THE USE OF CITRATED BANKED BLOOD FOR OPEN-HEART SURGERY

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ONE of the most vexing problems in extracorporeal circulatory systems has been the provision of an adequate supply of fresh donor blood. It is the purpose of this paper to report on the use of routinely collected and processed banked blood in hypothermic extracorporeal circulation, using the double helical system.[1]

METHOD

ACD banked blood as collected and processed by the Oklahoma City Community Blood Bank was circulated through the double helical reservoir oxygenator-sigmamotor pump (fig. 1).[1,4] Donor blood was drawn by vacuum through silicone-coated donor sets into silicone-coated glass bottles containing 120 ml. ACD solution, with the flow rate regulated at 90–100 ml. per minute. The blood was processed according to National Institute of Health approved blood banking techniques.

In vitro studies included determinations of hematocrit, white blood count, platelet count, plasma hemoglobulin, and plasma sodium, potassium, and chloride made before the blood was subjected to the double helical system; after thirty minutes; after sixty minutes of pump operation at a flow of 250 ml. a minute for a 500 ml. reservoir. Temperature of the blood was maintained at either 25 C. or 37 C.

Clinical studies included determinations of hematocrit and plasma hemoglobin on each bottle of banked blood used; on each patient before perfusion, at varying intervals during perfusion, and at the end of the perfusion; and on blood drawn from the double helical reservoir at the end of cardiopulmonary bypass. Tests to measure mechanical fragility and os-

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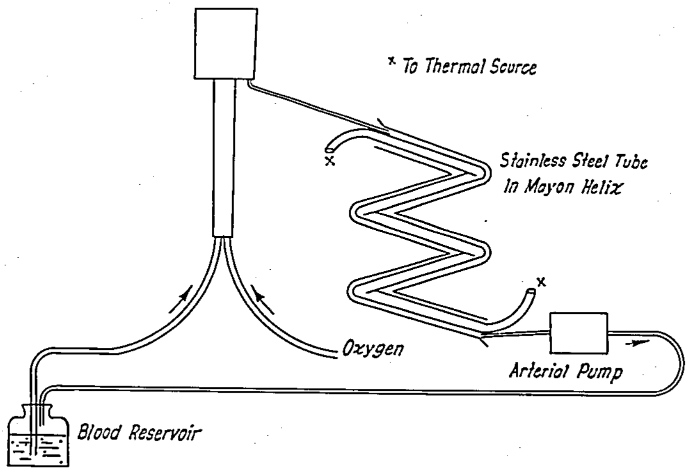

FIG. 1. Diagram of system used both experimentally and clinically.

motic fragility of blood are being conducted and some preliminary results will be reported. In all patients reported in this series, 5 per cent dextrose in water was used as the priming fluid for the heart-lung machine,[1] and ACD banked blood to replace that lost during surgery.

Techniques

All determinations were done in duplicate. The techniques used included: Hematocrit determinations: microhematocrit capillary tubes, and international microhematocrit centrifuge and reader. Platelet counts: direct count method, using a modified Deese-Ecker diluting fluid.[5] Plasma hemoglobin: modified benzidine method as described by Crosby and Furth.[6] Plasma sodium and potassium levels: Coleman flame photometer attached to Coleman Junior spectrophotometer.[7]

Plasma chloride levels: method of Schales and Schales.[8] Quantitative osmotic fragility: modification of the method described by Ham.[5] Mechanical fragility: modification of the method of Ham and Shen.[5]

Results

In vitro studies show that citrated banked blood, stored up to five days may be circulated through a system such as that described above without undergoing significant changes in the factors measured (Tables 1 and 2). The low chloride levels reported may be explained by

TABLE 1

In Vitro Studies on Blood Circulated at 25 C. Through the Double-Helical Oxygenator and Sigmamotor Pump at a Flow Rate of 250 ml. a Minute with a 500 ml. Reservoir

