JECT. 2006;38:188–193
The Journal of The American Society of Extra-Corporeal Technology

Classic Pages of the *Journal of ExtraCorporeal Technology*

Section Editor: Jeff Riley, MHPE, CCT

Solis RT, Scott MA, Kennedy PS, Wilson RK. Cardiotomy suction particulate microembolization. Filtration of cardiotomy reservoir blood. J Extra Corpor Technol. 1976;8:69–72.

The classic article topic for this issue of *JECT* is particulate microembolization during cardiopulmonary bypass (CPB) and comes from Dr. Solis and his 1974–1976 Baylor College of Medicine team. Solis et al. (1) assessed the filtration characteristics of blood filters inserted in the cardiotomy reservoir drain line in vitro and during CPB. They measured 13- to 80-μm particles before and after the integral cardiotomy filters, and filters cut into the cardiotomy drain line in vitro using a pooled blood bank challenge. Solis et al. also measured particulate counts in the cardiotomy drain in-line filters during 10 CPB patient procedures. It is of historical interest that the best filter in their study was the Dacron wool depth filter. It became known at the time that the Dacron filter removed a significant number of platelets also. Solis et al. challenged manufacturers at the time to produce more efficient cardiotomy reservoir filtration systems.

In 1974, Solis also wrote a *JECT* companion article relevant to our topic (2). Solis systematically reviewed 65 publications dealing with microaggregates during CPB. Referencing four articles from the 1961–1969 thoracic surgery literature, he listed the infusion of fat, fibrin, and other foreign material through the coronary suction system as one of five major factors implicated in microemboli during CPB. Of course, the advent of membrane oxygenators reduced the particulate microembolization; however, considerable particulate material is found in the blood returning through the cardiotomy return system, especially during complex intra-cardiac procedures and large incisions (3,4).

In this issue of *JECT*, Ajzan et al. (5) from the Hammersmith Hospital in London publish an article dealing with fat embolization with and without CPB. Ajzan et al. set out to see whether fat embolization is still the problem with CPB that Solis et al. aptly described in a 1974 scientific review and a 1976 study and whether there is a difference in the free fat emboli load between off-pump coronary artery bypass (OpCAB) and CPB patients. Ajzan et al. report the absence of fat aggregates in the blood of OpCAB patients. They found significant fat emboli in the CPB patients that came from the cardiotomy suction system. Ajzan et al. stated that CPB patients remain at risk for fat embolization just as reported by Solis et al. in the early 1970s and that the highest fat embolic load was found in the cardiotomy suction blood. Ajzan et al. reported the majority of the fat emboli to be in the 5- to 20-μm range and that the CPB circuit equipment was not completely effective at removing fat emboli before patient arterial infusion.

Solis (2) reviewed the role microaggregates played in the development of pulmonary insufficiency. He points out that CPB blood should be efficiently filtered before arterial infusion. Solis called for the clinical comparison of the efficiency of various filters and reported that human studies identifying the consequences of microaggregate infusion had not been performed as yet in 1974. Although it was not the direct purpose of the study of Ajzan et al., it reported no apparent gross signs of embolic or neurologic injury in either patient group in the study.

Today there are recommendations to avoid the reinfusion of cardiotomy blood (6), yet despite these recommendations, the subject remains in debate. "The more closed the bypass system, the better (7)." How many times have we heard this? We are taught this in our perfusion education programs—yet, in clinical practice, rarely do we see a completely closed CPB circuit? How about miniature extracorporeal (ECCs)? Authors are reporting only marginal changes as assessed by blood loss, need for blood products, and intensive care unit and clinical stays when using miniaturized CPB circuits (8). However, safety margins for volume loss, air emboli, and weaning from CPB decrease, because of the closed circuit. Results are mixed—modification of perfusion management with optimized air management needs to be further studied as an effective strategy in reducing the inflammatory response and influencing the coagulation system (9). It is time to perform a systematic review or meta-analysis on the recent body of work (10–16) comparing CPB outcomes with and without direct cardiotomy suction blood infusion.

Jeff Riley, MHPE, CCT
The Ohio State University
Riley.267@osu.edu

REFERENCES

1. Solis RT, Scott MA, Kennedy PS, Wilson RK. Filtration of cardiotomy reservoir blood. J Extra Corpor Technol. 1976;8:69–72.
2. Solis RT. Blood filtration during cardiotomy bypass. J Extra Corpor Technol. 1974;6:64–72.

