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Perioperative fluid therapy in children: a survey of current prescribing practice†

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Background. Fluid therapy in children may be associated with iatrogenic hyponatraemia. We surveyed anaesthetists' current fluid prescribing practice during the perioperative period, departmental fluid protocols and awareness of the concerns of the Royal College of Paediatrics and Child Health (RCPCH) about the use of dextrose 4%/saline 0.18% in children.

Methods. Questionnaire survey of 477 consultant anaesthetists in two training areas in the UK.

Results. Responses were received from 289 anaesthetists (60.6%)—responses from the 203 consultants that anaesthetized children were analysed. A total of 67.7% did not have a local departmental policy for fluid prescription, and 58.1% were unaware of the concerns of RCPCH. A total of 60.1% of anaesthetists said that they prescribed hypotonic dextrose saline solutions in the intraoperative period and 75.2% did so in the postoperative period. Anaesthetists working in specialist paediatric hospitals were 5.1 times more likely to prescribe isotonic fluids intraoperatively than those working in district hospitals (95% CI 1.48–17.65, P=0.01), but they all prescribed hypotonic dextrose saline solutions postoperatively. The Holliday and Segar formula for maintenance fluid was quoted by 81.8% of anaesthetists; only 5.9% of anaesthetists would restrict fluids in the immediate postoperative period. Anaesthetists working in specialist paediatric hospitals were 13.2 times more likely to restrict fluids postoperatively than those working in district hospitals (95% CI 2.8–61.8, P=0.001).

Conclusions. The prescription of hypotonic dextrose saline solutions by anaesthetists may be putting children at risk from iatrogenic hyponatraemia. Departmental protocols for perioperative fluid prescription in children are uncommon. We suggest that national guidance is required.

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There have been more than 50 case reports of serious morbidity or death in previously healthy children associated with the administration on i.v. fluids and hospital-acquired hyponatraemia.[1] Deaths have been reported after both major and minor surgery in children, including tonsillectomy, orchidopexy, reduction of fractures and appendicectomy.[2–5] The postoperative course in these children is typified by progressive lethargy, headache, nausea and vomiting, followed by rapid deterioration to respiratory arrest and coma.[2] Fatal cerebral oedema occurring during surgery has also been reported.[3] Children have usually had continued administration of large volumes of hypotonic i.v. fluid in the presence of a low plasma sodium.[2 6 7] The deaths of three children believed to be as a result of hospital-acquired hyponatraemia is currently the subject of a public enquiry in Northern Ireland.[8] Central to discussion in the literature and also to the enquiry is whether too much fluid is being given, or the wrong type of fluid.[2 8–12]

†This article is accompanied by Editorial II.

There are several i.v. fluid solutions in common use in paediatric practice in the UK. Dextrose 4%/saline 0.18% and dextrose 2.5%/saline 0.45% are isotonic when administered but effectively hypotonic once the glucose has been metabolized; these are referred to as hypotonic solutions hereafter. After a report of another death, the use of dextrose 4%/saline 0.18% in children was discussed by the Medical Control Agency/Committee on Safety of Medicines and by the Joint Royal College of Paediatrics and Child Health (RCPCH)/Neonatal and Paediatric Pharmacists Standing Committee on Medicines in 2002. They concluded that the problem was an issue of clinical practice rather than product regulation and that dextrose 4%/saline 0.18% could continue to be used but should be prescribed carefully, especially to children in the postoperative period. Their concerns were communicated to the Royal College of Anaesthetists for dissemination to members. A letter was sent to College Tutors and Heads of Departments of Anaesthesia and the issue featured as a news item on the Royal College of Anaesthetists website in 2002. The letter was published in the College Bulletin in 2003.[13]

It is our practice, as specialist paediatric anaesthetists, to only use solutions in the intraoperative period that are isotonic with plasma, compound sodium lactate solution (Hartmann's solution) being our standard intraoperative maintenance fluid. This solution is used for children of all ages, with or without added dextrose as required. However, in discussions with trainee anaesthetists and Operating Department Practitioners from non-specialist institutions, it seemed that the practice of non-specialist anaesthetists may vary.

We therefore conducted a survey of a sample of anaesthetists in the UK to find out about their perioperative fluid prescriptions for children, the existence of departmental protocols, whether they were aware of the concerns from the RCPCH and whether this had affected their prescribing practice.

