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apparatus and techniques

System for umbilical artery monitoring

REED M. GARDNER, PHD; JULIA PARKER, RN; L. RICHARD FEINAUER, M.D.

A simple, safe, and effective system for umbilical artery monitoring controls continuous fluid infusion to prevent fluid overinfusion and keep the catheter from clotting. Accurate and continuous pressure measurements can be recorded simultaneously with fluid infusion. A convenient method for checking dynamic response fidelity is provided. The system is easy to set up and maintain. Because it is a closed system, contamination of the neonate is minimized.

Umbilical artery catheters in neonates are a source of arterial blood samples for blood gas analysis, an infusion site for drugs and parenteral nutrition, and a means of arterial pressure monitoring. Insertion of umbilical artery catheters has become increasingly common.[1, 2] Indications and risks of such a procedure have recently been outlined.[3–5] Optimal catheter function and monitoring capability requires the following: (1) controlled continuous infusion to provide drug and nutritional needs and to prevent loss of catheter function due to catheter clotting;[6] (2) simultaneous and continuous pressure recording during fluid infusion and adequate and measurable dynamic reponse; (3) a simple and reliable system which is easy to understand and use; and (4) a "closed" system, except during sample withdrawal times, to prevent system contamination.[7, 8]

The three most common sources of error when measuring umbilical artery pressure are: (1) inadequate dynamic response,[9–12] (2) static pressure errors caused by continuous fluid infusion, and (3) pulsatile pressure artifact caused by infusion pump coupling. We have developed a simple, effective, and safe method for umbilical artery monitoring.

MATERIALS AND METHODS

Figure 1 outlines the blood pressure monitoring system. A fluid-filled 3½ Fr or 5 Fr umbilical artery catheter (depending on the infant's size) is inserted into the umbilical artery. The catheter is attached to a three-way stopcock which provides a source for arterial blood samples and can be attached to a syringe for flushing the catheter. A 48-in piece of polyethylene pressure tubing, with inside diameter 0.049 in, is connected to an Intraflo continuous flushing device (CFS 30). The Intraflo is attached to a pressure transducer and the side port of this transducer is closed with a two-way stopcock. The fluid source of the Intraflo system can be one of several types of fluid infusion pumps, such as the IVAC Model 530, the IMED Model 922 or 960 volume infusion pump, or a Harvard syringe pump. The transducer is connected to a suitable pressure amplifier/display device, in this case, a Tektronix Model 413 neonatal monitor.

Dynamic response characteristics of catheter-tubing-transducer systems were determined by sinusoidal testing and by squarewave testing using the flush method with Intraflo[12] (Fig. 2). Results from both methods were nearly identical. The flush method was used for the clinical testing. In adults, the Intraflo flush causes a large pressure rise followed by a characteristic oscillation.[12] However, in the neonatal systems, little or no flow occurs when the flush valve is open, because the flow rate is controlled by the infusion pump.

To test the dynamic response of the neonatal monitoring system, the fast-flush valve on the Intraflo is pulled. The pigtail is then released and the valve allowed to close rapidly. Valve closure excites the entire monitoring system and causes it to "ring", as seen by the oscillations on the monitor oscilloscope (Fig. 2). The natural frequency and damping coefficient can then be easily determined from a strip recording.[12] With a little experience, observation of the flush on an oscilloscope gives all the needed dynamic response information. Because the Intraflo is already in place and because the flush tests the dynamics of the entire monitoring system (catheter, tubing, transducer), the method is ideal and convenient in the clinical setting. Alternatively, one can "tap" the tubing to excite the system and test its dynamic response. Both the 3½ Fr and 5 Fr catheters produce natural frequencies and damping coefficients sufficient to adequately record pressure.

Static and pump artifact pressure errors can occur whenever an umbilical catheter system is connected to measure pressure during fluid infusion. These errors are

From the Department of Medical Biophysics and Computing, LDS Hospital and University of Utah, Salt Lake City, UT 84143.
Address requests for reprints to: Dr. Gardner, Department of Medical Biophysics and Computing, LDS Hospital and University of Utah, 325 Eighth Avenue, Salt Lake City, UT 84143.

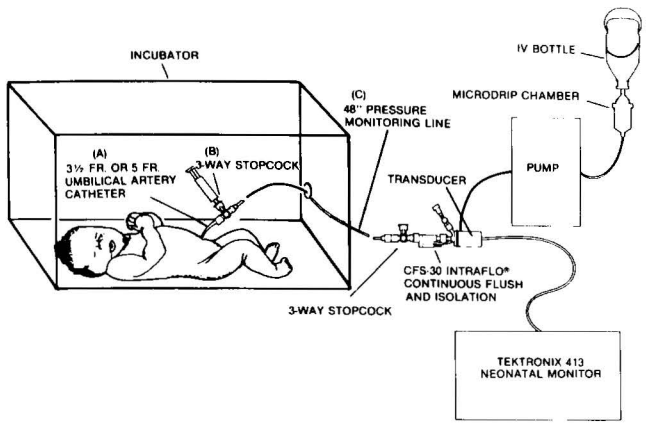

FIG. 1. Neonatal pressure monitoring/infusion system showing umbilical catheter in place, pressure tubing, continuous flush device, and infusion pump. The system is closed except when the three-way stopcock near the baby is opened for sample withdrawal. Special care is taken to keep the three-way stopcock clean and covered, to prevent it from being a source of infection (note syringe in the stopcock).

