

The consensus statement of the Paediatric Section of the Polish Society of Anaesthesiology and Intensive Therapy on general anaesthesia in children under 3 years of age

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Anaesthesia in young children, newborns or infants, in particular, is a challenge for anaesthetists. The gravity of this issue is reflected in many documents published by the European Society of Anaesthesiology (ESA), as well as by the Polish Society of Anaesthesiology and Intensive Therapy, e.g., the Helsinki Declaration on Patient Safety in Anaesthesiology of 2010 or the Guidelines for Safe Paediatric Anaesthesia of the Committee on Quality and Safety of Anaesthesia of the Polish Society of Anaesthesiology and Intensive Therapy [1].

The safety of anaesthesia in children has always evoked emotion; the younger the patient involved, the stronger the emotions. Younger children have bigger differences in body structure and physiology compared to adults. Moreover, the pharmacokinetics and pharmacodynamics of the drugs used during anaesthesia differ by age. An appropriate assessment of a child's health and suitable preparation of anaesthesia can markedly reduce the number of complications, whereas insufficient and improper qualifications can lead to many hazards. The incidence rates of circulatory and respiratory failure are likely to be substantially higher in young children. The younger the child, the more dangerous the consequences of such disturbances; hypoxia and hypotension can result in kidney and liver damage or even in CNS ischaemia. Impaired circulation and respiration occur more frequently in patients with other concomitant diseases and congenital defects. In the age group ≤ 3 years,

the number of complications and adverse effects associated with respiratory disturbances is 17.8%; 1 in 200 children undergoing sedation requires instrumental restoration of airway patency and ventilation support [2–5].

The knowledge of anaesthesia-related risk factors in young children, the completion of examinations of children before scheduled anaesthetic procedures and appropriate preparation for anaesthesia all can decidedly prevent or reduce the incidence of complications.

The safety of young children during anaesthesia depends on the proper preparation of an anaesthesia workstation, as well as on the knowledge and experience of the entire anaesthetic team involved in the anaesthesia and surgery.

SAFETY OF ANAESTHESIA

A neonate, i.e., a baby aged up to four weeks of life, is the youngest child that can end up on an operating table; premature babies constitute a special group. From the anaesthesiological point of view, any child whose postconceptional age does not exceed 46 weeks should be considered a neonate [6–8].

The differences in the bodily functioning of the youngest children directly affect the course of anaesthesia; therefore, reliable knowledge of the anatomy and physiology of children under 3 years of age is essential, particularly of the differences in the anatomical structures of the cardiovascu-

lar and respiratory systems in comparison with preschool aged children.

The aforementioned differences necessitate particular specifications regarding the operating room equipment, anaesthesia workstation and work organisation in the operating suite for paediatric patients.

The anatomical and physiological differences in the neonatal and infantile period are presented in Table 1.

The anatomical and physiological characteristics of children aged 1–3 years are listed in Table 2.

OPERATING ROOM EQUIPMENT

It is essential that the temperature in the operating room be regulated within the range of 19–24°C, usually $\pm 2^\circ\text{C}$ in relation to the planned temperature. The operating room temperature should be adjusted to the patient's age and type of procedure. Higher temperatures are required when a neonate is anaesthetised (neutral temperature for a term newborn is approximately 33°C, while that for a preterm baby is approximately 36°C), while lower temperatures should be provided for scheduled cardiac defect repairs under extracorporeal circulation.

DEVICES THAT ENABLE THE MAINTENANCE OF NORMOTHERMIA IN THE CHILD UNDERGOING THE OPERATION:

- an incubator with a system of heat lamps,
- an electric water mattress,
- a warming device using warm air,
- a head cover protecting the loss of heat through the head,
- thermo-insulating foils,
- intravenous fluid warming systems,
- a humidifier and a device for warming respiratory gases, including anaesthetic gases.

The thermal comfort of the patient is also ensured by the following:

- avoiding heat loss by conduction — minimising the contact with cold elements of the equipment,
- reducing heat loss through evaporation — minimising the body surface exposed to washing or disinfection
- preventing heat loss through convection — limiting the movement of cold air around the patient.

Moreover, the skin sensitivity of newborns, especially of preterm babies, should be considered. Therefore, the use of any direct warming measures lacking temperature control is not suggested [11, 14, 15].

ANAESTHESIA WORKSTATION EQUIPMENT:

1. The equipment of an anaesthesia workstation should be in accordance with the directive of the Minister of Health

and should consist of the following elements, taking into account the specificity of anaesthesia in small babies:

- the set for difficult intubation,
 - the Quick-Trach device for emergency conicotomy,
 - syringe infusion pumps, at least 3 [16].
2. The anaesthesia machine should be equipped with the following:
 - a ventilator allowing for the ventilation of children, with the parameters adjusted to their body weights and ages,
 - a humidifier and a heater of respiratory gases,
 - a circular system with a suitably small tube diameter,
 - Kuhn or Rees half-open systems,
 - evaporators of inhalation anaesthetics,
 - an aspirator
 3. Monitoring systems tailored to the patient's age and weight for the following:
 - heart rate
 - ECG recordings (electrodes designed for newborns have to be available),
 - arterial blood haemoglobin saturation with oxygen (a pulse oximeter should be equipped with bands or clips suitable for measurements of saturation in newborns and infants),
 - non-invasive arterial blood measurements (a set of neonatal and infantile cuffs),
 - invasive arterial blood measurements,
 - concentration of oxygen and anaesthetic gases in the respiratory system,
 - concentration of CO_2 in the expiratory air (a capnograph should measure the level of CO_2 using the system adjusted to newborns),
 - central and peripheral body temperature [11, 14, 15].
 4. Anaesthetic trolley equipment:
 - central venous catheters (3 to 4.5 F; smaller sizes are recommended for pre-term newborns),
 - peripheral venous catheters; diameter 0.6–1.0 mm,
 - aspiration catheters — 6.8 and 10F (the diameter should be 1/3 of the endotracheal tube diameter),
 - endotracheal tubes, 2–5 mm, with or without a low-pressure cuff,
 - setons,
 - oropharyngeal airways (000, 00, 0),
 - transparent face masks (0–1),
 - laryngeal mask airways (1, 1.5 and 2),
 - a laryngoscope with the small straight and/ or curved intubation spatula — sizes 000, 00, 0.1 (lateral oxygen supply tubing is advocated),
 - gastric probes,
 - endotracheal tube guides,
 - Magill forceps,

