

Original Article

Errors in Flow and Pressure Related to the Arterial Filter Purge Line

Kerri Lee-Sensiba, MS; Nancy Azzaretto, RN, CCP; Clifford Carolina, CCP; Nancy DiCarmine, RN, CCP; Don Hymowitz, BS, CCP; Stuart Kay, MS, CCP; Karlene Kooker, BS, CCP; Michelle Salogub, RN, CCP; Elaine Wong, BS, CCP; and Yehuda Tamari, MS, CCE

Division of Cardiovascular Surgery, Dept. of Surgery, North Shore University Hospital, New York University School of Medicine, Manhasset, New York

Keywords: cardiopulmonary bypass, arterial filter, purge line, flow, pressure

Presented in part as a poster at the 16th Annual Pathophysiology and Techniques of Cardiopulmonary Bypass Surgery Symposium, San Diego, CA, February 29-March 2, 1996.

ABSTRACT

The purge line is a necessary component on arterial filters, although its presence may affect the amount of flow reaching the patient as well as the pump outlet pressure in the extracorporeal circuit. In-vitro and clinical studies conducted to investigate these effects with a commonly used purge line showed that at flows less than 1.5 L/min, rates for pediatric or infant patients, the purge line diverts as much as 40% of the intended pump flow away from the patient. A small diameter resistance tube connected in series with the purge line reduced purge flow such that over 80% of the pump flow reached the patient. Pressure monitored at the arterial filter port with the purge line open could be as much as 45 mmHg lower than the pressure measured with the purge line closed to the filter. Studies should be done to determine if the arterial filter purge line compromises flow to the patient, and if an additional resistance to the purge line is appropriate to reduce the flow through it.

Address correspondence to:
Kerri Lee-Sensiba
North Shore University Hospital
350 Community Drive
Manhasset, NY 11030

INTRODUCTION

Arterial filters trap particulate microemboli within the filter material (1) in the extracorporeal circuit, and route gaseous microemboli (2) to a port where it can be cleared from the arterial line via a vent or purge line to the cardiotomy reservoir (3). Since filter manufacturers recommend an open purge line during pump operation, blood flow is continually diverted away from the patient, whether or not there is air to vent. Although the amount of diverted blood flow may be insignificant with adult patients, it may be very significant with the pediatric or infant patient.

The objectives of this study were to determine the flow-pressure characteristics of a commonly used arterial filter purge line, to determine its impact on patient perfusion and pressure measurements, and to investigate simple means to reduce flow through the purge line.

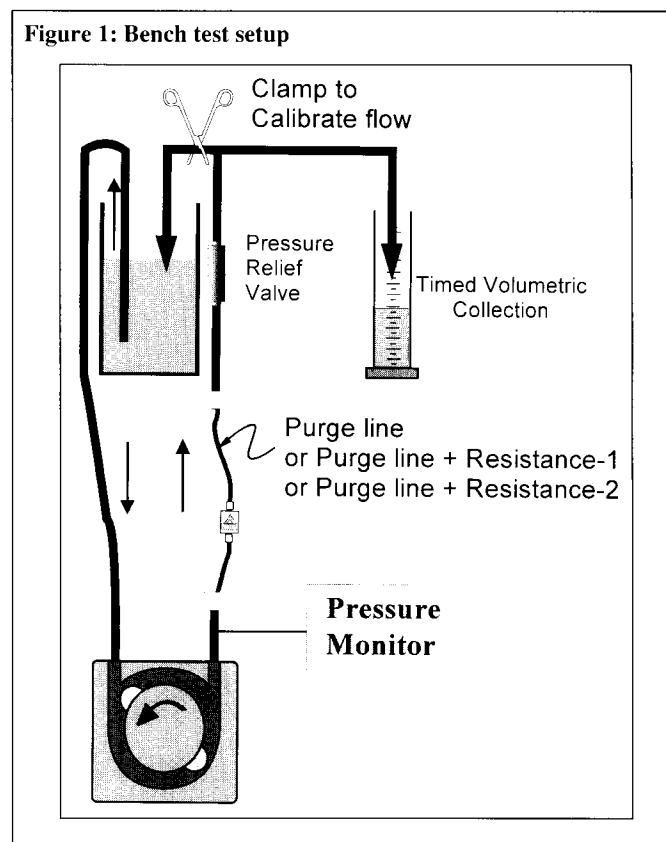
MATERIALS AND METHODS

The Intersept® Purge Line^a consists of a 1/8" diameter, 36 inch long tubing with a one-way duckbill type valve in the line, a male Luer connector at each end, and a four-way stopcock attached to the connector at one end. It was evaluated in both in-vitro tests and clinically.

