Principles and practice of paediatric anaesthesia

M. Jöhr

Summary

Anaesthetic risk is markedly higher in children than in adult surgical patients. To make correct decisions in daily clinical work, it is therefore imperative to possess basic knowledge of airway management, the cardiovascular system and fluid therapy. Young children have a relatively active metabolism with high oxygen consumption. Apnoea tolerance is very limited. Desaturation can only be avoided by ventilating the child. The modified approach of rapid sequence induction is becoming generally accepted. Beyond neonatal age, cuffed tubes are widely used. When using a laryngeal mask airway, an L-shape is advantageous. Special attention should also be given to blood pressure and perfusion because hypotension may have serious consequences. If necessary, vasoactive drugs are indicated in paediatric patients as well. The normal values for blood pressure are age-dependent. The number of veins which can be easily punctured is often very limited, especially in infants and chronically-ill children, but anaesthesia without venous access must remain an ultima ratio. Hyponatraemia is a latent threat, so that only solutions with a physiological saline concentration should be used. Altogether, daily paediatric anaesthesia practice can be markedly improved. “Good anaesthesia“ with perfection in every detail and maintained homeostasis is in the focus of interest; differences between compounds or techniques as well as the theoretical question of neurotoxicity are of minor importance.

General aspects

Concerns of the anaesthetist

General anaesthesia of small children puts an unusual strain on many anaesthetists; they are not familiar with the small dimensions and the manual basics of the discipline – such as intravenous access and intubation – suddenly become difficult procedures. The fact that these patients are children, afraid and often lacking compliance, accounts for additional stress. Furthermore, anaesthetists who usually do not take care of children or work in paediatric hospitals on a regular basis are often confronted with questions and problems they never have been asked to solve before, at least not in this particular age group, and the unknown causes fear.

A familiar situation causes less fear, and experience is useful – but the timely analysis of a problem can also help.

The child‘s risk

The risk of general anaesthesia in children is markedly higher than in adults, although healthy children without comorbidity are usually involved.

Complications such as cardiovascular arrest [1,2] and airway problems are more common; it is assumed that the occurrence of anaesthesia-related fatal

The author declares the absence of any conflict of interest.

Keywords
Paediatric Anaesthesia – Airway – Circulation – Complications – Homeostasis

outcomes is 10 times higher in children than in adults [3]. Obvious endpoints such as cardiovascular arrest with fatal outcome are probably only the tip of the iceberg – and severe disorders of homeostasis with imponderable consequences are still tolerated all too often.

Much can be improved in the everyday practice of children's general anaesthesia – the so-called SAFETOTS Initiative (SAFE ANAESTHESIA FOR EVERY TOT) refers to the necessity of perfection in the detail and maintenance of homeostasis [4]. The "good anaesthesia" stands in the centre of interest, and differences between drugs or procedures or even the question of neurotoxicity lose their importance.

The common goal of paediatric general anaesthesia is to achieve "good anaesthesia" while maintaining homeostasis.

Structural changes including the transfer of very young children to specialised centres and treatment delivered by especially-experienced physicians, aiming for high institutional and individual competence, are the subject of professional and sociopolitical discussion. But, every anaesthetist should be capable of anaesthetising an older child for a common intervention, with deliberation and assuredness, and bridging emergency cases until help arrives.

The body of the child

Basic considerations

Babies have proportions which are different to those of adults; relatively, they have a large head, a large abdomen, a small chest and small limbs. This has clinical implications not only when it comes to the evaluation of burns, but also in other areas:

- The large, heavy head is unstable in the supine position; here, a head ring will be useful (Fig. 1). Due to the large head, the intubation cushion is "built in", but a bolster for the shoulders or neck would instead be necessary.
- The large head, in particular, causes the potential for loss of body heat.
- Blood loss in children is latently underestimated. An isolated craniocerebral injury – as opposed to adults – might lead to a hypovolemic shock due to blood flowing into the galeal aponeurosis or into the cranium.

Tab. 1
Equation for estimating body weight (b.w.).

Age	Equation
Babies	b.w. = (age in months + 9) : 2
Children	b.w. = (age in years + 4) x 2

Length, weight and age

The anaesthetist should be able to estimate whether the length/height and body weight (b.w.) of a child matches its age:

- The child doubles birth weight by five months,
- triples it by one year,
- quadruples it by two years.

Whenever possible, therapy should be based on the currently-measured body weight.

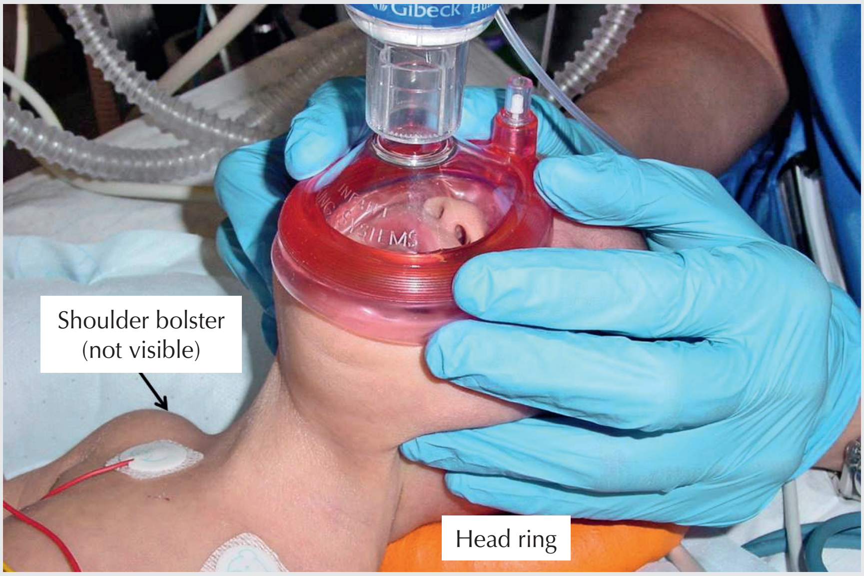
Equations to estimate body weight (Tab. 1) can be useful in emergency situations and for preparing oneself mentally for anaesthesia – especially if the patient has not yet been seen, e.g. upon announcement that "the emergency physician is bringing in a nine-month-old child."

External information might be useful to **determine the age** in emergency situations (Tab. 2).

Tab. 2
Age determination and tube selection in emergency cases.

Finding	Likely age	Tube size
Baby without teeth	Less than 6-8 months	3.0 with cuff
Baby with open fontanel	Less than 18-24 months	3.5 with cuff
Toddler with diapers and apparently normal development	Less than 4 years old	4.0 with cuff
Child with missing frontal teeth	6-7 years old	5.0 with cuff

Fig. 1



A head ring stabilises the position of the head and facilitates the induction of general anaesthesia in children. The shoulders are supported by a rolled towel (not visible).

In addition, the anaesthetist should be able to estimate whether the child's development is in agreement with its age; smiling by 6 weeks, head-raising by 2 months, eyes following movements by 3 months, sitting by 6 months, standing by 9 months, and walking by 12 months. The anaesthetist should pay attention to speech development, inquire about feeding (breastfeeding, bottled milk, at the table) and perhaps school attendance.

Thermoregulation

Newborns are already capable of thermoregulation and try to control the core temperature of their bodies (BCT) – however, their relatively large body surface and thin skin facilitate heat loss.