Table 1. Anatomical and physiological differences in the neonatal and infantile periods [9–14]

Features of newborns and infants	Clinical consequences and practical implications
Head — large with the prominent occiput on the short, flaccid neck	Flexion of the head towards the thorax impairing upper airway patency → a scapula-supporting towel roll required in the dorsal decubitus position
Nose — poorly developed cavernous bodies in the mucous membrane	Insufficiently warmed and humidified inspired air irritates the mucous membrane, increases the secretion of mucus, induces bronchial over-reactivity → warming and humidification of respiratory gases are required
Nose — narrow and long nostrils	
Newborns breath only through the nose	Predisposition to airway obstruction, obstructive apnoea and other respiratory disturbances
Large tongue, highly placed larynx, acute angle between the tongue base and true glottis	Predisposition to airway obstruction and hinder intubation → the suitable position with slight head bent is necessary
Long, hanging epiglottis	Hinders intubation → the suitable position and proper choice of laryngoscope spatula are needed
Physiological constriction below vocal cords at the level of the cricoid cartilage	Predisposition to stridor due to mucosal oedema or laryngospasm → endotracheal tubes of suitable diameters, without inflatable cuffs or with low-pressure cuffs
Small distance between the cricoid cartilage and bifurcation of the trachea	
In neonates, bronchi mainly run from the trachea at the precise angle of 51°	Facilitates saliva and food transfer to the right bronchus, which favours the development of aspiration pneumonia and the translocation of the endotracheal tube to the right bronchus → appropriate stabilisation of the endotracheal tube is necessary
Flaccidity and high compliance of airway	Predisposition to tracheal and bronchial collapse during airway blockade
Small cross-section of airways and proneness of mucosal oedema	Predisposition to obstruction → humidification and warming of respiratory gases and bronchial tree toilet are required
Low compliance of lungs (particularly in pre-term babies)	Hinders mechanical ventilation → careful adjustment of parameters is necessary
Low functional residual capacity of lungs	Predisposition to atelectasis → the use of PEEP is required
Incompletely developed cough reflex	Predisposition to aspiration pneumonia → a suitable position, bronchial tree toilet and gastric decompression are necessary
Reduced sensitivity of the respiratory centre to increases in PaCO ₂	Predisposition to dyspnoea
Disproportion between body weight and surface	Predisposition to overcooling → thermal comfort has to be provided
Immature skin	Favours high unnoticeable fluid loss → meticulous fluid balance is necessary
Incompletely developed mechanisms of thermoregulation	Predisposition to thermoregulatory abnormalities → thermal comfort has to be provided
Increased metabolism and oxygen consumption	Favours hypoxia and hypoglycaemia → careful monitoring of oxygenation and glycaemia is necessary
A small number of myocardial contractile elements in the myocardium	The Frank-Starling curve is shifted to the left, showing limited possibilities to increase cardiac output
Immature immune system	Favours infections → strict sanitary regime, suitable perioperative antibiotic prophylaxis have to be provided
Immature excretory system	Causes reduced conduction tolerance and the delayed elimination of drugs removed through kidneys → meticulous fluid balance and suitable drug doses are required
Immature liver	Causes the delayed metabolism of many drugs, including opioids and hypnotics → appropriate doses of drugs are needed

- stethoscope,
- oesophageal stethoscope (optionally),
- urinary catheters (6–10 F).

ANAESTHETIC TEAM

The directive of the Minister of Health of 20 December 2012 states that anaesthesia in the newborn or infant can be administered by a physician-specialist in anaesthesiolo-

gy and intensive therapy or by an anaesthesiologist with written approval given by the head of the department of anaesthesiology and intensive therapy, by the head of the department of paediatric anaesthesiology and intensive therapy or by a resident under the direct supervision of a specialist in anaesthesiology and intensive therapy [16].

According to the majority of anaesthesiologists delivering anaesthesia to children, newborns or infants should be

Table 2. Anatomical and physiological characteristics of children aged 1–3 years

Body weight	10 kg (1 year of age)	15 kg (3 years of age)
Height increase	25–12–8 cm per each year	100 cm (3 years of age)
Heart rate	70–140 min ⁻¹ (avg 115)	70–110 min ⁻¹ (avg 105)
Arterial pressure	100/50 mm Hg	110/65 mm Hg (formula: 80 + age × 2)
Respiration rate	20–30 min ⁻¹	
Blood volume	70–75 mL kg b.w. ⁻¹	
Hb concentration	12 g dL ⁻¹	
Peripheral blood smear	Lymphocytes outnumber neutrophils	
Haemostasis	Similar to that of adults	

anaesthetised by specialists in anaesthesiology and intensive therapy who have experience with anaesthesia in this age group. The anaesthetist should be accompanied by a nurse anaesthetist with suitable knowledge and experience caring for children under the age of 3 years.

PREPARATION OF A CHILD FOR ANAESTHESIA

Similar to older children and adults, children below the age of 3 years should be examined prior to anaesthesia by the attending anaesthesiologist, whose responsibility is to obtain current laboratory results and to order additional consultations, if necessary [14, 15, 17].

LABORATORY TESTS

Before the scheduled procedures, basic laboratory testing is recommended, including peripheral blood tests or selected coagulation parameters (kaolin cephalin clotting time - KCCT, prothrombin time — PT and international normalised ratio — INR). As far as the last two parameters are concerned, visible benefits resulting from their routine determination have not been demonstrated. Although often ordered by operators, routine clotting testing is controversial, even before high bleeding risk procedures like tonsillectomy.

The volume of blood collected from newborns and infants under the age of 6 months should be minimised. In newborn cases, the child and mother's blood group types have to be determined.

When the child's general health status is good, the results of laboratory tests performed 3 months before anaesthesia are acceptable unless its condition has significantly changed. In ASA ≥ 3 children, as well as previous to any procedures associated with high risks of blood loss, it is necessary to determine the blood group, serum electrolyte concentration, clotting parameters and certain biochemical parameters (serum urea and creatinine concentration, ALT and AST activity, acid-base balance). The range of other additional examinations (ECG, echo, thoracic X-ray) should depend on the presence of concomitant diseases, the

patient's general state, and the type and extent of surgery [14, 15].