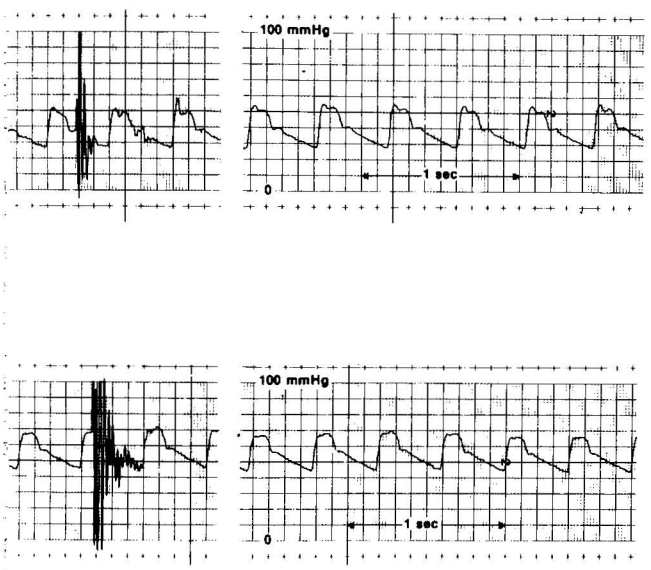

FIG. 2. Pressure recordings from neonates. *Left panels* "ringing", caused by pulling the fast-flush valve of the Intraflo or by "tapping" the 4-ft pressure tubing. Natural frequencies and damping coefficients can be determined from these data.[7] *Top*: Pressure recorded from a 3½ Fr umbilical artery catheter: HR 153, BP 54/31, fn = 33 Hz, $\zeta = 0.28$. *Bottom*: Pressure from a 5 Fr umbilical artery catheter: HR 155, BP 48/42, fn = 33 Hz, $\zeta = 0.10$. All records run at 50 mm/sec, pressure scale 0–100 mm Hg.

caused by flow resistance of the catheter and tubing system. Flow resistance of each element in the system (Fig. 3) was measured and static errors caused by several flow rates were determined for both 3½ and 5 Fr catheters (Table 1).

RESULTS AND CONCLUSION

We used this system to monitor more than 134 neonatal infants for a total of 513 days (average 3.75 days/infant). There was no loss of catheter function, disconnection, blood loss, or infection caused by the catheter monitoring system. One catheter was in continuous operation for over 6 weeks. Frequent culturing of this monitoring system showed no contamination.

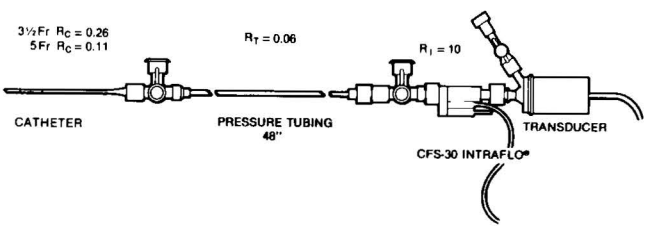

FIG. 3. Flow resistances of each element in the pressure-measuring system. Resistance values are mm Hg/ml·h.

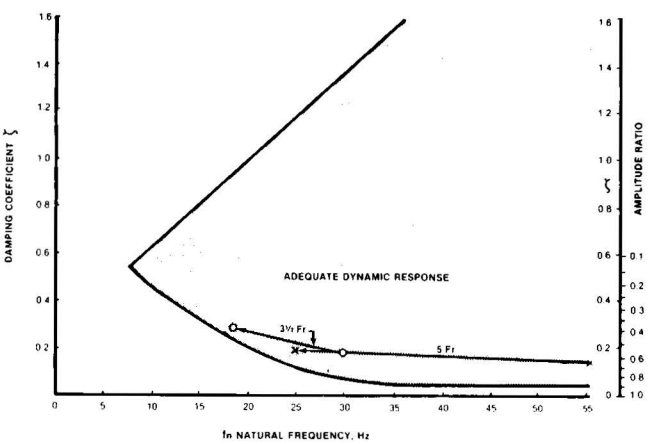

FIG. 4. Plot of natural frequency and damping coefficient shows the range of values which give accurate systolic and diastolic blood pressures. The *arrows* show the effect of adding 4 ft of pressure tubing to either a 3½ or 5 Fr umbilical artery catheter. Adding the tubing dramatically decreases the natural frequency and increases the damping coefficient.[12]

TABLE 1. Pressure Errors Caused by Catheter Resistance (R_c) and Tubing Resistance (R_t)

Catheter type	R_c (mm Hg/ml·h)	Tubing type	R_t (mm Hg/ml·h)[a]	Pressure error** (mm Hg) at 3 flow rates[b]		
				1 ml/h	5 ml/h	10 ml/h
3½ Fr	0.26	4 ft long, .049 in ID	0.06	0.30	1.52	3.0
5 Fr	0.11	4 ft long, .049 in ID	0.06	0.15	0.77	1.5

[a] $R_t = \dfrac{8.49 \times 10^{-8} \times \text{tubing length, cm}}{(\text{tubing inside diameter, cm})^4}$

[b] Total pressure error = flow rate × (R_c + R_t).

In summary, this monitoring system controls infusion rate with an infusion pump. Simultaneous and continuous arterial pressure can be measured during fluid infusion, and when infusion rates are below 10 ml/h, static pressure errors are small (Table 1). The continuous flush resistor of the Intraflo eliminates pulsatile artifacts caused by the infusion pump. Dynamic response is optimized by decoupling the elastic tubing of the infusion pump, by use of relatively short noncompliant pressure tubing to connect the catheter to the transducer, and because the system is simple to set up and rid of air bubbles. Its dynamic response characteristics, as determined by fast-flush testing, faithfully record the pressure waveform (Fig. 4). The system is simple to use, safe, and effective. If pressure monitoring is not required, the transducer port can be blocked.

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