The core temperature should be measured or be known before, during and after the general anaesthesia of a child; an active supply of warmth is advisable while the operation is in progress.

- **Convective warming systems** such as the Bair-Hugger™ or Warm-Touch™ have proven useful and should be applied to all children weighing less than 5 kg, and regularly to older children undergoing interventions of longer duration.
- **Fever** is a common symptom encountered in children and it is essential that the anaesthetist is aware of what the child's BCT has been during the intervention.

Children with development disorders, e.g. cerebral palsy, have a slower metabolism and rapidly become hypothermic.

- The author's practice in cases like these is to increase the temperature of the theatre and invariably use two Bair-Huggers™ for supplying "top and bottom heat".

The active metabolism with huge endogenous heat production explains the typical temperature rise in prolonged anaesthesias without excessive losses.

- An active heat supply is not regularly required in the case of prolonged ear, nose and throat (ENT) interventions.
- In examinations carried out by way of **magnetic resonance imaging (MRI)**, the energy supply from the magnetic field accounts for the fact that **infants** do not become hypothermic despite the cold environment (without additional measures) – however, the hyperthermia feared by the radiologists does not occur [5, 6]. **Newborns**, however, in the author's experience, do become hypothermic during the course of an MRI examination. MRI examinations constitute a case of exception with respect to thermoregulation.

Respiratory system, airway-management and ventilation

Special physiological and anatomical features

Small children have a very active metabolism as characterised by a high oxygen requirement and large alveolar ventilation (Tab. 3). The functional residual capacity (FRC) is small; it is also relatively small in proportion to the total lung capacity, because the still very elastic ribcage follows the lungs into the expiration position.

Tab. 3
Respiratory handicaps in childhood.
PEEP = positive end-expiratory pressure.

Facts	Consequences
High oxygen consumption (6-10 ml/kg b.w./min.)	High consumption despite limited reserves results in a short apnoea tolerance
Huge carbon dioxide production	Extensive alveolar ventilation
Small functional residual capacity (FRC) – absolute and relative	Limited reserves
Large closing capacity	Strong tendency toward atelectasis formation – sufficient PEEP is essential
Narrow airway, unstable thorax, immature respiratory muscles	Designed for drinking, digesting and growth – higher demand is not intended

Tab. 4
Time in seconds (s) until SpO_2 without pre-oxygenation reaches 50 percent of the maximum decline rate and then rapidly declines further. Data derived from Nottingham physiology simulator [7].
SpO_2 = arterial oxygen saturation determined by pulse oximetry.

Age	Time
1 month	6.6 s
1 year	10.8 s
8 years	15.0 s
18 years	31.2 s

High oxygen consumption despite small reserves results in a short apnoea tolerance [7].

- Even short-term apnoea in a young baby inevitably results in a decline of SpO_2 (arterial oxygen saturation determined by pulse oximetry) and arterial oxygen content (Tab. 4).
- Induction techniques, as well as diagnostic and therapeutic procedures with phases of apnoea are not appropriate and potentially hazardous for small children [8].
- The **modified rapid sequence induction (RSI)** including pre-oxygenation and mask ventilation observes all precautionary measures of a rapid and deep induction; however, the children are ventilated, effectively oxygenated and subsequently intubated without hastiness. This development is an essential step forward

towards a safer treatment of children and has proven its worth in clinical routine work.

In a clinical series, every second newborn desaturated after more than one minute under 90% SpO_2, and every fourth after more than one minute under 80% SpO_2 [9]. This must not necessarily have serious consequences, however, it shows that small children often approach the potentially hazardous range.

Airway management using a tracheal tube

Basic considerations

Airway management problems are often the cause of serious complications. The smaller the child, the more often intubation becomes difficult (Fig. 2).

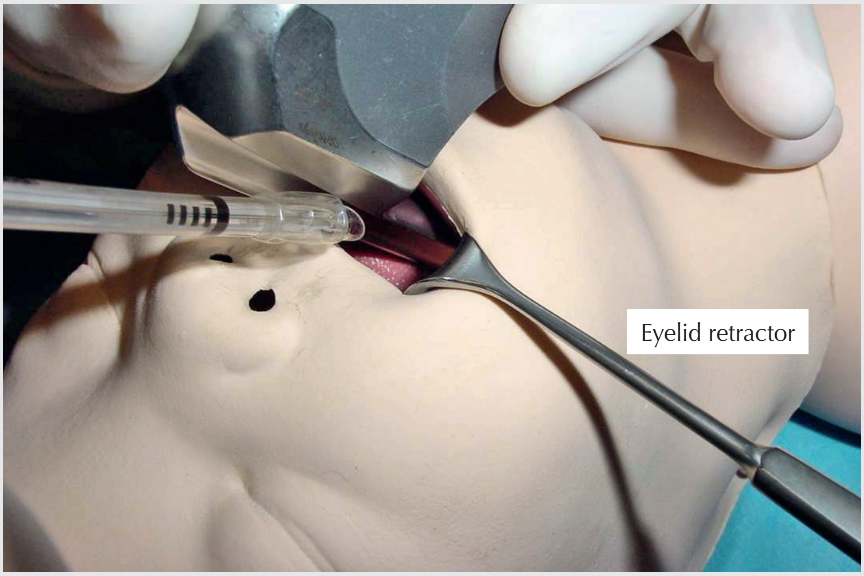
Essentially, there are three reasons for this (Tab. 5). It is hard to compensate for a lack of experience. Possible approaches to a solution are the transfer of newborns and babies in particular to hospitals that have pertinent experience, optimised advanced training and supervision, and/or the establishment of

Tab. 5
The three causes of difficulties in airway management.

Cause	Comments and proposed solutions
1. Lack of experience	Beginners work under supervision; video-laryngoscopy for instruction
2. Inadequate material	Textbooks and courses, standards and check lists; optimal preparation of instruments
3. Great time pressure	Appropriate procedures and algorithms help to optimally utilise the short time available

"children's teams". Occasionally, it is demanded that all small children be intubated invariably (rather than ventilated via laryngeal mask airway) in order to create sufficient training opportunities for physicians who require practice, something which profoundly contradicts the author's opinion that every child should get the best possible anaesthesia – and that oftentimes consists of a laryngeal mask airway and not a tracheal tube [10].

Fig. 2



The intubation of newborns and babies is difficult, for example, because of the existing narrow spatial conditions; an eyelid retractor improves the insight of the examiner considerably and is regularly used at the Paediatric Hospital in Lucerne (inspired by Dr. Jörg Schimpf, Augsburg).

Orotracheal or nasotracheal intubation

The dislocation of the tube presents a problem – nasotracheal intubation permits a reliable fixation and thus decreases the risk.

It is therefore the author's practice to perform nasotracheal intubation on new-borns and babies, provided that the intervention allows for it. The risk of haemorrhage is minimal in this age group due to the absence of adenoids, and long-term nasotracheal intubation is also possible without the maxillary sinus problems often appearing in adults. On the other hand, other hospitals carry out sophisticated interventions on orally-intubated newborns which are subsequently transferred to the intensive care unit this way.

Tracheal tube with or without cuff

The previous, very emotional discussion on the significance of blocked tubes for the general anaesthesia of children has abated to a great extent. In neonatology, unblocked tubes are used nowadays almost without exception, whereas regularly blocked tubes are applied in older children.