Methods

We surveyed all the consultant anaesthetists in two training Schools of Anaesthesia in the UK, thus including anaesthetists working in a variety of different hospital settings, both specialist and non-specialist (Bristol School of Anaesthesia and the North Western School of Anaesthesia). Names and addresses of hospitals were obtained from the Royal College of Anaesthetists College Tutors website. The departmental administrator for each hospital was contacted and a survey sent to all 477 consultant anaesthetists in the two Schools in May 2004 with a numbered postage-paid reply envelope. An independent research fellow opened the replies. Anonymity was maintained by separating the completed surveys from the envelope, noting the identifying number. Non-respondents were contacted by telephone or email after 4 weeks and then 6 weeks.

The questionnaire included details of the setting in which the anaesthetist worked, their paediatric anaesthesia training, the frequency with which they anaesthetized children, whether they had a departmental protocol for perioperative fluid administration and whether they were aware of the warning letter from the RCPCH concerning the use of dextrose 4%/saline 0.18% in children. They were asked about their choice of fluid for routine intraoperative maintenance and postoperative maintenance, what type of fluid they would prescribe as a fluid bolus in case of hypovolaemia and the volume of postoperative maintenance fluid they would routinely prescribe. There were four fluid choices: saline 0.9% or Hartmann's solution, both isotonic with plasma; dextrose 2.5%/saline 0.45% or dextrose 4%/saline 0.18% (hypotonic dextrose saline solutions); and a chance to specify 'other'. A pilot study was performed to exclude ambiguous questions. Multi-centre Research Ethics Committee approval was obtained from the South West Multi-centre Research Ethics Committee.

Statistical analyses

We used logistic regression to compare the use of isotonic fluids (saline 0.9% or Hartmann's solution) intraoperatively and postoperatively within different hospital settings and between anaesthetists with differing years of practice as a consultant, training, frequency of anaesthetizing children and knowledge/response to the RCPCH warning. Univariate odds ratios are presented and multivariable models were used to investigate whether associations found were independent. Results are presented with 95% confidence intervals (95% CI).

Results

A total of 289 replies were received giving a response rate of 60.6%. Eighty-six of these anaesthetists indicated that they never anaesthetized children and their replies were not analysed further. The results are based on the remaining 203 respondents.

One hundred and twenty-three (60.6%) respondents worked in district hospitals, 67 (33.0%) in teaching hospitals and 13 (6.4%) in specialized paediatric units. A total of 25.6% indicated that they had not received any specific training in paediatric practice, 22.7% had received training in paediatric anaesthesia for 3 months or less, 23.6% for 6–12 months and 27.6% had more than 12 months training. A total of 59.1% of respondents currently anaesthetized children occasionally, 32.0% had regular paediatric sessions amounting to <50% of their workload ('interest' in paediatric anaesthesia) and 7.9% had >50% of their workload made up of paediatric anaesthetic sessions ('specialist' paediatric anaesthetists).

Eighty-five (41.9%) respondents were aware of the RCPCH warning of November 2002, and of these only 26 had changed their practice as a result. A total of 67.7% indicated that they had no departmental policy regarding perioperative fluids in children.

Table 1 Choice of fluids from questionnaire responses of 198 who gave details of their fluid prescribing practice out of the 203 respondents who anaesthetize children. *Numbers do not add up to 100% as some respondents would give a mixture of fluids

Operative period	Fluid choice	Number of anaesthetists (%)
Intraoperative fluid maintenance*	Hypotonic dextrose saline solutions	
	Dextrose 4%/saline 0.18%	99 (50%)
	Dextrose 2.5 or 5%/saline 0.45%	31 (15.7%)
	Isotonic solutions	
	Hartmann's solution	72 (36.4%)
	Saline 0.9%	48 (24.2%)
Bolus for hypovolaemia intraoperatively	Hypotonic dextrose saline solutions	22 (11.1%)
	Isotonic solutions (saline 0.9%, Hartmann's or colloid)	161 (81.3%)
Postoperative fluid maintenance*	Hypotonic dextrose saline solutions	
	Dextrose 4%/saline 0.18%	130 (65.7%)
	Dextrose 2.5 or 5% with saline 0.45%	43 (21.7%)
	Isotonic solutions	
	Hartmann's solution	25 (12.6%)
	Saline 0.9%	24 (12.1%)