BASIC GOALS OF AN ANAESTHETIC VISIT:

1. Familiarisation with the anaesthetic questionnaire data regarding the following:
 - Past diseases:
 - infectious, with antibiotic therapy applied during two previous weeks,
 - contagious,
 - systemic diseases that can markedly affect anaesthesia, e.g., muscular dystrophy, congenital coagulation disorders, congenital heart defects,
 - history of vaccinations,
 - previous anaesthetic and surgical procedures, difficulties (including difficult tracheal intubation) and complications during or after surgery,
 - allergies,
 - spontaneous or fever-related convulsions,
 - family history — diseases, surgeries or any surgery- and/or anaesthesia-associated deaths,
 - tobacco smoking by parents/carers (correlation between passive smoking and incidence of respiratory complications in children has been documented) [2, 3].

In cases of emergency surgical procedures in newborns, taking a history is often impossible. In such situations, parents give their written consent for surgery under general and regional anaesthesia; the consent and complete medical records are sent to the centre at which the child will undergo the operation.

2. Physical examinations to evaluate the child's health status that might be relevant for the safety of the anaesthesia and surgery.
3. Familiarisation with the patient's medical history, including the following:
 - qualification for surgery (category and type of surgery),
 - assessment of test results and consultations.

4. Classification according to the ASA scale.
5. Additional tests or specialist consultations whenever required.
6. Informing parents/carers about the type of anaesthesia for a particular scheduled procedure, completing the anaesthesia fitness chart and obtaining informed written consent for anaesthesia.

PHARMACOLOGICAL PREMEDICATION

The pharmacological premedication orders do not concern newborns and infants under 7 months of age [14].

In children > 7 months of age, the agents used include the following:

- midazolam, 0.25–0.3 mg kg b.w.⁻¹ (max. 0.5 mg kg b.w.⁻¹ when continuous surveillance is feasible), orally, rectally (in children under 1 year) or nasally, 30–60 minutes before anaesthesia,
- diazepam (Relsed — rectal microinfusion containing 5 mg of diazepam in 2.5 mL of solution); dosing 0.5 mg kg b.w.⁻¹ 30–60 min. before the planned onset of anaesthesia; after the rectal administration, the child should be in a ventral decubitus position for approximately 15 min.,
- in exceptional cases, it is possible to use receptor α -2 agonists (dexmedetomidine, clonidine) in an „off-label” use, i.e., inconsistent with the summary of product characteristics (SPC)¹.

EATING AND DRINKING RESTRICTIONS BEFORE SCHEDULED SURGERY

The 2-4-6 rule should be observed, as follows:

- 2 hours before the induction of anaesthesia, the child can eat/drink clear liquids (10 mL kg b.w.⁻¹, max. 100 mL per portion is recommended),
- 4 hours before the induction of anaesthesia — maternal milk,
- 6 hours before the induction of anaesthesia — milk mixtures (formulas) and other food products [18–20].

During the preoperative feeding breaks, newborns should be provided with parenteral hydration.

When emergency surgery is to be performed, the above rules are no longer valid, and management according to the anaesthesia rules for full stomach patients should be instituted.

ANAESTHETIC RULES IN PATIENTS WITH FULL STOMACHS

1. Prevention of pulmonary aspiration of the gastric contents:
 - administration of antiemetic and gastric acid-neutralising agents,
 - abandonment of general anaesthesia and ventilation through a face mask,
 - special management during the induction of anaesthesia.
2. Prevention of gastric content aspiration:
 - pharmacological reduction of the volume and pH of gastric contents (i.v. omeprazole, ranitidine, metoclopramide),
 - chyme alkalisation (0.3 M sodium citrate, orally, 20–30 min before anaesthesia).
3. Induction of anaesthesia
 - preparation of a suction with the large-lumen catheter,
 - positioning: elevation of the head (30°) and lower limbs,
 - quick induction:
 - preoxygenation with 100% oxygen for 3–5 min.,
 - thiopentone, 5–7 mg kg b.w.⁻¹ or propofol 1–2 mg kg b.w.⁻¹ in a quick i.v. injection (doses should not be reduced to maintain a suitable depth of anaesthesia during induction),
 - precurarisation: 5–10% of the planned dose of a non-depolarising agent (not always necessary),
 - succinylcholine chloride in a dose of 1 – 1.5 mg kg b.w.⁻¹ — intubation possible after at least 30 sec., or rocuronium 1.2 mg kg b.w.⁻¹ — intubation possible after 60 seconds,
 - the Sellick manoeuvre during endotracheal intubation,
 - avoidance of ventilation via a mask,
 - quick intubation through an oral tube with a sealing cuff and immediate filling of the latter (in newborns, the tube with a cuff is not always available, seton sealing is recommended),
4. Extubation once the protective reflexes are restored.

DISQUALIFICATION FROM SCHEDULED SURGERY AND ANAESTHESIA

The reasons for disqualification are presented in Table 3.

¹The use of drugs different from those described in the SPC has not been defined in the Polish legislation. However, in light of the Medical and Dental Profession Act, the physician is obliged to practice according to current medical knowledge, available methods and agents for prevention, detection and treatment of diseases consistently with professional ethics and due meticulous rules. The responsibilities of physicians and medical personnel include undertaking such a management (treatment) option that should guarantee the anticipated effect (i.e., recovery), and most importantly, avoiding all risks of the patient's health deteriorating (based on <http://www.prawodlalekarza.pl/baza-wiedzy/uzycie-leku-off-label/>).

Table 3. Criteria of unfitness for surgery and anaesthesia based on [1, 2, 3]

Child immediately after vaccination — anaesthesia not earlier than:		
DPT, Heine-Medina, Haemophilus	3 days after vaccination	
parotitis, rubella, rubeola	2 weeks after vaccination	
Contact with infectious disease - anaesthesia not earlier than:		
Infectious disease	contact	past disease
varicella	21 days	when the last eruption has dried
parotitis	24 days	10 days after the occurrence of skin changes
rubeola	12 days	5 days after the occurrence of skin changes
rubella	21 days	7 days after the occurrence of skin changes
pertussis	20 days	21 days after the first symptoms appeared or 6 days after the initiation of antibiotic therapy
Different deviations from the norm found in physical examinations and laboratory tests		
Acute upper respiratory tract infection	Reddened throat + increased amount of secretion in airways, or elevated temperature ($> 37.8^{\circ}\text{C}$).	
Antibiotic therapy	Up to 2 weeks after treatment	
Leucocytosis	$> 20 \text{ G L}^{-1}$	
Anaemia	$\text{Hb} < 8 \text{ g dL}^{-1}$, $\text{Ht} < 28$ newborns $< 10 \text{ g dL}^{-1}$	
Dyselectrolytaemia	$\text{K} > 6.5 \text{ mmol L}^{-1}$, $\text{K} < 3.0 \text{ mmol L}^{-1}$, $\text{Na} < 130 \text{ mmol L}^{-1}$, $\text{Ca} < 1.5 \text{ mmol L}^{-1}$ (3 mg dL L^{-1})	

SURGICAL PLAN

The order of surgeries carried out both in and outside the operating suite should consider the age of patients undergoing surgical procedures.