These tubes have considerably facilitated airway management for the anaesthetist responsible for e.g. older children in matters concerning ENT. If the age recommendation printed on the package is followed, the primarily-chosen MicroCuff® tube will almost always fit, a tube change will hardly ever become necessary and postoperative stridor does not occur more frequently [11]. However, neither does this apply if actions are taken against the recommendation; nor is the MicroCuff® tube the right choice for newborns weighing less than 3 kg b.w. It is also associated with an increased incidence of stridor [12].

The size of the tracheal tube depends particularly on the child's age. The same also applies to nasotracheal intubation.

Tab. 6
Tube table for premature infants, newborns, babies and children up to 12 years of age.

Age and/or weight	Tube without cuff	Tube with cuff	Oral insertion depth
Premature infants <600 g	2.0-2.5		
Premature infants 1 kg	2.5		7 cm
Premature infants 2 kg	2.5 -3.0		8 cm
Newborns 3 kg	3.5	3.0 with cuff	9 cm
3 kg-4 months	3.5	3.0 with cuff	10 cm
4 months-8 months	4.0	3.0 with cuff	11-12 cm
8 months-2 years	4.5 (>1 year)	3.5 with cuff	12-13 cm
2 years-4 years	5.0	4.0 with cuff	13-14 cm
4 years-6 years		4.5 with cuff	14-15 cm
6 years-8 years		5.0 with cuff	15-16 cm
8 years-10 years		5.5 with cuff	16-17 cm
10 years-12 years		6.0 with cuff	18-19 cm

- Tables are available for newborns and babies in particular (Tab. 6).
- Equations may also be used after completion of the first year of life (Tab. 7).
- In the case of children with development disorders (e.g. 14 years/12 kg b.w.), the tube size should preferably be chosen according to age and not to body weight – because of the age-dependent growth of larynx and trachea.

The tube size is selected in such a manner that a small leakage occurs without inflation of the cuff. Afterwards, the cuff is blocked with a pressure of 20 cm H_2O.

- A completely deflated and thus ribbed cuff increases the risk of damaging the tracheal mucosa.
- Routinely blocking with 20 cm H_2O appears to cause fewer mucosal lesions than minimal pressure just preventing leakage, as the flaccid low-pressure cuff might flap back and forth with each breath of air and thus injure the mucosa.

Tab. 7
Equations to calculate the tube sizes in children over 1 year of age.

Tube type	Equation for internal diameter in mm
With cuff	3.5 + (age in years : 4) Example: 6 years = 5.0
Without cuff	4.5 + (age in years : 4) Example: 2 years = 5.0)

Position of the tracheal tube

An optimal position of the tube's tip prevents both accidental extubation and endobronchial intubation in the event of position changes.

- Inclination of the cervical spine will make the tube tip descend deeper, whereas reclination will move it towards the plane of the vocal cords – in a baby ± 1 cm, in a ten-year-old child ± 2 cm [13].
- The trachea of a term infant measures 4 cm in length; in this age class, the objective is to place the tip of the tube in the middle of the trachea (Tab. 8).
- In case of laparoscopic interventions, the pneumoperitoneum – especially when performed in a head-down position – causes a relevant descent of the tube tip [14].

The expected insertion depth of the tube should be known before induction of general anaesthesia.

Tab. 8
The optimum position of the tube tip.

Age	Optimum tube tip position
Newborns	2 cm above the carina tracheae
5-year-olds	3 cm above the carina tracheae
Adults	4 cm above the carina tracheae

In the case of newborns, the "1, 2, 3 kg – 7, 8, 9 cm rule" is helpful; there are equations that apply to older children (Tab. 9).

The author is convinced that the Micro Cuff® tubes adapted to children have advantages, particularly in ENT applications. If the tube is inserted to the corresponding mark, the size will fit and tube tip will never be too deep, provided that the age recommendation printed on the package is observed [15].

Tab. 9
The expected insertion depth of the tube.
b.w. = body weight.

Age/weight	Insertion depth
Newborns	1, 2, 3 kg b.w. - 7, 8, 9 cm rule
1 kg	7 cm
2 kg	8 cm
3 kg	9 cm
> 1 year, oral	12 cm + ½ cm per year
Nasal	+ 20% Example: 2 years: 13 + 2.6 = ca. 16 cm

Airway management using laryngeal mask airway

Basic considerations

The laryngeal mask airway (LMA) is associated with fewer postoperative complications than exist in endotracheal intubation [16] and should be taken into consideration whenever the risk of aspiration is not elevated and excessive airway pressures are not expected.

In the induction phase, it seems to provide protection against problems such as obstruction and desaturation as well, since the airway can be secured very early and even in moderately-deep general anaesthesia. On the other hand, the LMA and other supraglottic airway devices have an increased dislocation tendency as long as the child possesses an anatomy optimised for milk drinking. This speaks in favour of a restrictive indication for newborns and babies, whenever the access to the airway cannot be assured during the operation or complex positioning is necessary. Nevertheless, the LMA is increasingly chosen as the primary option in emergency medicine – including the resuscitation of newborns – unless physicians with experience in paediatric anaesthesiology are available on site. Ventilation proceeds with a higher efficiency than with a face mask and the risks of endotracheal intubation (e.g. false intubation, airway trauma or the necessity of a deep general anaesthesia) cease to exist.

Choosing the right laryngeal mask airway

The LMA in L-shape (Fig. 3) – such as LMA Supreme™ and Ambu® AuraGain™ etc. – seem to have a lower dislocation tendency in younger children as compared to the classical LMA. LMAs possessing a channel designed for gastric tube placement probably provide an additional safety measure since the inlying tube helps to prevent the dislocation of the LMA's tip from the upper oesophageal sphincter like a Seldinger guide wire. On the other hand,, the i-gel®-LMA – well suited for adults – has a high dislocation tendency in babies and infants and cannot be recommended [17].

- Choosing the right size traditionally depends on the patient's body weight (Tab. 10), but is also determined by the experience of the anaesthetist.
- The size of the patient's ear might give indication of size regarding classical LMA [18].
- The cuff pressure should be limited to 40-60 cm H_2O

Fig. 3

L-shaped laryngeal mask airways have a lower dislocation tendency in children and should be preferred over the classical laryngeal mask.

Tab. 10

Choosing the right laryngeal mask airway (LMA). The tube (without cuff) as well as fitting gastric tube matching with the respective LMA are shown. **Ch.** = Charrière; **ID** = internal diameter in mm.

Body weight	LMA Size	Tube (without cuff)	Gastric tube for LMA Supreme™/ AuraGain™
2-5 kg	1	3.0 ID	6 / 6 Ch.
5-10 kg	1.5	3.5 ID	6 / 8 Ch.
10-20 kg	2	4.0 ID	10 / 10 Ch.
20-30 kg	2.5	5.0 ID	10 / 10 Ch.
30-50 kg	3	6.0 ID	14 / 16 Ch.
50-70 kg	4		14 / 16 Ch.
>70 kg	5		14 / 16 Ch.

Laryngeal mask airway for fibre-optic intubation

A fibre-optic intubation through the LMA is the method of choice in case of a difficult intubation, provided that the patient's mouth can be opened and using an oral tube has been intended [19].