Bottle No.	Days Old	Hematocrit			White Blood Cells			Platelets per mm.³		
		Base Line	30 min.	60 min.	Base Line	30 min.	60 min.	Base Line	30 min.	60 min.
F5766	1	44	42	41	7,600	7,000	6,450	212,000	200,000	196,000
F5742	1	40	37	36	11,300	10,900	10,600	206,000	186,000	178,000
Average		42	39	38	9,450	8,950	8,500	209,000	193,000	187,000
F6281	2	41	38	36	8,100	7,700	7,350	203,000	189,000	171,000
F6222	2	39	37	36	9,600	9,000	8,750	208,000	197,000	186,000
F5935	2	45	44	42	6,000	5,500	5,300	196,000	187,000	182,000
Average		41	39	38	7,900	7,400	7,100	202,000	191,000	179,000
F6215	3	43	41	39	8,600	7,900	7,300	147,000	125,000	118,000
F6176	3	45	43	41	7,650	7,400	7,100	139,000	130,000	118,000
F5902	3	44	42	41	6,900	6,750	6,700	143,000	129,000	118,000
Average		43	40	38	7,600	7,300	7,000	154,000	140,000	128,000
F6194	4	39	39	35.5	7,450	6,800	6,150	139,000	124,000	111,000
F6161	4	45	43	42.5	7,400	7,050	6,800	109,000	103,000	98,000
F5866	4	42	41	40	5,450	5,200	4,950	117,000	110,000	106,000
Average		42	40	39.3	6,800	6,350	5,950	121,000	112,000	105,000
F6153	5	39.5	36	33.5	6,300	5,850	5,400	107,000	98,000	86,000
F6122	5	53	49	45	6,750	6,700	6,200	99,000	87,000	83,000
F5101	5	42	38	37	5,300	5,000	4,850	202,000	186,000	168,000
Average		44.8	41	38.5	6,150	5,850	5,450	136,000	123,000	112,000
F5864	7	40	35	33	4,100	4,000	3,500	12,000	8,600	7,000
F5867	7	43	38	36	3,900	3,500	3,000	15,000	7,000	4,500
Average		41	36	34	4,000	3,700	3,200	13,000	7,800	5,700
F5834	8	39	36.5	35.5	3,850	3,400	3,300	8,000	4,000	3,000
F5827	8	41	39	37	3,200	2,500	2,000	7,500	3,500	2,000
F5835	8	44	42	41	2,500	2,000	1,500	5,000	3,000	1,800
Average		41	39	37.8	3,200	2,600	2,000	6,800	3,500	2,200

TABLE 1—*Continued*

Bottle No.	Days Old	Plasma Hemoglobin—mg. %			Sodium—mEq./l.			Potassium—mEq./l.			Chloride—mEq./l.		
		Base Line	30 min.	60 min.	Base Line	30 min.	60 min.	Base Line	30 min.	60 min.	Base Line	30 min.	60 min.
F5766	1	20.3	39.1	53.4	138	140	142	5.6	5.7	6.0	70	70	72
F5742	1	44.5	62.3	80.1	138	136	137	4.6	4.4	4.6	70	69.5	70.5
Average		32.4	50.7	66.7	138	138	139	5.1	5.0	5.3	70	69.8	71.3
F6281	2	9.3	18.4	33.2	135	133	130	6.5	6.3	6.6	72.5	73	75.1
F6222	2	10.0	14.3	17.8	138	137	137	6.3	6.2	6.3	69.8	68.4	69.5
F5935	2	12.5	35.0	40.0	127	125	127	4.4	4.6	4.7	67.3	66.8	66.6
Average		10.6	22.5	30.3	133	131	131	5.7	5.7	5.8	69.8	69.4	70.1
F6215	3	11.0	19.1	26.7	128	129	130	5.8	5.7	5.9	77	79.5	76.8
F6176	3	7.2	13.9	19.4	136	139	137	4.4	4.6	4.7	74	74.9	73.7
F5902	3	9.0	89.2	106.0	118	120	119	4.6	4.9	5.1	72.8	73.1	73.2
F5720	3	22.3	65.5	89.3	135	135	136	6.2	6.4	6.5	66	73	76
Average		12.3	46.9	60.3	129	130	130	5.2	5.4	5.5	72.5	75.1	74.9
F6194	4	6.5	19.9	27.6	125	123	127	6.2	6.5	6.4	69.8	69.8	70.0
F6161	4	11.5	16.3	18.0	134	135	135	5.4	5.3	5.3	79	79.7	78
F5866	4	8.0	48.0	58.0	125	127	128	4.9	5.1	5.2	69.8	69.8	70.0
Average		8.6	28.0	34.5	128	128	130	5.5	5.6	5.6	72.8	73.1	72.6
F6153	5	10.3	15.4	19.2	137	134	138	6.9	6.7	7.1	73.2	73	73.1
F6122	5	8.9	13.7	16.0	138	140	138	7.1	7.3	7.2	75	73.4	74
F5101	5	15.7	58.9	98.5	134	135	137	7.1	7.6	8.1	71	72	75
Average		11.6	29.3	44.5	136	136	137	7.0	7.2	7.4	73	72.8	74
F5864	7	7.5	137.5	200.0	135	136	136	8.7	9.8	10.1	70	75	77
F5867	7	10.0	50.0	75.0	139	140	138	8.1	8.7	9.2	68	67	69
Average		8.7	93.7	137.7	137	138	137	8.4	9.2	9.6	69	71	73
F5834	8	7.5	33.4	45.7	133	134	135	8.1	8.5	8.8	72	73	73
F5827	8	12.5	20.0	45.5	128	130	129	9.1	9.5	9.6	71	73.6	72
F5835	8	12.5	22.5	39.8	128	127	129	9.0	9.3	9.5	74	73	73
Average		10.8	25.3	43.6	129	130	131	8.7	9.1	9.3	72	73.1	72

the dilution of the whole blood with 20 ml. of the citrate solution. *In vitro* changes at 25 and 37 C. at the end of one hour are summarized in table 3.

