Technical Report

Accuracy and dynamic response of disposable pressure transducer-tubing systems

Peter Hunziker RRT

Accuracy and dynamic response of seven different disposable saline-filled transducer-tubing systems were evaluated in two configurations; a pole-mount version (60-inch tubing) and patient-mount version (12-inch tubing). Natural frequencies (Fn) and damping coefficients were measured as were pressure waveform recordings. A 0.03 ml air bubble was inserted into the different systems in close proximity to the transducer and measurements were repeated. There were dramatic changes in dynamic response with lengthening of tubing to a pole-mount configuration and air bubble additions. Only one transducer-tubing system had adequate accuracy and dynamic response in both the pole- and patient-mount version. Pressure waveforms in the pole-mount versions and with the air bubble produced systolic overshoots up to 35 mmHg. The performance characteristics dictate that the choice for a disposable transducer-tubing system must be made not only by design, but dynamic response which is directly related to clinical set-up.

Key words

MEASUREMENT TECHNIQUES, PRESSURE: dynamic response, natural frequency, damping coefficient, pressure waveform; EQUIPMENT: disposable pressure transducer, automatic flush device.

From the Department of Respiratory Therapy, Sunnybrook Medical Centre, University of Toronto, Toronto, Ontario.

Address correspondence to: Mr. P. Hunziker, Department of Respiratory Therapy, Sunnybrook Medical Centre, 2075 Bayview Avenue, Toronto, Ontario, M4N 3M5.

In September 1984, the Emergency Care Research Institute (ECRI) published a report on four disposable pressure transducer systems and evaluated many aspects of their use.[1] Since then more manufacturers have developed disposable transducers.

The ECRI report on disposable transducers did not completely address the effect of dynamic response on the accuracy of waveform reproduction and systolic pressure measurements.

The performance of fluid filled catheter systems used for pressure-wave transmission and measurement is determined by the compliance of the system, mass of the fluid and frictional forces associated with fluid movement. These factors determine the resonant frequency or natural frequency (Fn) and the damping coefficient.[2–5] These two parameters can be measured as described by Gardner,[2] and can be used to graphically determine if a pressure monitoring system will provide an adequate dynamic response.

We evaluated the accuracy and dynamic response of seven different disposable pressure transducers and their accompanying monitoring kits.

Methods

Systems from the following manufacturers were tested: Cobe, Model 41-500; Medex, Model Novatrans MX800; Norton, Model 014404; Gould, Model DXT; Sorenson, Transpack; Deseret, Model 8000; Isotec, Model 700-00-400.

Each manufacturer's entire kit is composed of a transducer, flush device, two stopcocks, 48-inch connecting tubing and a 12-inch tubing extension which will be referred to as the pole-mount version (60-inch tubing kit). The patient-mount version (12-inch tubing kit) has the 48-inch connecting tubing and one stopcock removed. All kits were carefully filled, using a syringe, with a 0.9 per cent saline solution through the flush device tail.

A sine-wave generator, Hewlett-Packard model 200CD, and a Biotek 601 simulator, were used with a

