and applications. John Wiley and Sons, New York, 1974,
5. Rapaport E, Dexter L. Pulmonary "capillary" pressure in Methods in Medical Research. Waren JV (Ed) Year Book Publishers, Chicago. 1958, pp. 85-93.
6. Gardner RM. Direct Blood pressure measurement-dynamic response requirements. Anesthesiology 1981; 54:227-236.
7. Morris AH, Chapman RH, Gardner RM. Frequency of technical problems encountered in the measurement of pulmonary artery wedge pressure. Crit Care Med 1984; 12:164-170.
8. Morris AH, Chapman RH, Gardner RM. Frequency of wedge pressure errors in the ICU. Crit Care Med 1985; 13:705-708.
9. Morris AH, Chapman RH. Wedge pressure confirmation by aspiration of capillary blood. Crit Care Med 1985; 13:756-???
10. Woods SL, Mansfield LM. Effect of body position upon pulmonary artery and pulmonary capillary wedge pressures in non-critically ill patients. Heart and Lung 1976; 5:83-90.
11. Sprage CL. The pulmonary artery catheter: Methodology and clinical applications. University Park Press, Baltimore, 1983.
12. Gore JM, Alpert JS, Benotti Jr, Kotilainen PW, Haffejee CI. Handbook of hemodynamic monitoring. Little, Brown and Co. Boston 1985.
14. Armstrong PW, Baigre RS. Hemodynamic monitoring in the critically ill. Harper and Row, Cambridge 1980.
15. Geddes LA. The direct and indirect measurement of blood pressure. Year Book Medical Publishers, Inc., Chicago, 1970.
16. Gardner RM. Blood pressure monitoring: Sharing common elements, problems. March 1982; IEEE--EMB Magazine 1:28-31.
17. Nancy
18. Tubing
19. Air

??. Gardner RM, Parker J, Feinauer R. System for umbilical artery monitoring. Crit Care Med 1982; 10:456-458.

??. Gardner RM, Clemmer TP. Selection and standardization of respiratory monitoring equipment. Respiratory Care 1985; 560-571.

??. Hansen AT, Warburg E. The theory of elastic liquid-containing membrane manometers. Acta Physiol Scand 1949; 19; (Suppl 65) 306-332.

?? Hansen AT. Pressure measurement in the human organism. Acta Physiol Scand 1949; 19: (Suppl 68) 1-227.

?? Gardner RM, Bond EL, Clark JS. Safety and efficacy of continuous flush systems for arterial and pulmonary artery catheters. Annals of Thoracic Surgery 1977; 23:534-538.

?? Jacobs MK. Sources of measurement error in noninvasive electronic instrumentation. Nursing Clinics of North America 13(4): Dec 1978.