Due to high risk of hypoglycaemia and dehydration, newborns and infants should be scheduled for surgeries first to avoid prolonged fasting. During procedural planning, the possibility of transfer to the ICU should be checked, as such transfers are predominantly required in cases of newborns undergoing operations for congenital defects and in cases of patients with serious conditions.

Because the results of tests regarding the possible neurotoxic effects of the drugs used for general anaesthesia are inconsistent or inexplicit, great caution is recommended when qualifying the youngest children (www.SmartTots.org) for surgeries/scheduled procedures under general anaesthesia that could be performed at older ages without detriment to the patient's health [21–28].

METHODS OF INDUCING ANAESTHESIA

In newborns, infants and small children, the possible induction methods [15] include the following:

- inhalation induction,
- intravenous induction,
- rectal induction,
- nasal induction.

INHALATION INDUCTION

Inhalation induction is important for paediatric anaesthesiology. It is particularly recommended in children with anticipated difficult intravenous access.

Two methods of inhalation induction are suggested. The first option consists of gradual incremental increases in the concentrations of inhalation agents, whereas the other uses high anaesthetic concentrations from the onset. The latter enables the quick induction of anaesthesia, which is especially valuable in uncooperative patients but carries higher risks of adverse side effects of drugs.

The only agent used for the inhaled induction of anaesthesia is sevoflurane. The routine use of sevoflurane in concentrations exceeding 5 vol% is not recommended, with an exception for cases of difficult intubation under inhalation anaesthesia, for which higher concentrations of sevoflurane (up to 6 vol%) can be used. Complete airway patency is essential for the safety and efficacy of this method of induction.

In newborns, routine intubations or insertions of a laryngeal mask (if the type of procedure allows for it) are advisable due to difficulties in maintaining the airway's patency. In infants and small children, the decision on intubation depends on the type of surgery, its anticipated duration and an individual assessment of their possible non-instrumental maintenance of airway patency. Intubation is thought to be obligatory in procedures lasting more than 1 h, those performed in the lateral or ventral decubitus position and those within the region of head or neck, as well as in preterm newborns [1, 11, 14, 15].

INTRAVENOUS INDUCTION

Intravenous induction is possible in children of all ages but requires an earlier insertion of the vascular access. Its insertion in the youngest children may be difficult and pain-

Table 4. Methods of anaesthesia for intubation [27, 28]

Anaesthesia	Drugs used for anaesthesia
Local	Local anaesthetic in aerosol superficially or rectally
Inhalation general	Gas mixture — O ₂ /N ₂ O or O ₂ /air + inhalational anaesthetics → sevoflurane
Intravenous general	barbiturates — thiopental 3–5 mg kg ⁻¹ or propofol 2–5 mg kg ⁻¹ or midazolam 0.1–0.3 mg kg ⁻¹ ketamine 0.5–2 mg kg ⁻¹ opioids — fentanyl 1–2 mcg kg dose ⁻¹ , morphine 0.1 mg kg ⁻¹ , remifentanyl 1 mcg kg ⁻¹ during 30–60 s, sufentanil 0.5 mcg kg ⁻¹ muscle relaxants — depolarising succinylcholine chloride 1–3 mg kg ⁻¹ skeletal muscle relaxants – non-depolarising • rocuronium 0.6 mg kg ⁻¹ • vecuronium 0.1 mg kg ⁻¹ • cisatracurium 0.1 mg kg ⁻¹ • atracurium 0.5 mg kg ⁻¹ • mivacurium 0.15–0.25 mg kg ⁻¹
General — inhalation and intravenous	Inhalational anaesthetics + O ₂ /N ₂ O or O ₂ /A+ opioids + skeletal muscle relaxants

ful. The pain related to vein injection can be alleviated using a cream/gel containing local anaesthetics.

Currently, the most commonly used drug for intravenous induction is propofol in a dose of 2–5 mg kg b.w.⁻¹. The use of preparation of 0.5% concentration is associated with less severe pain. To reduce the pain at the injection site, analgesics should be administered before an intravenous supply of propofol (i.v., through the same cannula: fentanyl in a dose of 1–2 mcg kg b.w.⁻¹ or lidocaine in a dose of 1–2 mg kg b.w.⁻¹). Moreover, thiopental, one of barbiturates, can be used (3–5 mg kg b.w.⁻¹).

It should be remembered that both propofol and thiopental have depressive effects on the respiratory system (inducing apnoea) and on the cardiovascular system (likely to cause hypotension associated with reduced systemic vascular resistance).

Due to its lack of depressive effects on the cardiovascular system and minimal respiration depression, ketamine is used in children in severe conditions who have unstable circulation (e.g., in shock). It can be administered intramuscularly in doses of 2–4 mg kg b.w.⁻¹ and intravenously in doses 1–2 mg kg b.w.⁻¹.

RECTAL INDUCTION

In special cases, when a difficult insertion of intravenous access is suspected in advance or the child is extremely anxious, anaesthesia can be induced rectally. The most common drug used in this method is ketamine in a dose of 10 mg kg b.w.⁻¹ administered with midazolam in a dose of 0.5 mg kg b.w.⁻¹. The child usually falls asleep 15–20 min after their administration [15].

NASAL INDUCTION

This type of induction, e.g., dropping midazolam and sufentanil to the nose, has not been widely used due to its poor tolerance in children. Moreover, opioids can be used for nasal induction, while muscle relaxants are applied for intubation.

In small children, the vagus nerve is frequently excited during various manipulations, including those associated with endotracheal intubation. At present, however, routine administration of atropine to newborns and infants during anaesthesia induction is not recommended. A syringe with the suitable solution of this drug should be always at hand before the initiation of anaesthesia in case its emergent use is needed. As a standard, one ampoule of atropine containing 1 mg mL⁻¹ is dissolved in 10 mL 0.9% NaCl to obtain the atropine solution of 0.1 mg mL⁻¹ (dosing: 0.01–0.015 mg kg b.w.⁻¹).