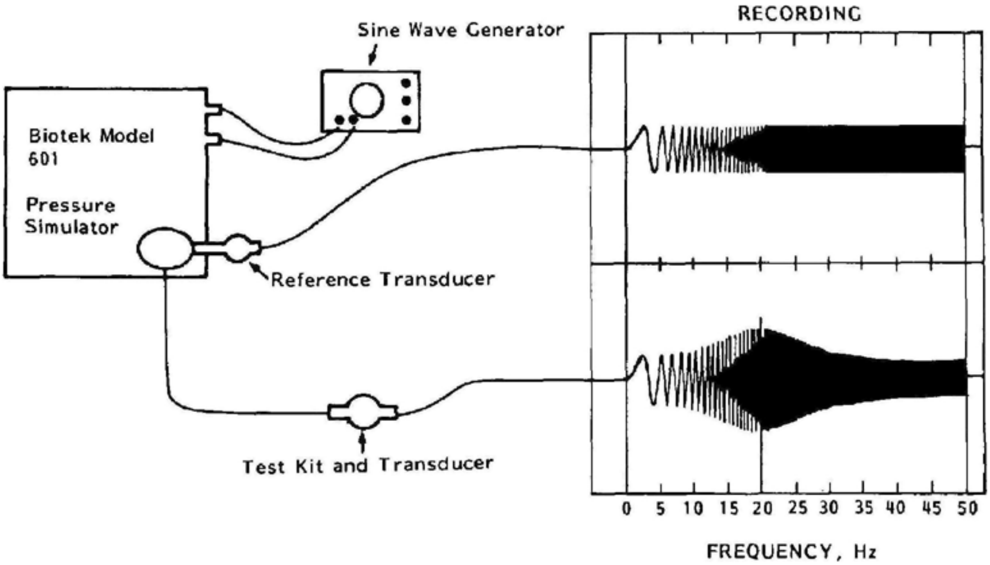


FIGURE 1 The assembly of the equipment used for the measurements.

Hewlett-Packard monitor 1309A with chart recorder (frequency bandwidth flat to >100 Hz), oscilloscope 8805C and pressure amplifier 7758A (unfiltered mode) to collect the data. The reference transducer that was used for all test comparisons was a Cobe disposable (fn > 100 HZ, linearity ± 1.5 per cent). It was decided to use a disposable rather than a reusable transducer, because of the possible errors associated with a dome which is fluid-coupled to the transducer diaphram. Some of the other disposable transducers on the market (e.g., Norton, Deseret) would have also been acceptable to use as a reference transducer. Figure 1 shows the assembly of equipment used for the measurements.

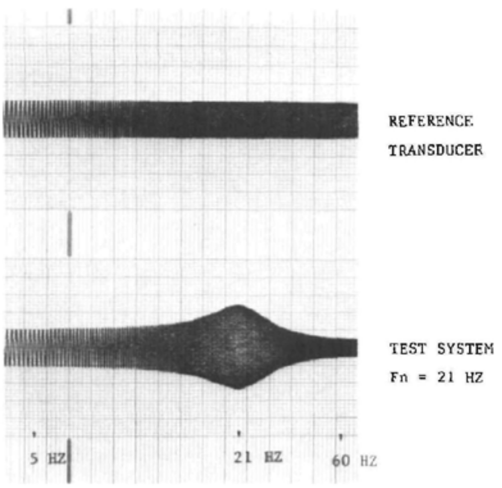


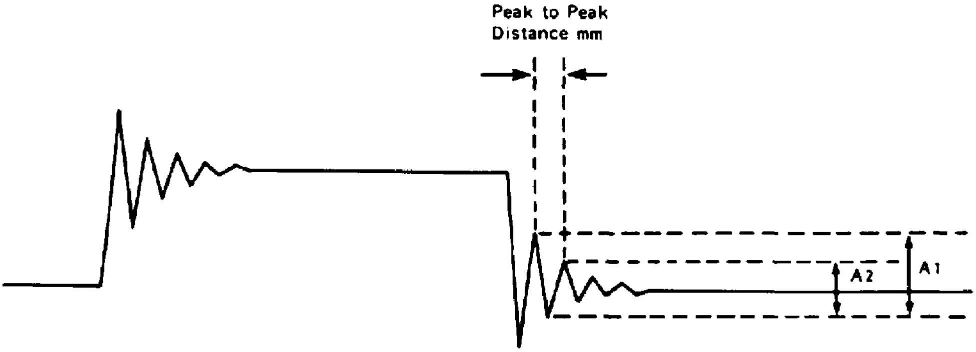
FIGURE 2 A graphical description of the reference transducer versus one of the test kits using the sine wave generator to determine the Fn. (Graph speed 25 mm·sec^{-1}.)

Natural frequencies were determined in two ways, (i) using the sine wave generator (sweeping 1 to 100 Hz) (Figure 2), and (ii) a step response to a square wave generated by the Biotek. The step response was also used to derive the damping coefficient as shown in Figure 3.

The two methods of obtaining Fn were used to determine accuracy of the measurement. Each of the measurements taken in both methods produced identical results.

