Fluid therapy using a balanced crystalloid solution and acid–base stability after cardiac surgery

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ABSTRACT

Objective: To evaluate the effect of fluid therapy using Accusol (Baxter Healthcare, McGaw Park, Ill, USA), a crystalloid solution containing sodium bicarbonate and other electrolytes and having a strong ion difference of 35 mEq/L, on acid–base stability after cardiac surgery.

Design: Retrospective per-protocol comparison.

Setting: Intensive care unit of St Vincent's Hospital, a teaching hospital in Melbourne, Australia.

Participants: Consecutive adult patients admitted in daytime hours after elective on-pump coronary artery bypass graft surgery between May and October 2008 constituted the "pre-Accusol group" ($n = 40$), and those admitted between May and October 2009 and who were treated with Accusol constituted the "Accusol group" ($n = 51$).

Main outcome measures: The fluids and their component electrolytes administered; change in standard base excess (SBE) between the time of intensive care admission and 04:00 h the next day.

Results: The Accusol group received a median Accusol dose of 1.86 mL/kg/h (interquartile range, 1.51–2.20 mL/kg/h), which accounted for 38% (SD, 10%) of the total volume of fluid administered. The change in SBE was +0.03 mmol/L (95% CI, –0.57 to 0.64 mmol/L; $P = 0.91$) in the Accusol group compared with –2.05 mmol/L (95% CI, –2.64 to –1.45; $P < 0.01$) in the pre-Accusol group. The strong ion difference of the electrolytes administered as components of fluid therapies was higher in the Accusol group by 55.5 mEq (95% CI, 40.0 to 71.0 mEq; $P < 0.01$). Only 8% of the Accusol group received albumin compared with 48% of the pre-Accusol group ($P < 0.01$).

Conclusions: SBE was more stable in patients treated with Accusol. Further studies are needed to determine whether use of solutions such as Accusol influences important patient outcomes.

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There is increasing interest in the acid–base implications of intravenous fluid therapy. According to Stewart's quantitative physical–chemical approach, the pH of body fluids is the result of the interplay between the partial pressure of carbon dioxide (PCO_2), the total concentration of non-volatile weak acids (A_{TOT}), and the strong ion difference (SID).[1] Acid–base changes that occur after administration of intravenous fluid can be understood by considering the resulting changes in extracellular SID and A_{TOT}.[2,3] Based on these concepts, a perfectly "balanced" fluid could be considered to be one in which any change it induces in A_{TOT} is offset by a change it induces in SID, so that the pH remains stable.

Sodium chloride 0.9% contains equal amounts of sodium and chloride and so has an SID of zero. Rapid administration of sodium chloride 0.9% causes a decrease in the extracellular fluid SID, inducing a metabolic acidosis that overwhelms the concurrent A_{TOT} dilutional alkalosis, and the pH falls. Hartmann's solution contains sodium, potassium, calcium, chloride and lactate. Assuming lactate is rapidly and completely metabolised, Hartmann's solution has an SID of 29 mEq/L, which is considered close to optimal for a crystalloid fluid in terms of maintaining extracellular acid–base balance.[2,3] Compared with sodium chloride 0.9%, the use of Hartmann's solution has been found to result in a lower incidence of metabolic acidosis.[4-7] Consensus guidelines recommend the use of Hartmann's solution in preference to sodium chloride 0.9% when crystalloid fluid therapy is indicated.[8]

A randomised trial in 60 cardiac surgery patients compared fluid therapy with unbalanced crystalloid and colloid to therapy with "balanced" crystalloid and colloid.[9] In patients who received the balanced fluids, there was a smaller reduction in base excess, and levels of markers of kidney injury and inflammation were lower. The "balanced" fluids in that study had an SID of 34 mEq/L, assuming complete and rapid metabolism of organic anions.

Accusol (Baxter Healthcare, McGaw Park, Ill, USA) is a crystalloid fluid that contains sodium 140 mEq/L, calcium 3.5 mEq/L, magnesium 1.0 mEq/L, chloride 109.5 mEq/L and bicarbonate 35 mEq/L, giving it an SID of 35 mEq/L. Accusol does not depend on metabolism of strong organic anions, and its relatively high SID may offer a defence against any underlying metabolic acidosis.

