EFFECT OF CARDIOPULMONARY BYPASS AND HAEMODILUTION ON SOME CONSTITUENTS OF BLOOD

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WHOLE-BODY PERFUSION using haemodilution has been proved to be a safe, advantageous procedure. The purpose of this study was to compare operative and postoperative plasma concentrations of sodium, chloride, potassium, urea, and sugar in six patients (group 1) perfused with whole blood and in twelve patients (group 2) using a diluted perfusate. In six patients of group 2, levels of a haematocrit and plasma protein were determined to permit closer examination of the period of perfusion.

METHODS

All eighteen patients underwent open-heart surgery with the Mayo-Gibbon pump-oxygenator by techniques previously described¹. Flow rates for the twelve haemodiluted perfusions were 2.0 litres/min/sq m. For the nondiluted perfusions, flow rates averaged 2.2 litres/min/sq m. All perfusions but one (in group 1) were carried out at 30° C. The average time of perfusion was 64 minutes for group 1 (range 50 to 163) and 90 minutes for group 2 (range 41 to 165).

Samples of venous blood were drawn before anaesthesia, before perfusion, at the end of the operation, and again at 6 and 18 hours after the operation. Samples were taken from the pump-oxygenator before perfusion, after 15 minutes, and at the end of perfusion. Additional samples were taken for haematocrit and plasma protein determinations at 10, 25, 40, 60, and 90 minutes of perfusion in six haemodiluted perfusions.

For group 1, the perfusate was fresh, heparinized whole blood containing 20 ml of 0.9 per cent sodium chloride solution and 5 ml of concentrated serum albumin per 500 ml. In group 2, the heparinized blood was diluted with a solution containing 5 per cent dextrose in 0.2 per cent sodium chloride and 80 ml of serum albumin per 500 ml of diluent, so that the perfusate averaged 60 per cent blood.

LABORATORY DETERMINATIONS

Serum potassium and sodium levels were determined by flame photometry. Plasma chloride was measured by the Schmidt-Osterberg modification of the Volhard method². Blood sugar and urea levels were determined in an auto-

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analyzer (Technicon Instruments) The capillary-tube method was used to determine haematocrit values Serum-protein electrophoretic patterns were determined with the Durrum Spinco apparatus, using 0.075 M barbital (Veronal) buffer at pH 8.6 for 15 hours

CASE MATERIAL

In group 1 there were three patients less than 16 years of age with congenital heart disease and three adults with acquired valvular lesions In group 2 there were six patients with congenital lesions and six patients with valvular heart disease, four were children less than 16 years of age Fourteen of the patients were considered to have the severe form of their disease

Those in group 1 were from 5 to 59 years of age and ranged in weight from 55 to 163 pounds Two patients died after surgery One was a 46-year-old man in whom a stenotic aortic valve was replaced, and the other was a 59-year-old woman (case 6) with previous congestive failure and atrial fibrillation, who underwent closure of an atrial septal defect

The ages of patients in group 2 ranged from 4 to 62 years, and the weights ranged from 26 to 177 pounds Three deaths occurred, one being that of a 6-year-old girl, 29 hours after repair of the severe form of tetralogy, the second (case 17), a 62-year-old woman with severe mitral insufficiency and heart failure, 24 hours after surgery, and the third (case 18), a 60-year-old man with severe mitral insufficiency, pulmonary vascular disease, and renal failure, 9 hours after operation Both of these adult patients were treated by insertion of the Starr-Edwards prosthesis

RESULTS

Data on blood chemistry for the two groups are shown in Figures 1, 2, and 3

Sodium No abnormal values were seen in group 1 throughout the study period The haemodiluted perfusate averaged 100 mEq/litre The level attained early in perfusion (127 mEq/litre) changed little during perfusion Sodium returned to low-normal level by the end of the operation and remained there

Chloride Patients perfused with whole blood had normal values throughout The paediatric patients had lower concentrations of serum chloride than did the adults during operation, and the serum chloride decreased to 91 mEq/litre on the day after the operation

The diluted perfusate averaged 76 mEq/litre in group 2 Chloride concentration changed only slightly in 90 minutes of perfusion It also increased to low-normal by the end of the operation and averaged 94 mEq/litre on the morning after the operation

