Safety and Efficacy of Continuous Flush Systems for Arterial and Pulmonary Artery Catheters

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ABSTRACT **Air embolism and static pressure errors have been attributed to continuous infusion systems. Experiments show that the primary source of air bubbles in such a system is the drip chamber. A drip chamber that minimizes this problem was tested and is recommended. Pressure errors due to the flush system are shown to be clinically insignificant. Fast flushing through a central arterial catheter is shown to be a minimal hazard.**

After more than 6 years of clinical use and widespread dissemination of information about continuous flush systems [6, 7], a few reports are now appearing concerning the safety and efficacy of the continuous flush system. The hazards of air embolism are well known [10]. A recent study [9] reported the possible hazard of air embolism as a result of supersaturated infusate solutions. Another area of concern is related to static pressure errors due to the flow of flush solution through small internal diameter catheters, primarily the Swan-Ganz catheters. When manually flushed, centrally placed (subclavian) arterial catheters have been reported [4, 5] to lead to central embolism.

This paper responds to these problems and further expands on our experience at LDS Hospital in Salt Lake City with more than 8,000 central arterial catheter placements. Several experiments were performed to define the clinical problems of pressure monitoring and to provide recommendations for updating techniques and making improvements in the currently available continuous flush system.

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Materials and Methods

As a follow-up to the possible air embolism hazard pointed out by Kayser [9], we examined the genesis of air bubble formation in monitoring lines. Four 500 ml Travenol Viaflex saline infusion bags were connected to a continuous flush system* through each of the following infusion sets:

1. A Fenwal HA-10 arterial recipient set with a microdripper air chamber.
2. A Travenol (4C2100) Blood Component Recipient Set with large dripper.
3. IV tubing with no drip chamber.
4. A Medlon† (BF 436) arterial pressure monitoring set with 20 μ filter screen at the bottom.

Each of these tubing attachments was connected to the continuous flush system and pressurized to 300 mm Hg by a pressure infuser bag (Sorenson pressure administration cuff). The tubing was then filled with normal saline by pulling the fast flush valve. The presence or absence of air bubbles in the line, resulting from the fast flush, was noted.

To determine the amount of gas that can come out of solution due to supersaturation of the infusion fluid, the experiment outlined in Figure 1 was set up. The pressurized saline bag was maintained at 300 mm Hg (with mercury manometer) at room temperature (23° to 25°C). The continuous flush solution was then run through a 1 m long Teflon catheter (Sorenson Intrasufor 18) into a water bath at 37° C, simulating the patient's body temperature. Air bubbles in the catheter were sensed with an optical microdensitometer [2, 3] attached to the catheter. The two

*Intra Flo, Sorenson Research Co, Box 15588, Salt Lake City, UT 84115.

†Medlon, 2940 N Naomi St, Burbank, CA 91504.