Intraoperative fluids

One hundred and ninety-eight of the 203 responders regularly anaesthetizing children provided information on the fluid they gave in the perioperative period, the remaining anaesthetists stating that they did not prescribe perioperative fluids for children. The most common choice for routine intraoperative fluid maintenance was dextrose 4%/saline 0.18% (50%) (Table 1). Other choices included Hartmann's solution (36.4%), saline 0.9% (24.2%) or dextrose 2.5 or 5% with saline 0.45% (15.7%). Several respondents indicated that they would give a mixture of fluids. Overall, 60.1% respondents indicated that they would give hypotonic dextrose saline solutions intraoperatively, 34.9% indicated that they would only give Hartmann's solution or saline 0.9%.

Isotonic fluids were the most common choice of fluid to be used as a bolus in the event of hypovolaemia (saline 0.9%, Hartmann's or colloid). A total of 11.1% respondents indicated that they would use their standard maintenance fluid (hypotonic dextrose saline) as a bolus to correct intraoperative hypovolaemia.

Postoperative fluids

The most commonly prescribed fluid for postoperative maintenance was dextrose 4%/saline 0.18% (65.7% of respondents), or dextrose 2.5 or 5% with saline 0.45% (21.7% of respondents). Isotonic fluids were not commonly prescribed (24.7% of respondents). Several respondents indicated that they would give a mixture of fluids: overall, 75.2% of respondents indicated they would only give hypotonic dextrose saline solutions postoperatively, 14.1% indicated that they would only give Hartmann's solution or saline 0.9%. No respondent indicated that they would give dextrose containing physiological saline fluids postoperatively (e.g. dextrose 5%/saline 0.9%).

In the intraoperative period (Table 2), there were significant associations between the prescribing practices of the anaesthetist and the type of hospital they worked in, the extent of their specialist training and the frequency with which they anaesthetized children. Those within specialist paediatric hospitals were 5.1 times more likely to use only isotonic solutions than the anaesthetists within district hospitals (95% CI 1.48–17.65, P=0.01). Similarly, they were more likely to use only isotonic solutions if they had more specialist training [odds ratio >12 months *vs* none 2.40 (1.08–5.33), P=0.03] or >50% of their workload was with children [cf. occasional work with children, odds ratio 3.86 (1.30–11.44), P=0.015]. After taking account of hospital type, none of the other variables was independently significant.

Use of isotonic saline solutions in the postoperative period (Table 3) was not significantly associated with hospital type, years of practice, training or experience, or with awareness of the 2002 correspondence. All anaesthetists working in specialist paediatric hospitals used hypotonic dextrose saline solutions postoperatively. However, those who were aware of the 2002 correspondence were 4.1 times more likely to use dextrose 2.5 or 5%/saline 0.45% (95% CI 1.6–10.4, P=0.003), and not to use dextrose 4%/saline 0.18%, than those not aware of the correspondence.

One hundred and ninety-four respondents provided information on how they calculated postoperative maintenance fluids. The majority (81.8%) based the calculation on the formula originally described by Holliday and Segar formula (Table 4).[9 14] Nineteen (9.3%) respondents quoted an approximate but incorrect formula. One hundred and seventy-six respondents provided information on how much of the calculated fluid volume they would prescribe postoperatively: only 5.9% would fluid restrict, 72.4% would prescribe 100% of predicted maintenance fluid and 2% would give volumes in excess of the amount calculated. Those within specialist paediatric hospitals were 13.2 times more likely to restrict postoperative fluids than those working in district hospitals (95% CI 2.8–61.8, P=0.001). Ten respondents said that the amount of fluid prescribed would depend on the type of surgery.

