

# A Study of Hemolysis

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The damage to blood during cardiopulmonary bypass has been well documented.<sup>1,2</sup> Indeed, it is not surprising in view of the number of insults to which the blood is exposed. First, the rapid introduction of large volumes of transfused blood despite adequate crossmatching may induce the homologous blood syndrome. Next, the blood is subjected to anticoagulation with Heparin. In the pump, the blood is exposed to shearing and squeezing. In the tubing the blood tumbles against foreign surfaces and is forced through constricting apertures. Once in the oxygenator, the force of oxygen bubbling up through the blood, as well as frothing and exposure to gas interfaces, is responsible for cell destruction. In addition to this, overheating of the blood can cause severe damage.

What are the results of these insults on blood? The most notable effect is that of hemolysis and destruction of cellular elements. There is also destruction of proteins with a loss of fibrinogen, loss of platelets and sludging of blood. Hemolysis leads to a rise in plasma hemoglobin which at first is bound to heptoglobin, but as this plasma binding capacity is exceeded, hemoglobin is liberated in a free, unbound state. It is this free hemoglobin which, although cleared rapidly, may cause nephrotoxicity and lead to acute renal failure and death.

Attempts have been made by other experimenters to determine the area where blood is most severely damaged. Improvements in these areas would reduce the degree of hemolysis and lower the plasma hemoglobin level.

At the Ottawa Civic Hospital we have attempted to show that there is another cause of blood destruction hitherto unappreciated in surgery involving cardiopulmonary bypass. This is the cardiotomy suction device.

Twelve adult patients were selected at random from among those operated on at the Ottawa Civic Hospital using the cardiopulmonary bypass system. The apparatus employed for all patients was the American Optical pump and the Temptrol Bentley disposable bubble-type oxygenator.

Two cardiotomy reservoirs were used, one of which is a vent placed in the left ventricle. The other is the cardiotomy suction reservoir, vacuum suction was used on both systems. (Table 1.)

When the caval veins are occluded for the purpose of diverting venous blood into the extracorporeal circuit, there is still a sizeable amount of venous blood returning directly to the right heart cavity by the coronary sinus and the anterior coronary veins, amounting to about 10% of the cardiac output.

When the heart or coronary vessels are open, this blood would soon fill the chest cavity and obscure the operative field, and result in exsanguination were it not for the cardiotomy suction. This device brings blood to the reservoir where it can be returned to the pump if necessary.

Of the twelve patients selected, five had coronary artery disease, four had valvular insufficiency (one of which had mitral insufficiency and tricuspid insufficiency), two had ventricular septal defect and one had an atrial septal defect. Samples of blood for determination of plasma hemoglobin using the colorimetric method were taken off the pump five minutes after total cardiopulmonary bypass had begun, from the cardiotomy suction reservoir and from the vent reservoir in those cases where a vent was used.

In those cases where cardiotomy suction blood was returned to the system a sample was taken from the pump five minutes after the blood had been added. In all cases blood was taken from the pump midway through the operation and immediately after bypass had been terminated for plasma hemoglobin determination.

All but two of the patients were on total bypass for more than fifty minutes. All the patients had high estimated blood flow rates ranging from 2.5 to 4.9 litres/min., and all the patients received between 500 and 1,500 c.c. of A.C.D. blood to prime the apparatus. Hemodilution was used, using 30 ml./kg. of body weight (Ringer's Lactate).

## Results:

Study of the data shows the tremendous rise in plasma hemoglobin associated with cardiotomy suction. Mean plasma hemoglobin at the beginning of the procedure was 7.7 mg.%. The mean plasma hemoglobin in the cardiotomy was 20.5 mg.% while in the vent reservoir, since the vent sits in the left ventricle, the mean plasma hemoglobin was near that of the first figure.

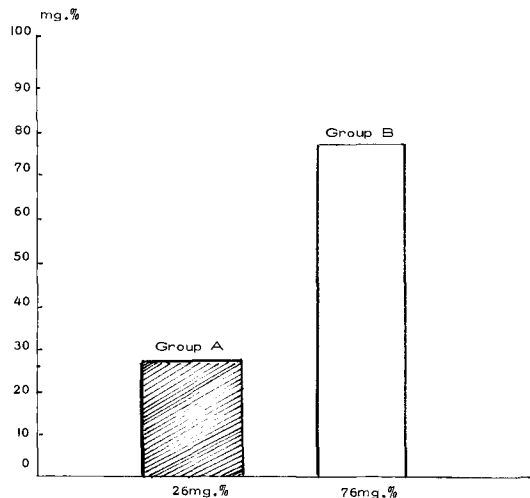
Halfway through the procedure the plasma hemoglobin was seen to rise consistent with the findings that mean plasma hemoglobin varies directly with the length of time on the pump and with the rate of flow. At the end of the procedure the plasma hemoglobin was seen to rise still further to 59 mg.%.