To look at the effect that variations in dynamic response parameters might have on a pressure waveform we used the post-surgical radial artery pressure waveform (dp/dt, 1500 mmHg·sec^{-1}) and a heart rate of 90 beats·min^{-1} of the Biotek simulator to compare disposable kits and transducers to the reference transducer connected directly to the Biotek simulator as shown in Figure 1. The output of the Biotek simulator was set to produce a reference pressure of 150/70 mmHg on the Hewlett-Packard monitor and recorder.

All measurements were then repeated using each manufacturer's kit and transducer with the deliberate



$$fn = \frac{\text{Paper speed mm/sec}}{\text{Peak to Peak Distance mm}} \quad \text{Hz}$$

$$\text{Attenuation Ratio} = A_2/A_1$$

$$\text{Damping Coefficient} = \frac{-\ln\ [\text{Ratio}]}{\sqrt{\pi^2 + (\ln\ (\text{Ratio}))^2}}$$

FIGURE 3 The method for obtaining the damping coefficient is described and an alternate method for measuring resonant frequency is shown and can be used at the bedside using the flush device to produce the square wave test.

addition of a 0.03 ml air bubble in close proximity to the transducer via a stopcock using a tuberculin syringe. The purpose for using such a small air bubble was to describe the large errors associated with commonly found small air bubbles that are often overlooked.

Each manufacturer supplied two complete kits, each with a transducer, which were tested twice, obtaining four results. From these four results, the highest natural frequency and subsequent lowest damping coefficient is reported.

Results

In Table I, the measured natural frequencies and damping coefficients are displayed. All kits tested were underdamped (damping coefficients 0.10 to 0.28). In Figure 4 these results are plotted on the dynamic response graph.

In the patient-mount version, all kits tested lay within the adequate response wedge. With lengthening of the connecting tubing to the pole-mount version, there was an average reduction in natural frequency of 55.8 ± 1.36 per cent (mean ± SEM), and an average increase in damping

TABLE I Results: resonant frequencies and damping coefficients

	Cobe	*Medex*	*Norton*	*Gould*	*Sorenson*	*Deseret*	*Isotec*
Resonant (natural) frequencies (fn)–Hertz (cycles·sec^{-1})							
Pole-mount	28	19	20	25	21	18	22
Pole-mount (air-bubble)	13	8	11	8	8	9	10
Patient-mount	73	41	43	55	50	43	45
Patient-mount (air-bubble)	32	17	25	20	20	24	17
Damping coefficients							
Pole-mount	0.15	0.15	0.17	0.18	0.22	0.21	0.14
Pole-mount (air bubble)	0.20	0.20	0.20	0.22	0.28	0.25	0.16
Patient-mount	0.12	0.10	0.11	0.12	0.14	0.12	0.12
Patient-mount (air bubble)	0.16	0.18	0.20	0.15	0.19	0.18	0.20