Early results during the highly controlled in-vitro tests showed no differences, so measurements were taken once at each condition. Clinical measurements could not be repeated due to the changing conditions throughout the case.

IN-VITRO TESTS

A simple circuit was set up to test the flow characteristics of the purge line (Figure 1). The purge line was connected via a perfusion connector with a Luer fitting to the outlet of a calibrated, occlusively set roller pump containing 3/8" inner diameter (ID) tubing. The fluid was pumped at nominal flow rates of 670, 1350, 2770, and 3860 ml/min. These flows correspond to pump speeds of 25, 50, 100, and 150 RPM. Pump flow was calculated by multiplying RPM by the flow constant for the tube (approximately 27 ml per RPM for the 3/8" ID tube used). At each pump speed, nominal pump outlet pressures of 100, 200, 300, and 400 mmHg were established by adjusting the resistance of a pressure relief valve (cut out from a Better-Header™ model BH12^b) placed distal to the purge line. This range of pressures covers those expected clinically during extracorporeal procedures (due to the resistances imposed by the patient, the aortic



cannula, and other devices in the arterial line). A calibrated pressure transducer placed at the pump outlet recorded the pressure at the inlet to the purge line. Fluid out of the purge line was clocked into a graduated cylinder. Volumetric flow through the purge line was then calculated from the measurements and expressed as a percentage of the pump flow. Tests were conducted first with water and then with a blood analog mixture of 37% glycerin in water. This mixture approximates the higher viscosity of blood.

The tests above were then repeated with an additional resistance line connected in series with the purge line to determine its effect on flow through the purge line. Two resistance lines were used: a 30 cm long, 2.0 mm ID tube (Resistance-1^c), and a 13 cm long, 1.3 mm ID tube (Resistance-2^d). Tests were also conducted to determine the maximum air flow rate through the purge line and resistances by pumping air through them at various rates and measuring the pressure drop across the lines.

CLINICAL MEASUREMENTS

During two pediatric bypass cases in which calculated flows were less than 1 L/min, two three-way stopcocks attached to the port on top of the arterial filter^e provided a connection for the purge line alone, the purge line with a 100 cm long, 1.3 mm ID tube added (Resistance-3^f), and a pressure monitor^g (Figure 2). The purge line alone was connected to the first stopcock. The additional resistance caused by the second stopcock was small

a Medtronic Blood Systems, Inc., Anaheim, CA

b Circulatory Technology Inc., Oyster Bay, NY

c Baxter Pressure Tubing model 50-P112, Irvine, CA

d Vygon lockable extension tube model 1155.01, Ecouen, France

e Pall STAT Prime™ Blood Filter, Glen Cove, NY

f Vygon lockable extension tube model 1155.10, Ecouen, France

g DLP 60000, Grand Rapids, MI

compared to Resistance-3, and therefore did not affect the flow through the purge line connected to Resistance-3. Flow to the patient was measured with a calibrated flowmeter^h using a flow probe that was placed distal to the filter and clamped on the outside of the tubing. Since pump flow was known from the pump console and patient flow was measured, purge flow could be determined indirectly as [Purge Flow = Pump Flow - Patient Flow]. Flow and pressure at the purge port were recorded with the filter stopcocks adjusted to three positions: no purge, purge, and purge+Resistance-3. In the no purge position, full patient flow was recorded [Patient Flow = Pump Flow]. In the other two stopcock positions, the flow measured by the flowmeter was [Patient Flow = Pump Flow - Purge Flow], where purge flow was either that through the purge line alone or through the purge line with Resistance-3.

Measurements of pressure at the filter purge port, pump flow, and patient flow were taken at various times throughout the case, including times of pumping at less than the full calculated flow. Since obtaining these measurements required changing stopcock positions and several seconds of equilibrium with no changes in pressure or adjustments in pump speed, the frequency of measurements was dictated by the particulars of the case.

RESULTS

IN-VITRO TESTS

Figure 3 shows flow through the purge line versus pressure at its inlet, at the four flows tested with water (Figure 3a) and the blood analog (Figure 3b). The curves indicate that flow through the purge line is dependent on line pressure. For example, at a pressure of 100 mmHg and pump flows ranging from 670 ml/min to over 4 L/min (corresponding to pump speeds ranging from 25 to 150 RPM), flow through the purge line was approximately 250 ml/min with water. At the same range of pump flows but at a pressure of 200 mmHg, purge flow was approximately 400 ml/min. At the same parameters with the blood analog, purge flow was reduced to approximately 300 ml/min due to the higher viscosity of the fluid.