Discussion

The most striking finding of this survey of a sample of more than 200 anaesthetists who anaesthetize children was that >60% were using hypotonic dextrose saline solutions in the intraoperative period. The practice of specialist paediatric anaesthetists differed significantly from non-specialists for intraoperative fluid prescription (isotonic fluids significantly more likely to be used). However, specialist paediatric

Table 2 Intraoperative fluid prescription practice amongst the 198 respondents who gave details of their prescribing. Some fields do not total to 198 because of missing values. *Odds ratio given is per additional year of practice

	Only isotonic fluid given (number of anaesthetists, % total in that category)	Univariate odds ratio for the use of isotonic solutions (95% confidence interval)	*P*-value
Type of hospital			
District hospital (*n*=121)	37 (30.6%)	1	
Teaching hospital (*n*=64)	25 (39.1%)	1.46 (0.77–2.74)	0.246
Specialist paediatric hospital (*n*=13)	9 (69.2%)	5.11 (1.48–17.65)	0.01
Years of practice as a consultant anaesthetist*		1.004 (0.96–1.05)	0.87
Specialist training in paediatric anaesthesia			
None (*n*=51)	15 (29.4%)	1	
<3 months (*n*=44)	12 (27.3%)	0.9 (0.37–2.21)	0.82
6 to <12 months (*n*=46)	16 (34.8%)	1.28 (0.54–3.01)	0.57
12 months or more (*n*=56)	28 (50%)	2.40 (1.08–5.33)	0.03
Frequency of anaesthetizing children			
Occasional (less than once a month) (*n*=116)	35 (30.2%)	1	
Interest (<50% workload) (*n*=65)	25 (38.5%)	1.45 (0.76–2.74)	0.26
Specialist (>50% of workload) (*n*=16)	10 (62.5%)	3.86 (1.30–11.44)	0.015
November 2002 correspondence			
Not aware of correspondence (*n*=13)	38 (33.6%)	1	
Aware but did not change practice (*n*=56)	22 (39.3%)	1.23 (0.51–2.98)	0.64
Changed practice as a result (*n*=26)	10 (38.5%)	1.27 (0.66–2.48)	0.47

Table 3 Postoperative fluid prescription practice amongst the 198 respondents who gave details of their prescribing. Some fields do not total to 198 because of missing values. *Odds ratio given is per additional year of practice. †All of the specialist paediatric hospital staff used dextrose products and a confidence interval could therefore not be calculated

	Only isotonic fluid given (number of anaesthetists, % total in that category)	Univariate odds ratio (95% confidence interval)	*P*-value
Type of hospital			
District hospital (*n*=121)	16 (13%)	1	
Teaching hospital (*n*=64)	12 (19.4%)	1.61 (0.71–3.65)	0.258
Specialist paediatric hospital (*n*=13)	0	0†	0.999
Years of practice as a consultant anaesthetist*		0.98 (0.93–1.05)	0.58
Specialist training in paediatric anaesthesia			
None (*n*=51)	12 (23.5%)	1	
<3 months (*n*=44)	5 (11.4%)	0.42 (0.13–1.30)	0.13
6 to <12 months (*n*=46)	5 (10.6%)	0.39 (0.13–1.20)	0.10
12 months or more (*n*=56)	6 (10.9%)	0.40 (0.14–1.16)	0.09
Frequency of anaesthetizing children			
Occasional (less than once a month) (*n*=116)	16 (13.9%)	1	
Interest (<50% workload) (*n*=65)	10 (15.4%)	1.13 (0.48–2.65)	0.79
Specialist (>50% of workload) (*n*=16)	1 (6.3%)	0.41 (0.05–3.34)	0.41
November 2002 correspondence			
Not aware of correspondence (*n*=13)	17 (15.2%)	1	
Aware but did not change practice (*n*=56)	4 (6.9%)	0.41 (0.13–1.29)	0.13
Changed practice as a result (*n*=26)	6 (23.1%)	1.68 (0.59–4.78)	0.33

anaesthetists were just as likely to prescribe hypotonic dextrose saline postoperatively as non-specialists. 74% of anaesthetists prescribed full volume maintenance fluids postoperatively (or more), according to the formula described by Holliday and colleagues,[9] but specialist paediatric anaesthetists were significantly more likely to restrict fluids postoperatively. A total of 67.7% of anaesthetists did not have a local departmental policy for fluid prescription, and 58.1% were unaware of the correspondence from the RCPCH regarding iatrogenic hyponatraemia in children and the use of dextrose 4%/saline 0.18%.