It is the author's method of approach to

- introduce a tube into the trachea through the LMA using fibre-optics,
- subsequently remove the primarily-introduced tube together with the LMA using an exchange catheter, replacing the tube with the correct one.

Pushing the tube forward blindly is not likely to produce the desired result [20]. Intubation through the LMA Supreme™ is impossible. The matching sizes of tube and LMA must be determined and known beforehand in every institution.

Ventilation

Basic considerations

Tidal volume (6-8 ml/kg b.w.) and airway pressures are similar in all age groups. A greater alveolar venti-

lation (in ml/kg b.w./min.) – and the respiratory minute volume related hereto – is achieved by a higher respiration rate.

In line with the awake child, the following respiration rates are chosen:

- Newborns: 40/min.,
- 1-year-olds: 30/min.,
- 10-year-olds: 20/min.,
- Adolescents (and adults): 14/min.

Spontaneous ventilation is acceptable during general anaesthesia, provided that airway resistances are low and drug-induced respiratory depression must not be feared, for example, in cases when superficial inhalation anaesthesia and regional anaesthesia are combined. Otherwise, assisted and/or controlled ventilation modes are applied.

Recruitment

After securing the airway with a tube or LMA, a recruitment manoeuvre should be carried out regularly in newborns and babies – and in older infants most often – in order to expand atelectatic lung segments.

This is performed at the Paediatric Hospital in Lucerne either carefully by hand (when a LMA is in use) or with the ventilator (in an intubated infant) using an adapted Lachmann manoever, whereby a peak pressure of 30 cm H_2O and PEEP (positive end-expiratory pressure) of 20 cm H_2O are applied over five respiratory cycles. During the entire duration of anaesthesia, PEEP of at least 5 cm H_2O is regularly maintained, even when a LMA is used.

Respirator settings

A pressure-controlled ventilation mode (PCV) is usually applied in paediatric anaesthesia.

- In children with healthy lungs, a peak pressure of 14 cm H_2O with PEEP of 5 cm H_2O can be initially set in all age groups.
- The respiration rate is set according to age (see above).
- Air-flow curves permit an optimisation of the inspiration time; a typical value for newborns is 0.5 s, for infants 1.2 s and for adolescents 2 s.

Constant-volume flow-adapted ventilation modes are successfully applied in babies and infants. The author uses them intraoperatively, mainly to balance the inconsistent pressure of the surgeons on chest and abdomen, but not for induction or positioning – in this phase, a bent tube, for example, should not be compensated automatically (and thus unnoticed) by the respirator with higher ventilation pressures.

The **respiratory minute volume** is selected by adjustment of the respiration rate and to a lesser extent of the tidal volume in such a manner that – at least in a child without intracranial pressure or pulmonary arterial hypertension – high-normal to moderately-increased end-tidal carbon dioxide values in the range of 45 mm Hg will result.

A high inspiratory **oxygen concentration** is selected during induction for pre-oxygenation. At the Paediatric Hospital in Lucerne, FiO_2 after completed airway management for newborns is usually at 21-25% and for larger children at 30-60%; for extubation at 80%.

Cardiovascular system and blood pressure limits

Special physiological and anatomical features

Foetal blood circulation

In the foetus's circulatory system, the blood which has been oxygenised in the placenta and loaded with nutrients flows through the umbilical vein to the inferior vena cava and the right atrium, from where the major proportion passes over to the left atrium by the open oval foramen and reaches the foetal organs via the left ventricle. Ninety percent of the small amount of blood which passes into the right ventricle is led by Botallo's duct into the descending aorta while bypassing the lungs. Under these conditions, the partial pressure of oxygen (pO_2) in the best oxygenated parts of the body amounts to about 25 mmHg. When breathing begins and the lungs expand, the vascular resistance of the lungs decreases, the right-left shunt ceases to exist and the SpO_2 rises successively [21]:

The preductal SpO_2 is at 60% one minute after birth, at 70% after 3 minutes, and at 80% after 5. A value of 90% is reached after 10 minutes.

Myocardium and cardiac output

As compared to an adult, the myocardium of the newborn and baby in particular contains fewer contractile elements and the compliance of the ventricles is lower – the cardiac output consequently depends predominately on the heart rate and less on an increase of inotropy.

The positive inotropic effect of **catecholamines** is thus lesser than in adults. Under physiological conditions, however, there is no demand for an increase of inotropy or a massive increase of oxygen supply to the organs – nature calls for drinking, digesting and growing, not for greater physical exertions.

Inhalation anaesthetics exert a much stronger cardiodepressive effect in newborns than in older children. This sensitivity is opposed by a relatively high minimal alveolar concentration (MAC value), at which one half of the patients no longer responds to pain stimuli: the heart is sensitive, the brain resistant.

The leading cause of bradycardia is hypoxia – this must be taken into consideration first.

- Other causes (e.g. opioids or the oculocardiac reflex) may be considered only after hypoxia has been excluded.
- In case of children with trisomy 21, induction with sevoflurane typically leads to bradycardia – even without hypoxemia. The reason for this is unknown, the bradycardia seems to be temporary and benign [22].

- Malignant tachycardiac arrhythmias appear only seldomly in children: "a child's heart does not fibrillate." Exceptions are, for example, children with myocarditis, hyperkalaemia, or hereditary long-QT syndrome [23].

The high oxygen demand of the infant (kg b.w.^{0,75} x 10 ml/min) requires a high cardiac output.

The cardiac output of a baby lies at 250 ml/kg b.w. /min., whereas it amounts to approx. 70 ml/kg b.w./min. in an adult – the blood volume of a baby circulates three times per minute, that of an adult only once per minute. This has a massive impact on pharmacokinetics:

- The distribution of drugs proceeds very fast and the plasma levels decrease rapidly.
- As a result, higher doses are needed in general – as compared to an adult – to reach the same concentrations at the site of action.
- The time until maximum effect sets in ("time-to-peak") is shorter.

Blood pressure and perfusion

Basic considerations

The tissues of the body depend primarily on a sufficient supply of oxygen and thus on a sufficient perfusion – the blood pressure level is secondary. However, a certain minimum blood pressure is necessary to guarantee sufficient perfusion especially in organs possessing autoregulation of the blood flow (e.g. the brain).

The actual organ perfusion interest cannot be measured directly in the clinical routine situation. Only surrogate parameters are available; next to perfusion of the skin, estimable by capillary refilling time (Fig. 4), the blood pressure is the most important parameter.

In addition, there are metabolic parameters such as lactate concentration in plasma and base excess (BE) which must be observed. In the presence of an indwelling central venous catheter, the central venous oxygen saturation can provide valuable information as to whether the global perfusion is sufficient [24].

Fig. 4

Extremely delayed capillary refilling in a premature infant 10 s after thumb pressure release as a sign of massively impaired perfusion.

The standard reference values for blood pressure are age-dependent and defined with only little accuracy. They rely on the systolic pressure – mostly for historical reasons – because the mean arterial pressure (MAP), which is of primary interest, could not be measured exactly before the introduction of oscillometric blood pressure measurement in the 1980s.