3. Solis RT, Noon GP, Beall AC Jr, DeBakey ME. Particulate microembolism during cardiac operation. Ann Thorac Surg. 1974;17:332.
4. Solis RT, Kennedy PS, Noon GP, et al. Cardiopulmonary bypass: Microembolization and platelet aggregation. Circulation. 1975;52: 103.
5. Ajzan A, Modine T, Punjab P, Ganeshalingam K, Philips G, Gourlay T. Quantification of fat mobilization in patients undergoing coronary artery revascularisation using off-pump and on-pump techniques. J Extra Corpor Technol. 2006;38:116–21.
6. Lilly KJ, O'Gara PJ, Treanor PR, et al. Heparin-bonded circuits without a cardiotomy: a description of a minimally invasive technique of cardiopulmonary bypass. Perfusion. 2002;17:95–7.
7. Koster A, Bottcher W, Merkel F, Hetzer R, Kuppe H. The more closed the bypass system the better: a pilot study on the effects of reduction of cardiotomy suction and passive venting on hemostatic activation during on-pump coronary artery bypass grafting. Perfusion. 2005;20:285–8.
8. Nollert G, Schwabenland I, Maktav D, et al. Miniaturized cardiopulmonary bypass in coronary artery bypass surgery: marginal impact on inflammation and coagulation but loss of safety margins. Ann Thorac Surg. 2005;80:2326–32.
9. Kiessling AH, Khalil M, Assaf O, Isgro F, Kretz KU, Saggau W. Blood-air interface during cardiopulmonary bypass. Asian Cardiovasc Thorac Ann. 2004;12:198–201.
10. Westerberg M, Bengtsson A, Jeppsson A. Coronary surgery without cardiotomy suction and autotransfusion reduces the postoperative systemic inflammatory response. Ann Thorac Surg. 2004;78:54–9.
11. Jewell AE, Akowuah EF, Suvarna SK, Braidley P, Hopkinson D, Cooper G. A prospective randomised comparison of cardiotomy suction and cell saver for recycling shed blood during cardiac surgery. Eur J Cardiothorac Surg. 2003;23:633–6.
12. Pierangeli A, Masieri V, Bruzzi F, et al. Haemolysis during cardiopulmonary bypass: how to reduce the free haemoglobin by managing the suctioned blood separately. Perfusion. 2001;16:519–24.
13. Appelblad M, Engstrom G. Fat contamination of pericardial suction blood and its influence on in vitro capillary-pore flow properties in patients undergoing routine coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2002;124:377–86.
14. Kincaid EH, Jones TJ, Stump DA, et al. Processing scavenged blood with a cell saver reduces cerebral lipid microembolization. Ann Thorac Surg. 2000;70:1296–300.
15. Aldea GS, Soltow LO, Chandler WL, et al. Limitation of thrombin generation, platelet activation, and inflammation by elimination of cardiotomy suction in patients undergoing coronary artery bypass grafting treated with heparin-bonded circuits. J Thorac Cardiovasc Surg. 2002;123:742–55.
16. Kaza AK, Cope JT, Fiser SM, et al. Elimination of fat microemboli during cardiopulmonary bypass. Ann Thorac Surg. 2003;75:555–9.

JECT. 2006;38:188–193
The Journal of The American Society of Extra-Corporeal Technology

Filtration of Cardiotomy Reservoir Blood

R. THOMAS SOLIS, MICHAEL A. SCOTT, PETER S. KENNEDY, and R. KEITH WILSON

Microembolization resulting from platelet aggregation, air embolization and infusion of particulate material with stored and coronary suction blood has been implicated in the pathogenesis of certain complications following heart surgery[1-5]. In previous studies we have noted that particulate microembolization is reduced and platelet function is preserved following cardiopulmonary bypass with a membrane oxygenator when compared to a bubble oxygenator[6,7]. However, although microembolization resulting from blood oxygenation is reduced with membrane oxygenation, considerable particulate material was found in blood returning to the patient through the cardiotomy return system. In the present study, the filtration characteristics of various devices used in the cardiotomy reservoir system were evaluated.