In vivo studies on patients undergoing open-heart surgery with hypothermic perfusion using the system and techniques described above showed an average decrease in hemato-

TABLE 2

In Vitro Studies on Blood Circulated at 37 C. Through the Double-Helical Oxygenator and Sigmamotor Pump at a Flow Rate of 250 ml. a Minute with a 500 ml. Reservoir

Bottle No.	Days Old	Hematocrit			White Blood Cells			Platelets per mm.^{3}		
		Base Line	30 min.	60 min.	Base Line	30 min.	60 min.	Base Line	30 min.	60 min.
F6448	1	46	42	40	8,600	8,000	7,850	207,000	193,000	180,000
F6411	2	40.5	37.5	35.5	9,650	9,000	8,300	201,000	183,000	161,000
F6315	3	46	42.5	40	7,400	6,900	6,100	154,000	126,000	101,000
F6255	4	42.5	36	34	5,950	5,400	5,050	113,000	103,000	87,000
F6207	5	42	39	35	6,400	5,300	5,000	99,000	76,000	54,000

TABLE 2—*Continued*

Bottle No.	Days Old	Plasma Hemoglobin—mg. %			Sodium—mEq./l.			Potassium—mEq./l.			Chloride—mEq./l.		
		Base Line	30 min.	60 min.	Base Line	30 min.	60 min.	Base Line	30 min.	60 mip.	Base Line	30 min.	60 min.
F6448	1	6.5	37.5	52.0	131	133	132	4.6	4.6	4.7	71	70.9	71.3
F6411	2	9.0	16.5	22.0	129	130	128	5.0	5.1	4.9	68.4	68.9	69.3
F6315	3	8.0	21.5	28.0	128	130	131	6.7	6.5	6.7	70.1	70.1	71
F6255	4	7.5	16.5	19.0	130	135	134	6.2	6.3	6.3	73.0	72.4	72.9
F6207	5	11.5	21.5	39.5	129	127	127	7.0	6.9	7.1	70.1	72	71.5

crit of only 2.3 per cent and an average rise in plasma hemoglobin of only 18.9 mg. per cent. The maximum rise in plasma hemoglobin was 45.8 mg. per cent (Table 4). Osmotic and mechanical fragility tests on red blood cells during two human perfusions with the 5 per cent dextrose in water primed heart-lung machine and the use of banked citrated blood to replace that lost during surgery are summarized in table 5.

Discussion

Freshly drawn heparinized blood [9, 10, 11] has been advocated for open-heart surgery; fresh to secure the least altered blood and heparinized to avoid citrate poisoning and over loading with fluids. However, citrated banked blood obtained in routine fashion would do away with special programs for blood recruitments currently in progress.

Our studies indicate that banked blood stored up to five days maintains most of its measured elements and does not change markedly when subjected to our double helical system. Postoperative blood loss compared favorably with the blood loss observed when fresh blood was used. The possible decrease of the life span of the red blood cell is currently being investigated but the degree and frequency of postoperative anemia observed does not seem to be unusual.

TABLE 3

Summary of Changes in Blood at the End of One Hour Run at 25 C. and 37 C.

	Average Change at 25 C.*	Average Change at 37 C.*
Hematocrit	−4.4%	−6.5%
White blood cells	−850 cells	−1,100 cells
Platelet count	−17,500/cu. mm.	−38,000/cu. mm.
Plasma hemoglobin	+46.1 mg. %	+23.6 mg. %
Plasma sodium	+1 mEq./l.	+1 mEq./l.
Plasma potassium	+0.5 mEq./l.	+0.02 mEq./l.
Plasma chloride	+1.3 mEq./l.	+0.7 mEq./l.

* − indicates a decrease and + an increase.