In November 2008, intravenous administration of Accusol 1.5 mL/kg/h was introduced for postoperative cardiac surgery patients in our intensive care unit. Additional Accusol, as bolus doses of 250–500 mL, could also be given at the discretion of clinical staff. We hypothesised that fluid therapy with Accusol would be associated with

less change in standard base excess (SBE) compared with fluid therapy using standard intravenous fluids. We conducted a retrospective study with a "per protocol" design to evaluate the effect of Accusol on changes in SBE and on the intravenous fluids and their component electrolytes administered in the early postoperative period after coronary artery bypass graft (CABG) surgery. The project was approved as a quality audit by the hospital's Human Research Ethics Committee.

Methods

Patient selection

Our study was conducted in the ICU of St Vincent's Hospital, Melbourne. During the period 1 May to 31 October 2008, there were 57 consecutive patients who met the eligibility criteria of admission to intensive care after elective on-pump CABG surgery. Seventeen of these patients were excluded: 12 because they were admitted after 19:00 h, one because of surgical bleeding, and four because they received a fluid that contained sodium bicarbonate. The remaining 40 patients constituted the "pre-Accusol group".

During the period 1 May to 31 October 2009, after the introduction of Accusol, there were 80 consecutive patients who met the eligibility criteria of admission to intensive care after elective on-pump CABG surgery. Twenty-nine of these patients were excluded: 17 because they were admitted after 19:00 h, three because of surgical bleeding, and nine because they did not receive any Accusol. The remaining 51 constituted the "Accusol group".

Inclusion and exclusion criteria were defined before collecting data. Patients admitted after 19:00 h were excluded because admission late in the day was thought to excessively shorten the period of exposure to fluid therapy. Patients with surgical bleeding were excluded as they were thought to have special fluid resuscitation requirements.

Study outcomes

Because biochemistry, haematology and arterial blood gases were assessed as part of usual care on admission to intensive care and at 04:00 h the next day, we chose to evaluate changes in SBE and fluid therapies during this period.

The main study outcomes were change in SBE from intensive care admission to 2.5 hours after intensive care admission, and change in SBE from intensive care admission to 04:00 h the next day. SBE was calculated using the equation suggested by Kellum.[10]

Other outcomes were the types and volumes of fluids administered for resuscitation and maintenance therapy, and the quantities of electrolytes given as components of these fluids.

Haemodynamic management

A strict protocol for haemodynamic goals and therapies was not followed. However, typical goals were to maintain the mean arterial pressure above 70 mmHg, the cardiac index above 2.5 L/min/m^2, and the urine output above 0.5 mL/kg/h. Fluid was usually administered to maintain a central venous pressure of 10–15 mmHg. Hypotension despite adequate fluid resuscitation was usually managed with a noradrenaline infusion if the systemic vascular resistance was low. An inadequate cardiac index despite adequate fluid resuscitation was usually managed with a dobutamine or adrenaline infusion.

Intravenous fluid therapy

Before the introduction of Accusol, there were no local guidelines on the choice of fluid when a crystalloid or colloid was required, except for administration of glucose 5% 1000 mL with potassium chloride 80 mmol at 40 mL/h, which was part of usual practice throughout the study. The addition of magnesium sulphate 20 mmol to this solution became part of usual practice in February 2009, and so affected the Accusol group. Packed red blood cells were usually given to maintain the haemoglobin concentration above 80 g/L. Nursing staff recorded fluid therapies on the patients' charts using the electronic clinical information systems CareVue or ICIP (Philips, Eindhoven, The Netherlands).

Blood tests

Arterial blood gas samples were collected from arterial lines into heparinised syringes and analysed in intensive care using the Rapidlab 1265 analyser (Bayer HealthCare LLC, Tarrytown, NY, USA). Serum biochemistry and haematology samples were collected from arterial lines and analysed by the hospital pathology service using the AU2700 chemistry analyser (Olympus Diagnostics/Beckman Coulter, Brea, Calif, USA) and the Advia 2120 haematology analyser (Bayer HealthCare LLC, Tarrytown, NY, USA).