METHODS

The *in vitro* filtration characteristics of cardiotomy reservoir and of in-line blood filters were determined using previously described methods[8,9]. A large pool of type specific O-positive outdated human stored blood and packed red cells was prepared by initial filtration through a clot mesh filter and subsequent dilution with isotonic saline to an hematocrit of 38%. Aliquots of the blood were taken for electronic particle size analysis and platelet counts[10] before and after gravity flow through the device being tested. The level of the pool of blood was 20 inches above the device. The six different cardiotomy reservoirs tested are listed in the legend in Figure 1, while the in-line blood filters tested were: 1) Swank Dacron wool Blood Filters, CA100 Cobe Laboratories, Denver, Colorado; 2) The Intersept Cardiotomy Blood Filter, Johnson & Johnson, New Brunswick, N.J.; 3) The Poly Filter Bypass Blood Filter, Model PF427, Bentley Laboratories, Irvine, Calif.; and 4) The Ultipore, both a 40 x 40 μ and a 25 x 40 μ pore mesh in-line Blood Filter, Pall Corporation, Glen Cove, N.Y.

The electronic particle size analysis was performed with a Coulter Counter® (Model T Coulter Electronics, Hialeah, Fla.) immediately after dilution of 0.5 ml aliquots of blood in 50 ml of a diluent containing four drops of a hemolyzing solution (Isoton® & Zap-Isoton® respectively, Coulter Electronics). Particles of nine different diameter sizes ranging from 13 to 80 μ were counted as 2 ml of the suspension passed through a 200 μ aperture. The data are reported as either the total volume in μ^3/mm^3 of particles in two arbitrary diameter ranges (32 to 80 μ and 13 to 25 μ) or as the percent of particles remaining after passage through each of the blood filters plotted against the particle diameter.

From the Department of Medicine, Baylor College of Medicine, Houston, Texas.
This work was partially supported by U.S. Army Medical Research and Development Command Contract #DADA-17-73-C-3149, U.S. Public Health Service Grant (HL-138-03) (HE-0543) and (HE-05387), and a grant from the American Heart Association, Texas Affiliate, Inc. The blood filters and cardiotomy reservoirs used in this study were provided by Pioneer Filters, Johnson & Johnson, Pall Corp., Cobe Laboratories and Bentley Laboratories.

In order to assess the filtration characteristics of the in-line cardiotomy reservoir blood filters during cardiopulmonary bypass, each of the filters was evaluated as previously described[6,9]. Each filter to be tested was inserted in the line draining blood from the cardiotomy reservoir to the oxygenator and samples of blood were drawn through T-connectors before and after passage through the filter every ten minutes while on bypass. Each filter was evaluated in ten patients and the three measurements with the highest total volume of particles 13 to 80 μ in diameter were used to determine the filter's efficiency at removal of particles in the two arbitrary size ranges.

RESULTS

Measurements of microemboli in stored blood before and after passage through various cardiotomy reservoirs are shown in Figure 1. None of the reservoirs was able to remove a significant volume of microemboli smaller than 32 μ. The Harvey was the most effective reservoir at removal of particles larger than 32 μ. However, it was much less efficient at removal of microemboli in this size range than the least effective of the in-line blood filters (25 μ pore mesh filter in Table I). The Bentley (Q120) and Travenol (5m-03-91) reservoirs did not remove a significant volume of particles 32 μ and larger, while the other reservoirs were not as efficient as the Harvey but did remove a significant volume of particles in the larger size range.

In contrast to the cardiotomy reservoirs, all of the in-line blood filters removed a significant volume of microemboli larger than 32 μ (Table I and Figure 2). However, these filters differed in their ability to remove the smaller microemboli. The 25 μ pore mesh and the polyurethane foam filters were the least efficient at removal of microemboli smaller than 32 μ and did not differ except in the 20 μ size range where the 25 μ pore mesh filter was slightly less efficient ($p<0.05$). Both of these filters were significantly less efficient ($p<0.001$) at removal of particles 13 to 25 μ in diameter than the Dacron wool and woven fabric filters which did not differ in their filtration efficiency over the size range tested. Only the Dacron wool removed a significant number of platelets from the outdated stored blood (Table I).

