Manual of Pediatric Anesthesia

Seventh Edition

Jerrold Lerman
Charles J. Coté
David J. Steward
Editors

Springer

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With an Index of Pediatric Syndromes

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Jerrold Lerman, MD, FRCPC, FANZCA
Clinical Professor of Anesthesiology
Women and Children's Hospital of Buffalo,
Department of Anesthesiology, State University of New York
Buffalo, New York, USA

Charles J. Coté, MD, FAAP
Professor of Anaesthesia, Harvard Medical School
MassGeneral Hospital for Children at the Massachusetts General Hospital
Division of Pediatric Anesthesia, Department of Anesthesia, Critical Care and Pain Medicine
Boston, MA, USA

David J. Steward, MB, FRCPC
Honorary Professor
Department of Anesthesiology, Pharmacology and Therapeutics
University of British Columbia
Vancouver, British columbia

Springer

Jerrold Lerman
Buffalo, NY, USA

Charles J. Coté
Quincy, MA, USA

David J. Steward
Blaine, WA, USA

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Preface

In the tradition of the first six editions, this seventh edition of the *Manual of Pediatric Anesthesia* is designed as a concise but comprehensive pocketbook guide to pediatric anesthesia practice. We are honored and excited to join with the Springer Publishing family of anesthesia texts to produce this latest edition. Since its inception, this has been a book to be carried in the pocket or available on the desk for handy reference. With this edition, Springer will add an online version for even easier immediate pocketsize reference.

The Manual outlines the important considerations when anesthetizing infants and children, describes management problems, and presents a course of action for treating many of your pediatric patients. Each chapter also directs you to further reading. For the resident in training, it provides a compact but comprehensive source of current information concerning pediatric anesthesia practice.

The three authors have a combined total of more than a century of clinical experience in providing perioperative care for children of all ages having all types of surgical procedures. In recent years, our practices have extended outside the operating room to care for children having a wide variety of medical and minor surgical procedures as well as to provide pain management throughout the hospital.

In preparing this edition of the Manual, we have compiled an evidence-based approach based on the literature and fused this with our own experiences to synthesize optimal clinical strategies for each scenario. The information presented has been reviewed by all three authors and a consensus reached on controversial topics. In many instances, we recommend a course of action for a given clinical situation. When we do this, it is based on what has worked well for us. However, we recognize that others may have different ideas, approaches, and constraints on their practices that may require them to adapt to ensure a successful outcome.

It is now over 35 years since the first edition of this book appeared. Many changes in our practice have occurred during this time. Some occurred in response to the expanding scope of pediatric surgery; others resulted from the

progressive introduction of new anesthesia drugs and technologies, plus new visions of what constitutes optimal pediatric anesthesia care. It is satisfying that many of these changes were a result of the simultaneous proliferation of clinical investigations relating to anesthesia care for infants and children. We are now able to practice evidence-based anesthesia care much of the time.

Yet still, questions remain. The current debate regarding the safety of the use of general anesthetics in the very young child demonstrates that we must constantly be ready to meet new challenges and accept possible new concepts if we are to continue to deliver safe care to our youngest patients.

Children remain the most rewarding patients to manage. There is great satisfaction in the successful management of the tiny infant, the reticent child, or the many other children that you will meet in your practice. We hope that our handbook will help you to achieve this satisfaction.

Buffalo, NY — Jerrold Lerman
Quincy, MA — Charles J. Coté
Blaine, WA — David J. Steward

Abbreviations and Acronyms

$A\text{-}aDN_2$	Alveolar-arterial nitrogen difference
$A\text{-}aDO_2$	Alveolar-arterial oxygen tension gradient
ACE	Angiotensin-converting enzyme
ACT	Activated clotting time
ASD	Atrial septal defect
AV	Arteriovenous (AVM arteriovenous malformation)
BiPAP	Biphasic positive airway pressure
BP	Blood pressure
BSA	Body surface area
CBF	Cerebral blood flow
CF	Cystic fibrosis
CHD	Congenital heart disease
CHF	Congestive heart failure
CK	Creatine kinase
Cl	Clearance
CL	Lung compliance
$CMRO_2$	Cerebral metabolic rate for oxygen
CNS	Central nervous system
CO	Carbon monoxide
CoHb	Carboxyhemoglobin
CPAP	Continuous positive airway pressure
CPB	Cardiopulmonary bypass
CPK	Creatine phosphokinase
CPP	Cerebral perfusion pressure
CSF	Cerebrospinal fluid
CT	Computed tomography
CV	Closing volume
CVP	Central venous pressure
DDAVP	1-deamino-8-D -arginine vasopressin
DIC	Disseminated intravascular coagulopathy
DN	Dibucaine number
2,3-DPG	2,3-diphosphoglycerate
EACA	Epsilon-aminocaproic acid
EBV	Estimated blood volume
ECF	Extracellular fluid