Data collection

Fluid therapies recorded on the patients' charts were gathered by electronic search and checked by hand search of individual patient records. Results of blood tests were gathered by hand search of individual patient records.

Statistical analysis

Analysis was performed using Stata software, version 10.1 (StataCorp, College Station, Tex, USA). Categorical variables are presented as percentages, and differences between the groups were assessed using χ^2 or Fisher exact tests. Continuous variables with non-skewed distributions are presented as mean and standard deviation, and differences between groups were assessed using Student's *t* test. Continuous

Table 1. Demographic characteristics, medical history and operation characteristics*

Characteristic/history	Pre-Accusol ($n = 40$)	Accusol ($n = 51$)
Age in years	63.7 ±9.9	66.8 ±9.2
Female	7 (18%)	9 (18%)
AMI in the 3 months before surgery	6 (15%)	3 (6%)
Preoperative eGFR < 60 mL/kg/1.73m^2	4 (10%)	6 (12%)
Body mass index in kg/m^2	28.7 ±4.8	30.4 ±3.8
Number of coronary grafts	3.5 ±0.9	3.3 ±1.1
Duration of cardiopulmonary bypass in minutes	116 (103 to 140)	110 (82 to 136)

AMI = acute myocardial infarction. eGFR = estimated glomerular filtration rate. * Values are mean ±standard deviation, number (%) or median (interquartile range).

variables with skewed distributions are presented as median and interquartile range (IQR), and differences between groups were assessed by the Wilcoxon rank-sum test. *P* values < 0.05 were taken to signify statistical significance.

Results

Demographic characteristics, medical history and operation characteristics

The patients had a mean age of 65 years and the two groups were similar in age. Women constituted 18% of each group. In 12% of the Accusol group and 10% of the pre-Accusol group, the preoperative estimated glomerular filtration rate was < 60 mL/kg/1.73m^2. The mean number of distal coronary anastomoses was similar: 3.3 in the Accusol group and 3.5 in the pre-Accusol group. The median duration of cardiopulmonary bypass was just under 2 hours for each group. Demographic characteristics, medical history and operation characteristics of the groups are shown in Table 1.

Types and volumes of fluids administered

The period of fluid therapy (from intensive care admission to 04:00 h the next day) had a mean duration of 12.3 hours and was similar for each group. During this period, the crystalloids and colloids used for intravenous fluid therapy were Accusol, sodium chloride 0.9% (Baxter Healthcare, Sydney, Australia), Hartmann's solution (Baxter Healthcare, Sydney, Australia), Albumex 4 (CSL, Melbourne, Australia), Gelofusine (B. Braun, Sydney, Australia), and glucose 5% (Baxter Healthcare, Sydney, Australia) with electrolytes. The components and SID of each fluid are shown in Table 2.

The volumes of Hartmann's solution, Gelofusine, glucose 5% with electrolytes and packed red blood cells administered to each group were similar, but there was significantly less use of sodium chloride 0.9% and Albumex 4 in the Accusol group. The proportion of patients treated with sodium chloride 0.9% was only 4% in the Accusol group compared with 65% in the pre-Accusol group ($P < 0.01$), and the proportion treated with Albumex 4 was only 8% in the Accusol group compared with 48% in the pre-Accusol group ($P < 0.01$). The Accusol group received a median Accusol dose of 1.86 mL/kg/h (IQR, 1.51 to 2.20 mL/kg/h), which accounted for 38% (SD, 10%) of the total volume of fluid administered. The groups had similar total fluid intake,