- MAP value (in mmHg) corresponding to the gestation age (in weeks) is often demanded for premature infants.
- As premature birth does not constitute a physiological condition, standard values do not exist. At best, there are values to aim for. Older measurements suggest that cerebral autoregulation in non-anaesthetised premature infants is retained up to an MAP value of 30 mm Hg [25].
- For older children (Tab. 11), the criteria applicable to the resuscitation of children are often drawn upon.

Tab. 11
Lower physiological boundaries of the systolic pressure in awake children.

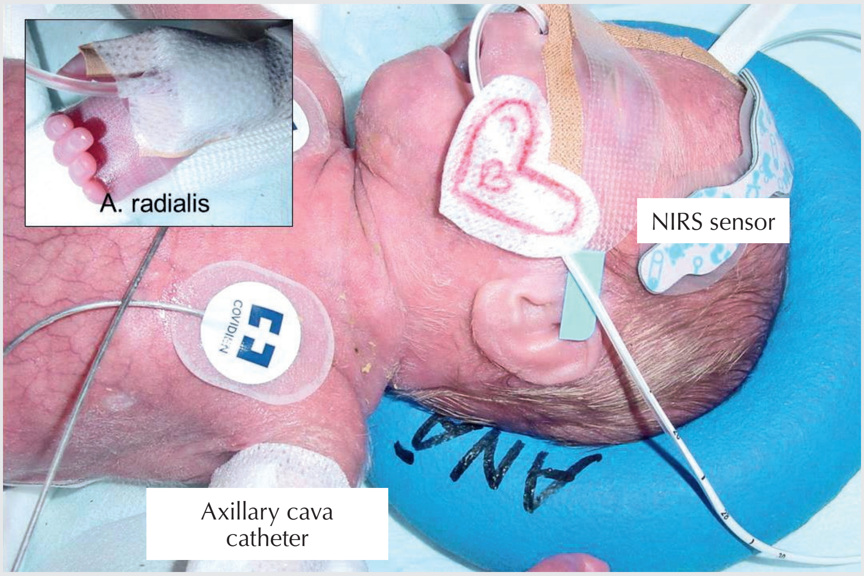
Age	Systolic pressure
Term newborns	60 mm Hg
Babies 1-2 months	70 mm Hg
Infants 1-10 years	70 mm Hg + (2 x age in years)
infants >10 years	90 mm Hg

Doing without blood-pressure measurements in shorter anaesthesias of children, as used to be common practice in the past, can no longer be advocated with good conscience – the blood pressure should be measured in every anaesthesia of a child.

Low blood pressure as a risk

Low blood pressure values are associated with serious consequences [26], particularly when they appear in combination with hypocapnia [27].

Fig. 5



The oxygen concentration in brain tissue of this premature infant weighing 1,050g is being monitored by near-infrared spectroscopy (NIRS), in addition to blood pressure.

Low blood pressure values occur very often in the period after induction before the onset of surgery [28]. The decisive question is about the minimum acceptable blood pressure.

- The proposed reliance on tolerating a maximum decline of 20% or 30% of the initial blood pressure [29] is difficult because it is often impossible to determine a reliable initial value in a baby or infant prior to the induction of general anaesthesia.
- Measurements of cerebral blood circulation under 1 MAC sevoflurane anaesthesia suggest that the lower autoregulation boundary in babies younger than 6 months is reached at a mean arterial pressure of about 40 mm Hg [30].
- The oxygen saturation measured with near-infrared spectroscopy (NIRS; Fig. 5) in brain tissue seems to decline only when blood pressure values are somewhat lower [31;32].

In the author's view the following threshold limits appear to be practicable:

- The target MAP for term newborns and babies is >40 mmHg; a MAP of <30 mmHg must be urgently treated.
- For small children, the target-MAP is >50 mm Hg, a MAP <40 mm Hg must be urgently treated.
- In school children the target-MAP is >60 mm Hg, a MAP <50 mm Hg must be urgently treated.

Practical procedure in cases of hypotension

In case of low blood pressure, general conditions such as anaesthetic depth and concomitant diseases must be examined, followed by application of fluid and vasoactive substances, if required (Tab. 12).

Although a relative volume deficiency will prevail in most cases, a broad differential diagnosis must always be taken into consideration.

- In case of additional regional anaesthesia, the requirement of anaesthetics is not seldomly overestimated and inappropriately-deep anaesthesia is applied.
- Concomitant diseases, which might induce strong hypotension, are e.g. heart disease, anaphylaxis, tension pneumothorax or cortisol deficiency, but also cardiovascular suppression by auto-PEEP due to excessive intrathoracic pressure.

If other causes are ruled out, infusion therapy will usually be given priority over administration of vasoactive substances and catecholamines.

Infusion therapy and its special circumstances will be described separately in the next section.

Apart from fluid supply, children also might need vasoactive substances and catecholamines, the selection of which is often determined by personal experience and established local practice.

- Bolus injections of 0.1 mg/kg b.w. ephedrine IV, for example, usually produce only a small and temporary improvement.
- In Germany, cafedrine/theodrenaline (Akrinor®), which has vasoconstrictive as well as positive inotropic actions, is frequently used as a bolus injection.
- A case of protracted hypotension requires a continuous supply of medication by means of a syringe pump. The infusion of dopamine (5-10 µg/kg b.w./min. IV) is almost always

Tab. 12

Practical procedure in the case of hypotension in children.

Measure	Comment
Review of general conditions	Anaesthetic overdose, concomitant disease
Fluid supply	10 ml/kg b.w. plasma-adapted electrolyte solution, perhaps repeated 2 or 3 times
Vasoactive substance	e.g. dopamine, 5-10 µg/kg b.w./min.

successful. Dopamine is well established in paediatric medicine; the substance enhances the cardiac output and produces vasoconstriction in higher doses. The accompanying tachycardia and subsequent increased cardiac output is almost always appreciated in children. The arrhythmogenic potential does not present a problem outside of paediatric cardiac anaesthesia, and the endocrine effects are not clinically relevant. Thus, the reasons which have largely expelled dopamine from adult medicine do not apply to children. Furthermore, dopamine can be safely applied through peripheral veins.

- Instead of dopamine, other institutions use a combination of dobutamine (positive inotropic) and noradrenaline (mainly vasoconstrictive) or adrenaline alone (positive inotropic and vasoconstrictive).

Fig. 6

Examples of light sources with LED technology, which may be used for puncturing the veins of the dorsum of the hand in babies and infants. Attention: Common flashlights or even cold light sources might cause severe burns.

Infusion therapy

Vascular access

Basic considerations

While successful peripheral vein access in adults belongs to the basic skills of an anaesthetist, the same procedure in a child may turn out to be very demanding. Even under optimal conditions – in anaesthetised children with experienced personnel at a paediatric hospital – vein punctures do not succeed on the first attempt in 20-30% of the cases; in children under one year of age the failure rate is even 50%. Ultrasound and optical devices can help, but successful puncture depends primarily on the experience and skill of the anaesthetist. Trans-illumination by means of LED technology is very helpful for puncturing the veins of the dorsum of the hand of babies and infants (Fig. 6). Infrared devices (e.g. AccuVein®), do not increase the success of puncture [33], but they are useful for training purposes and for locating the best puncture site.

If venous access fails in a case of emergency or appears to be futile right from the start, intraosseous (IO) access is required.

