Erratum: The following article originally appeared in Volume 22, Number 2, and was published with incomplete data tables. Since publishing data tables alone would be a disservice to author and readers, the entire article with data tables is being published here.

Original Article

The Optimal Preservation of the Patient's Hematocrit When Cardiopulmonary Bypass Is Required

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Abstract

The following study demonstrates a method of perfusion management by which a patient can be placed on cardiopulmonary bypass with a minimal drop in the individual's hematocrit while using any extracorporeal tubing pack or oxygenator. This method involves replacing the crystalloid solution used to prime the circuit with the patient's own blood. The process is performed after the patient is heparinized and cannulated, but just prior to initiating bypass. This study includes 100 patients who underwent cardiopulmonary bypass. The average change in the patient's hematocrit 15 minutes into bypass was 3.69, while the average change in the hematocrit at the end of bypass compared to that seen before bypass was 4.31. These patients did not require ultrafiltration techniques or blood donations of any type.

Introduction

Cardiopulmonary bypass has opened up an avenue of surgical treatment for many heart, liver, lung and circulatory disfunctions. Cardiopulmonary bypass has always presented the disadvantage of hemodilution with a crystalloid or colloid solution, which many surgical teams feel is needed to extend the circulatory volume to accomodate the heart lung machine. This hemodilution has always been treated via mechanical treatments of the blood using ultrafiltration or cell saver techniques, or by the use of blood bank donations. The former treatment adds to the financial consideration of the surgical procedure, not necessarily negating the additional need for the latter treatment. Blood bank donation, in today's social environment, causes the concern for patients of possibly receiving transfusion transmitted diseases. Other disadvantages of homologous transfusion are the decrease in 2,3 diphosphoglycerate levels which are involved in dissociating oxygen from the hemoglobin, as well as the threat of transfusion reactions.

The challenge today for the perfusionist is to initiate, conduct and terminate cardiopulmonary bypass in an optimal fashion, with the least amount of hemodilution possible. This paper details such a perfusion method which exclusively involves the expertise of the perfusionist. This method can be used with any extracorporeal circuit, and will afford important benefits to the patient.

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Materials and Method

One hundred patients were included in this study; of these, 19 percent were female and 81 percent were male. Eight different procedures were performed on these patients as listed in Table 1. In this study, cardiopulmonary bypass was performed at five different hospitals using a total of three different extracorporeal circuit configurations and six different oxygenators: Cobe CML; Cobe CML-2; Cobe EXCEL; Cobe VPCML; Bentley CMS-10; Terumo Capiox II oxygenator.

Table 1

Procedure	*# of patients*
Myocardial Revascularization*	77
Valve Replacement**	9
Valve Replacement and M.R.	4
W.P.W. Syndrome	5
A.S.D.	2
Heart Transplant	1
I.H.S.S.	1
False Aortic Aneurysm***	1

* 5 were first time redo, 1 was a third time redo
** 1 was a first time redo
*** 1 was a third time redo

Procedure

The method devised by the author is designed to eliminate the crystalloid solution in the extracorporeal circuit and replace this volume with the patient's own blood. This practice lends the perfusionist a nearly total blood prime just prior to initiating bypass. The nearly total blood prime can be achieved as follows: after the patient is fully heparinized and cannulated, (but just prior to initiating bypass): 1: totally empty the venous reservoir of the oxygenator; 2: drain back the venous line(s) by removing the tubing clamp(s) and allowing the blood to flow back and push the crystalloid solution out of the tubing and into a separate waste container (This can be done by placing a "Y" connector in the tubing just prior to the venous inlet port of the oxygenator. The "Y" can have a dead end piece of tubing (1/4-inch diameter) which can be used for draining back the venous line(s) and afterwards it can be clamped off. At this point, the venous line(s) are primed with the patient's own