There have been more than 50 case reports of neurological injury as a result of hospital-acquired hyponatraemia in children, many cases after routine surgery for the common conditions of childhood.[15] Concerns have focused on the use of hypotonic fluids for maintenance therapy, in particular, the use of dextrose 4%/saline 0.18%. These concerns have been relayed to anaesthetists via the RCPCH and Royal College of Anaesthetists.[13] Although there is some debate,[9 12] and only a few, very small randomized studies in children in the perioperative period,[15] the weight of expert opinion favours the use of isotonic fluids for maintenance therapy in children at risk of hyponatraemia.[1 7 10 11 15 16] It has been suggested that most cases of hospital-acquired hyponatraemia would be prevented by the use of isotonic saline in the perioperative period.[15]

Table 4 The Holliday and Segar formula: the average maintenance requirement for fluid[9 14]

Body weight (kg)	Average maintenance allowance for fluid	
	ml day^{-1}	ml h^{-1}
0–10	100 ml kg^{-1}	4 ml kg^{-1}
10–20	1000 ml + 50 ml kg^{-1} for each kg more than 10 kg	40 ml + 2 ml kg^{-1} for each kg more than 10 kg
20–30	1500 ml + 20 ml kg^{-1} for each kg more than 20 kg	60 ml + 1 ml kg^{-1} for each kg more than 20 kg

Table 5 Sodium content and osmolality of commonly used crystalloid solutions

Intravenous fluid	Sodium (mmol litre^{-1})	Osmolality (mosm kg^{-1} H_2O)	% electrolyte-free water
Dextrose 5%	0	252	100
Saline 0.18%/dextrose 4%	30	282	80
Saline 0.45%/dextrose 2.5%	75	293	50
Hartmann's solution	131	278	16
Dextrose 5%/Ringer's solution	130	525	16
Saline 0.9%	150	308	0
Dextrose 5%/saline 0.9%	150	560	0

Children are particularly vulnerable to the effects of acute hyponatraemia and become symptomatic at higher plasma sodium concentrations than adults. More than 50% of children with serum sodium <125 mmol litre^{-1} develop hyponatraemic encephalopathy.[15]

Dilutional hyponatraemia occurs when there is a source of electrolyte-free water and an inability to excrete free water in the kidney. The i.v. fluids include those that are isotonic with plasma or hypotonic when compared with plasma, the differences being most clearly illustrated by the relative proportions of electrolyte-free water (Table 5). The excretion of water in the kidney is controlled by vasopressin (antidiuretic hormone, ADH). Vasopressin release is controlled by osmotic stimuli so that healthy individuals are able to excrete large volumes of dilute urine in response to a water load by suppression of vasopressin release. Plasma osmolality is thus regulated within narrow limits despite wide variations in fluid intake. Vasopressin release is also controlled by a variety of non-osmotic stimuli. These include factors commonly encountered in the perioperative period—decreased extracellular fluid volume, hypovolaemia, pain, nausea, stress and drugs such as morphine, also CNS and pulmonary disturbances. These non-osmotic stimuli override the osmotic control so that the perioperative period is characterized by high concentrations of vasopressin and an inability to excrete a free water load. Administration of hypotonic fluids in this situation will lead to hyponatraemia.[2 15–17] A recent observational study in a tertiary children's hospital indicated a 10% incidence of hospital-acquired hyponatraemia in children presenting to the emergency department. Children in the hospital-acquired hyponatraemia group received significantly more electrolyte-free water in the form of hypotonic i.v. fluids.[7]

I.V. fluids are used as 'replacement' fluids to expand the extracellular fluid volume, maintain arterial pressure or replace abnormal fluid losses, and 'maintenance' fluid to replace insensible and urinary losses when oral intake is suspended.[18] The rationale for fluid administration needs to be carefully considered during the intraoperative and postoperative periods.