TABLE I.

| Average Perfusion Flow c.c./Kg. | Patient        | Diagnosis  | Group | Pump #1 | Suction #2 | Vent #3 | 5 mins. after #2 blood for system #4 | Mid-Pump #5 | Post-Pump #6 | Perfusion Time |
|---------------------------------|----------------|------------|-------|---------|------------|---------|--------------------------------------|-------------|--------------|----------------|
| 80                              | O. Sloan       | M.I., T.I. | B     | 11 mg%  | 125 mg%    | 11 mg%  | 18 mg%                               | 29 mg%      | 44 mg%       | 91 mins.       |
| 70.5                            | G. Carly       | C.A.D.     | B     | 8 mg%   | 106 mg%    | 7 mg%   | -                                    | 7 mg%       | 12 mg%       | 61 mins.       |
| 90                              | E. St. Laurent | A.I.       | B     | 14 mg%  | 258 mg%    | -       | 50 mg%                               | 17 mg%      | 50 mg%       | 62 mins.       |
| 81                              | H. McNamara    | C.A.D.     | A     | 1 mg%   | 323 mg%    | -       | -                                    | 31 mg%      | 53 mg%       | 69 mins.       |
| 86                              | K. Koosiva     | V.S.D.     | B     | 9 mg%   | 79 mg%     | -       | 16 mg%                               | 8 mg%       | 17 mg%       | 16.1 mins.     |
| 118                             | E. Hartley     | A.S.D.     | B     | 13 mg%  | 28 mg%     | -       | 18 mg%                               | 14 mg%      | 18 mg%       | 23.1 mins.     |
| 72                              | W. Sims        | V.S.D.     | B     | 2 mg%   | 15 mg%     | 4 mg%   | 19 mg%                               | -           | 39 mg%       | 58 mins.       |
| 100                             | V. Blackledge  | M.I.       | B     | 5 mg%   | 218 mg%    | 12 mg%  | 33 mg%                               | 12 mg%      | 68 mg%       | 61 mins.       |
| 85                              | E. Fullond     | C.A.D.     | A     | 5 mg%   | 157 mg%    | -       | 20 mg%                               | 9 mg%       | 36 mg%       | 115.9 mins.    |
| 82                              | B. Brennan     | A.I.       | A     | 7 mg%   | 249 mg%    | 8 mg%   | -                                    | 19 mg%      | 19 mg%       | 66 mins.       |
| 74                              | J. Butler      | C.A.D.     | B     | 13 mg%  | 321 mg%    | 9 mg%   | 61 mg%                               | 17 mg%      | 333 mg%      | 116 mins.      |
| 70                              | R. Goss        | C.A.D.     | A     | 6 mg%   | 573 mg%    | -       | -                                    | 16 mg%      | 21 mg%       | 64 mins.       |

**TABLE 2.**

Group A—No cardiotomy suction return to the system.  
Group B—Cardiotomy suction returned to the system.



How much of this rise was due to the addition of blood from the cardiotomy suction reservoir can be seen in the following data.

The twelve patients were divided into two groups. Group A consisted of four patients who did not have blood from the cardiotomy suction reservoir returned to the system. Group B consisted of the remaining patients. These patients did have blood returned to the system. The difference in post-pump plasma hemoglobin is readily apparent: 26 mg.% in Group A as compared with 76 mg.% in Group B.

When we further compare Group A and Group B we find they are quite similar in other respects. Time on total cardiopulmonary bypass was 57 minutes in Group A and 61 minutes in Group B (despite wide variation in individual cases). Blood flow corrected for

differences in weight and surface area of the patients was also quite similar: 4.25 litres/minute in Group A and 3.9 litres/minute in Group B.

If, however, we correct for time on the pump by expressing plasma hemoglobin per minute on the pump for each patient and compare these results, we again observe the gross difference in the two groups. For Group A mean plasma hemoglobin per minute was .47, whereas for Group B it was 1.17 mg.% per minute. (Table 2).

**Conclusion:**

Thus it is possible to conclude that the cardiotomy suction device is an important cause of red cell destruction and that addition of this blood from its separate reservoir to the system significantly alters the level of plasma hemoglobin in the immediate post-operative period.

Strictly speaking, testing could have been more accurately performed in vitro by recirculating the same amount of blood under the same mechanical, thermal and biochemical conditions. This would have eliminated the compensation made by the patient by clearance of damaged blood in the kidneys and reticular endothelial system.

It would also have eliminated the differences inherent in the procedure itself; namely, amount of transfused blood used, amount of cardiotomy suctioned blood returned to the system, the length of tubing used, the size of the femoral artery cannula and many more too numerous to mention.

However, in spite of the drawbacks inherent in the study, it is still possible to see that in addition to the pump and the oxygenator, which at the present time are unalterable sources of blood destruction, the cardiotomy suction reservoir should be considered a major cause of hemolysis during cardiopulmonary bypass.

**References**

- Cardiac Surgery, Norman: 1967
- Galletti and Brecher: 1962