The results of the study of filtration of microemboli present in cardiotomy reservoir blood during cardiopulmonary bypass were similar to those noted with stored blood (Figure 3). The woven fabric and Dacron wool filters were the most effective filters at removal of particles in both the large and small size ranges. The percent by volume of particles remaining after passage through these two filters did not differ significantly, but both were significantly more effective at removal of

TABLE I

Percent of particulate microemboli by volume in 2 size ranges and platelets remaining in stored blood after passage through cardiotomy in-line blood filters (mean ± SE, n=8)

Type of Filter	Particulate Microemboli (13–25 u)	Particulate Microemboli (32–80 u)	Platelets
25 μ pore mesh	45 ± 5	7 ± 1	81 ± 12
Poly Urethane Foam	36 ± 3	6 ± 1	79 ± 19
Woven Fabric	13 ± 2	4 ± 1	78 ± 10
Dacron wool	12 ± 2	4 ± 1	67 ± 12

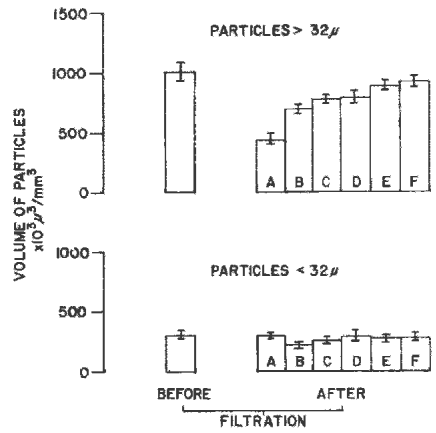

Fig. 1

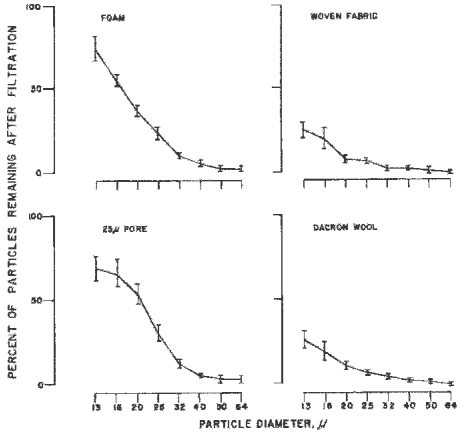

Fig. 2

Fig. 1 Volume of particles larger (top panel) and smaller (bottom panel) than 32 in stored blood before and after passage through cardiotomy reservoirs: A) Harvey Cardiotomy Reservoir, H50, William Harvey Research Corp., Santa Ana, Cal.; B) Variflo Cardiotomy Reservoir 5M-0-305, Travenol Laboratories, Morton Grove, Ill.; C) Cobe Cardiotomy Reservoir, Experimental System consisting of these three layers of polyurethane foam with 30, 160 and 30 pores, Cobe Laboratories, Lakewood, Colo.; D) Cobe Cardiotomy Reservoir, similar to C but with only 2 layers of foam with 30 pores; E) Cardiotomy Reservoir, Q120, Bentley Laboratories, Irvine, Ca.; F) Cardiotomy Blood Reservoir 5M-03-91, Travenol Laboratories, (mean ± S.E., n = 8).

Fig. 2 Filtration efficiency of cardiotomy in-line blood filters. Percent of particles remaining in stored blood after passage through different filters is plotted against particle diameter in (mean ± S.E., n = 8).

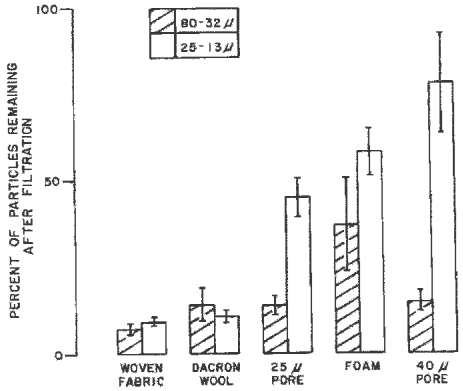

Fig. 3

Fig. 3 Filtration efficiency of cardiotomy in-line blood filters. Percent by volume of particles in cardiotomy reservoir blood in two different size ranges remaining after passage through five different filters (mean ± S.E., n = 30).

particles smaller than 32 μ than the other three filters tested. The 40 μ pore mesh filter was least effective at removal of microemboli smaller than 32 μ. As would be expected, the data show that the removal of particles smaller than 32 μ by the mesh filter was improved ($p < 0.05$) as a result of reduction of the pore size from 40 x 40 to 25 x 40 μ.