Urea The patients having whole-blood perfusate had normal blood levels throughout the study period Those with haemodilution maintained urea concentrations slightly above normal range One patient (case 6) in group 1 (non-diluted) and one (case 17) in group 2 (diluted) had elevated levels pre-operatively that remained so until death

FIGURE 1 Mean values for serum sodium and chloride and for blood urea in group 1 (non-diluted) and group 2 (haemodiluted)

FIGURE 2 Data on blood sugar and serum potassium in groups 1 and 2

FIGURE 3 Results of haematocrit, serum albumin, and total protein determinations in six cases of group 2 (haemodiluted)

Potassium The serum potassium concentrations in the three paediatric patients of group 1 decreased steadily before perfusion, remained at 3.4 mEq/litre until after perfusion, and increased afterward. The serum potassium concentrations of the adults did not follow this pattern but remained normal throughout.

In the diluted perfusate before perfusion, potassium concentration averaged 2.4 mEq/litre and rose gradually during perfusion. The end of the operation and the early postoperative hours were characterized by subnormal and decreasing levels in the patients having haemodilution. The values for serum potassium in two patients (cases 17 and 18) who died are shown separately in Figure 2.

Blood Sugar The average values in both groups increased during pre-perfusion anaesthesia and during the operation. In group 1, this rise continued through perfusion and was maximal 6 hours after operation, at 165 mg/100 ml of blood. Each patient received approximately 50 ml of 5 per cent dextrose in water during the operation.

Blood-sugar concentration of the perfusate averaged 1039 mg/100 ml in the haemodiluted group. After the perfusate was mixed with the patient's blood volume, blood sugar averaged 539 mg. There was a small decrease during perfusion with a more rapid decrease afterward, to approximately 250 mg/100 ml at the end of the operation. Blood-sugar values were almost identical in the two groups both 6 hours after the operation and on the next day.

Haematocrit The average haematocrit value for the diluted perfusate was 31 per cent while for the patients it was 43 per cent. Haematocrit values remained stable at 34 to 35 per cent for 90 minutes of perfusion, rose to 40 per cent within an hour after perfusion, and changed little after the operation.

Serum Albumin Low-normal concentrations prevailed before perfusion. The

average concentration in the diluted perfusate was below the normal range. Albumin increased slowly during perfusion and more rapidly afterward, and stayed in the normal range from the middle of perfusion onward.

Total Proteins The low values in the haemodiluted perfusate, when mixed with a normal amount in the patient's blood, resulted in an average level of 5.45 gm/100 ml of serum early in perfusion. A gradual increase occurred during perfusion, and the total protein values increased more rapidly after perfusion and were in normal range within 1 hour.

DISCUSSION

Whole-body perfusion with haemodilution has been described by Greer and associates,^{3,4} DeWall and associates,^{5,6} Zuhdi and co-workers,⁷ Panico and Neptune,⁸ De Moraes and associates,⁹ Ablaza and associates,¹⁰ and Cooley and co-workers.¹¹ None of these studies reported the behaviour of all the biochemical entities herein presented, so that comparisons are difficult, but in general our results agree with those previously reported.

Linder and co-workers¹² compared four types of diluent, including dextrose and water, 5 per cent dextrose in 0.2 per cent sodium chloride, 5 per cent dextrose in 0.11 per cent sodium chloride, and normal saline, for use in the disposable-bag oxygenator. They concluded that 5 per cent dextrose in 0.2 per cent sodium chloride was the best priming solution because of minimal electrolytic changes, low haemolysis, and good postoperative urinary outputs noted in patients given this solution.

The group of patients perfused with whole blood revealed little difference from the normal levels of electrolytes and crystalloids occurring with present-day techniques of perfusion. Chloride and potassium values tended to be at low-normal levels at the end of the operation. Blood-sugar levels increased steadily during the operation, closely paralleling the rise in cortisol concentration previously found.¹³ The respiratory alkalosis employed during anaesthesia appeared to be more effective in lowering serum potassium levels in children than in the adults.

Similarly, the outstanding finding in the group having 40 per cent haemodilution was the rapidity and completeness of the return to normal after perfusion of all measured parameters. Another feature was the stability of electrolytic, crystalloid, and colloid concentrations during 90 minutes of perfusion.

