Evaluating Dynamic Response Characteristics of Pressure Monitoring Systems

Reed M. Gardner, Ph.D.
Professor of Medical Biophysics and Computing
University of Utah;
LDS Hospital
Salt Lake City, Utah

Introduction

This paper will present criteria for judging the adequacy of dynamic response and a clinically applicable method for measuring the dynamic response characteristics of direct blood pressure monitoring systems.

It has been clearly shown that except for cases where a pressure monitoring system is severely overdamped (damped), merely observing the patient's pressure waveform does not provide sufficient data to establish the adequacy of dynamic response. Unlike a stereo sound system, whose fidelity can be judged by listening to a familiar piece of recorded music, pressure monitoring systems must be carefully and accurately measured to obtain optimal dynamic response data.

Any pressure monitoring system distorts pressure waveforms, distortions which can cause the systolic pressure to be grossly over- or underestimated. Diastolic pressure, which can also be distorted, is, however, much more tolerant to dynamic response inadequacies.

Determinants of Dynamic Response Characteristics

The primary determinants of the dynamic response characteristics of pressure monitoring systems are the catheter-tubing-transducer "plumbing" elements. The *natural frequency* of the system—which can be equated to an automobile tire bouncing on a highway—and its *damping coefficient*—how quickly the car stabilizes following each bounce—are the two key characteristics of a hemodynamic monitoring system that enable it to faithfully transmit the patient's pressure from the catheter tip to the monitor.

Based on carefully devised mathematical equations, it is apparent that a catheter of short length and large internal diameter would provide the highest natural frequency, the most common measure of fidelity. Studies have shown that if the natural frequency is below about 7 Hz, the pressure waveform will be distorted regardless of the damping coefficient. However, if the natural frequency can be increased to 24 Hz, the damping coefficient can range from 0.15-1.0 without distorting the waveform. Therefore, a major objective of any pressure monitoring system is to achieve as high a natural frequency as possible, and this will overcome any tendency toward waveform distortion.

While systolic pressure is most susceptible to such distortions, diastolic pressure can also be affected. With experience and careful waveform analysis, however, the optimal combination of frequency and damping can be selected in each case to provide the most accurate reproduction.

Evaluating Dynamic Response in the Clinical Setting

The dynamic response characteristics of the pressure monitoring plumbing system can be quickly and easily determined in the clinical setting. The "fast-flush" method, using the Intraflo® or similar type of continuous flush device, is ideal because

1. the Intraflo® is already in place;
2. the test evaluates the entire system on each patient as it is actually being used clinically, not in an idealized laboratory setting; and
3. the test is quick and easy to perform, requiring only a pull of the flush valve on the Intraflo® and releasing it with a "snap."

The natural frequency can be calculated by dividing the paper speed by the period of one full oscillation on a strip chart recorder. The damping coefficient can be obtained by measuring two successive peak amplitudes, dividing to get an amplitude ratio, then determining the damping coefficient graphically.

In the clinical setting, 2-3 fast flushes should be performed, to assure that one occurs during the diastolic runoff phase of the pressure waveform, which will prevent reading errors caused by the patient's pressure pulse. After an initial familiarization period, nurses and physicians should be able to estimate the adequacy of dynamic response by visual observation of the "fast flush" waveform on an oscilloscope.

Since strip chart recorders—especially thermal paper recorders—may have difficulty responding to the oscillation of systems with natural frequencies above 20 Hz, ink-writing recorders are recommended.

The accompanying figure shows a typical series of waveforms recorded from systems with a variety of natural frequencies and damping coefficients.

Optimizing Dynamic Response

If the pressure monitoring system being used clinically should prove suboptimal, the following corrective steps should be taken:

1. *Remove all air bubbles* from the system, to increase the natural frequency—this can be facilitated by using transparent tubing, stopcocks and fluid paths.

2. *Use simple systems*, with as few components as possible—this will eliminate unnecessary volume displacement and facilitates set-up and removal of air bubbles.

3. *Use the least compliant devices* in the pressure monitoring system. These should include high-quality, non-compliant tubing; non-compliant catheters, with as short a length and as large an internal diameter as practical; stopcocks with air bubbles removed from all internal ports; and continuous flush devices such as Intraflo®, with low compliance and ability to perform a fast flush test. Compliant elements such as injection sites should not be used.