The effect of additional resistance in the purge line on the purge flow with the blood analog is shown in Figure 4. The curves obtained with water were slightly above yet parallel to those obtained with the blood analog, indicating the same effect of fluid viscosity seen in Figure 3 and similar effects of the purge resistances on flow. The greater the resistance (Resistance-2), the greater the re-

duction in purge line flow. For example, at a pressure of 200 mmHg, blood analog flow through the purge line was 311 ml/min. At the same pressure, a length of tubing added to the purge line (Resistance-1) reduced purge flow to 195 ml/min. Replacing Resistance-1 with a smaller diameter tube (Resistance-2) further reduced purge flow to 83 ml/min.

The tests on maximum air flow rates through the lines showed that at a pressure of 100 mmHg, the purge line with Resistance-1 could pass 5 L/min of air, while the purge line with Resistance-2 could pass 3 L/min of air. At a pressure of 150 mmHg, air flows over 6 L/min and 4 L/min were achieved with Resistance-1 and Resistance-2, respectively.

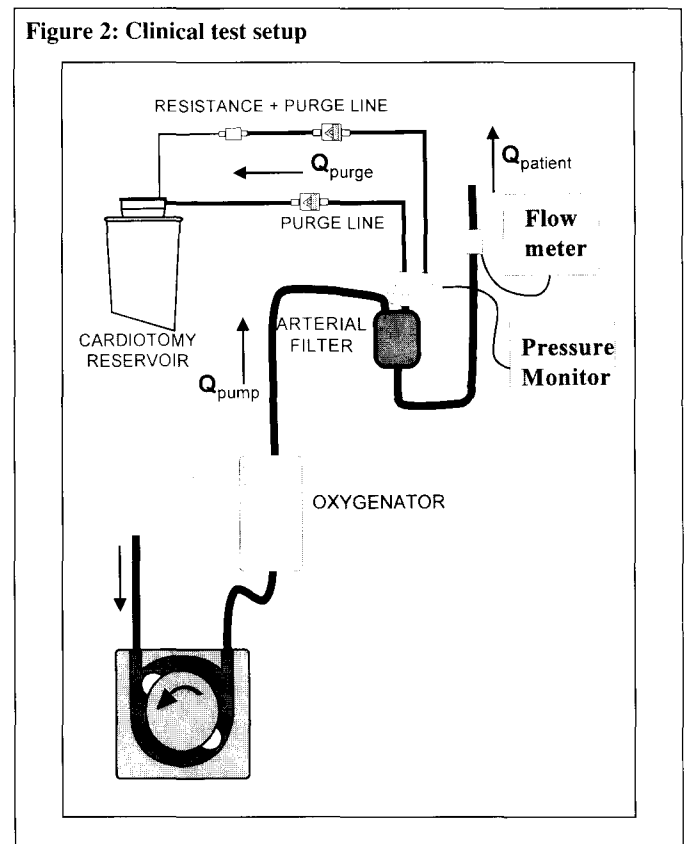
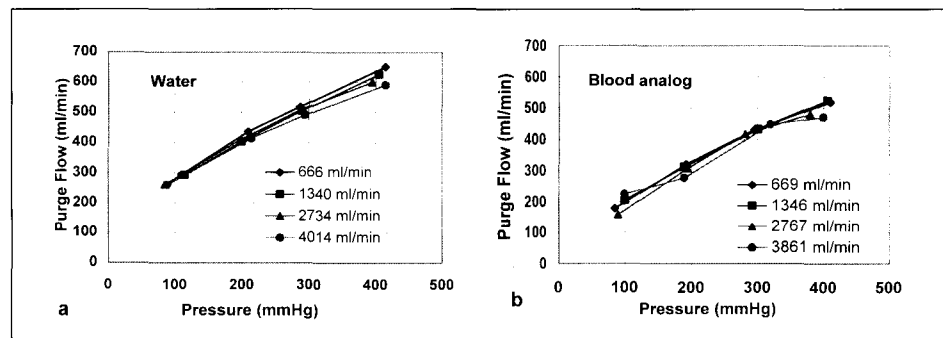
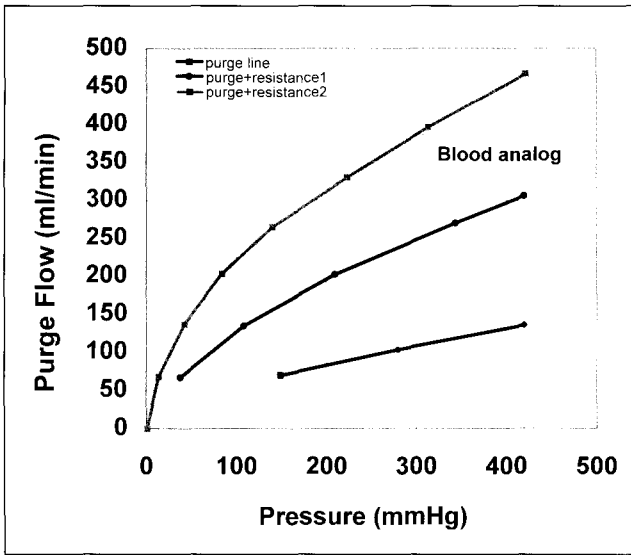