Nowadays, the EZ-IO® drill is almost exclusively used for this purpose [34]; the use of injection guns, special needles with holders or thick metal cannulas is limited to exceptional cases. For severely ill children, the IO access can be used to induce general anaesthesia in cases of emergency [35], e.g. postoperative tonsil bleeding or in a highly septic child.

The "capital of veins"

The number of veins that can be easily punctured – the "capital of veins" – is often limited, especially in babies and chronically-ill children. In this context, it is of particular importance that the last available vessel is not entirely damaged by an inexperienced colleague. The provision of optimum conditions is already important on the first puncture attempt.

There are situations in which only the best should carry out the puncture, and trainees must stand back.

- In the case of children receiving medical treatment over a longer period of time and requiring repetitive vein punctures while awake, easily-punctured veins, e.g. on the dorsal surface of the hand, should be spared in an anaesthetised child. Alternative puncture sites can often be found on the trunk of the body, the wrists, or, in cases of exception, on the scalp.
- Furthermore, it must always be reconsidered whether venous access or blood samples are really necessary – for example, an infant with febrile convulsion needs neither an intraosseous cannula nor an intubation. Infants with isolated fractures will probably receive analgesia faster by way of nasal drug application than by the attempt to gain intravenous access under difficult conditions.

Food for thought: Many anaesthetists still exploit the veins of their patients in the same way that mankind exploits the planet's resources.

The question of whether vascular access is necessary in every elective general anaesthesia of a child is a matter of controversial debate. Looking at it unemotionally, an inhalative induction is often possible – and experienced colleagues report that they occasionally carry out short-term anaesthesia without vascular access. Longer general anaesthesia, e.g. for dental treatments, also proceed at certain centres – in highly professional environments – routinely without vascular access [36]. On the other hand, absent or lost access is often the beginning of a downward spiral for an inexperienced colleague. For this reason, only very experienced colleagues should perform general anaesthesia without vascular access and in exceptional cases only.

Infusion therapy

Basic considerations

Relative to their body weight, small children have larger extracellular space, larger blood volume, higher metabolic rate, and higher fluid turnover. Homeostatic disorders therefore occur sooner than in adults under inadequate fluid supply – regarding both amount and composition – or underestimated fluid loss.

Intraoperative cardiovascular arrest in children is caused relatively often by underestimated blood loss.

In adult medicine, a well-considered restrictive infusion therapy is recommended for major interventions [37], and a rather generous supply of fluids for small interventions in healthy patients [38]. It must be assumed that similar principles generally apply to children, although knowledge on this subject is still rather scarce [39,40,41].

Type of infusion solution

The body possesses distinctive water-saving mechanisms. In the event of disease, accident, operation – or stress – an increased amount of antidiuretic hormone (ADH) is released and the excretion of water limited.

The exclusive supply of free water by means of infusion solutions or excessive drinking results in hyponatremia with consequences which are potentially fatal – hyponatremia is a constantly impending lethal risk in paediatric acute medicine.

There are innumerable reports about children who have died as a result of hyponatremia caused by inadequate infusion therapy [42]. A fatal course within 24 hours – still in the immediate perioperative environment – is possible [43]. The understanding that only infusion solutions with a physiological sodium concentration can help avoid serious hyponatremias has prevailed in paediatric medicine as well [44]. In North America, 0.9% sodium-chloride (NaCl) solution with added glucose is still predominately used for this purpose, although it is associated with the risk of hyperchloraemic dilution acidosis.

In Europe, **plasma-adapted** (synonymous: **balanced) solutions** with a physiological sodium content (at least 120 mmol/l) are nowadays usually preferred:

- Physiological saline prevents the occurrence of hyponatremias.
- The addition of metabolisable anions (acetate, malate or lactate), which are metabolised to bicarbonate in the body, prevents dilution acidosis.
- The addition of 1% glucose (10 mg/ml; a rate of 10 ml/kg b.w./h is equivalent to a dose rate of 1.66 mg/kg b.w./min.) helps to prevent low blood sugar concentrations and catabolism.

These solutions have already gained acceptance in emergency and intensive care medicine and will probably replace 0.9% NaCl to a great extent [45].

As a rule, children are also designed for **intermittent** food uptake: a continuous glucose supply is therefore not absolutely necessary for babies and infants. However, some children who are ill or were fasted for a longer period can develop very low blood sugar levels, become catabolic and display an increase of free fatty acids and ketone bodies [46]. This can be prevented by a moderate glucose supply of 1-2 mg/kg b.w./min. [47] – at the Paediatric Hospital in Lucerne, a plasma-adapted electrolyte solution supplemented with 1% glucose has already been applied in daily clinical routine for over 30 years.

- Solutions containing 1% glucose are safe and only induce a moderate increase of plasma glucose levels, even after accidental hyperinfusion with, for example, 100 ml/kg b.w./h [48].
- Children who are brought into the surgical theatre in a catabolic state, displaying high metabolic rates or very low glycogen reserves (e.g. newborns) require higher infusion rates

Tab. 13

Information on dosage of glucose supply. These are empirical values; the target is a high-normal blood sugar concentration. **b.w.** = body weight.

Situation	Dosage and comments
Newborns, awake	5 mg/kg b.w./min. – in order to prevent hypoglycaemia
Newborns, intraoperative	3 mg/kg b.w./min.
Children, intraoperative	1-2 mg/kg b.w./min
Glycogenosis type I or disorders of fatty acid oxidation	5-8 mg/kg b.w./min.
Children, intraoperative, if subject to parenteral diet regimes	Half of the preceding glucose supply
Severe hypoglycaemia	200 mg/kg b.w. as mini bolus

Tab. 14

Practical calculation of the glucose dose. **b.w.** = body weight. b.w. x 6 is equivalent to the infusion rate (in ml/h) of a 1 % solution in order to reach 1 mg/kg b.w./min.

Step	Statement
1	1 ml glucose 1% contains 10 mg glucose
2	1 mg/kg b.w./min = 60 mg/kg/h
3	b.w. x 6 = ml/h of a 1% solution, in order to achieve 1 mg/kg b.w./min.
4	b.w. x 30 = ml/h of a 1% solution, in order to achieve 5 mg/kg b.w./min.
Example	Target 1 mg/kg b.w./min. in a child weighing 6 kg: 36 ml/h 1% sol. = 3.6 ml/h 10% sol. = approx. 1 ml/h 40%

(Tab. 13). At the Paediatric Hospital in Lucerne, a high-percentage glucose solution (usually 40%) is added to the plasma-adapted electrolyte solution through a side connection **like a drug**.

Glucose should generally be handled like a drug and should therefore be dosed with precision (Tab. 14).

In the case of sick children or major interventions, regular laboratory follow-up measurements will be necessary, e.g. hourly blood sugar and blood gas analyses (including lactate); if required, the haemoglobin concentration and plasma electrolytes should be determined as well.

Tab. 16

Rule of ten for rapid onset of fluid and volume therapy; later, individually-adapted doses are used. **HES** = hydroxyethyl starch; **b.w.** = body weight

	Solution for infusion	Initial and repetitive dose
Maintenance requirement	Plasma-adapted electrolyte solution with 1% glucose	10 ml/kg b.w./h
Additional fluid therapy	Plasma-adapted electrolyte solution without glucose	10-20 ml/kg b.w., repeatedly if necessary
Forced volume therapy	Colloids – HES, gelatines, albumin	10 ml/kg b.w., repeatedly if necessary
Transfusion	RBC concentrate, Platelet concentrate	10 ml/kg b.w., repeatedly if necessary

Infusion volumes

The **maintenance requirement** can be estimated beyond the newborn period by applying the 4-2-1 Rule (Tab. 15).