The changes observed in serum sodium and chloride levels were those to be expected from dilution of whole blood. The potassium levels in the perfusate also were below normal. A period of potential hypokalaemia occurred at the end of surgery and soon after. Most of the patients with acquired disease had been on intensive medical regimens including digitalis and diuretics. Possibly depleted tissue levels of potassium existed, including the level in the myocardium. Our present management of such patients includes careful observation for cardiac arrhythmias, plus supplemental potassium administered during and after perfusion, and surgery if renal function is satisfactory.

Patients perfused using blood diluted with 5 per cent dextrose in 0.2 per cent

sodium chloride received a large sugar load. No ill effects of this have been found, and the stimulation for an osmotic diuresis is a favourable result.

Changes in blood urea concentration appeared to depend more on the pre-operative state of cardiac and renal function than on whether or not haemodilution was used. Adults in both groups maintained high levels of blood urea after the operation when elevated levels were present before the operation.

Concentrated serum albumin was added to the perfusate in an attempt to retain the diluent in the vascular compartment. On the basis of a steady haematocrit level for 90 minutes of perfusion, the attempt appeared to be successful. Soon after perfusion, the haematocrit value increased, along with sodium and chloride levels. This may indicate that the diluent left the vascular compartment soon after establishing a satisfactory circulation with normal pulsatile flow.

In six patients perfused with haemodiluted perfusate, electrophoretic patterns for proteins were determined. Total osmotic pressure is primarily due to electrolytes, mainly sodium, and governs the amount of water in the body. The plasma proteins, however, especially albumin, are largely responsible for colloid osmotic pressure which determines the distribution of water between the plasma and the interstitial fluid.¹⁴ When albumin and total protein concentrations are low during perfusion, serum water value may also be low. After the operation, the return of these colloids to normal would tend to draw more fluid into the plasma.

SUMMARY

Serial determinations of electrolytes and crystalloids were done in 18 patients undergoing whole-body perfusion with moderate hypothermia. In six patients, the perfusate used was whole blood, and in twelve patients the perfusate used was diluted and contained 60 per cent blood. In six patients perfused with haemodilution, haematocrit and electrophoretic protein patterns were also studied.

The patients receiving undiluted blood had little change in concentrations of sodium, chloride, potassium, urea, and blood sugar during the operation, during perfusion, and after the operation.

The haemodiluted patients showed the decreases in these entities to be expected from the dilution of whole blood. An exception was the high level of blood sugar caused by the addition of large quantities of dextrose in the diluent. Hypokalaemia may occur after perfusion in patients with acquired heart disease. The composition of the perfusate remained stable during 90 minutes of perfusion. All abnormalities in electrolytes, crystalloids, and colloids returned to the normal range soon after surgery, but there was a trend to hypokalaemia.

RÉSUMÉ

Chez 18 malades subissant une perfusion corporelle sous hypothermie légère, nous avons fait des recherches en série des électrolytes et des cristaalloïdes. Chez six malades la solution perfusée consistait en du sang entier et, chez 12

malades, la solution était diluée et contenait 60 pour cent de sang. Chez six malades qui ont reçu une solution diluée nous avons étudié également l'hématocrite et l'électrophorèse des protéines.

Chez les malades qui ont reçu du sang non dilué, nous n'avons trouvé que très peu de changement dans les concentrations de sodium, de chlore, de potassium, d'urée et de glucose durant l'opération, la perfusion et au cours des suites opératoires.

Chez les malades à qui nous avons donné une solution diluée, nous avons trouvé, comme nous nous y attendions, une diminution de concentration de ces éléments. Il faut faire exception de la glycémie qui était élevée à cause de l'addition de grandes quantités de dextrose employées comme diluant. Chez les porteurs de maladies cardiaques acquises, il est possible de trouver de l'hypokaliémie. La composition de la solution injectée demeure stable durant 90 minutes de perfusion. Toutes les modifications dans les électrolytes, les cristalloïdes et les colloïdes reviennent à la normale peu de temps après la chirurgie à l'exception de la tendance à l'hypokaliémie.

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