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I.V. FLUIDS DURING SURGERY

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SUMMARY

During an attempt to measure renal function during operation in six patients undergoing major abdominal surgery involving intestinal resection and blood loss in excess of 300 ml, it became apparent that the conventional recommendation for i.v. crystalloid fluid of 5–10 ml kg^{-1} h^{-1} was not sufficient to maintain cardiovascular stability and urine output, but a volume of 15 ml kg^{-1} h^{-1}, given to a subsequent six patients, was adequate. Administration of low sodium (glucose) solutions also produced biochemical abnormalities of a severity not documented previously. A survey of the published literature on volumes of crystalloid fluids used supports the contention that, during major surgery, crystalloid requirements may be of the order of 10–15 ml kg^{-1} h^{-1} rather than 5–10 ml kg^{-1} h^{-1}.

KEY WORDS

Fluid balance: i.v. crystalloids, intraoperative fluids. Surgery: abdominal.

Crystalloid solutions are normally given during surgery (in addition to replacement of significant blood loss) to maintain cardiovascular stability and urine output. The literature on this subject recommends a volume of 5–10 ml kg^{-1} h^{-1} for a desirable urine output for the average adult of 30 ml h^{-1} [1–7]. Some authorities recommend only "balanced salt solution," such as Hartmann's, or saline [2, 4, 5, 7]. Some recommend isotonic (5%) glucose followed by Hartmann's solution [3], whilst others recommend iso-osmotic mixtures of glucose and saline [6]; recently there has been a move to restrict the volume of infused crystalloids by use of colloids [8].

During a recent attempt to measure renal blood flow and glomerular filtration rate during major abdominal surgery (i.e. surgery involving intestinal resection and a measured blood loss in excess of 300 ml) in which crystalloids were given at the recommended rates, it became apparent that these recommendations were inadequate, and that the biochemical abnormalities produced by infusing 5% glucose or 0.18% saline–4% glucose were more severe than had been realized previously. Largely because of the problems to be described in this report, the renal measurements are unfortunately not available, but the consequences are presented here of infusing crystalloid solutions (in addition to replacement of measured blood loss), high and low in sodium concentration during major surgery in 12 patients at rates of 10 and 15 ml kg^{-1} h^{-1}.

PATIENTS AND METHODS

Twelve patients devoid of cardiovascular and renal disease (no cardiac abnormalities detectable on clinical examination, ECG or chest x-ray, a normal plasma creatinine and taking no medication) gave consent. The study was approved by the local Ethics Committee.

Patients were allocated randomly to receive 5% glucose or Hartmann's solution 10 ml kg^{-1} h^{-1} during operation. For the renal study, they received 4% glucose–0.18% saline 1000 ml i.v. during the 60 min before induction of anaesthesia [9]. With the first six patients it became apparent that 10 ml kg^{-1} h^{-1} did not maintain arterial pressure and urine output (see later), so the

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second six patients received 15 ml kg^{-1} h^{-1} as Hartmann's solution or 0.18% saline–4% glucose. After operation, all were given 0.18% saline–4% glucose 1.8 ml kg^{-1} h^{-1}.

A radial artery cannula and urinary catheter were inserted. A bolus of inulin and PAH was given (for the renal study), and inulin and PAH in whatever fluid the patient was to receive during operation, infused at 240 ml h^{-1}. After 25 min, urine output was measured for 15 min, the patient anaesthetized and urine output measured for a further 15 min. Intraoperative fluids were then commenced at a rate to provide a total, in combination with the 240 ml h^{-1} being given, of 10 or 15 ml kg^{-1} h^{-1}.

Anaesthesia was induced with thiopentone followed by pancuronium i.v. to facilitate tracheal intubation and muscle relaxation, and morphine was given for intraoperative analgesia. Halothane 0–1% was given as required. At the end of surgery, residual neuromuscular block was antagonized with neostigmine. Morphine was used i.m. for postoperative analgesia. Drugs were given as judged clinically and the dose recorded. Every 30 min during surgery and every 1 h for 5 h after operation, urine volume and urinary sodium were measured and arterial blood analysed for $P\text{CO}_2$, glucose and sodium concentrations and osmolality.