ECG	Electrocardiogram
ECHO	Echocardiography
ECMO	Extracorporeal membrane oxygenation
ED_{95}	Effective dose in 95% of patients
EDTA	Ethylenediaminetetraacetic acid
EEG	Electroencephalography
EMG	Electromyography
ETT	Endotracheal tube
EUA	Examination under anesthesia
FESS	Functional endoscopic sinus surgery
FFP	Fresh frozen plasma
FIO_2	Fraction of inspired oxygen
FN	Fluoride number
FRC	Functional residual capacity
GERD	Gastroesophageal reflux disease
GFR	Glomerular filtration rate
Hb	Hemoglobin
HbA	Adult hemoglobin
HbC	Hemoglobin C
3-HBDH	3-hydroxybutyrate dehydrogenase
HbF	Fetal hemoglobin
HbS	Sickle cell hemoglobin
Hct	Hematocrit
HFOV	High frequency oscillatory ventilation
HME	Heat and moisture exchanger
HpD	Hematoporphyrin derivative
IAP	Intra-abdominal pressure
ICF	Intracellular fluid
ICP	Intracranial pressure
ICU	Intensive care unit
ID	Internal diameter
IJV	Internal jugular vein
IOP	Intraocular pressure
IPPB	Intermittent positive-pressure breathing
IPPV	Intermittent positive-pressure ventilation
IVAC	Intravenous accurate control [device]
IVH	Intraventricular hemorrhage
KTP	Potassium titanyl phosphate laser
L/S	Lecithin-sphingomyelin [ratio]
LDH	Lactate dehydrogenase
LES	Lower esophageal sphincter
LMA	Laryngeal mask airway

LV	Left ventricle
MABL	Maximal allowable blood loss
MAC	Minimum alveolar concentration
MEP	Motor evoked potential
MetHb	Methemoglobin
MH	Malignant hyperthermia or hyperpyrexia
MHS	Malignant hyperthermia-susceptible
MRI	Magnetic resonance imaging
N_2O	Nitrous oxide
NEC	Necrotizing enterocolitis
NGT	Nasogastric tube
NO	Nitric oxide
NSAID	Nonsteroidal antiinflammatory drug
NSF	Nephrogenic systemic fibrosis
OCR	Oculocardiac reflex
OELM	Optimal external laryngeal manipulation
OLV	One lung ventilation
OR	Operating room
OSA	Obstructive sleep apnea
P_{50}	PO_2 with 50% hemoglobin saturation
PA	Pulmonary artery
PACU	Postanesthesia care unit
PaO_2	Arterial oxygen pressure
PAR	Postanesthesia room
PC	Partition coefficient (λ)
PCA	Patient-controlled analgesia
PCEA	Patient controlled epidural analgesia
pCO_2	Partial pressure of carbon dioxide ($PaCO_2$ arterial carbon dioxide; $PetCO_2$ end-tidal carbon dioxide)
PDA	Patent ductus arteriosus
PEEP	Positive end-expiratory pressure
PGE_1	Prostaglandin E_1
PIP	Peak inspiratory pressure
PNF	Protamine neutralization factor
pO_2	Partial pressure of oxygen
PONV	Postoperative nausea and vomiting
PPIA	Parental presence at induction of anesthesia
PPM	Parts per million
PRBC	Packed red blood cells
PSV	Pressure support ventilation
PT	Prothrombin time
PTT	Partial thromboplastin time