Table 2. Components of intravenous fluids*

Component	Accusol	Sodium chloride 0.9%	Hartmann's solution	Albumex 4	Gelofusine	Glucose 5% with electrolytes
Sodium	140	150	129	140	154	—
Potassium	—	—	5	—	—	80
Calcium	3.5	—	4	—	—	—
Magnesium	1.0	—	—	—	—	40†
Chloride	109.5	150	109	128	120	80
Bicarbonate	35	—	—	—	—	—
Lactate	—	—	29	—	—	—
Octanoate	—	—	—	6.4	—	—
Sulphate	—	—	—	—	—	40†
Albumin (g/L)	—	—	—	40	—	—
Gelatin (g/L)	—	—	—	—	40	—
Strong ion difference‡	35	0	29	12	34	0

* Units are mEq/L unless otherwise specified. † Magnesium sulphate 40 mEq was present in glucose 5% with electrolytes solution only during the Accusol period. ‡ Assumes lactate and octanoate are fully metabolised on administration.

total fluid output and fluid balance. Fluid therapies and fluid balance details are shown in Table 3.

Quantities of electrolytes administered as fluid therapies

The accumulated quantities of electrolytes administered as components of Accusol, sodium chloride 0.9%, Hartmann's solution, Albumex 4, Gelofusine and glucose 5% with electrolytes are shown in Table 4. The SID of these electrolytes was higher in the Accusol group by 55.5 mEq (95% CI, 40.0 to 71.0 mEq; $P < 0.01$). The Accusol group received much less albumin, but had higher magnesium intake (18.0 mEq [IQR, 14.2 to 22.2 mEq] v 0.0 mEq [IQR, 0 to 0 mEq]; $P < 0.01$).

Biochemistry

On the day after surgery, serum albumin concentration was lower in the Accusol group (27 g/L [IQR, 24 to 30 g/L] v 30 g/L [IQR, 27 to 34 g/L]; $P < 0.01$), and serum magnesium concentration (corrected for serum albumin concentration) was higher in the Accusol group (1.14 mmol/L [IQR, 1.04 to 1.24 mmol/L] v 0.98 mmol/L [IQR, 0.86 to 1.16 mmol/L]; $P < 0.01$). These results are in keeping with the lower quantity of albumin and higher quantity of magnesium administered to the Accusol group.

At the time of admission to intensive care, the Accusol group had lower SBE (0.8 mmol/L [IQR, –0.9 to 1.9 mmol/L] v 2.3 mmol/L [IQR, 0.7 to 4.2 mmol/L]; $P < 0.01$), but on the morning after surgery, SBE was similar in each group (0.41 mmol/L [SD, 2.10 mmol/L] v 0.25 mmol/L [SD, 2.10 mmol/L]; $P = 0.71$; 95% CI for difference, –1.05 to 0.72 mmol/L). Results of blood tests performed on admission to intensive care and at 04:00 h the next day are shown in Table 5.

Change in standard base excess

Between the time of intensive care admission and 2.5 hours later, SBE changed in the Accusol group by –0.74 mmol/L (95% CI, –1.16 to –0.33 mmol/L) ($P < 0.01$) and in the pre-Accusol group by –1.98 mmol/L (95% CI, –2.52 to –1.43 mmol/L) ($P < 0.01$). The difference between the groups in the change in SBE was –1.23 mmol/L (95% CI, –1.91 to –0.56) ($P < 0.01$).

The change in SBE between the time of intensive care admission and 04:00 h the next day was +0.03 mmol/L (95% CI, –0.57 to 0.64 mmol/L) ($P = 0.91$) in the Accusol group and –2.05 mmol/L (95% CI, –2.64 to –1.45 mmol/L) ($P < 0.01$) in the pre-Accusol group. The difference between the groups in the change in SBE was –2.08 mmol/L (95% CI, –2.92 to –1.24 mmol/L) ($P < 0.01$). Changes in SBE and differences between the groups in these changes are shown in Table 6.