Blood loss was measured by weighing all swabs and measuring wound suction. When losses totalled 600–700 ml, blood transfusion was commenced and a minimum of 2 units of fluid given, the first unit being whole blood and all units thereafter "plasma reduced".

RESULTS

For the purpose of analysis, the 12 patients have been classified into two groups in two ways: one classification according to the volume of fluid (i.e. 10 ml kg^{-1} h^{-1} or 15 ml kg^{-1} h^{-1}), so that the two groups of six patients each consisted of three who received high sodium solutions and three who received low sodium (glucose) solutions, and the other according to the type of fluid, so that of the two groups of six (high and low sodium (glucose)), each consisted of three who received 10 ml kg^{-1} h^{-1} and three who received 15 ml kg^{-1} h^{-1}. The details are not presented, but under both classifications each of the two groups were comparable for age, body mass index, blood loss, blood transfused, anaesthetic drug doses and duration and extent of surgery. Surgery lasted for between 104 and 189 (median 134 min). Data for all patients have been analysed therefore, over the first four 30-min periods of surgery and over the 5 h of the recovery period.

Clinical details

In two patients receiving 10 ml kg^{-1} h^{-1}, the procedure had to be modified because of clinically unacceptable hypotension and oliguria (systolic arterial pressure < 90 mm Hg for 10 min and urine output < 10 ml h^{-1}). One was receiving Hartmann's solution, the other 5% glucose. Both were given an extra 1 litre of Hartmann's solution; one received 500 ml during the last 15 min of surgery and a further 500 ml during the second 1 h of the recovery period. The other patient was given 1 litre of Hartmann's solution during the fifth hour of recovery. A third patient became acutely hypotensive and oliguric that evening. In the absence of further blood loss, he was resuscitated with Hartmann's solution. All patients receiving 15 ml kg^{-1} h^{-1} maintained a satisfactory arterial pressure and urine output throughout the operation and recovery period.

Arterial pressure, urine output and Pa_{CO_2}

There were no differences in arterial pressure between the patients receiving glucose or Hartmann's solution either during surgery or after operation. When patients were classified according to the volume of fluid, mean arterial pressure (MAP) over the first 30 min of surgery was 100 (7) mm Hg (mean (SEM)) in the 10-ml kg^{-1} h^{-1} group and 102 (7) mm Hg in the 15-ml kg^{-1} h^{-1} group. In the latter group this was maintained, but in the 10-ml kg^{-1} h^{-1} group, MAP over the second 30 min decreased to 85 (7) mm Hg. Over 60–90 min, MAP was significantly lower in the 10-ml kg^{-1} h^{-1} group than the 15-ml kg^{-1} h^{-1} group (82 (6) mm Hg *vs* 99 (6) mm Hg) ($P < 0.05$) and over 90–120 min this difference increased (79 (4) mm Hg *vs* 105 (5) mm Hg) ($P < 0.01$). During surgery, urine output was significantly greater in the patients receiving fluid at 15 ml kg^{-1} h^{-1} than at 10 ml kg^{-1} h^{-1} ($P < 0.05$) and greater in the group receiving glucose than the patients receiving Hartmann's solution ($P < 0.01$). The median rate of output of urine in the Hartmann's group during surgery was less than 0.5 ml min^{-1}, but in the patients receiving glucose it was always greater than 1 ml min^{-1}. During operation, sodium excretion in the patients receiving glucose was 18.0 (7.1) mmol, comparable to that in the postoperative period (23.9 (7.0) mmol). Sodium excretion in the patients receiving Hartmann's solution was 6.8 (2.7) mmol during operation and this increased five-fold to 35.2 (8.5) mmol after operation ($P < 0.01$).