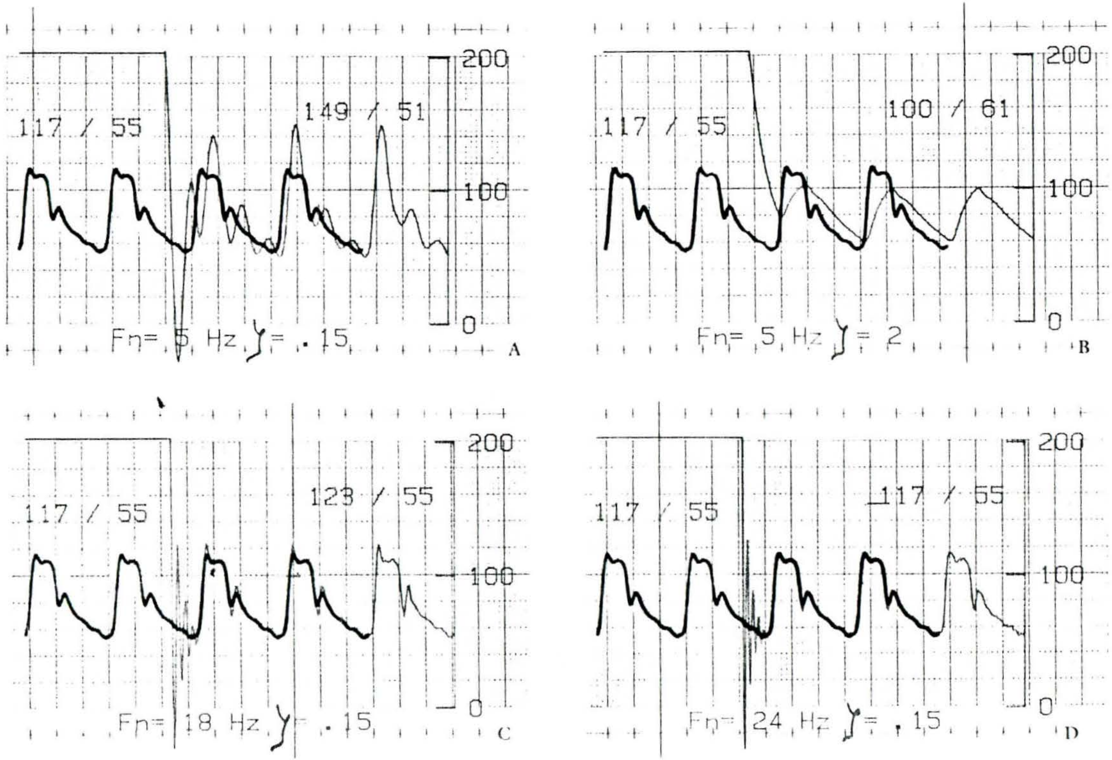
4. *Minimize the length of connecting tubing*; longer lengths of tubing (greater than 18 inches) cause reduced dynamic response, because of tubing compliance and the greater probability of air entrapment.

If there is still dynamic response performance in the underdamped region after taking all of the above steps, a small disposable device, the Accudynamic®, can be used. This device, placed near the pressure transducer, can increase the damping coefficient by adjusting the "needle valve."

In conclusion, optimized dynamic response is required if systolic and diastolic pressures in the arterial or pulmonary artery system are to be measured accurately.

FIGURE. Representative hemodynamic monitoring readings. The black tracings are the waveforms as recorded in the patient's artery, and the red tracings are the waveforms as they would be recorded by the monitoring system.

Each red waveform also contains a fast flush.



Discussion

Question:

Would you comment on the need for mechanical calibration with mercury manometers in some systems?

Dr. Gardner:

I would hope that within five years, transducer and monitoring equipment technology will have advanced to the point where no calibration is necessary. Today's transducers, particularly the disposable type, are correct within 1%, which is sufficient for our purposes, but some monitors are less accurate and may respond differently with different transducers. Hopefully, continuing technological advances will soon solve this problem.