PVC	Polyvinyl chloride
PVOD	Pulmonary vascular obstructive disease
PVR	Pulmonary vascular resistance
$\dot{Q}$	Perfusion
Qp:Qs	Ratio of pulmonary to systemic blood flow
RA	Right atrium
RAE	Ring, Adair, Elwyn
RAST	Radioallergosorbent testing
RBC	Red blood cell
RDS	Respiratory distress syndrome
REM	Rapid eye movement
RES	Reticuloendothelial system
ROP	Retinopathy of prematurity
RSI	Rapid sequence induction
RV	Right ventricle
SaO_2	Arterial oxygen saturation
SBE	Subacute bacterial endocarditis
SCIWORA	Spinal cord injury without radiologic abnormality
SGOT	Serum glutamic oxaloacetic transaminase
SIADH	Syndrome of inappropriate antidiuretic hormone secretion
SNP	Sodium nitroprusside
SpO2	Saturation pulse oximetry
SSEP	Somatosensory evoked potentials
SVR	Systemic vascular resistance
TCI	Target controlled infusion
TEE	Transesophageal echocardiography
TEF	Tracheoesophageal fistula
TGA	Transposition of the great arteries
TIVA	Total intravenous anesthesia
TLC	Total lung capacity
URTI	Upper respiratory tract infection
V_A	Alveolar ventilation
V_D	Dead space volume
$\dot{V}$	Ventilation
$\dot{V}O_2$	Rate of metabolism (or consumption) for oxygen
$(\dot{V}/\dot{Q})$	Ventilation-perfusion [matching]
V_t	Tidal volume
VACTERL association	The VATER association with added cardiac and limb defects
VAE	Venous air embolism

VATER association	Vertebral defects, anal atresia, tracheoesophageal fistula, esophageal atresia, radial and renal dysplasia
VATS	Video-assisted thorascopic surgery
VILI	Ventilator induced lung injury
VIP	Vasoactive intestinal polypeptide
VSD	Ventricular septal defect
VTV	Volume targeted ventilation
WBC	White blood cell

Contents

CHAPTER 1

Foundations of Pediatric Anesthesia

PSYCHOLOGICAL ASPECTS OF ANESTHESIA FOR CHILDREN

Hospitalization and/or medical procedures can have profound emotional consequences for infants and children. Some children demonstrate behavior disturbances that persist long after the event. The extent of the upset is determined by several factors, the most important of which is the child's age.

Infants younger than 6 months of age are not upset by separation from parents and readily accept a nurse as a substitute mother. From a psychological viewpoint, this is probably a good age for major surgery, although prolonged separation may impair parent-child bonding.

Older infants and young children (6 months to 5 years) are much more upset by a hospital stay, especially with separation from family and home; ambulatory surgery is much less upsetting. Separation of a preschool-age child from their parents at the time of surgery, even ambulatory surgery, is a stress that requires consideration. Explanations of procedures and the need for them are difficult at this age, and, not surprisingly, these children show the most severe behavior regression after hospitalization.

School-age children are usually less upset by separation and more concerned with the surgical procedure and its possible mutilating effect. They often have the wildest misconceptions of what their surgery involves. In contrast, adolescents fear the process of narcosis, the loss of control, of waking up during the surgery, and the possibility of not being able to face the process calmly. It is for these reasons that providing as much information as possible is essential, along with assuring them that they will not awaken during anesthesia and feel the pain of surgery and that they will awaken at the end.

The type and extent of the surgery is an important factor. Major surgery, craniofacial surgery, and amputation of a limb are especially distressing, and appropriate psychiatric support is essential. Surgery of the genitalia in particular may have important psychological implications in children over 18 months of age.

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Factors other than age also influence the child's emotional response. For example, a prolonged hospitalization is much more disturbing than a brief admission, although the former has been mitigated in part by having parents "live in" with their children during hospital stays. Ambulatory surgery usually has a negligible emotional effect on most children, whereas repeated hospitalizations and surgeries may cause significant psychological disturbance; a previous bad experience may be long remembered.

Children vary in their responses to impending hospitalization or medical intervention. Some seek information and participate keenly in preparation programs; they have an active coping style. These children are likely to benefit from psychological preparation and can be expected to cooperate. Others maintain an air of disinterest; they have an avoidant coping style (the "silent child"). Children in the latter group may not benefit and indeed may be further sensitized by efforts at psychological preparation. They may benefit more from an effective anxiolytic premedication (see later discussion).

Psychological Preparation

Preoperative psychological preparation is very important and has been clearly demonstrated to benefit the children. In most cases, the parents prepare the children for surgery, although the extent to which the children can be prepared is determined by the child's age. The basic objective is to explain to the child in simple, understandable, and reassuring terms what will happen at the hospital. Older children and adolescents should be prepared well in advance, as soon as hospitalization is arranged. Younger children should not be prepared too far in advance—it is unnecessary and will be a continuing source of worry for them. Rather, they should be prepared a day or so beforehand.