DISCUSSION

With the advent of membrane oxygenators with good gas transfer characteristic and low priming volumes, a reduction in complications resulting from blood trauma during cardiopulmonary bypass will be possible. This has been shown during clinical

avoid the blood trauma and particulate microembolization resulting from autotransfusion of extravasated blood through the coronary suction system[7]. The present study shows that the currently available cardiotomy reservoirs are not effective at removal of particulate microemboli.

The filtration studies are consistent with previous evaluations of cardiotomy and blood transfusion filters[1,6,8,9]. The efficiency of the Dacron wool filter in removing particles regardless of size is due to the large surface which it provides for adhesive particles to stick to. This is shown not only by its ability to remove particles down to 13 μ in size but by the finding that it is the only filter which removed a significant number of platelets (2-3 μ in diameter) from the stored blood. The woven fabric filter is a combination of a 20 μ pore mesh with a large surface area. It is as effective at particle removal as the Dacron wool filter and is more effective than the other three filters tested. It seemed justified to attempt to remove all particles larger than leukocytes from cardiotomy reservoir blood, but there is no clinical evidence demonstrating the superiority of filters which remove microemboli in the smaller size range. Although insertion of one of the more effective blood filters in the cardiotomy line can eliminate particulate microemboli, this constitutes an additional expense. The implication is that a cardiotomy reservoir with improved filtration characteristics needs to be developed.

REFERENCES

1. Swank, R.L.: Alteration of Blood on Storage: Measurement of Adhesiveness of "Aging" Platelets and Leukocytes and Their Removal by Filtration. *New Eng J Med,* 265:728, 1961
2. Allardyce, D.B., Yoshida, S.H., and Ashmore, P.G.: The Importance of Microembolism in the Pathogenesis of Organ Dysfunction Caused by Prolonged Use of the Pump Oxygenator. *J. Thorac. [Cardiovasc. Surg.* 52:706, 1966
3. Osborn, J.J., Swank, R.L., Hill, J.D., Aguilar, M.H., and Gerbode, F.: Clinical Use of a Dacron Wool Filter During Perfusion for Open-Heart Surgery. *J. Thorac. [Cardiovasc. Surg.* 60:575, 1970
4. Kessler, J. and Patterson, R.H., Jr.: The Production of Microemboli by Various Blood Oxygenators. *Ann. Thorac. Surg.* 9:221, 1970
5. Connell, R.S. and Swank, R.L.: Pulmonary Fine Structure After Hemorrhagic Shock and Transfusion and Shock. *Microvasc. Res.* 1:15, 1968
6. Solis, R.T., Noon, G.P., Beall, A.C. et al.: Particulate Microembolization During Cardiac Operation. *Ann. Thorac. Surg.* 17:332, 1974
7. Solis, R.T., Kennedy, P.S., Noon, G.P. et al.: Cardiopulmonary Bypass: Microembolization and Platelet Aggregation. *Circulation* 52:103, 1975
8. Solis, R.T., Gibbs, M.B.: Filtration of the Microaggregates in Stored Blood. *Transfusion* 12:245, 1972
9. Solis, R.T., Noon, G.P., DeBakey, M.E.: Filtration Characteristics of Microemboli in Stored Blood and in Autotransfused Blood. *Trans. Amer. Soc. Artif. Int. Organs* vol. XX:1974
10. Brecher, G., and Cronkite, E.P.: Morphology and Enumeration of Human Blood Platelets. *J. Appl. Physiol.* 3:365, 1959
11. Clowes, G.H.A., Jr.: Extracorporeal Maintenance of Circulation and Respiration. *Physiol. Review.* 40:826, 1960
12. Carlson, R.G., Lande, A.J., Ivey, L.A., et al.: The Lande-Edwards Membrane Oxygenator for Total Cardiopulmonary Support in 110 Patients During Heart Surgery. *Surgery* 72:913, 1972
13. Liddicoat, J.E., Bekassy, S.M., Beall, A.C., et al: Membrane vs Bubble Oxygenation, Clinical Comparison. *Ann. Surg.* in press, 1975
14. Karlson, K.E., Murphy, W.R., Kakvan, M. et al: Total Cardiopulmonary Bypass With a New Microporous Teflon Membrane Oxygenator. *Surgery* 76:935, 1974