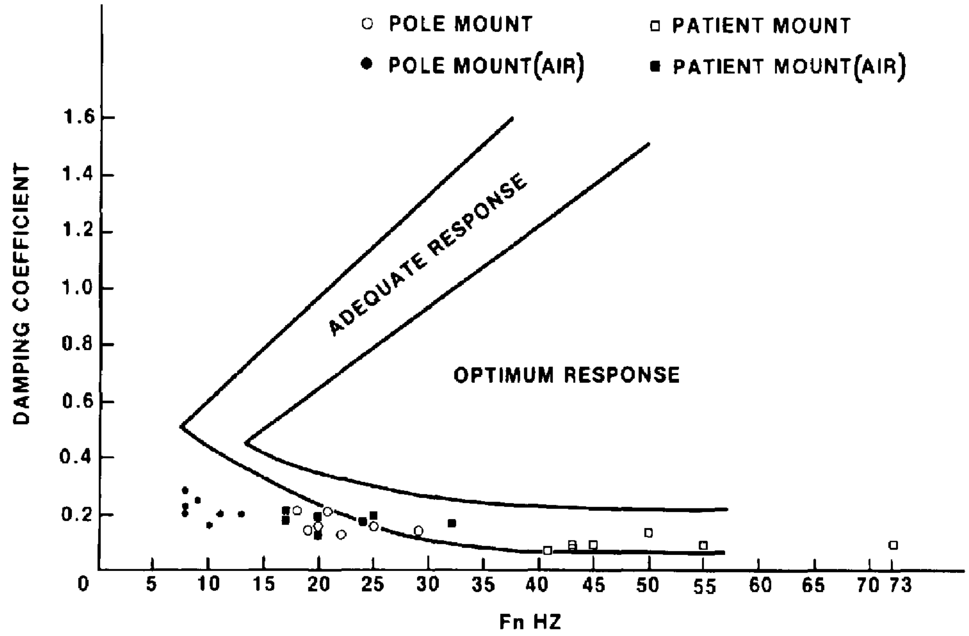


FIGURE 4 Results from the seven kits and transducers are plotted. Note that all systems have very low damping coefficients.

coefficient of 46.9 ± 7.50 per cent, and only the Cobe kit remained within the adequate response wedge.

Introduction of the 0.03 ml air bubble resulted in an average decrease in natural frequency of 55.8 ± 2.87 per cent in both the pole-mount version and 55.2 ± 3.25 per cent in the patient-mount version, and an average increase in damping coefficient of 23.9 ± 2.87 per cent in the pole-mount version and 53.0 ± 8.75 per cent in the patient-mount version. None of the pole-mount kits and only three patient-mount kits remained within the adequate response wedge.

Table II and Figure 5 display the pressures recorded from the kits when the Biotek post-surgical radial artery pressure waveform was set to give a pressure of 150/70 mmHg on the reference transducer. The diastolic pressures recorded by all kits tested were identical. Our maximum acceptable pressure error standard was five per cent for the products tested. In the patient-mount version, the systolic pressure overshoot was between 0 and 5 mmHg (1.6 per cent average increase ± 0.45 per cent). With the tubing lengthened to the pole-mount version, the systolic overshoot varied between 5 and 15 mmHg (8.1 per cent average increase ± 0.93 per cent).

Introduction of the 0.03 ml air bubble produced, in the patient-mount version, a systolic overshoot of up to 20 mmHg (7.3 per cent average increase ± 1.8 per cent)

TABLE II Results: recorded pressure

	Cobe	*Medex*	*Nurton*	*Gould*	*Sorenson*	*Deseret*	*Isotec*
Recorded pressures (input 150/70 mmHg)							
Pole-mount	155/70	165/70	163/70	160/70	162/70	165/70	165/70
Pole-mount (air bubble)	173/70	185/70	175/70	180/70	175/70	180/70	183/70
Patient-mount	150/70	155/70	150/70	153/70	153/70	153/70	153/70
Patient-mount (air bubble)	150/70	170/70	155/70	163/70	167/70	157/70	165/70

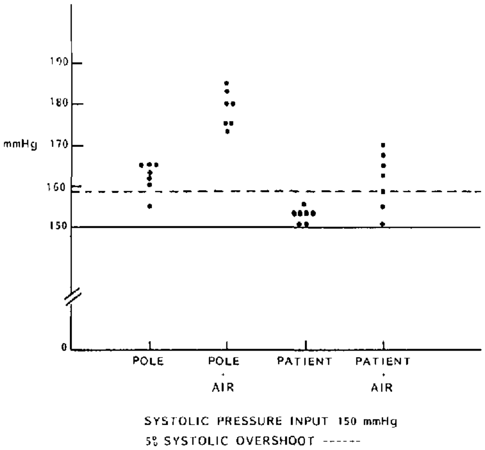


FIGURE 5 The systolic pressures recorded are displayed. The acceptable overshoot limit is five per cent or 158 mmHg for a 150 mmHg input.

and in the pole-mount version, a systolic overshoot of up to 35 mmHg (19.1 per cent average increase ± 1.13 per cent).

Figure 6 displays the actual pressure trace from one of the kits studied. The waveform distortion and systolic overshoot produced by the long tubing and the 0.03 ml air bubble is easily seen.