Intensive care and hospital outcomes

A significantly smaller proportion of the Accusol group required inotropes (infusion of adrenaline, dobutamine, milri-

Table 3. Volumes of fluid therapies, total fluid intake, total fluid output, and fluid balance between time of admission to intensive care and 04:00 h the next day*

Fluid measurement	Pre-Accusol	Accusol	$P^{\dagger}$
Period of observation (hours)	12.6 ± 2.1	12.1 ± 2.2	0.27
Accusol	0	1980 ± 593	< 0.01
Accusol (mL/kg/h)	0	1.86 (1.51 to 2.20)	< 0.01
Sodium chloride 0.9%	1000 (0 to 1400)	0 (0 to 0)	< 0.01
Hartmann's solution	1000 (0 to 2000)	0 (0 to 1000)	0.15
Albumex 4	0 (0 to 1000)	0 (0 to 0)	< 0.01
Gelofusine	1000 (500 to 1750)	1000 (545 to 1500)	0.82
Glucose 5% with electrolytes	460 (320 to 510)	400 (320 to 500)	0.56
Packed red blood cells	0 (0 to 260)	0 (0 to 265)	0.79
Total intake	4911 (4007 to 5870)	5423 (4261 to 6437)	0.12
Total intake (mL/kg/h)	4.96 ± 1.66	5.36 ± 1.67	0.26
Urine	1150 (818 to 1700)	1190 (855 to 1600)	0.96
Chest drainage	510 (370 to 710)	460 (320 to 675)	0.42
Total output	1781 (1426 to 2264)	1750 (1430 to 2158)	0.71
Total output (mL/kg/h)	1.58 (1.27 to 2.25)	1.83 (1.40 to 2.18)	0.67
Fluid balance	+3082 ± 1272	+3559 ± 1248	0.08
Fluid balance (mL/kg/h)	+3.05 ± 1.40	+3.56 ± 1.43	0.09

* Values are mean ± standard deviation or median (interquartile range). Units are mL unless otherwise specified. † *P* values are for comparison of groups.

Table 4. Accumulated quantities of electrolytes administered as components of intravenous fluids* between time of admission to intensive care and 04:00 h the next day†

Electrolyte	Pre-Accusol	Accusol	P‡
Sodium	507 (376 to 628)	555 (434 to 687)	0.24
Potassium	40 (31 to 47)	37 (27 to 45)	0.29
Calcium	4.0 (0.0 to 8.0)	9.0 (6.8 to 11.7)	< 0.01
Magnesium	0	18.0 (14.2 to 22.2)	< 0.01
Chloride	465 (359 to 601)	482 (372 to 569)	0.88
Sulphate	0	16.0 (12.8 to 20.0)	< 0.01
Lactate	29 (0 to 58)	0 (0 to 29)	0.15
Bicarbonate	0	69 (52 to 81)	< 0.01
Albumin (g)	0 (0 to 40)	0	< 0.01
Gelatin (g)	40 (20 to 70)	40 (22 to 60)	0.82
SID of administered electrolytes§	73.3 ±35.0	128.8 ±39.3	< 0.01

SID = strong ion difference. * Accusol, sodium chloride 0.9%, Hartmann's solution, 5% glucose with electrolytes, Gelofusine and Albumex 4. † Values are mean ±standard deviation or median (interquartile range). Units are mEq unless otherwise specified. ‡ P values are for comparison of groups. § SID = [sodium + potassium + magnesium + calcium] – [chloride + sulphate].

none or levosimendan) after surgery (14% v 33%; $P = 0.03$). The groups were similar in relation to use of vasopressors (noradrenaline by infusion), duration of mechanical ventilation, duration of hospitalisation and survival to hospital discharge. These outcomes are summarised in Table 7.

Change in standard base excess by intention-to-treat

An intention-to-treat analysis for the change in SBE was performed after the per-protocol analysis was completed. The four patients excluded from the pre-Accusol group because they were treated with a fluid that contained sodium bicarbonate were included in the pre-Accusol group for the intention-to-treat analysis, so that the sample size was 44. The nine patients excluded from the Accusol group because they did not receive Accusol were included in the Accusol group for the intention-to-treat analysis, so that the sample size was 60. Between intensive care admission and 2.5 hours later, the difference between the groups in the change in SBE was –0.93 mmol/L (95% CI, –1.58 to –0.28 mmol/L) ($P < 0.01$). Between intensive care admission and 04:00 h the next day, the difference between the groups in the change in SBE was –1.79 mmol/L (95% CI, –2.60 to –0.98 mmol/L) ($P < 0.01$). Results of the intention-to-treat analysis are shown in Table 6.