ENDOTRACHEAL INTUBATION

Various types of anaesthesia for endotracheal intubation are presented in Table 4. The drugs used for intubation and approved for children aged 0–3 years, as well as those used off label, are listed in Table 5. The algorithm of management during endotracheal intubation is depicted in Figure 1.

The size of the endotracheal tube and depth of its insertion depends on the newborn's body weight — Table 6. The depths of the tube insertion to the trachea depending on the gestational age are presented in Table 7.

Prior to endotracheal intubation, it is necessary to confirm a lack of awareness and to provide suitable oxygenation for the child. During the oxygenation of newborns, preterm babies in particular, caution is advisable due to the extreme sensitivity of such patients to the toxic effects of oxygen [27].

Table 5. Drugs used for intubation approved for children aged 0–3 years or used off-label [29–37]

Drug	Newborn	Infant aged 1–6 months	Infant > 6 months of age	Child aged 1–3 years
Morphine	+	+	+	+
Fentanyl	+	+	+	+
Sufentanil	+*	+*	+*	+*
Remifentanyl	off-label (FDA approved drug)	off-label (FDA approved drug)	off-label (FDA approved drug)	+
Midazolam	off-label	off-label	+	+
Thiopental	+	+	+	+
Propofol	off-label	+**	+**	+**
Ketamine	+	+	+	+
Sevoflurane	+	+	+	+
Isoflurane	+	+	+	+
Desflurane	+	+	+	+

+ The summary of product characteristics (SPC) does not contain reservations as to its use in the defined age group

* Information in the SPC: the efficacy and safety of administering sufentanil to children ≤ 2 years have been documented only in a limited number of cases

** Information in SP: Great caution is recommended when propofol is used in infants and children ≤ 3 years, although the present data do not indicate any significant differences in its safety compared to children > 3 years of age

The optimal modality of anaesthesia for intubation is the use of an inhalation or intravenous anaesthetic with an opioid, with or without a muscle relaxant. In cases of anticipated difficult intubation, muscle relaxants should be abandoned. The same strategy is usually recommended for the intubation of preterm infants.

The use of atracurium or cisatracurium in newborns is justified due to their special metabolisms.

In patients with full stomachs and in cases with other indications for a quick induction, it is advocated to provide muscle relaxation with suxamethonium in a dose of 2 mg kg b.w.⁻¹ for children aged < 2 years or 1–1.5 mg kg b.w.⁻¹ for those > 2 years of age.

An alternative to suxamethonium is rocuronium in a dose of 0.6 mg kg b.w.⁻¹, which enables intubation after 60 seconds. The action of rocuronium can be reversed with sugammadex in a dose of 2 mg kg b.w.⁻¹ in children > 2 years of age (its use in younger children or in higher doses is off-label).

MAINTENANCE OF ANAESTHESIA

Anaesthesia can be maintained using an inhalation anaesthetic (sevoflurane, desflurane or isoflurane) combined with an i.v. opioid, with or without a muscle relaxant or total intravenous anaesthesia (TIVA). The modality for anaesthesia maintenance should be chosen individually, depending on each patient's state, type of surgery and indications/contraindications, as well as on the availability of various forms of anaesthesia. Fentanyl and sufentanil can be administered in a continuous infusion or in repeated doses. When the quick extubation of a child is the priority, remifentanyl in a continuous infusion can be used (off label). TIVA can prove useful

when inhalation anaesthetics are contraindicated (e.g., the risk of malignant hyperthermia), short-acting drugs are used (e.g., remifentanyl), a very stable course of anaesthesia is given, the patient will not be awoken from anaesthesia during the transfer to the ICU (e.g., congenital heart defect surgery), or when anaesthesia has to be performed outside the operating suite (for instance, in the intensive therapy unit where inhalation anaesthetics cannot be used).

INTRAOPERATIVE MECHANICAL VENTILATION PRINCIPLES OF MECHANICAL VENTILATION

Generally, positive pressure ventilation (controlled) is applied during general anaesthesia. It should be remembered that during general anaesthesia, certain changes occur in the patient's respiratory system, including the following [14, 15]:

- reduced functional residual capacity (FRC) by 15–20%,
- decreased lung volume,
- absorption and compression atelectasis,
- increased airway resistance,
- impaired ventilation-perfusion ratio (increased pulmonary leak, increased dead space),
- surfactant injuries
- hypoxic pulmonary vasospasm due to effects of inhalation anaesthetics on the function of pulmonary vessels.

In the group of patients ≤ 3 years of age, PCV), time-controlled with low positive end-expiratory pressure, is used. PCV prevents excessive inspiratory pressures, reduces the risk of barotrauma, and improves the ventilation-perfusion ratio in cases of decreased lung compliance. The tidal volume depends on compliance and respiratory resistances; changes in either of these are sometimes difficult to detect.