Blood concentration of glucose during infusion of glucose increased to mean 23.0 (SD 4.6) mmol litre^{-1}. One patient had an osmotic diuresis (urine output greater than 12 ml min^{-1} and 3+ glucose in the urine when tested with Labstix (Ames Laboratories, Slough)). Two other patients receiving glucose had 1+ glucose in the urine, but no evidence of a diuresis. No glycosuria occurred beyond the first 1 h of recovery. Blood concentration of glucose at 5 h was comparable to that in patients receiving Hartmann's solution. Plasma concentration of sodium in the Hartmann's group remained within 1–2 mmol of the value before operation, but decreased to mean 117 (SD 5) mmol litre^{-1} in the patients receiving glucose. It remained in the range 117–123 mmol litre^{-1} for 5 h after operation and throughout the postoperative period was significantly less than the range of 135–138 mmol litre^{-1} seen in the patients who had received Hartmann's solution ($P < 0.01$). The day after surgery the plasma concentration of sodium in the patients who received Hartmann's solution was 133 (SEM 1) mmol litre^{-1} and that in the glucose group 130 (1) mmol litre^{-1} (ns). Mean plasma osmolality remained about 280 mosmol kg^{-1} in the Hartmann's group, but decreased during operation to about 270 mosmol kg^{-1} in the patients receiving glucose and decreased further after operation, to 255–260 mosmol kg^{-1}. There was no difference in Pa_{CO_2} (which has profound effects on both cardiac output [10] and on urine flow [11]) between groups in either of the classifications, either during surgery or after operation. Pa_{CO_2} was generally in the range 4.3–4.8 kPa and after operation 5.1–5.3 kPa.

DISCUSSION

This report provides only some preliminary information, so any conclusions must be tentative. There were only 12 patients, the fluid regimens were not given in random order and the investigators were not blinded to either the type or the volume of fluid administered. In contrast, crystalloid was given by infusion pump and the infusion rates were not altered, extra Hartmann's solution being given separately over relatively short periods. This report derives from an attempt to measure renal function during and after surgery; in part this failed, because the conventional recommendations for intraoperative fluid replacement did not maintain arterial pressure and urine output, despite a preoperative fluid load of 1240 ml. It also shows that giving fluid as low sodium (glucose) solutions in volumes large enough to maintain cardiovascular stability and urine output produced degrees of hyponatraemia and osmolality that have not been reported hitherto and are probably unacceptable. On the other hand, urine output was greater during operation with glucose than with Hartmann's solution. There were large differences in patterns of sodium excretion; these probably reflect the effects of the different sodium loads and osmolalities on aldosterone and arginine vasopressin (antidiuretic hormone) secretion, but in the absence of any hormone measurements this is speculative.

Views on what fluids should be given during operation have varied over the years, from Moore's contention that sodium was retained during and after surgery so its administration should be restricted [12] to the concept of Shires, Williams and Brown of a "third space" and the need to fill it with balanced salt solution [13]. In an attempt to reduce the volume of fluids given during operation, colloids have been advocated in place of crystalloids [8]. The preliminary observations presented here suggest that, if crystalloids are given during major surgery, the requirement may be 10–15 ml kg^{-1} h^{-1} and not 5–10 ml kg^{-1} h^{-1}. This is more than any other published recommendation, and is 50% greater even than that recommended by Shires' group [13] and, in view of the danger of pulmonary oedema, might be considered excessive. However, several papers that have recorded volumes of fluid given during major surgery have produced similar values. Shires and colleagues [14] reported 1123 (449) ml h^{-1} with surgery lasting 4.8 h, Slotman, Jed and Burchard 1100 ml h^{-1} [15] and Virgilio and colleagues 1161 ml h^{-1} [16]; assuming a body weight of 70 kg, these volumes correspond to 16 ml kg^{-1} h^{-1}. Roberts and coworkers reported even greater values—24 ml kg^{-1} h^{-1} [17]. In two of these studies [14, 17], extravascular lung water and extracellular fluid volume were measured and did not change from the preoperative value, so 15 ml kg^{-1} h^{-1} may not be an unreasonable figure.

The use of colloids during operation has been reported by Shires and colleagues [14] to reduce the volume of fluid given during operation by 50%, but postoperative urine output also decreased by 50%. This may be considered undesirable because of the danger of renal failure. Teleologically, fluid retention at the time of injury (perhaps by sequestration in "third space") serves as a reservoir from which urine output may be maintained after injury when the ability of an organism to forage for food and drink is impaired [18–20]. In two studies, restriction of intraoperative crystalloid and replacement only of blood loss resulted in a plasma volume deficit after operation [17, 21]. Perhaps administration of fluid during operation should be designed to fill up the "third space", as suggested by Shires [14], the appropriate volume to achieve this being 10–15 ml kg^{-1} h^{-1}.

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