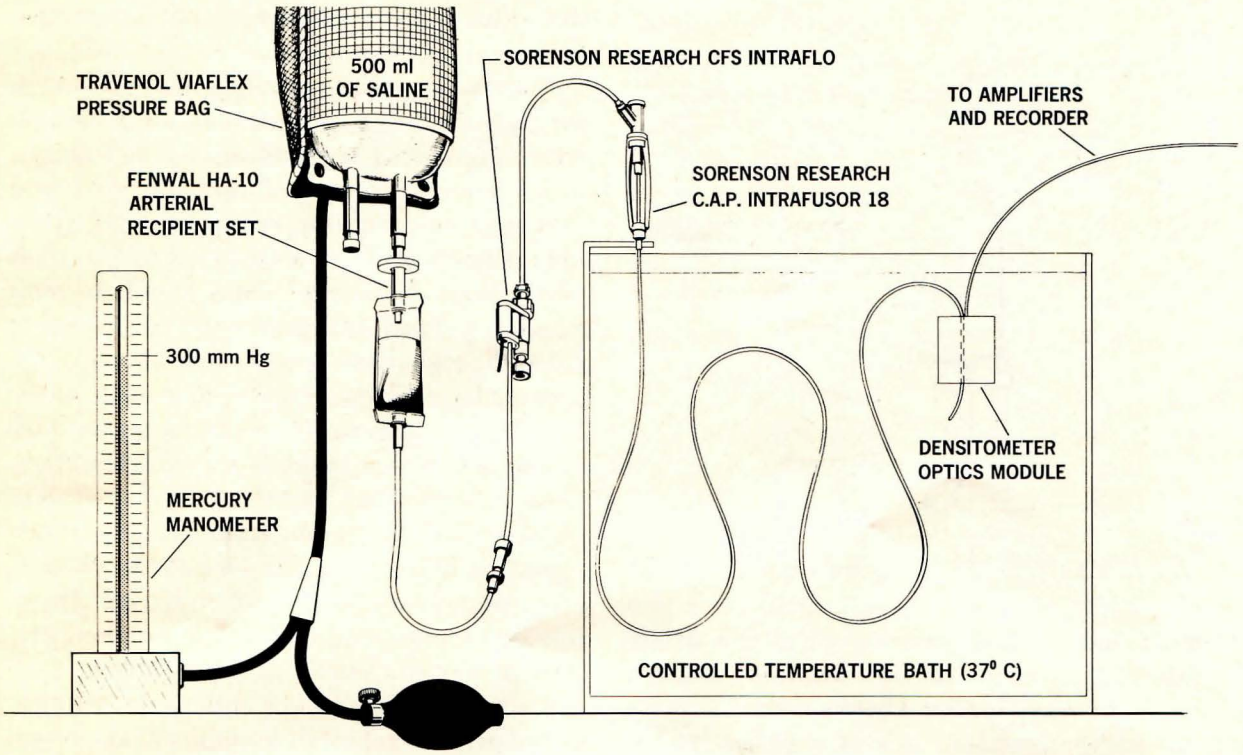

Fig 1. System for air bubble detection from supersaturated solution.

photocell outputs of the densitometer were recorded on paper and by magnetic tape recorder, allowing the outputs to be quantitated into approximate microbubble size. The number and size of gas bubbles passing through the distal length of the catheter were measured under two different conditions: with the gas phase in the saline bag, as provided by the manufacturer, and in the drip chamber; and with both gas phases removed in the second set of experiments.

The possibility of thrombus migration with a manual flush was explored using the central arterial catheter (Sorenson Intrafusor 18) commonly used at the LDS Hospital. Studies were conducted in simulated arteries consisting of plastic tubes of various sizes (3/16 to 1/2 inch diameter; 4.8 to 12.7 mm) with no flow and with continuous flow (1.7 liters per minute) of normal saline provided by a roller bypass pump. To determine the distance the dye would travel upstream through the simulated artery, rapid injections of Cardio-Green were made through the catheter using a 3 ml and a 1 ml tuberculin syringe. Maximum distances that the contrast medium traveled were observed visually and recorded. To simulate clearing a catheter, three trials for each set of conditions were performed by forceful hand injection.

To investigate the problem of static pressure errors, measurement of the flow resistance of several catheters was conducted. A 100 mm Hg pressure head of normal saline was applied to the catheter being measured, and the volume was recorded for at least 40 minutes.

Results

The set of experiments conducted to examine air bubble formation when initially filling the flush system suggests that the drip chamber is the major source of the air bubbles Kayser [9] found in his lines. Figure 2 shows the mechanism by which these bubbles are formed. With a high-velocity jet of fluid flowing through the air-filled drip chamber, a Venturi effect is formed, pulling air into the flowing stream and injecting that air into the liquid below. The air bubbles then flow out through the flush system. These bubbles were found in major proportions when a microdrip chamber was used. They were less of a problem when the larger drip chamber was