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blood.); 3: fill the venous reservoir of the oxygenator with enough of the patient's blood to replace the crystalloid solution in the membrane portion of the oxygenator with the patient's blood. This is done simply by unclamping the venous line(s) until the desired amount of blood is achieved; 4: replace the solution in the membrane portion of the oxygenator with the patient's blood. This can be done by disconnecting and unclamping the recirculation line (a 1/4-inch diameter line "Y'ed" to the arterial line just past the outlet port of the oxygenator), after a clamp is placed distal to the "Y" connector of the arterial line, then pumping the crystalloid solution into a waste container. At this point, the venous line(s) and the oxygenator are primed with the patient's blood. The last step is to replace the solution in the arterial line with the patient's blood. This is done by unclamping the recirculation line and passively allowing the aortic pressure to back fill the arterial line with blood. The crystalloid solution can be eliminated into a waste container. Now the entire extracorporeal circuit is primed with the patient's blood, and bypass can be initiated. These five steps, which can be accomplished in about 10 to 15 seconds, will give rise to an average pressure drop of approximately 20-55 mmHg, depending on the patient's size, and the total prime of the circuit being used. This drop in pressure is easily overcome once bypass is initiated.

Results

For the 100 cases evaluated in this study, pressures, flows, esophogeal temperature, and bladder temperature were recorded every five minutes while on bypass. Blood gases were evaluated about 15 minutes into bypass, followed by samples at 45 to 60 minute intervals until bypass was terminated. The patient weights ranged from 30 kg to 119 kg with an average weight of 76.9 kg. The final crystalloid prime in the extracorporeal circuit before starting bypass ranged from 50 cc to 400 cc, with an average of 183 cc prime. This is due to a mixing of blood and clear prime while draining the system. Of these 100 patients, cardioplegia was employed 40 percent of the time. The hematocrit just prior to bypass was recorded for each case. This time span ranged from 15 minutes to 60 minutes. These values ranged rrom 23 percent to 44 percent, with an average of 32.95 percent. The first hematocrit on bypass (15 minutes) ranged from 19 percent to 40 percent with an average of 29.26 percent. The last hematocrit prior to termination of bypass ranged from 19 percent to 39 percent with an average of 28.64 percent. The change in hematocrits is quite significant. For these 100 patients, the range of change for the hematocrit before bypass to 15 minutes into bypass ranged from -1[a] to 6 (The -1 means that the hematocrit was one point higher on bypass than before bypass.) The average drop in the hematocrit was 3.69 points. The range of change for the hematocrit before bypass to that of the last hematocrit was -1 to 9. The average drop in the hematocrit was 4.31 points. Pressures recorded every five minutes on bypass ranged from 52.3 mmHg to 83.4 mmHg, with an average pressure of 67.2 mmHg. The flow rates ranged from 3.67 l/min to 5.93 l/min. (44.7 cc/kg/min to 77.1 cc/kg/min.) with an average of 4.38 l/min (56.86 cc/kg/min.). Bypass times ranged from 20 to 210 minutes with an average of 103.25 minutes. The range of the aortic cross clamp times were 0 to 113 minutes, with an average time of 38.3 minutes. Hypothermia was used on all cases except for those patients with Wolff-Parkinson-White Syndrome. All patients were kept at temperatures ranging from 20°C to 36.1°C. Urine output for the 100 patients averaged 331 cc, which is appropriately 192 cc/hr. This rate is felt to be adequate since the average crystalloid prime of the extracorporeal circuits was 183 cc. Accordingly, the total crystalloid prime of the circuits was removed by the kidneys within the first hour of bypass.

(a) The -1 means that the hematocrit was one point higher on bypass than before bypass.