Hospital tours, puppet shows, and/or audiovisual presentations should be available, as all have been shown to be beneficial. Videotapes are most useful and may be loaned to parents. In some centers, prehospital preparation programs for children have been televised via community television stations on a weekly basis. In this way, a whole population of children can be prepared for the possibility of hospitalization, rather than just those scheduled for surgery. Many older children (older than 5 years) benefit from preoperative information about the operation itself, how much it will hurt afterward and for how long, and what will be done to ease the pain.

Meeting with the Parents

> Being unable to choose parents for your patients, you must make do with those who come with the child … ; it would be abnormal if they showed no anxiety
>
> Mellish (1969)

Parents are playing an increasingly active role in the perioperative care of their children; many expect to be present at induction of anesthesia and in the recovery room. However, some parents are more anxious than others, and this is readily perceived and may further upset the child. Good preparation of the parents reduces parental anxiety and indirectly helps the child.

There are many factors that influence the extent of parental anxiety when a child requires surgery. Even parents of children with only minor problems may initially be very anxious. Complete explanations and good communication with the medical and nursing teams usually do much to reduce their anxiety level. In particular, it is important to describe to parents how their child could respond during induction of anesthesia (eyes rolling up, movements of the arms and legs, and turning of the head) and to reassure them that these are normal and expected responses.

Obtaining Consent

The anesthesiologist is placed in a difficult situation when obtaining informed consent for general anesthesia; providing information on all the potential risks before a minor surgical procedure might well be expected to increase the level of anxiety of the parents. Parents benefit from an appropriate discussion of the risks of anesthesia in that this fulfills their own needs of responsibility and understanding. The parents should be permitted to dictate the extent of the information they wish to be given. Most parents of healthy children having minor procedures accept that there are risks and prefer to have the opportunity to discuss these risks. Such discussions should, of course, be outside the earshot of the young child.

In general, the anesthesiologist should rely on some well-established general principles in dealing with anxious parents. An approach that has been found most helpful in decreasing parental anxiety is one built on genuine warmth and friendliness, empathy, and understanding. Parents like to be listened to; discussions should allow ample time for questions and for the parents to express their concerns and ideas about the child and the proposed anesthesia process. Parents are reassured after a clear and thorough discussion of the plan for preoperative anxiolysis, how their child will be anesthetized, monitored (and the information

the monitors will provide), and provided with postoperative pain relief. A videotaped explanation may be helpful, but should be augmented by a personal interview. An overall discussion of risks, in particular those specific to their child, helps to place risk in perspective. Assurance that their child's anesthesia will be specifically designed with their child's safety and the surgeon's needs in mind also helps to relieve anxiety. Every parent will be pleased if you communicate the message, "We will design your child's anesthetic with his/her medical issues and the needs of the surgeon in mind. We will be with your child at all the times during the anesthetic!" (see Chap. 4 for further discussion re: consent).

Parental Presence at Induction

Although many parents express a desire to be present at induction of anesthesia for their child, a large body of evidence has demonstrated that while parental presence at induction of anesthesia (PPIA) may reduce parental anxiety, it has either no effect or less effect than other strategies (i.e., midazolam) in reducing the child's anxiety. Practitioners and institutions vary widely in embracing PPIA; some only permit PPIA under special circumstances, whereas others allow all parents to be present. The entire surgical team must endorse adopting PPIA. We believe that parents should be educated regarding their role and responsibilities at the induction through a presurgical education program (e.g., by video demonstration or attending a class). Such a practice will reduce disruptions and outbursts at induction, at a time when all attention should be focused on the child. Certainly, many parents of handicapped children or of children with life-threatening disease (e.g., cancer) can often be of great assistance to the anesthesiologist during the induction. Many parents are calm and supportive of their child and benefit from participating in the induction process. Having the child sit on their parent's lap while the parent hugs their child and holds their arms at the side allows the parents to feel that they are part of the process in a supportive way, while a mask is gently applied to the child's face.

The overanxious parent requires special consideration. Excessive anxiety is often of multifactorial origin and may not be entirely related to the child's present surgical condition. These parents may not reduce their anxiety levels from additional information about the forthcoming procedure. An anxious parent who insists on remaining with the child may do more harm than good and may increase the child's anxiety level. Such anxious parents should be counseled and excluded if possible. Adequate preoperative sedation of the child may help them to agree to this course. Certainly, there is no benefit for parental presence for a neonate or infant who is not fearful of strangers due to their young developmental level or for the child in need of a rapid sequence induction. It must be clear

that parental presence during induction is a privilege given at the discretion of the anesthesiologist in what you deem to be for the best interests of the child and the child's safety.