- In the clinical routine at the Paediatric Hospital of Lucerne, volumes of 15-25 ml/kg b.w. are infused during small interventions.
- In babies of <5 kg b.w., infusion proceeds by means of a syringe pump, otherwise by an infusion pump.
- Gravity infusions should no longer be applied; however, in the case of small interventions, older children and the use of small containers (maximum 250-500 ml) the risk of overinfusion should be minimal.

Pre-existing fluid deficiencies in dehydrated children can often be best estimated on the basis of the previously-known body weight. In addition, clinical signs such as standing skin folds, sunken fontanel, and prolonged time to recapillarisation must be evaluated.

- Pre-existing fluid deficiencies must be balanced in addition to the maintenance requirement.

Urinary excretion is regularly reduced during surgery – intraoperative diuresis is not a good measure for volume status, especially in the case of pneumoperitoneum.

Intravascular volume losses are initially substituted by a plasma-adapted electrolyte solution without glucose supplement, supplied at a rate of 10-20 ml/kg b.w.

- Synthetic colloids can be used in the event of insufficient effect [49]. When applied for a short time, they have no disadvantageous effects on renal function.

The rule of 10 can be applied in order to rapidly achieve an initial adjustment of the syringe and infusion pumps (Tab. 16); therapy is subsequently adjusted and optimised to the individually-required conditions [50].

Tab. 15

Maintenance requirement for an infusion fluid calculated by applying the 4-2-1 Rule. Special reference values apply to newborns in the first days of life. **b.w.** = body weight.

Age/b.w.	Per hour	Per day
Newborns		100 - 150 ml/kg b.w./d
<10 kg	4 ml/kg b.w.	100 ml/kg b.w.
10-20 kg	40 ml plus 2 ml/kg b.w. (per kg >10 kg b.w.)	1,000 ml plus 50 ml/kg b.w. (per kg >10 kg b.w.)
>20 kg	60 ml plus 1 ml/kg b.w. (per kg >20 kg b.w.)	1,500 ml plus 20 ml/kg b.w. (per kg >20 kg b.w.)

Conclusions

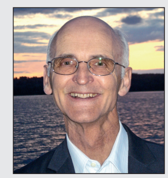
Paediatric anaesthesia belongs to the most beautiful and demanding fields of anaesthesiology. Next to practical and technical skills, the knowledge of paediatric diseases belongs to the fundamental prerequisites, along with an ability and appreciation to communicate with children and their parents in a manner that builds trust. Additionally, a theoretical knowledge of airways, blood circulation and infusion therapy must be at hand when it comes to making the right decisions in clinical routine situations.

References

1. Morray JP, Geiduschek JM, Ramamoorthy C, Haberkern CM, Hackel A, Caplan RA, et al: Anesthesia-related cardiac arrest in children: Initial findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry. Anesthesiology 2000;93:6-14
2. Bhananker SM, Ramamoorthy C, Geiduschek JM, Posner KL, Domino KB, Haberkern CM, et al: Anesthesia-related cardiac arrest in children: Update from the Pediatric Perioperative Cardiac Arrest Registry. Anesth Analg 2007;105:344-350
3. Jöhr M, Schuhmacher P, Lippuner T: Kinderanästhesie – Info Stiftung für Patientensicherheit in der Anästhesie. http://www.sgarssar.ch/fileadmin/user_upload/Dokumente/Flyer_Sicherheitshinweise/1_11_Kinderflyer_2011_d_Website.pdf
4. Weiss M, Vutskits L, Hansen TG, Engelhardt T: Safe anesthesia for every tot – The SAFETOTS initiative. Curr Opin Anaesthesiol 2015;28:302-307
5. Lo C, Ormond G, McDougall R, Sheppard SJ, Davidson AJ: Effect of magnetic resonance imaging on core body temperature in anaesthetised children. Anaesth Intensive Care 2014; 42:333-339
6. Machata AM, Willschke H, Kabon B, Prayer D, Marhofer P: Effect of brain magnetic resonance imaging on body core temperature in sedated infants and children. Br J Anaesth 2009;102: 385-389
7. Hardman JG, Wills JS: The development of hypoxaemia during apnoea in children: A computational modelling investigation. Br J Anaesth 2006;97: 564-570
8. Engelhardt T: Rapid sequence induction has no use in pediatric anesthesia. Paediatr Anaesth 2015;25:5-8
9. de Graaff JC, Bijker JB, Kappen TH, van Wolfswinkel L, Zuithoff NP, Kalkman CJ: Incidence of intraoperative hypoxemia in children in relation to age. Anesth Analg 2013;117:169-175
10. Drake-Brockman TF, Ramgolam A, Zhang G, Hall GL, von Ungern-Sternberg BS: The effect of endotracheal tubes versus laryngeal mask airways on perioperative respiratory adverse events in infants: a randomised controlled trial. Lancet 2017;389:701-708
11. Weiss M, Dullenkopf A, Fischer JE, Keller C, Gerber AC: Prospective randomized controlled multicentre trial of cuffed or uncuffed endotracheal tubes in small children. Br J Anaesth 2009;103: 867-873
12. Sathyamoorthy M, Lerman J, Asariparampil R, Penman AD, Lakshminrusimha S: Stridor in neonates after using the Microcuff® and uncuffed tracheal tubes: A retrospective review. Anesth Analg 2015;121:1321-1324
13. Weiss M, Knirsch W, Kretschmar O, Dullenkopf A, Tomaske M, Balmer C, et al: Tracheal tube-tip displacement in children during head-neck movement – A radiological assessment. Br J Anaesth 2006;96:486-491
14. Böttcher-Haberzeth S, Dullenkopf A, Gitzelmann CA, Weiss M: Tracheal tube tip displacement during laparoscopy in children. Anaesthesia 2007;62:131-134
15. Weiss M, Dullenkopf A, Böttcher S, Schmitz A, Stutz K, Gysin C, et al: Clinical evaluation of cuff and tube tip position in a newly designed paediatric preformed oral cuffed tracheal tube. Br J Anaesth 2006;97:695-700
16. Luce V, Harkouk H, Brasher C, Michelet D, Hilly J, Maesani M, et al: Supraglottic airway devices vs tracheal intubation in children: A quantitative meta-analysis of respiratory complications. Paediatr Anaesth 2014;24:1088-1098
17. Theiler LG, Kleine-Brueggeney M, Luepold B, Stucki F, Seiler S, Urwyler N, et al: Performance of the pediatric-sized i-gel compared with the Ambu AuraOnce laryngeal mask in anesthetized and ventilated children. Anesthesiology 2011;115:102-110
18. Zahoor A, Ahmad N, Sereche G, Riad W: A novel method for laryngeal mask airway size selection in paediatric patients. Eur J Anaesthesiol 2012;29:386-390
19. Jöhr M, Berger TM: Fiberoptic intubation through the laryngeal mask airway LMA as a standardized procedure. Paediatr Anaesth 2004;14: 614
20. Kleine-Brueggeney M, Nicolet A, Nabecker S, Seiler S, Stucki F, Greif R, et al: Blind intubation of anaesthetised children with supraglottic airway devices AmbuAura-i and Air-Q cannot be recommended: A randomised controlled trial. Eur J Anaesthesiol 2015;32:631-639
21. Berger TM: Neonatal resuscitation: Foetal physiology and pathophysiological aspects. Eur J Anaesthesiol 2012;29:362-370
22. Roodman S, Bothwell M, Tobias JD: Bradycardia with sevoflurane induction in patients with trisomy 21. Paediatr Anaesth 2003;13:538-540
23. Whyte SD, Nathan A, Myers D, Watkins SC, Kannankeril PJ, Etheridge SP, et al: The safety of modern anesthesia for children with long QT syndrome. Anesth Analg 2014;1194:932-938
24. Osthaus WA, Huber D, Beck C, Roehler A, Marx G, Hecker H, et al: Correlation of oxygen delivery with central venous oxygen saturation, mean arterial pressure and heart rate in piglets. Paediatr Anaesth 2006;16:944-947
25. Munro MJ, Walker AM, Barfield CP: Hypotensive extremely low birth weight infants have reduced cerebral blood flow. Pediatrics 2004;114:1591-1596
26. McCann ME, Schouten AN: Beyond survival; influences of blood pressure, cerebral perfusion and anesthesia on neurodevelopment. Paediatr Anaesth 2014;24:68-73
27. McCann ME, Schouten AN, Dobija N, Munoz C, Stephenson L, Poussaint TY, et al: Infantile postoperative encephalopathy: Perioperative factors as a cause for concern. Pediatrics 2014;133: e751-e757
28. Nafiu OO, Kheterpal S, Morris M, Reynolds PI, Malviya S, Tremper KK: Incidence and risk factors for preincision hypotension in a noncardiac pediatric surgical population. Paediatr Anaesth 2009;19:232-239
29. Nafiu OO, Voepel-Lewis T, Morris M, Chimbira WT, Malviya S, Reynolds PI, et al: How do pediatric anesthesiologists define intraoperative hypotension? Paediatr Anaesth 2009;19:1048-1053
30. Rhondali O, Mahr A, Simonin-Lansiaux S, De Queiroz M, Rhzioual-Berrada K, Combet S, et al: Impact of sevoflurane anesthesia on cerebral blood flow in children younger than 2 years. Paediatr Anaesth 2013;23:946-951
31. Rhondali O, Juhel S, Mathews S, Cellier Q, Desgranges FP, Mahr A, et al: Impact of sevoflurane anesthesia on brain oxygenation in children younger than 2 years. Paediatr Anaesth 2014;24: 734-740
32. Rhondali O, Pouyau A, Mahr A, Juhel S, De Queiroz M, Rhzioual-Berrada K, et al: Sevoflurane anesthesia and brain perfusion. Paediatr Anaesth 2015;25:180-185
33. de Graaff JC, Cuper NJ, Mungra RA, Vlaardingerbroek K, Numan SC, Kalkman CJ: Near-infrared light to aid peripheral intravenous cannulation in children: A cluster randomised clinical trial of three devices. Anaesthesia 2013;68:835-845
34. Neuhaus D: Intraosseous infusion in elective and emergency pediatric anesthesia: When should we use it? Curr Opin Anaesthesiol 2014;27:282-287
35. Neuhaus D, Weiss M, Engelhardt T, Henze G, Giest J, Strauss J, et al: Semielective intraosseous infusion after failed intravenous access in pediatric anesthesia. Paediatr Anaesth 2010;20:168-171
36. Wilson G, Engelhardt T: Who needs an IV? Retrospective service analysis in a tertiary