During the intraoperative period, the stress response to surgery causes maximal vasopressin release and urinary losses will be low. Insensible losses (sweating/respiratory water losses) will also be low—the requirement for maintenance water is low. However, there is a need to maintain arterial pressure to counter the effect of anaesthetic agents, and to replace fluid deficits because of fasting and ongoing losses associated with surgery. These deficits/losses are from the extracellular compartment and should logically be replaced by a solution approximating to the composition of extracellular fluid. Hypotonic solutions would be expected to result in a decrease in plasma sodium. Balanced salt solutions have been recommended for fluid replacement during surgery in standard paediatric texts for many years,[19 20] in line with adult practice. Of note, much of the published work concerning fluids in children in the paediatric anaesthetic literature has been concerned with the need for glucose during surgery,[21–23] rather than consideration of the sodium content of maintenance fluids. In one study, children undergoing elective minor surgery were randomized to receive either dextrose 2.5%/saline 0.43% or dextrose 5%/saline 0.33%. In both groups there was a decrease in plasma sodium, significantly greater in the group receiving more electrolyte-free water.[24] A small study in children undergoing scoliosis surgery randomized patients to receive either Hartmann's solution or hypotonic dextrose saline intraoperatively and postoperatively. Patients receiving hypotonic fluid had significantly lower plasma sodium at all time points up to 48 h, including the first postoperative sample.[17] Intraoperative dilutional hyponatraemia and fatal cerebral oedema has been reported.[3]

It was surprising that 60% of anaesthetists in this survey indicated that they give hypotonic dextrose saline intraoperatively. This practice may be related to concerns about intraoperative hypoglycaemia, especially in small infants undergoing prolonged surgery. Children requiring preoperative dextrose infusion or parenteral nutrition are especially vulnerable.[24] However, for routine surgery, these concerns may be exaggerated as fasting times have been liberalized in recent years, and even healthy infants have been shown to maintain blood glucose concentrations within normal limits during surgery, with or without added dextrose.[25] Use of dextrose 0.9 or 1% is sufficient to avoid hypoglycaemia and prevent ketosis in infants but fluids containing dextrose 4 or 5% are associated with

hyperglycaemia, which may have deleterious effects.[21 22] We think that there is no justification to use either dextrose 4%/saline 0.18% or dextrose 2–5%/saline 0.45% as maintenance during surgery as this fluid will be associated with dilutional hyponatraemia and hyperglycaemia. Intraoperative fluid should be an isotonic solution with or without low-dose dextrose (0.9–1%).[22]

A survey of intraoperative glucose administration by two specialist paediatric anaesthetic groups, the Association of Paediatric Anaesthetists (APA) and the French Language Society of Paediatric Anaesthesiologists (ADARPEF) indicated that the majority of anaesthetists use glucose containing solutions in neonates and infants, less frequently in older children.[23] Ninety-seven per cent of APA members used glucose concentrations >4% whilst only 59% of ADARPF members used glucose concentrations in this range. It was suggested that the differences were related to commercial availability; solutions containing low-dose dextrose have been available in European countries for many years.[22] It seems likely that anaesthetists in the UK (including one third of specialist paediatric anaesthetists in this survey) are using commonly available 'off the shelf' fluids containing dextrose to avoid the possibility of intraoperative hypoglycaemia (dextrose 4%/saline 0.18%, or dextrose 2.5 or 5%/saline 0.45%). We recommend that an isotonic solution containing low-dose dextrose should be available in the UK to address these concerns.

A few anaesthetists in the survey stated that they only anaesthetized children for minor surgery and therefore did not administer fluids to children. Recent studies in adults have demonstrated that preoperative i.v. fluid therapy (Hartmann's solution) decreases postoperative nausea and pain in high-risk patients undergoing gynaecological surgery,[26] and that liberal *vs* restrictive fluid administration improves recovery after laparoscopic surgery.[27] Children undergoing minor surgery such as tonsillectomy are at particularly high risk of postoperative nausea and vomiting. Administration of intraoperative fluids and withholding oral fluids for 4–6 h has been shown to reduce vomiting in children undergoing day surgery, particularly those receiving opioids.[28] A small study in children undergoing tonsillectomy showed that perioperative saline infusion was associated with significantly lower postoperative ADH concentrations compared with control children who did not receive intraoperative fluids, the difference presumed to be as a result of correction of hypovolaemia.[29] Many anaesthetists give intraoperative fluid such as Hartmann's solution, even for minor surgery in children, to ensure adequate hydration and to allow children to take oral fluids on demand postoperatively. Excessive fluids should be avoided—hyponatraemia secondary to hypervolaemia inducing desalination has been reported.[30] The I.V. fluids should only be started after minor surgery if the child is unable to tolerate oral fluids—much better to allow the child to control their own water balance postoperatively.