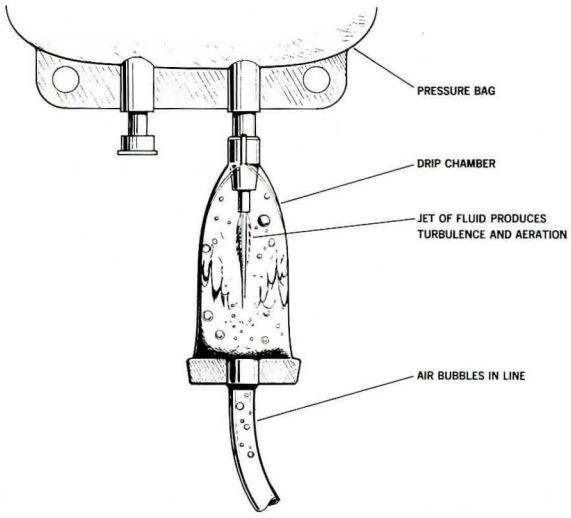

Fig 2. Mechanism of air bubble formation.

used, and they were nonexistent when a directly attached venous tubing system (no drip chamber) was connected between the saline bag and the continuous flush system. When the systems were filled with the saline bag at low pressure (50 mm Hg), both drip chambers generated fewer air bubbles and were nearly equivalent to the no-drip chamber setup. When pressurized to 300 mm Hg, the microdrip system caused micro air bubbles to form. Eventually the drip chamber filled with fluid as a result of air being displaced and transmitted through the flush system.

Because the microbubbles occur during the filling procedure as a result of air entrainment during fast flushing, we investigated the screen filter Medlon system. When this system is carefully filled with flushing solution at low pressure (50 mm Hg), it works extremely well by filtering out microbubbles generated during the fast flush. Bubbles are generated in the drip chamber as before, but they are blocked from the pathway to the patient by the filter mechanism.

Another potential cause of gross gas emboli through the infusion system is the degree to which the Viaflex bags are emptied if all the gas is not removed from the fluid bags. We found that most new pressure infuser systems would not totally empty a saline-filled bag. The average remaining volume was about 75 ml. In most pressure infuser systems in use for a year or more the nylon mesh stretched, allowing approximately 250 ml of saline to remain in the bag. This is a fortunate circumstance since small amounts of air left in the flush bag will not migrate into the flush system. However, it does point out the serious potential problem of infusing 20 to 50 cc of air into the patient when an efficient pressure infuser system is used. Therefore, we recommend that air be completely removed from the Viaflex saline-filled bag.

Air bubble detection by the microdensitometer experiment showed that the volume of gas evolving from the supersaturated flush solution is much smaller than had been expected [1, 9]. Bubbles with volumes of 0.2 to 0.4 μl were observed to form at a maximum rate of 2 per hour, in contrast to theoretical prediction of an excess of 60 bubbles per hour.

The results of four measurement sets are given in Table 1. In sets A and B a gas phase existed in both the saline bag and the drip chamber. In sets C and D no gas phase was present in the system. No significant difference was observed in the rate of gas formation under the two conditions. Supersaturation of flush solution in sets A and B may have resulted from the pressurized gas phase going into solution as well as from an increase in temperature of the solution as it passed through the catheter. Supersaturation in sets C and D was due to the temperature gra-

Table 1. Summary of Air Bubble Formation Studies

Measurement Set	Time Interval (minutes)	No. of Bubbles	Rate of Gas Formation (μl/hr)
A	188	6	0.68
B	105	3	0.39
C	91	3	0.45
D	148	4	0.43

dient alone. The similarity of the results in the four sets suggests that very little supersaturation is caused by dissolving of the pressurized gas phase. This result is explained by the small surface area of the gas-liquid interface and the slow diffusion of gases in solution.

Air bubble size was dependent on the internal diameter of the catheter. Growing air bubbles were observed to cling to the catheter wall until they became large enough to create a complete gas–catheter wall interface around the internal circumference of the catheter. The bubble would increase slightly in size as it merged with other, smaller air bubbles along the length of the catheter.