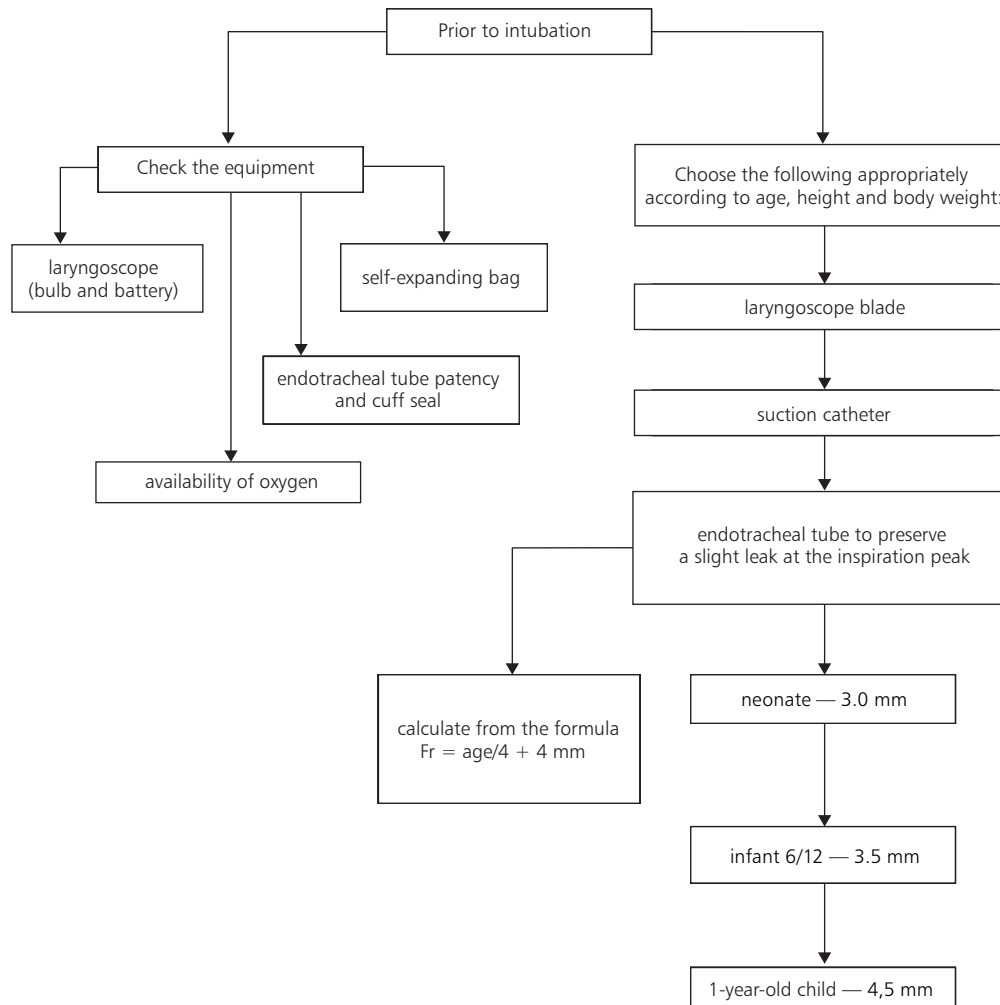


Figure 1. Technique of endotracheal intubation

ATELECTASIS

Atelectasis during mechanical ventilation for general anaesthesia poses a clinical problem mainly in newborns and infants. It occurs very quickly after the induction of anaesthesia and in most cases affects the lower pulmonary areas (during general anaesthesia with muscle relaxation and positive pressure ventilation, the upper pulmonary regions are better ventilated). The symptoms of atelectasis are impaired oxygenation and reduced lung compliance.

The type of general anaesthesia does not affect the development of intraoperative atelectasis. The factors favouring its occurrence include the following:

- patient's position: decubitus, lateral decubitus (reduced FRC),
- type of surgery — more atelectatic foci in cardiac surgeries with extracorporeal circulation,

- oxygen concentration in the respiratory mixture > 80% favours the development of atelectasis (the use of 100% oxygen by the end of anaesthesia can also substantially affect its occurrence).

Atelectasis induces gas exchange disturbances, hypoxia and subsequently increased postoperative morbidity. It can last up to 2 post-anaesthesia days and favours postoperative pneumonia. It can be prevented using suitable lung ventilation during anaesthesia.

INTRAOPERATIVE FLUID SUPPLY

The fluid supply during surgery should account for the basic requirements, as well as for intraoperative loss or possible deficiencies resulting from preoperative fasting. The basic requirement for an infant is estimated at approximately 100 mL kg⁻¹ day⁻¹, i.e., 4 mL kg⁻¹ h⁻¹ in infants and 40 mL h⁻¹

Table 6. The endotracheal tube size and depth of insertion according to body weight

Body weight	Tube size — internal diameter (mm)	Depth of intubation through the mouth (cm)	Depth of intubation through the nose (cm)
< 750 g	2.5	5.5–6	6.5–7
750–1000 g	3.0	6–7	7–8
1001–2000 g		7–8	9
2001–3000 g	3.5	8–9	10
3000–3500 g	4.0	9–10	11
> 3500 g		body weight (kg) + 6	body weight (kg) + 7

Table 7. Intubation depth according to gestational age

Gestational age (weeks)	Depth of intubation through the mouth (cm)
23–24	5.5
25–26	6.0
27–29	6.5
30–32	7.0
33–34	7.5
35–37	8.0
38–40	8.5
41–43	9.0

+ 2 mL kg⁻¹ h⁻¹ in children weighing more than 10 kg [38]. However, marked differences regarding the youngest patients should be considered.

In newborns, fluid requirements markedly change in their subsequent days of life; in preterm babies, these requirements also depend on the foetal maturity. The basic fluid requirements in newborns during the first days of life according to the body weight are presented in Table 8 [11]. Special attention should be paid to the undetectable fluid loss, which can be significant and intensify due to intensive evaporation when large intestinal areas are exposed during surgery (e.g., congenital evisceration, necrotising enteritis, ileus).

The conditions resulting from haemorrhage exceeding 10% of the circulating blood volume should be supplemented with colloid preparations, isotonic albumin solutions or blood preparations.

Hypotonic fluids (including hypotonic mixtures of 0.9% NaCl and 5% glucose) should be avoided during perioperative fluid therapy due to their increased risk of brain oedema [39–42].

According to the guidelines of the European Society of Paediatric Anaesthesiology (ESPA), children should be intraoperatively transfused using fluids with osmolality and sodium concentrations similar to physiological values (to avoid hypernatraemia) containing 1 to 2.5% glucose (to avoid hypoglycaemia, lipolysis or hyperglycaemia) and

Table 8. Basic fluid requirements in newborns (mL kg⁻¹ day⁻¹)

Chronological age	Newborns — body weight		
	< 1000 g	1000–1500 g	> 1500 g
day 1	100	80	60
day 2	120	100	80
day 3	140	120	100
day 4	160	140	120
Successive days	180	160	120–140

enriched with anionic bicarbonate precursors (acetate, citrate) [43]. Unfortunately, the ideal solution for widespread use is not available in Poland. Therefore, multi-electrolyte fluids, preferably balanced ones, are recommended, such as paediatric multi-electrolyte fluid. In the group of neonates and preterm babies at risk of hypoglycaemia who have not been provided with parenteral feeding, such fluids should be supplied simultaneously with the slow infusion of 10% glucose solution through the automated pump (4 to 6 mg kg b.w.⁻¹ min.⁻¹), under glycaemic control. In babies on parenteral feeding, its continuation should also be considered during surgery, while decreasing the flow and controlling the glycaemia [44–47].

AWAKENING FROM ANAESTHESIA

The awakening of a small child from anaesthesia is often difficult and extremely turbulent. In the neonatal period, this is caused by the prolonged metabolism of the majority of drugs used for anaesthesia, further enhanced by the unintended cooling of the child during surgery. There is a high risk of postoperative apnoea and predisposition to laryngo- and bronchospasms that can persist until the age of 3 or longer. For the aforementioned reasons, newborns should be awakened in the intensive care unit or in the intensive postoperative surveillance setting. In cases when intubated children are transported to the ICU, we must remember that the premature discontinuation of analgesedation is contraindicated due to the risk of unintended extubation.