In the postoperative period, maintenance fluids are required to replace insensible losses, urinary losses and provide a source of dextrose when oral intake is precluded or inadequate. In addition, isotonic replacement fluids may be required for ongoing or abnormal losses (such as gastrointestinal losses). Holliday and Segar proposed a formula to estimate the maintenance need for water in parenteral fluid therapy in 1957 and this formula has been in common use to calculate maintenance postoperative fluids since then (Table 4). The requirement for water was related to the caloric expenditure in healthy children, with estimations for average insensible losses and average urinary losses.[9 14] However, they pointed out that caloric expenditure is reduced in hospitalized children and urinary losses may vary according to the clinical situations and the effects of ADH; thus maintenance fluid requirements should be restricted postoperatively. The authors suggested that the ideal maintenance fluid in children was hypotonic dextrose saline but that volume deficits should be replaced with a 20–40 ml kg^{-1} bolus of isotonic saline.[9]

The syndrome of inappropriate ADH (SIADH) was described in 1957; production of inappropriately concentrated urine in the presence of hyponatraemia and low plasma osmolality (in the absence of hypovolaemia and with normal renal and adrenal function).[31] Experts have emphasized the dangers of administration of hypotonic saline solution in the presence of elevated ADH concentrations in a child who is acutely unwell, either advocating only isotonic solutions (with dextrose) in the postoperative patient,[15] or avoiding hypotonic solutions if the plasma sodium decreases below 138 mmol $litre^{-1}$.[2 7] Holliday argued against the use of isotonic saline for routine maintenance but highlighted the importance of correcting volume deficits with isotonic fluid boluses. He suggested that isotonic maintenance fluids would be associated with hypernatraemia or fluid overload and possible desalination as a consequence. However, in the presence of elevated ADH concentrations, Holliday and others recommend fluid restriction to 50% of maintenance requirements.[9–12] Specialist paediatric anaesthetists in this study appear to follow this pattern, and restrict fluids postoperatively, although we did not obtain information as to the degree of fluid restriction. Many of the cases of iatrogenic hyponatraemia have been associated with administration of hypotonic fluids in excess of maintenance values recommended by Holliday and Segar.[2]

It is surprising that in this era of evidence-based medicine there have been very few studies to compare the use of isotonic or hypotonic maintenance fluids in children in the postoperative period. The majority of anaesthetists in this survey would prescribe hypotonic dextrose saline postoperatively and all anaesthetists working in specialist paediatric hospitals indicated that they would prescribe hypotonic dextrose saline postoperatively. Some authors have suggested that only isotonic fluids should be used postoperatively and have questioned the ethics of

conducting a randomized study of hypotonic *vs* isotonic maintenance fluids in postoperative children.[11] Our survey shows that a carefully conducted trial may be justified, as the exclusive use of isotonic saline in the postoperative period would be a major change in current practice, including by specialist paediatric anaesthetists. A recent randomized study has investigated replacement fluids in children with gastroenteritis. This showed that saline 0.9% was preferable to saline 0.45% and protected against hyponatraemia. Urinary sodium excretion increased appropriately in normonatraemic children given saline 0.9%, and hypernatraemia did not occur.[32]

There are clearly limitations in a questionnaire survey of practice, but we feel that a 60% response rate and the opinions of more than 200 consultants who anaesthetize children allow useful conclusions to be drawn. There were very few specialist anaesthetists who contributed to the survey, but we estimate that this is an accurate reflection of the ratio of specialist to non-specialist paediatric anaesthetist in the UK, and in general, the views expressed by the specialist anaesthetists reflects that of expert opinion. Respondents to a questionnaire survey may not be able to qualify their responses—but we were looking at routine practice, not exceptions to practice such as the neonate or child in the intensive care setting. Although most major surgery in children will be in the specialist centres, the majority of children undergoing routine minor surgery are operated on outside specialist centres,[33] and thus the prescribing practices of non-specialists are important to the general welfare of children. It is important to reiterate that many of the case reports of iatrogenic hyponatraemia occur in previously healthy children undergoing routine surgery.