Evaluation of Data

The data presented can be used to compare the effects of different crystalloid primes in the extracorporeal circuits. In order to compare the noted results of this paper with those for circuits using crystalloid primes of 1,000 cc, 2,000 cc, 2,500 cc and 3,000 cc, the following mathematical calculations must be made. First, the amount of fluid given by the anesthesiologist between the point of the last ventilator blood gas and the commencement of bypass must be determined. The following equation can easily render this value:

Anesthesiologist volume = (((Ventilator Gas Hct)(80)(Patient Weight)) divided by (First HCT on pump))-(((80)(Patient Weight))-(Crystalloid Pump Prime))

After calculaling this value (amount of IV fluid added), an approximate change in hematocrit due to the various extracorporeal primes can be determined using the following equation:

New Hematocrit = ((Ventilator Gas Hct)(80)(Patient Weight)) divided by ((Patient Weight)(80) + (Crystalloid Pump Prime) + (Anesthesiologist IV Volume))

These two calculations were performed for each case in this study. Table 2 demonstrates how the hematocrit changes when using the different extracorporeal circuit primes. These changes in hematocrit are compared to those seen using the technique set forth by the author. As demonstrated, the different priming volumes of the extracorporeal circuit have a great deal of influence on the patient's hematocrit. Table 3 represents the approximate amount of donor blood (ml) needed to maintain the same value of the hematocrit 15 minutes into bypass when the author's technique is used compared to the various other circuit primes. This evaluation was done using the following equation: Donor Blood Needed = ((((80)(Patient Weight) + (Circuit Prime) + (Anesthesiologist IV Volume)) (First Hct on Pump)) divided by (100)) - (((Last Ventilator Gas Hct)(80)(Patient Weight)) divided by (100)).

Discussion

The author's technique of priming the extracorporeal circuit just prior to the initiating of cardiopulmonary bypass has many advantages. The elimination of crystalloid solution gives the perfusionist the ability to perform cardiopulmonary bypass on a patient without the problems that a low hematocrit may present. Although this paper has only presented 100 cases, it should be noted that this technique has been used on over 2,000 patients and has become a routine practice. This technique can be used on any patient, with any extracorporeal circuit configuration, without the fear of poor perfusion, low pressures or inadequate blood gas management. The potential of unacceptably high hematocrits during the perfusion period of the surgical procedure can be managed simply by allowing the anesthesiologist to draw off one or two units of blood just prior to heparinization and replace the lost volume with IV crystalloid solution. These units of blood can be preserved by using Adsol, and then given back to the patient at the end of the case following the administration of protamine. By doing so, the patient will receive his own blood, as well as his own clotting factors. This can possibly eliminate the need for fresh frozen plasma and/or platelets. The ability to maintain a change in hematocrit or about 4.31 points per pump run offers today's patient the chance to undergo many surgical procedures involving cardiopulmonary bypass without the need for blood transfusions, low hematocrit levels, or expensive ultrafiltration techniques.