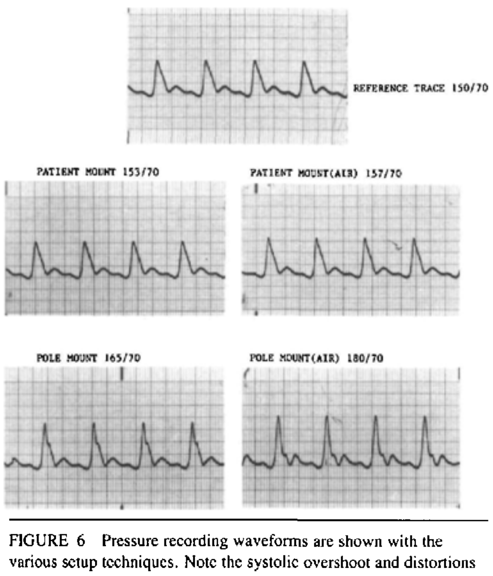


FIGURE 6 Pressure recording waveforms are shown with the various setup techniques. Note the systolic overshoot and distortions introduced by the addition of a long connecting tubing (pole-mount) and/or 0.03 ml air bubble.

Discussion

Gardner[2] has shown that fluid-filled catheter transducer systems with measured resonant frequencies and damping coefficients lying within his adequate response wedge will faithfully reproduce many of the arterial pressure waveforms encountered in clinical practice. In clinical situations with fast heart rates and rapid upstrokes in the pressure waveform, a system with performance characteristics lying within the optimum response wedge may be necessary for good fidelity of waveform reproduction.

The fidelity of the systems studied here was reduced, as natural frequency decreased with (i) increased inductance of the fluid complicated by the compliance due to an increase in tubing length, and (ii) the presence of a small air bubble. Only those systems whose natural frequency and damping coefficient lay within the adequate response wedge reproduced the simulated radial artery pressure waveform with sufficient fidelity that the systolic pressure overshoot was five per cent or less.

All of the systems tested had low damping coefficients and some may benefit from the use of a damping device such as the "Accudynamic"[2] (Sorenson Research) or the "Correctorr".[6]

The magnitude of the systolic overshoot observed in the testing procedures is consistent with the results reported by Shinozaki, Deane, and Mazuzan,[3] who have demonstrated that 0.05 and 0.25 ml of air would produce systolic overshoots of 10 to 40 mmHg in arterial pressure waveform monitoring.

The variations in dynamic response of the products tested are probably due to a combination of transducer and flush-device design. The complete monitoring system with all the essential rather than individual components is important when investigating the fidelity of a pressure monitoring system.

This study investigated the various disposable transducer-tubing systems in the laboratory setting; therefore it is important and advisable that institutions perform their own testing in the clinical situation as well.

The results of this study demonstrate that the patient-mount method is far superior to the pole-mount method.

Although it is not possible to use the patient-mount method in every case, every precaution must be taken to ensure that the monitoring system is bubble-free.

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Résumé

On a évalué la précision et la réponse dynamique de sept systèmes différents de tubulure jetable pour capteurs remplis de salin en installant les tubes de deux façons différentes: une installation sur tige (tube de 60 po.) et une installation sur les patients (tube de 12 po.). On a mesuré les fréquences naturelles (Fn), les coefficients d'amortissement, ainsi que les enrigistrements de courbes de pression. On a ensuite inséré une bulle d'air de 0.03 ml dans les différents systèmes et les mesures ont été répétées. Des changements dramatiques se produisaient dans la réponse dynamique avec l'allongement du tube dans l'installation sur tige et avec l'ajout d'une bulle d'air. Un seul système de tubulure pour capteur avait une précision et une réponse dynamique adéquates dans l'installation sur tige et dans l'installation sur le patient. L'ajout de bulle d'air dans l'installation sur tige amenait les courbes de pression à produire des dépassements systoliques allant jusqu'à 35 mmHg. Les caractéristiques de fonctionnement nous indiquent que le choix d'un système d'une tubulure jetable pour capteur ne doit pas se faire seulement selon le modèle (design), mais doit se faire selon la réponse dynamique qui est directement reliée au montage clinique.