A quarter of the anaesthetists indicated that they did not have any specific training in paediatric anaesthesia—the survey included clinicians who had been in practice for more than 20 yr, before the trend for centralization of paediatric services and modular training in paediatric anaesthesia. Worryingly, clinicians appeared to have low awareness of the concerns of the RCPCH concerning iatrogenic hyponatraemia and departmental policies for fluid management in children were uncommon. Unfortunately, communication between colleges does not appear to be an effective way of notifying risk to clinicians. Guidance is available in the BNF for children[34] and from the Department of Health in Northern Ireland,[35] the latter as a consequence of a number of high profile deaths in the province. Others have suggested that dextrose 4%/saline 0.18% should be labelled to highlight the risk of iatrogenic hyponatraemia.[36] It would seem sensible to address these issues with national guidance through an organization such as the National Patient Safety Authority.

In summary, this survey has indicated that the current prescribing practices of large numbers of anaesthetists may be putting children at risk from iatrogenic hyponatraemia, namely the use of hypotonic fluid intraoperatively and prescription of full volume hypotonic maintenance fluid postoperatively. Departmental policies are uncommon, as is awareness of the correspondence from the RCPCH regarding iatrogenic hyponatraemia in children and the use of dextrose 4%/saline 0.18%.

Simple measures could be taken to reduce the risk of death from iatrogenic hyponatraemia. We recommend that clinicians consider whether fluids are being given for 'replacement', to expand the extracellular fluid compartment, or as 'maintenance'. All replacement fluids should be with isotonic solutions; this includes all intraoperative fluids. Maintenance i.v. fluids should only be administered postoperatively if the child is unable to take fluids by mouth. If i.v. fluids are administered, especially if hypotonic fluids are given, fluid balance and electrolytes must be monitored. Fluid restriction should be considered in a child who is acutely unwell (elevated ADH). Children who are hyponatraemic should only receive isotonic fluids.

Appendix

Perioperative fluid survey in paediatric practice

Please tick the box next to your answer and write in more detail where asked. Please be as specific as you can. All responses are strictly confidential. Thank you for taking time to complete this questionnaire.

1. Do you work in a Specialist paediatric hospital? ☐
   Teaching hospital? ☐
   District general hospital? ☐

2. How many years have you been practicing as a consultant anaesthetist?

3. Have you had any specialist training in paediatric anaesthesia?

4. If you answered yes to Q3 please give details.....

5. How frequently do you anaesthetize children, elective or emergency cases?
   Never ☐
   Less than once a month ☐
   Once a month ☐
   Once a fortnight ☐
   More than once per week ☐

(If you answer 'never' please stop here and return survey)

6. How many elective paediatric sessions (or equivalent) do you anaesthetize for each week?
   No regular sessions ☐
   One to two sessions per week ☐
   Three or more sessions per week ☐

7. Do you have a standard practice for **perioperative** fluid management in your department?
   YES ☐ NO ☐ DON'T KNOW ☐
   Comments.....
   .....

8. What **type** of maintenance fluid would you give to a child requiring fluid **intraoperatively, assuming no rapid volume losses?**

Saline 0.9% ☐ Saline 0.18%/dextrose 4% ☐
Hartmann's solution ☐
Saline 0.45%/dextrose 2.5% ☐
Other (please specify).....

9. If you considered a bolus of fluid was required **intra-operatively**, what **type** of fluid would you give? For example, saline 0.9%

For a bolus of 10 ml kg^{-1} .....
For a bolus of 20 ml kg^{-1} .....
For a bolus of 30 ml kg^{-1} .....

10. What **type** of maintenance fluid would you give to a child requiring fluid postoperatively, assuming **no major ongoing volume losses?**

Saline 0.9% ☐ Saline 0.18%/dextrose 4% ☐
Hartmann's solution ☐
Saline 0.45%/dextrose 2.5% ☐
Other (please specify).....

11a. What **formula** would you use to calculate the postoperative fluid volume requirements? For example, 100 ml kg^{-1} per day

11b. What **proportion** of this calculated volume would you prescribe?

Full daily requirements ☐ i.e. 100% of the calculated volume
Above daily requirements ☐ please specify percentage.....%
Below daily requirements ☐ please specify percentage.....%

12. Have you changed your practice with respect to the correspondence from the Royal College of Paediatrics and Child Health/Royal College of Anaesthetists of December 2002?

YES ☐ NO ☐ Not aware of correspondence ☐
If yes, what is the nature of the change?.....

13. Please add any further comments about this issue.....
.....

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