In the remaining cases, children are awakened in the operating room or the recovery room. It is always essential

to reverse the neuromuscular block. The clinical evaluation of the degree of neuromuscular blockade requires considerable experience. The degree of relaxation and residual motor blockade can be objectively assessed after surgery using a peripheral nerve stimulator.

The management of postoperative pain should be planned in advance. Situations in which pain awakens the child from general anaesthesia are unacceptable. The child should receive rectal or intravenous paracetamol appropriately early (preferably just after induction of anaesthesia) in a dose tailored to its body weight. To achieve effective pain relief, some block anaesthesia techniques can also be used; they will enable the patient to reduce the intraoperative doses of opioids, hence decreasing the risk of postoperative respiratory failure and providing effective postoperative pain management, particularly when continuous techniques are applied [48].

EXTUBATION AFTER SURGERY

The decision on extubation is made when the child is capable of maintaining its airway unaided and has its own respiratory drive preserved. On extubation, the child should have the protective reflexes preserved. Before extubation, the gastric and oral cavity contents should be aspirated. Taking one deep breath is recommended while removing the tube (extubation during inspiration). This manoeuvre stimulates coughing and prevents atelectasis by expanding the lung.

After extubation, the child should be carefully observed, paying special attention to the movements of the thoracic cavity and any additional auscultation phenomena, e.g., stridor, that may suggest possible upper airway problems. Supporting the child's mandible can help to maintain the patent's airway. Moreover, simultaneous passive oxygen therapy can be applied. If the child breaths regularly, it is placed in the fixed lateral decubitus position. During the transport saturation of arterial haemoglobin, oxygen and pulse rate are monitored using a pulse oximeter. The child remains in the recovery room until complete recovery (conscious, with efficient respiration and circulation) and is transferred to the hospital ward when it reacts to external stimuli (adequately for its age and pre-surgery condition), when its SpO₂ and heart rate are normal, when its respiration is efficient, when no pain-associated behaviour is observed or reported, or when no vomiting and postoperative wound bleeding are noted. Drainages, if placed, must function properly, and intravenous lines should be adequately secured.

POSTOPERATIVE PAIN MANAGEMENT IN CHILDREN

Postoperative pain is an unpleasant sensory and emotional experience associated with intraoperative tissue or organ damage. The highest severity of pain is observed during the initial post-surgery days and depends on the type

of surgery, its duration, extent and degree of tissue trauma. Moreover, some other factors, such as age, emotional status, anxiety related to the hospital stay or past pain experiences, can be important. A proper management plan should be prepared for the entire perioperative period to provide effective postoperative pain treatment [49, 48].

A perioperative pain control plan is based on initial information about the underlying disease and concomitant diseases. It is important to determine whether the pain was present before surgery (analgesics required in premedication), to identify the type and extent of surgery (planning continuous epidural anaesthesia), to ascertain whether certain pain control methods used during earlier procedures (if performed) were effective or accompanied by side effects and to assess the patient's present mental status.

The psychological aspect is of pivotal importance for proper preoperative management, i.e., good contact between the child and the parents. The conversation with the parents should aim at learning about their ideas and expectations related to postoperative pain and presenting the options of pain prevention and control.

All painful procedures should be carried out after the induction of anaesthesia (e.g., after insertion of a percutaneous cannula for morphine administration in the postoperative period, additional venous access or an epidural catheter). The administration of the first dose of an analgesic prior to surgery should be ensured. Likewise, when block continuous analgesia is planned for the postoperative period, it is better to administer the first local analgesic dose before rather than after surgery. The pain should not awaken the child after the surgical procedure [51, 52]. Therefore, drugs reversing the effects of opioid receptor agonists should be used with great caution and prudence. Naloxone should be administered only in extreme cases, e.g., when post-extubation recurrent episodes of apnoea with significant SpO₂ decreases are observed and re-intubation might be an alternative. After its administration, one of the NSAIDs should be started, e.g., paracetamol.

Once the child has been awakened and its consciousness state evaluated, the severity of pain should be assessed to decide whether an additional analgesic dose is required. The pain experienced by the child, hence the effectiveness of the postoperative analgesia, should be assessed systematically, according to the protocols of a given centre. In cases of one-day surgeries, pain sensations should be assessed in the home setting by parents/caregivers informed by the anaesthesiologist on what they should be looking out for and on the drugs and dosages to be given. Moreover, parents/caregivers should be provided with information on whom and how they can contact in case the treatment administered is ineffective [53, 54].

Table 9. Dosing of NSAIDs and tramadol

Drug	Route of administration	Dose mg kg b.w. ⁻¹	Frequency of administration hours	Daily dose mg kg b.w. ⁻¹	Approved in Poland
Ibuprofen	<i>p. o.</i> <i>p. r.</i>	5–10	6–8	30	Since month 33
Diclofenac	<i>p. r.</i>	1	8	3	Since year 14 suppositories > 2 years
Tramadol	<i>p. r.</i> <i>i. v.</i>	1–2	4–6	8	> 1 year of age
Metamizole *	<i>p. o.</i> <i>p. r.</i> <i>i. v.</i>	5–20 10 4	8 4–6		> 15 years * *

* Used in children < 15 years of age when other similar drugs have been ineffective, particularly administered *i. v.*

When the surgery has been completed and the child awakened from anaesthesia with block techniques, the effectiveness and extent of blockade should be evaluated [55].

In the postoperative period, the child's conscious state should be assessed, as well as the severity of pain, in order to consider the additional analgesic dose immediately after the completion of the anaesthesia. Furthermore, the extent and quality of block anaesthesia are evaluated. Based on these measures, the final decision about the pain management strategy should be made (the preoperative plan should be verified). In the next few postoperative days, pain management should be adjusted to the patient's needs. All of the potentially painful procedures, e.g., placement/removal of drains, insertion of venous accesses (peripheral and central), provision of arterial accesses, changes of dressings, ambulation, physiotherapy, should be carried out after an additional dose of analgesics to alleviate the breakthrough pain [52, 53, 56].

After the completion of treatment, both parents and the medical personnel (using the unified protocol) should evaluate the entire pain management [57].