Discussion

We conducted a retrospective study with a per-protocol design to evaluate the effect of Accusol, a balanced crystalloid fluid, on changes in SBE and on the intravenous fluids and their component electrolytes administered during approximately the first 12 hours in intensive care after elective CABG surgery. SBE was more stable in the Accusol

Table 5. Haematocrit, serum biochemistry and arterial blood gas results at time of admission to intensive care and at 04:00 h the next day*

	Admission to intensive care		04:00 h the next day	
Measurement†	Pre-Accusol	Accusol	Pre-Accusol	Accusol
Haematocrit (%)	27 (25 to 30)	30 (26 to 32)	26.8 ±3.12	27.4 ±3.23
Albumin (g/L)	28.5 ±4.8	29.2 ±4.5	30 (27 to 34)	27 (24 to 30)‡
Magnesium (corrected)	1.03 (0.96 to 1.17)	1.00 (0.92 to 1.09)	0.98 (0.86 to 1.16)	1.14 (1.04 to 1.24)‡
Sodium	138 (137 to 139)	138 (136 to 139)	135.9 ±1.9	134.0 ±2.0‡
Potassium	3.9 (3.6 to 4.2)	3.8 (3.6 to 4.3)	4.3 (4.2 to 4.6)	4.3 (4.2 to 4.5)
Calcium (ionised)	1.079 ±0.065	1.073 ±0.053	1.061 ±0.048	1.066 ±0.043
Chloride	110 (107.5 to 111)	109 (107 to 111)	109.1 ±2.8	107.4 ±3.3
Lactate	1.6 (1.2 to 1.9)	1.6 (1.2 to 2.4)‡	1.6 (1.3 to 2.1)	1.8 (1.5 to 2.2)
pH	7.401 ±0.061	7.391 ±0.060	7.381 ±0.039	7.377 ±0.047
PCO_2 (mmHg)	45 (40 to 48)	41 (37 to 47)	43.1 ±5.0	43.9 ±5.4
Bicarbonate	27 (25 to 28)	25 (24 to 27)‡	25.0 ±2.2	25.2 ±2.1
Standard base excess	2.3 (0.7 to 4.2)	0.8 (–0.9 to 1.9)‡	0.25 ±2.10	0.41 ±2.10

* Values are mean ±standard deviation or median (interquartile range). Units are mmol/L unless otherwise specified. † Albumin and magnesium (corrected) were measured from serum arterial samples. Sodium, potassium, calcium (ionised), chloride, lactate, pH, PCO_2 and bicarbonate were measured from heparinised arterial blood samples. ‡ $P < 0.05$ for comparison of groups.

group. In the initial 2.5 hours after intensive care admission, there was a smaller decrease in SBE in the Accusol group than in the pre-Accusol group. On the day after intensive care admission, SBE in the Accusol group was very similar to SBE on admission to intensive care, while in the pre-Accusol group SBE was significantly decreased.

Both SID and A_{TOT} affect SBE. The Accusol group was administered fluid with a larger SID and also received less albumin, the combination of which could explain the more stable SBE observed in this group. SBE on admission to intensive care was higher in the pre-Accusol group. In a discussion with our Anaesthesia Department after data analysis, it emerged that patients in the pre-Accusol group received more sodium bicarbonate as part of the cardiopulmonary bypass regimen, and this might explain the higher SBE in this group on admission to intensive care. It is possible that the reduction in SBE observed in the pre-Accusol group could be due in part to homeostatic mechanisms attempting to return SBE to zero.