Figure 3: Purge flow measured in in-vitro tests as a function of pressure and pump flow using (a) water and (b) blood analog



^h Model 109, Transonic Systems, Ithaca, NY

Figure 4: The effect of additional resistance on purge flow with a blood analog



CLINICAL MEASUREMENTS

Figure 5a and 5b show the flow and pressure measurements, respectively, taken in the three stopcock positions (closed to purge, open to purge plus resistance, and open to purge alone) at four times during the case. These graphs illustrate the differences in flow and pressure measured depending on whether the purge line is open or closed during the measurement. For example, pressure measured at the arterial filter purge port with the purge line open can be over 45 mmHg lower than the pressure with the purge line closed.

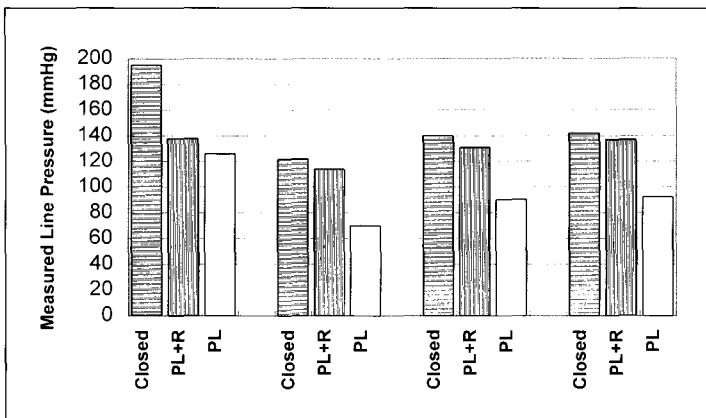
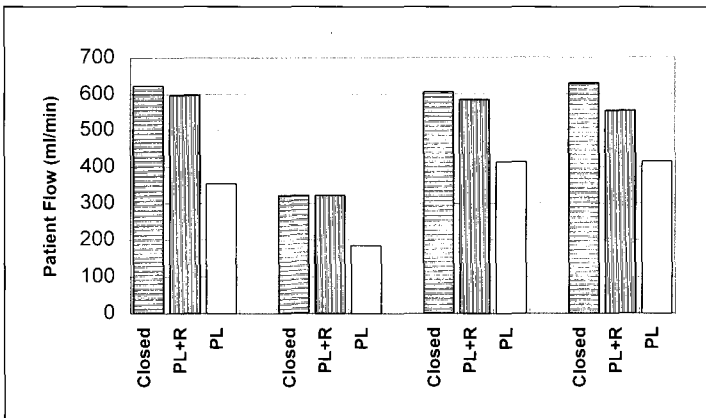
Table 1 summarizes the clinical data shown in Figure 5; values given are the average of six readings taken while pumping at full flow (mean 845 ± 17 ml/min). The mean pressure at the purge port was lower when the filter was open to the purge line alone than when it was open to the purge line with Resistance-3 (99 vs. 135 mmHg). Flow through the purge line alone, however, was five times greater (314 vs. 62 ml/min), resulting in a flow to the patient of only 63% of pump flow. With Resistance-3 added to the purge line, patient flow was 93% of pump flow.

