

# Filtration of Cardiotomy Reservoir Blood

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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<sup>1-5</sup>. 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<sup>6,7</sup>. 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<sup>8,9</sup>. A large pool of type specific O-positive outdated human stored blood and packed red cells was prepared by initial filtration through a clot mesh filter and subsequent dilution with isotonic saline to an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<sup>10</sup> 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  $\mu$  and a 25 x 40  $\mu$  pore mesh in-line Blood Filter, Pall Corporation, Glen Cove, N.Y.

The electronic particle size analysis was performed with a Coulter Counter<sup>®</sup> (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<sup>®</sup> & Zap-Isoton<sup>®</sup> respectively, Coulter Electronics). Particles of nine different diameter sizes ranging from 13 to 80  $\mu$  were counted as 2 ml of the suspension passed through a 200  $\mu$  aperture. The data are reported as either the total volume in  $\mu^3/\text{mm}^3$  of particles in two arbitrary diameter ranges (32 to 80  $\mu$  and 13 to 25  $\mu$ ) or as the percent of particles remaining after passage through each of the blood filters plotted against the particle diameter.

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In order to assess the filtration characteristics of the in-line cardiomy reservoir blood filters during cardiopulmonary bypass, each of the filters was evaluated as previously described<sup>6,9</sup>. Each filter to be tested was inserted in the line draining blood from the cardiomy 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  $\mu$  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 cardiomy reservoirs are shown in Figure 1. None of the reservoirs was able to remove a significant volume of microemboli smaller than 32  $\mu$ . The Harvey was the most effective reservoir at removal of particles larger than 32  $\mu$ . 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  $\mu$  pore mesh filter in Table I). The Bentley (Q120) and Travenol (5m-03-91) reservoirs did not remove a significant volume of particles 32  $\mu$  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 cardiomy reservoirs, all of the in-line blood filters removed a significant volume of microemboli larger than 32  $\mu$  (Table I and Figure 2). However, these filters differed in their ability to remove the smaller microemboli. The 25  $\mu$  pore mesh and the polyurethane foam filters were the least efficient at removal of microemboli smaller than 32  $\mu$  and did not differ except in the 20  $\mu$  size range where the 25  $\mu$  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  $\mu$  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 cardiomy 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 cardiomy in-line blood filters (mean  $\pm$  SE, n=8)

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

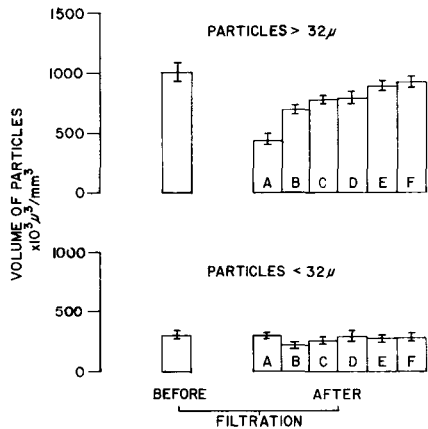


Fig. 1

Fig. 1 Volume of particles larger (top panel) and smaller (bottom panel) than  $32 \mu$  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  $\pm$  S.E.,  $n = 8$ ).

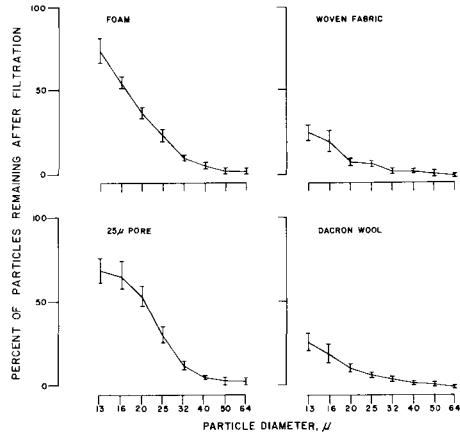


Fig. 2

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  $\mu$  (mean  $\pm$  S.E.,  $n = 8$ ).

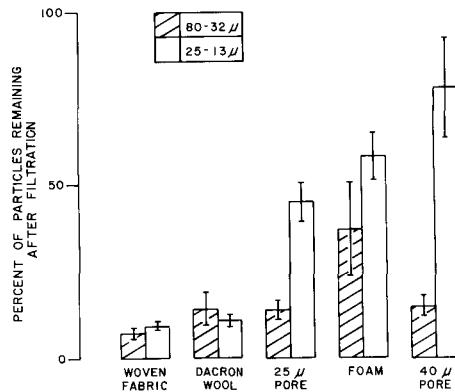


Fig. 3

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  $\pm$  S.E.,  $n = 30$ ).

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

## 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

use of the membrane oxygenator<sup>7,11-14</sup>. However, the membrane oxygenator does not avoid the blood trauma and particulate microembolization resulting from autotransfusion of extravasated blood through the coronary suction system<sup>7</sup>. 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<sup>1,6,8,9</sup>. 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  $\mu$  in size but by the finding that it is the only filter which removed a significant number of platelets (2-3  $\mu$  in diameter) from the stored blood. The woven fabric filter is a combination of a 20  $\mu$  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.

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