pediatric hospital. Paediatr Anaesth 2012;22:442-444
37. Corcoran T, Rhodes JE, Clarke S, Myles PS, Ho KM: Perioperative fluid management strategies in major surgery: A stratified meta-analysis. Anesth Analg 2012;114: 640-651
38. Doherty M, Buggy DJ: Intraoperative fluids: How much is too much? Br J Anaesth 2012;109:69-79
39. Mandee S, Butmangkun W, Aroonpruksakul N, Tantemsapya N, von Bormann B, Suraseranivongse S: Effects of a restrictive fluid regimen in pediatric patients undergoing major abdominal surgery. Paediatr Anaesth 2015;25: 530-537
40. Goodarzi M, Matar MM, Shafa M, Townsend JE, Gonzalez I: A prospective randomized blinded study of the effect of intravenous fluid therapy on postoperative nausea and vomiting in children undergoing strabismus surgery. Paediatr Anaesth 2006;16:49-53
41. Elgueta MF, Echevarria GC, De la FN, Cabrera F, Valderrama A, Cabezon R, et al: Effect of intravenous fluid therapy on postoperative vomiting in children undergoing tonsillectomy. Br J Anaesth 2013;110:607-614
42. Moritz ML, Ayus JC: Prevention of hospital-acquired hyponatremia: A case for using isotonic saline. Pediatrics 2003; 111:227-230
43. Sicot C, Laxenaire MC: Death of a child due to posttonsillectomy hyponatraemic encephalopathy. Ann Fr Anesth Réanim 2007;26:893-896
44. Wang J, Xu E, Xiao Y: Isotonic versus hypotonic maintenance IV fluids in hospitalized children: A meta-analysis. Pediatrics 2014;133:105-113
45. Raghunathan K, Bonavia A, Nathanson BH, Beadles CA, Shaw AD, Brookhart MA, et al: Association between initial fluid choice and subsequent in-hospital mortality during the resuscitation of adults with septic shock. Anesthesiology 2015;123: 1385-1393
46. Dennhardt N, Beck C, Huber D, Nickel K, Sander B, Witt LH, et al: Impact of preoperative fasting times on blood glucose concentration, ketone bodies and acid-base balance in children younger than 36 months: A prospective observational study. Eur J Anaesthesiol 2015;32:857-861
47. Sümpelmann R, Becke K, Crean P, Jöhr M, Lonnqvist PA, Strauss JM, et al: European consensus statement for intraoperative fluid therapy in children. Eur J Anaesthesiol 2011;28:637-639
48. Witt L, Osthaus WA, Lucke T, Juttner B, Teich N, Janisch S, et al: Safety of glucose-containing solutions during accidental hyperinfusion in piglets. Br J Anaesth 2010;105:635-639
49. Sümpelmann R, Kretz FJ, Luntzer R, de Leeuw TG, Mixa V, Gabler R, et al: Hydroxyethyl starch 130/0.42/6:1 for perioperative plasma volume replacement in 1130 children: Results of an European prospective multicenter observational postauthorization safety study PASS. Paediatr Anaesth 2012;22:371-378
50. Sümpelmann R, Becke K, Brenner S, Breschan C, Eich C, Höhne C, et al: Perioperative intravenous fluid therapy in children: Guidelines from the Association of the Scientific Medical Societies in Germany. Paediatr Anaesth 2017;10-18.

Correspondence address



Dr. med. Martin Jöhr

Klinik für Anästhesie, Rettungsmedizin und Schmerztherapie
Luzerner Kantonsspital
6000 Luzern 16, Switzerland

Phone: 0041 79 446 9176
Fax: 0041 41 370 5427

Mail: joehrmartin@bluewin.ch