DISCUSSION

The in-vitro tests showed that inlet pressure at the purge line determines the purge flow. As a generalization across patients, the pressure at the purge inlet may be the same at any number of pump flows, depending on the resistance distal to the filter (which depends primarily on the arterial cannula). Thus, at a given pressure and lower pump flows, a greater percentage of the pump flow is flowing through the purge line instead of to the patient (e.g., with smaller patients one would expect lower pump flows with higher pressures, and therefore greater purge flows). This is illustrated in Figure 6, where "patient" flow is expressed as a percentage of pump flow ($100 - \text{purge flow} / \text{pump flow} * 100$) with the blood analog. For example, at a pressure of 200 mmHg, the patient would receive 89% of pump flow at a pump flow of 2770 ml/min, whereas at a pump flow of 670 ml/min, the patient would receive only 52% of pump flow. Moreover, an increase in line pressure causes a greater relative drop in patient flow at lower pump flow speeds. This is illustrated by the steeper slope of the 670 ml/min curve compared to the 3860 ml/min curve in Figure 6. As an example, increasing pressure from 100 to 200 mmHg at a pump flow of 3860 ml/min only reduces patient flow from approximately 94% to 92%. Increasing pressure from 100 to 200 mmHg at a lower pump flow of 670 ml/min, however, reduces patient flow from approximately 70% to 50%.

Since resistance varies linearly with tube length and to the fourth power with tube diameter (4), adding a small diameter extension tube to the standard

Figure 5: Differences in clinical (a) flow and (b) pressure measurements, depending on whether arterial filter port is open or closed to purge line.



Closed: filter port closed to port line. PL+R: filter port open to purge line plus additional resistance. PL: filter port open to purge line.

purge line can reduce the purge flow significantly. The in-vitro tests indicated that at a line pressure of 200 mmHg (representative of line pressures observed during cardiopulmonary bypass procedures) purge flow was 311 ml/min with the purge line alone, but only 83 ml/min with Resistance-2 connected to the purge line. This data was used to calculate expected flow to the patient as a percentage of flow produced by the pump. Figure 7 illustrates these calculated values, at pump flows up to 2 L/min with an open purge line. Purge flow does not significantly affect flow to the patient at pump flows above 2 L/min, as shown by the leveling off of the curves in Figure 7; flow to the patient is at least 85% and 96% of pump flow with the purge line alone and the purge with Resistance-2, respectively. At pump flows below 1.5 L/min, however, purge flow is a much greater percentage of pump flow and therefore flow to the patient decreases by clinically significant amounts; at a pump flow of 1 L/min only 70% or 700 ml/min is perfusing the patient when the purge line alone is used on the arterial filter. At 0.5 L/min, patient flow is a mere 40% of intended flow! This problem is overcome if Resistance-2 is added to the purge line; Figure 7 shows that flow to the patient remains over 80% of pump flow at flows down to 0.4 L/min with the additional resistance.

Increased resistance in the purge line also decreases the maximum air removal rate through the filter, an important consideration in the case of gross air embolism in the circuit. The tests conducted with the two resistances used in the in-vitro studies showed that at typical pressures expected at the arterial filter, the air removal rates should be sufficient since the maximum air flow that needs to be cleared through the purge line would not exceed the maximum pump flow; even with Resistance-2 connected to the purge line, 3 L/min and 4 L/min of air could be cleared at 100 mmHg and 150 mmHg respectively.

It should be pointed out that other shunt lines in the extracorporeal circuit, such as the line from the sampling manifold, can divert additional flow from the patient when left open. These should be considered and investigated. The authors stress that in-vitro testing be conducted prior to modifying the circuit clinically, e.g., to determine a suitable resistance and assure adequate air removal from the filter.

It should also be noted that flow shown by the pump display (a calculated value) does not take into account the purge flow and therefore may not accurately indicate the flow the patient receives. If flow is measured with a calibrated flow probe placed distal to the filter, however, the flow the patient receives will be indicated whether the purge line is open or closed, and pump speed can be adjusted accordingly to achieve proper, in

Table 1: Pressure and Flows [mean(standard deviation)] measured clinically

	Pressure mmHg	Q _{pump} ml/min	Q _{patient} ml/min	Q _{purge} ml/min	Q _{patient} % of Q _{pump}
Purge Only	99(15)	845(17)	531(53)	314	63%
Purge + Resistance	135(19)	845(17)	783(36)	62	93%

Q_{pump} and Q_{patient} were measured. Q_{purge} was taken as the difference: Q_{purge}=Q_{pump}-Q_{patient}.