The rate of bubble formation is determined by a number of factors, which makes theoretical predictions difficult. Kayser [9] and Bass and Longmore [1] reported two of these factors. The first is the concept of pressure difference, ΔP, which is numerically equal to the gas tension minus the hydrostatic pressure. The second is the effect of temperature on gas solubility. These factors create a driving force for the formation of air bubbles, but the rate of formation is dependent on the diffusion constants and solubility of the gases, the surface tension of the gas-liquid interface, and the presence or absence of a gas phase in the fluid [8]. In the total absence of a gas phase an extreme driving force is required before a gas bubble forms.

Since a free spherical gas nucleus is usually unstable and tends to go into solution, an existing gas phase capable of bubble growth is normally found sticking to a solid surface. Surfaces that favor gas adherence include hydrophobic surfaces, rough and irregular surfaces, and dry surfaces [8]. The smooth, hydrophilic surface of the Teflon arterial catheter used in these experiments limits the number of gas nuclei available for bubble growth. The presence or absence of gas nuclei probably explains the variability in results. Shortly after set D was measured, and following a number of fast flushes, no air bubbles were detected for seven hours.

The effect of forced manual flushing on retrograde flow is shown in Table 2. Note that the maximum distance of "backwashing" was only 7.6 cm in the no-flow condition and less than 5 cm in simulated flow conditions. The small catheter diameter and its long length minimizes vigorous syringe flushes from backwashing air bubbles or clots into the coronary arteries or cerebral vessels.

Table 3 shows the results of the static pressure difference due to flow of 3 ml per hour through the catheter. With the continuous flush device the flow is normally 2 to 3 ml per hour. As can be seen, the errors are unimportant for any but the long arterial catheter (1.77 mm Hg). Even this error is unimportant when one considers that it can be compensated for by proper transducer zeroing, and that it is less than a 2% error for usual arterial pressures.

Comment

The primary source of air bubbles observed when using a continuous flush system is turbu-

Table 2. Maximum Syringe Flushing Distances for 1 M Long Arterial Catheter (ID 0.5 mm)

Diameter of Simulated Artery (in.)	Flow (liters/min)	Distance (cm)	
		3 ml Syringe	1 ml Syringe
1/2 (12.7 mm)	0	7.6	7.3
	1.7	4.8	4.0
3/8 (9.5 mm)	0	6.4	5.4
	1.7	2.7	2.7
5/16 (7.9 mm)	0	5.2	4.8
	1.7	2.1	1.9
1/4 (6.4 mm)	0	5.2	5.1
	1.7	1.4	1.4
3/16 (4.8 mm)	0	7.0	5.1
	1.7	1.4	1.3

Table 3. Static Pressure Differences for Various Catheters

Catheter Type	Average Resistance (mm Hg/ml/hr)	Pressure Error with 3 ml/hr flow (mm Hg)
Sorenson Intrafusor 18	0.589	1.77
Edwards Laboratories, Swan-Ganz 5F	0.081	0.24
Edwards Laboratories, Swan-Ganz 7F	0.033	0.10
Instrumentation Laboratories, 7F Thermodilution		
Proximal lumen	0.091	0.27
Distal lumen	0.083	0.25

lent mixing in the drip chamber. Air bubbles from supersaturation and differences of solution temperature are minor problems. The bubbles formed in the drip chamber can be eliminated with an appropriate filter and careful filling. Proximal thrombosis hazards from central arterial catheters are present but minimal because of the small internal diameter and the long length of the catheter used. Static pressure errors due to the continuous flow of "flushing" fluid through arterial and pulmonary artery catheters are clinically insignificant. Continuous flush systems are still the best method to keep catheters patent for pressure monitoring and as a source for blood samples. Their careful application prevents catheter clotting with subsequent loss of function or dangerous syringe flushing.

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