Table 2
Comparison of Patient's Hematocrits Using Various Pump Primes

Case	Pre-Pump Hematocrit	Pump (15 min) Hematocrit	Various Circuit Primes			
			1000 cc	2000 cc	2500 cc	3000 cc
1	34.0	30.0	25.7	22.4	21.0	19.7
2	24.0	19.0	16.7	14.5	13.6	12.8
3	36.0	30.0	27.7	24.5	23.2	22.0
4	37.0	31.0	28.3	25.2	23.9	22.7
5	39.0	34.0	31.6	28.3	26.8	25.6
6	34.0	29.0	26.9	24.1	22.9	21.9
7	33.0	29.0	26.7	24.1	22.9	21.9
8	31.0	26.0	21.0	16.4	14.7	13.4
9	32.0	27.0	24.7	22.1	20.9	19.9
10	31.0	25.0	22.7	20.1	19.0	18.0
11	34.0	30.0	27.0	24.3	23.1	22.0
12	30.0	26.0	20.9	17.2	15.7	14.5
13	35.0	29.0	26.5	23.5	22.2	21.0
14	39.0	34.0	30.1	27.7	26.3	25.1
15	35.0	32.0	29.5	26.5	25.2	24.1
16	30.0	29.0	25.9	23.0	21.7	20.6
17	33.0	27.0	24.8	22.0	20.8	19.7
18	35.0	30.0	28.0	25.3	24.0	23.0
19	31.0	26.0	23.4	20.5	19.3	18.2
20	31.0	29.0	26.8	24.1	23.0	21.9
21	44.0	39.0	35.5	31.9	30.3	29.0
22	28.0	22.0	19.8	17.7	16.7	15.9
23	35.0	29.0	26.7	23.6	22.3	21.0
24	31.0	29.0	25.4	22.2	20.9	19.8
25	34.0	28.0	25.4	22.4	21.0	20.0
26	31.0	25.0	22.1	19.3	18.2	17.3
27	36.0	30.0	27.5	24.5	23.3	22.2
28	36.0	32.0	29.2	26.3	25.1	23.9
29	33.0	29.0	26.4	22.9	21.5	20.3
30	31.0	26.0	23.5	20.7	19.5	18.5
31	36.0	33.0	30.3	27.7	26.6	25.5
32	36.0	30.0	27.6	25.0	23.9	22.9
33	30.0	26.0	23.6	21.3	20.2	19.3
34	31.0	26.0	23.0	20.2	19.0	17.9
35	34.0	29.0	27.2	24.7	23.6	22.6
36	33.0	32.0	24.2	19.2	17.5	15.9
37	40.0	36.0	33.5	30.5	29.2	27.9
38	37.0	34.0	31.6	29.0	27.9	26.9
39	33.0	28.0	24.9	21.5	20.2	18.9
40	38.0	34.0	30.2	26.5	24.9	23.6
41	31.0	31.0	27.0	23.9	22.7	21.5
42	30.0	28.0	24.4	20.9	19.6	18.4
43	41.0	40.0	36.1	32.3	30.7	29.2
44	38.0	32.0	28.6	25.4	23.9	22.7
45	26.0	24.0	21.1	18.3	17.2	16.2
46	34.0	29.0	25.8	22.6	21.3	20.2
47	27.0	25.0	21.6	18.5	17.2	16.2
48	31.0	25.0	22.7	20.3	19.3	18.4
49	37.0	33.0	29.9	26.9	25.6	24.4
50	38.0	34.0	30.8	27.2	25.7	24.3
51	34.0	28.0	25.3	22.9	21.9	20.9
52	35.0	34.0	29.3	25.3	23.7	22.3
53	23.0	20.0	18.5	16.5	15.6	14.8
54	31.5	28.0	24.7	21.2	19.7	18.5
55	30.0	25.0	22.2	19.4	18.3	17.3
56	27.0	26.0	22.7	19.9	18.8	17.7
58	27.0	22.0	19.7	17.7	16.8	16.0
58	42.0	37.0	34.4	31.3	30.0	28.8
59	33.0	28.0	25.1	22.2	21.0	19.9
60	28.0	26.0	23.1	20.5	19.5	18.5
61	36.0	35.0	31.5	28.0	26.5	25.2
62	35.0	31.0	27.9	24.9	26.4	22.5
63	37.0	31.0	27.9	24.9	23.6	22.5
64	32.0	26.0	23.8	21.6	20.7	19.8
65	35.0	30.0	26.0	22.8	21.4	20.2
66	27.0	21.5	18.4	15.9	14.9	13.9
67	29.0	26.0	22.4	19.4	18.2	17.1
68	33.0	31.0	26.5	22.8	21.4	20.1
69	36.0	35.0	30.7	27.1	25.6	24.2
70	35.0	30.0	27.0	24.3	23.1	22.1
71	34.0	32.0	29.4	26.9	25.8	24.9
72	27.0	26.0	22.6	19.8	18.6	17.6
73	31.0	27.0	23.3	20.2	18.9	17.8
74	37.0	33.0	29.4	26.3	24.9	23.8
75	32.0	30.0	25.9	22.5	21.1	19.9
76	30.0	27.0	24.2	21.4	19.2	20.2
77	28.0	27.0	22.8	19.6	18.3	17.1
78	29.0	30.0	24.8	21.7	20.5	19.3
79	39.0	36.0	32.2	28.8	27.3	26.0
80	28.0	25.0	21.2	18.3	17.1	16.1
81	28.0	26.0	21.6	18.4	17.1	16.0
82	32.0	28.0	23.5	20.1	18.7	17.5
83	32.0	27.0	23.5	20.5	19.3	18.2
84	34.0	29.0	26.4	24.1	23.1	22.2
85	37.0	34.0	29.8	26.4	24.9	23.7
86	32.0	29.0	24.5	21.1	19.7	18.5
87	31.0	30.0	24.9	21.2	19.7	18.4
88	36.0	31.0	27.4	24.5	23.2	22.1
89	36.0	32.0	29.1	26.6	25.5	24.4
90	32.0	29.0	24.7	21.3	19.9	18.6
91	38.0	36.0	31.6	28.1	26.6	25.2
92	32.0	27.0	24.1	21.5	20.4	19.4
93	25.0	23.0	18.9	15.9	14.7	13.7
94	29.0	30.0	24.8	21.7	20.4	19.2
95	30.0	26.0	23.4	21.2	20.2	19.3
96	35.0	30.0	26.8	24.1	22.9	21.9
97	31.0	29.0	25.8	22.9	21.7	20.7
98	31.0	32.0	27.3	24.4	23.1	22.0
99	35.0	34.0	30.9	28.2	26.9	25.8
100	33.0	29.0	25.7	22.9	21.8	20.7