Pain management should aim at the prevention of severe pain rather than the treatment of pain sensations that have already occurred. Pre-emptive or preventive analgesia used before, during or after surgery has beneficial effects over a period longer than the action of drugs, both early (reduced pain and analgesic requirements) and late (lower incidence of chronic pain) [67].

Analgesics used in single doses should be administered at constant time intervals according to their pharmacokinetics. They should not be given intramuscularly; this is the least effective route, as it does not provide the constant analgesic level in blood and the concentrations obtained are difficult to anticipate. Additionally, intramuscular administration is a source of unnecessary pain and stress for the child to experience. While under a continuous infusion of analgesics, the risk of their accumulation should always be considered.

The presence of parents during the postoperative period is a factor that clearly alleviates pain sensations, reducing the requirements for analgesics and sedatives [52, 56, 59].

PHARMACOTHERAPY OF POSTOPERATIVE PAIN

The oral, rectal or intravenous use of non-steroidal anti-inflammatory drugs (NSAIDs), paracetamol and tramadol is presented in Table 9 [60–62].

Intravenous nalbupin in children > 18 months of age in a dose of 0.1–0.2 mg kg⁻¹ b.w. every 3–6 hours [63].

Subcutaneous or intravenous administration of opioids (e.g., morphine), intravenous single injections or continuous infusions (morphine, fentanyl, tramadol and others); dosing is presented in Table 10 [52, 59].

Epidural use of opioids in single injections, continuous infusions.

Epidural, intrapulmonary or plexus administration of local anaesthetics (bupivacaine, lidocaine) in single injections or continuous infusions.

Analgesics should be discontinued gradually and according to the patient's needs. If opioids were used for more than 7 days, their sudden withdrawal is highly likely to induce withdrawal syndrome [60].

PAIN TREATMENT IN NEWBORNS AND PRE-TERM NEONATES

Newborns and infants require equally effective analgesia as older children, irrespective of whether postoperative substitutive ventilation is administered or not. The methods

Table 10. Doses of opioid analgesics used in intravenous infusions in children (> 3 months of age)

Opioid analgesic	Dose
Morphine	0.04–0.06 mg kg h ⁻¹
Fentanyl	0.002–0.004 mg kg h ⁻¹
Tramadol*	0.07–0.25 mg kg h ⁻¹

*in children > 1 year of age

Table 11. Dosing of paracetamol according to APA*

Age/month	Route of administration	Saturating dose (mg kg ⁻¹)	Maintenance dose (mg kg ⁻¹)	Interval between doses (h)	Max. Daily dose (mg kg ⁻¹)	Duration of max. daily dose use (h)
28–32 Hbd	<i>p.o.</i>	20	10–15	8–12	30	48
	<i>p.r.</i>	20	15	12		
33–52 Hbd	<i>p.o.</i>	20	10–15	6–8	60	48
	<i>p.r.</i>	30	20	8		
> 3 months	<i>p.o.</i>	20–30	15	4–6	90	48
	<i>p.r.</i>	30–40	15–20	6–8		
Term newborns and children up to 10 kg	<i>i.v.</i>	–	7.5	4–6	30	48
Children 10–50 kg	<i>i.v.</i>		15	4–6	60	48
Children > 50 kg	<i>i.v.</i>		1 g	4–6	4 g	48

*Association of Paediatric Anaesthesiologists of Great Britain and Ireland

The *p.o.* and *p.r.* doses regularly recommended by manufacturers are 10–15 mg kg⁻¹ every 4–6 h up to 60–65 mg kg day⁻¹ (max. total daily dose — 4 g day⁻¹), Saturating dose — used only optionally, but has to be included in the daily dose (total). The dose of 60 mg kg day⁻¹ in children < 3 months of age and 90 mg kg day⁻¹ (max. daily dose 4 g day⁻¹) in children > 3 months of age should never be exceeded. Doses > 60 mg kg day⁻¹ should not be used for more than 48 h.

of analgesia in children under 3 months of age should be suitably modified; analgesics are supplemented with sedatives most commonly used in newborns and small neonates requiring awakening and monitoring in the ICU setting [64].

1. **Opioids** — administered intravenously are the basis of analgesia and sedation in the early postoperative period; morphine, sufentanil and fentanyl are most frequently used [58]:

- in some proportion of newborns and small neonates, opioids can provide sufficient sedation, and awareness-suppressing drugs (sedatives) are not necessary,
- to diminish the risk of adverse effects (hypotension, bradycardia, myoclonus, thoracic rigidity), the minimal effective dose should be administered slowly,
- the drug dose should be modified after the stabilisation of the patient's condition, about every 12 hours,
- in children whose circulation is unstable, including those with an unclosed thorax (open sternum) or pulmonary hypertension, the infusion of sufentanil is preferable → the dosing range of 0.05–2 mcg kg h⁻¹ + boluses of 0.05–0.5 mcg kg⁻¹,
- an alternative is the infusion of fentanyl → in a dose of 1–5–10 mcg kg h⁻¹ + boluses 0.5–2 mcg kg⁻¹ [65]
- in the remaining newborns and infants, fractionated doses of morphine (25–50–100 mcg kg⁻¹) can be used; the suggested dosing → starting with lower doses repeated every 5–10 min, if required, to reach the total dose of 100–200 mcg kg⁻¹ or in the continuous infusion → starting with 10 mcg kg h⁻¹ and gradually increasing to 40 mcg kg h⁻¹ as necessary (additional boluses can also be administered in a dose of 5–25 mcg kg⁻¹).

Noteworthy: fractionated doses should be given slowly over the period of several minutes.

2. **Paracetamol** — administered as a constant order rectally, intravenously or orally in all children expect those with unstable circulation and features of low cardiac output [62, 66]:

- it is recommended to administer a single saturating dose (included in the 24 h dose),
- the max. daily dose for a given age and body weight should not be exceeded,
- the daily dose of paracetamol should be reduced after 48 hours,
- dosing according to the Association of Paediatric Anaesthesiologists of Great Britain and Ireland is presented in Table 11.

SUMMARY

The perioperative care of newborns and children under 3 years of age is particularly difficult and demanding for the anaesthetic team. The numerous problems that arise result from the specificity of the neonatal period, the differences in the pathophysiology of many defects and diseases in this age group, possible intra- and postoperative complications and specific surgery-related issues (e.g., extracorporeal circulation used for cardiac defect surgery). The majority of postoperative care standards for newborns and infants used in individual centres is based on both comprehensive medical knowledge, and long-term experience and well-documented studies on this group of patients remain few.

CONFLICT OF INTEREST

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