For the patients treated with Accusol, the volume of Accusol administered was in keeping with the local guideline of 1.5 mL/kg/h plus additional 250–500 mL bolus doses as required. Accusol, on average, amounted to less than 40% of the fluid volume administered to the Accusol group patients. The Accusol group received less sodium chloride 0.9% and less Albumex 4 than the pre-Accusol group, but the groups were similar in the volumes they received of Hartmann's solution, Gelofusine, glucose 5% with electrolytes and packed red blood cells. The use of Accusol appears to have occurred chiefly at the expense of sodium chloride 0.9% and Albumex 4. Some additional paperwork that became associated with administration of Albumex 4 as a result of a local administrative change may have played a role in the reduced use of this product in the Accusol group, with staff choosing an alternative product that did not require the completion of forms. Had Accusol been the only fluid used when a crystalloid or colloid was required, then perhaps even greater stability in SBE might have been observed, but an increase in SBE (driven by decreased A_{TOT} relative to the change in extracellular SID) is also a possibility.

Despite a 6-month period in which the Accusol administration guideline was "bedded down", 11% of potentially eligible patients in the Accusol period did not have any Accusol administration documented and were excluded from the analysis. Preference for other fluids, ignorance of the local Accusol guideline, and failure to chart Accusol that was actually given may each have played a role in the apparent non-administration of Accusol to these patients. Out of interest, we conducted an analysis of the change in SBE using an intention-to-treat approach. Using this approach, the results were in keeping with our original analysis and with what would be expected if the sodium bicarbonate-containing fluids were associated with a more stable SBE.

In addition to having a more stable SBE, the patients who received Accusol had a significantly reduced requirement for inotropic support. We did not set out to test whether such a difference existed, and this result may be a chance finding. However, it is possible that more favourable acid–base conditions due to the use of Accusol contributed to better cardiovascular performance. It is also possible that the method of administering Accusol — using an infusion pump to deliver a continuous background fluid rate of

Table 6. Mean change in SBE between time of ICU admission and (i) 2.5 hours after ICU admission; (ii) 04:00 h the next day* (per-protocol and intention-to-treat† analyses)

SBE change		Pre-Accusol mean	Accusol mean	Difference in means (95% CI)	P‡
SBE change from ICU admission to 2.5 h later	PP	–1.98	–0.74	–1.23 (–1.91 to –0.56)	< 0.01
	ITT	–1.88	–0.94	–0.93 (–1.58 to –0.28)	< 0.01
SBE change from ICU admission to 04:00 h next day	PP	–2.05	+0.03	–2.08 (–2.92 to –1.24)	< 0.01
	ITT	–2.01	–0.22	–1.79 (–2.60 to –0.98)	< 0.01

ICU = intensive care unit. ITT = intention-to-treat analysis.
PP = per-protocol analysis. SBE = standard base excess.
* Values are mmol/L. † See text for further explanation.
‡ *P* values are for differences in means.

Table 7. Intensive care and hospital outcomes*

Outcome	Pre-Accusol (*n* = 40)	Accusol (*n* = 51)	P†
Inotropes in first 24 h	13 (33%)	7 (14%)	0.03
Vasopressors in first 24 h	18 (45%)	16 (31%)	0.18
Duration of mechanical ventilation (hours)	12 (10 to 18)	13 (9 to 16)	0.47
Time in intensive care (hours)	23 (21 to 27)	22 (21 to 26)	0.52
Hospital stay (days)	7 (6 to 11)	8 (7 to 10)	0.14
Died in hospital	1 (3%)	1 (2%)	1.00

* Values are number (%) or median (interquartile range). † *P* values are for comparison of groups.

1.5 mL/kg/h — resulted in more efficient pursuit of fluid goals and contributed to the reduced requirement for inotropes. Aside from the solution of glucose 5% 1000 mL with electrolytes at 40 mL/h, we had not previously administered maintenance fluid at a continuous rate to our cardiac surgery patients. By using a higher rate of continuously administered fluid, smaller and/or less frequent fluid challenges may have been needed and there may have been fewer dips in haemodynamic performance.

Our study, with many inherent weaknesses, supports previous work that administration of balanced intravenous fluids can enhance acid–base stability. Further studies are needed to determine the optimal "balanced" fluid for patients having cardiac surgery and its effect on important patient outcomes.

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