Table 3
Red Blood Cells (ml) Needed to Equal the Study's Hematocrit Levels

Case	Various Circuit Primes			
	1000 cc	2000 cc	2500 cc	3000 cc
1	300	600	743	900
2	150	340	435	530
3	180	480	630	780
4	217	527	682	837
5	204	544	714	884
6	174	464	609	754
7	203	493	638	783
8	176	436	565	696
9	189	459	594	729
10	174	424	549	674
11	240	540	690	840
12	234	494	624	754
13	188	478	623	768
14	272	612	782	952
15	224	544	704	864
16	232	522	667	812
17	162	432	567	702
18	180	480	630	780
19	182	442	572	702
20	217	527	682	837
21	312	702	897	1092
22	176	396	506	616
23	174	464	609	754
24	261	551	696	841
25	196	476	616	756
26	200	450	575	700
27	210	510	660	810
28	256	576	736	896
29	174	464	609	754
30	182	442	572	702
31	297	627	792	957
32	240	540	690	840
33	208	468	598	728
34	208	468	598	728
35	174	464	609	754
36	304	624	784	944
37	252	612	792	972
38	272	612	782	952
39	196	476	532	756
40	272	612	782	952
41	310	620	775	930
42	224	504	644	784
43	326	726	926	1126
44	256	576	736	896
45	192	432	552	672
46	232	522	667	812
47	200	450	575	700
48	200	450	575	700
49	264	594	759	924
50	238	578	748	918
51	252	532	672	812
52	306	646	806	986
53	120	320	420	520
54	196	476	616	756
55	200	450	575	700
56	234	494	624	754
57	198	418	528	638
58	259	629	814	999
59	224	504	644	784
60	234	494	624	716
61	280	630	805	980
62	248	558	713	868
63	248	558	713	868
64	208	468	598	728
65	270	570	720	870
66	193	408	516	623
67	234	494	624	754
68	279	589	744	899
69	315	665	840	1015
70	270	570	720	870
71	288	608	768	928
72	234	494	624	754
73	243	513	648	783
74	297	627	792	957
75	270	570	720	870
76	216	486	621	756
77	256	526	661	796
78	360	660	810	960
79	324	684	864	1044
80	237	487	612	737
81	247	507	637	767
82	266	546	686	826
83	243	513	648	783
84	275	565	710	855
85	323	663	833	1003
86	275	565	710	855
87	285	585	735	885
88	294	604	759	914
89	304	624	784	944
90	261	551	696	841
91	342	702	882	1062
92	243	513	648	783
93	218	448	563	678
94	359	659	809	959
95	247	507	637	767
96	285	585	735	885
97	261	551	696	841
98	394	714	874	1034
99	306	646	816	986
100	275	565	710	855