Figure 6: Purge flow expressed as a percentage of pump flow for (a) water and (b) blood analog

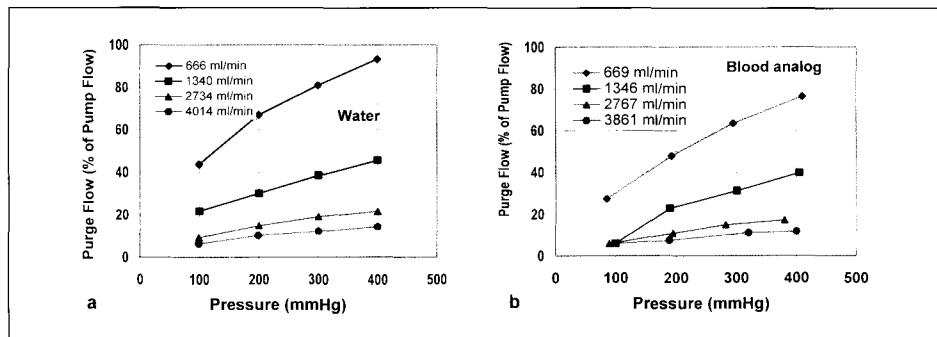
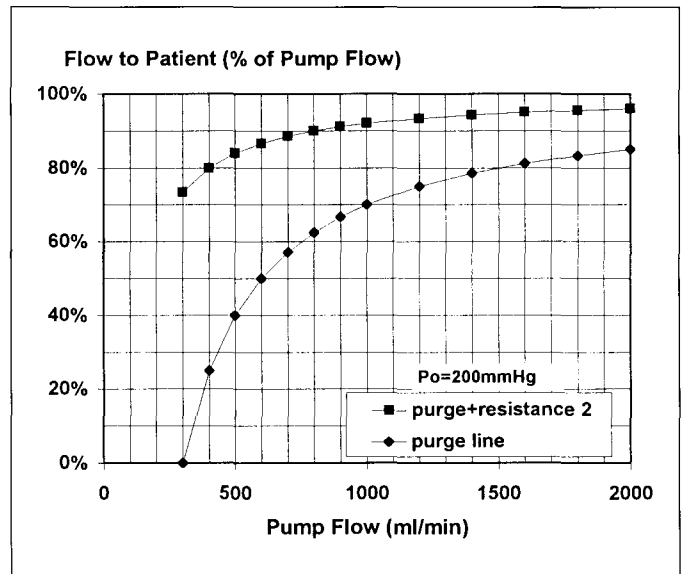


Figure 7: Calculated patient flow as a percentage of pump flow with and without an additional resistance in the purge line



tended flow rates.

The need for an arterial filter is undisputed (5). However, its recommended mode of operation (an open purge line) allows flow shunting back to the cardiomy reservoir and results in a significant reduction in the flow to the pediatric and infant patient (pump flows <2 L/min). Although one type of purge line was tested in this study, similar results with other purge lines are expected since they are comparable in diameter, length, and design. It would seem appropriate to have purge rates that are proportional to the required patient flow; that is, purge lines that are sized and rated for a flow range, so that the same, small percentage of pump flow is diverted through the purge line regardless of patient size. For example, assuming that the currently available purge lines have a resistance appropriate for adult flows of 6 L/min, a small patient who requires a flow of 1 L/min and whose line pressure is similar to that in the adult circuit may benefit from a purge line with a resistance approximately six times that of the standard purge line. Flow through the purge line also results in measured pressures at the purge port lower than those proximal to the filter. Users of arterial filters with purge lines should be aware of and correct for these flow and pressure effects in order to avoid underperfusion of their patients.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of Ariel Elkayam, Michael Kuo, and Danielle Pujdak to this project.

REFERENCES

1. Kurusz M, Christman EW, Williams EH, and Tyers GFO. Roller pump induced tubing wear: another argument in favor of arterial line filtration. *J Extra-Corpor Technol.* 1980; 12(2): 49-59.
2. Butler BD. Gaseous microemboli: a review. *Perfusion.* 1990; 5: 81-99.
3. Marshall L. Filtration in cardiopulmonary bypass: past, present and future. *Perfusion.* 1988; 3: 135-147.
4. Burton AC. Hemodynamics and the physics of the circulation. In: Ruch TC, Patton HD, eds. *Physiology and Biophysics.* Philadelphia: WB Saunders; 1965; 523-542.
5. Gourlay T. The role of arterial line filters in perfusion safety. *Perfusion.* 1988; 3: 195-204.