The first clinical instance of possible citrate poisoning during open-heart surgery was described by Dennis and associates, in 1951,[11] when late in the repair of an ostium primum defect, the force of the heart beats were noted to be weak following the use of citrated blood for substitution. However, multiple factors entered into the picture and could have led to the inability of the heart to sustain a strong beat. Bunker [9] stated that citrated blood should not be used during open-heart surgery or hypothermia because of the danger of citrate poisoning. The deleterious effects of the use of banked citrated blood during hypothermic perfusion were not encountered in our series of patients weighing from 10 kg. to 72 kg. and using up to 5,000 ml. of blood in one procedure. The amount of citrate fluid used in each pint of blood should be taken into consideration in the fluid balance sheet and accounted for during the computation of the 24 hour fluid requirements. The use of banked citrated blood during hypothermic perfusion is advocated only when used in conjunction with the system as described; we have not studied other systems.

Summary

Routinely collected and processed banked blood may be used successfully in an extracorporeal circulatory system using low flow rates as made possible by hypothermic perfusion. Blood banked for as many as five days may be used without significant changes occurring in hematocrit, white blood count, plate-

TABLE 4

STUDIES ON PATIENTS UNDERGOING HYPOTHERMIC PERFUSION WITH THE 5% DEXTROSE IN WATER PRIMED DOUBLE-HELICAL RESERVOIR HEART-LUNG MACHINE

Patient	Age in Years	Wt. in Kg.	Flow Rate	Length of Perfusion (min.)	Blood Bottle No.	Age in Days	Hematocrit		Plasma Hemoglobin-mg. %	
							Base Line	Post Perfusion	Base Line	Post Perfusion
L. J.	2½	12.55	300	26			41	36.5	11.0	20.0
					F6069	1	44		18.5	
					F6072	1	43		8.0	
					Blood from helix			37		12.5
G. B.	9	25.55	600	88			32	34.5	9.5	17.8
					F6081	1	40		26.5	
					F6082	1	43		15.0	
					F6075	1	41.5		19.7	
					F6074	1	42		12.0	
					F6086	1	44		8.6	
					Blood from helix			35		20.0
J. O.	2½	12.71	300	42			38	33.5	11.7	21.3
					F6171	2	42		9.6	
					F6182	2	40		15.9	
					Blood from helix			34		25.7
J. D.	10	39.0	800	62						
					F6166	6	43		12.0	
					F6378	1	41		9.5	
					F6376	2	44		8.6	
					Blood from helix					23.5
J. W.	21	35.05	700	82			40	36	11.6	23.1
					F6507	4	51		9.5	
					F6535	3	38		11.6	
					F6491	5	42		8.7	
					F6537	3	36		10.4	
					Blood from helix			35		19.7
N. D.	46	46.80	1,000	33			40	38	17.9	34.3
					F5922	1	36		19.3	
					F5921	1	39		23.4	
					Blood from helix			37		36.1
C. S.	54	70.87	1,500	189			47	41	13.9	67.7
					F6614	2	42		17.3	
					F6611	2	41		8.1	
					F6641	2	41		12.3	
					F6604	2	43		9.6	
					F6608	2	40		14.3	
					F6533	4	44		23.6	
					F6535	4	38		16.7	
					F6540	4	44		11.2	
					F6663	1	40		13.4	
					Blood from helix			42		70.3
E. L.	35	39.78	800	61			32	33.5	9.8	34.0
					F6807	4	51		8.3	
					F6809	4	40		15.6	
					F6803	4	41		21.3	
R. H.	7½	22.6	450	81			36.5	31	8.9	26.7
T. N.	7	21.0	400	31			41.5	33.5	9.45	17.8

TABLE 5

RBC Fragility Studies on Patients Undergoing Hypothermic Perfusion with the 5% Dextrose in Water Primed Double Helical Reservoir Heart-Lung Machine

Patient	Specimen	% Saline	Osmotic Fragility				Mechanical Fragility Plasma Hemoglobin after Agitation—mg. %
			0.85	0.45	0.30	0.00	
J. W.	Control	% hemolysis	0	3.7	97.6	100	75.6
	Patient—Base Line	% hemolysis	0	1.55	90.1	100	69.0
	Patient—1 hour perfusion	% hemolysis	0	2.1	96.3	100	76.1
	Patient—50 min. after end of perfusion—perfusion lasted 82 min.	% hemolysis	0	2.35	94.3	100	75.4
E. L.	Patient—Base Line	% hemolysis	0	1.4	88.5	100	
	Patient—at end of perfusion—perfusion lasted 61 min.	% hemolysis	0	2.75	90.6	100	

let count, plasma hemoglobin and plasma sodium, potassium and chloride concentrations. Comparison of studies made on blood at 25 C. with blood at 37 C. seem to indicate that it is the low flow rate that makes possible the use of banked blood. The system described has been successfully used on 30 patients undergoing open-heart surgery.

The technical determinations were made by Mrs. Betty Blackburn.

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