The Anesthesiologist and the Child

Anesthesia, and particularly the induction period, is recognized to have the potential to cause psychological trauma. Studies indicate that anesthesiologists vary in their ability to relate to children and minimize this upset. An *empathic approach* to the child before and during medical procedures is preferred (e.g., "*This may be a little uncomfortable and I know you are scared, but we are going to do all we can to help and it will soon be over. We don't mind if you cry*"). The alternative *directive approach* ("*Hold still and be big and brave*") is generally condemned.

Premedication with an oral anxiolytic is beneficial in decreasing anxiety during separation, increasing cooperation during induction, and decreasing post hospitalization behavior disturbance.

Caution should be exercised in caring for the silent child who has an avoidant coping style, especially the child who must undergo repeat procedures because such a child may not respond as well to routine preparation methods. Some may respond more favorably if they are allowed to continue with their avoidant coping pattern but are given a well-chosen preoperative medication.

Preparing Infants and Children for an Operation

1. Try to meet the young child with the parents so that the child can see them accept you.
2. Direct most of your attention at all times to the child, even if he or she is developmentally delayed. Try to maintain eye contact; it helps to sit alongside the child, on the floor if necessary.
3. Talk to the child in simple terms that the child can understand. Children who are old enough to understand and who have not had surgery previously should be informed that they will feel they were anesthetized for as long as it takes to "blink," but the surgery will be finished.
4. Pay special attention to the silent child and recognize that he or she may be very upset. Consider the use of a suitable sedative premedication if not otherwise contraindicated.
5. Explain all the procedures to be undertaken in clear and simple terms while avoiding unnecessary and alarming details. Some children may ask about the operation: try to help them understand what is to be done, using

drawings if necessary. Older children in particular may be scared and grossly overestimate the extent of the procedure. They must be reassured, for instance, about the small size of the incision. They may benefit from premedication (see p. 52).

6. Do not use the phrase "put you to sleep"—this may worry some children if they recall a family pet that never came back! It may also cause them to worry that they might wake up from their "sleep" when the operation starts or while it is still in progress.
7. Do not present the child with unpleasant and difficult choices. For example, avoid questions such as, "*Do you want the needle or the mask?*" Tell the child what you intend to do and then try to meet any special requests (e.g., "*I do not want a needle, I want to go to sleep with the mask*" or "*I'd like to hold the mask myself*"). For inhalational inductions, let the child select a flavor to apply to their anesthesia mask.
8. Avoid uncovering the child more than necessary to complete the physical examination; many children get upset at being disrobed.
9. Many distraction strategies reduce children's anxiety preoperatively as well as premedication including iPad tablets, hand-held computer games, television and cartoons, video glasses, music, and magic. Clowns are also effective but are much less practical for many facilities. Allow the child to continue using the distraction strategy until anesthesia is induced.
10. Allow the young child to bring a favorite toy or other security object to the operating room (OR). Label the toy with the child's name; if it is a doll, suggest that perhaps the doll should also get a cast or a dressing applied during the operation. If the child is able, let him or her walk hand in hand to the OR rather than be carried or wheeled: children are quite independent and feel more at ease walking.
11. If appropriate, allow those parents who are judged to be calm and supportive to accompany their child during the induction. If this is not possible, both the child and the parents may be helped by premedicating the child (e.g., oral midazolam, see p. 52). The parents are much more satisfied if their child separates from them very well sedated. It is sometimes useful to start an intravenous infusion away from the OR with the parents present, especially for handicapped or developmentally delayed children. The intravenous route can then be used for both premedication (e.g., midazolam) and/or induction of anesthesia as soon as the child is in the OR. Some prefer to use local analgesia to insert the intravenous cannula; topical anesthetic cream is ideal if it can be applied well in advance (see p. 634).
12. Select the most appropriate induction technique for each child and proceed without delay. Do not allow the child to wait on the OR table longer than is absolutely necessary to apply the basic monitors: a pulse oximeter may be

the only monitor that can be maintained during induction of anesthesia in a combative child.

13. Talk to the child throughout to explain or distract him or her as "magic laughing gas" (70 % nitrous oxide) is administered. Add 8 % sevoflurane to complete the induction.
14. Ensure that all extraneous noises and conversations are excluded during this time. Only one person should be talking to the child. Quiet soothing music may help.
15. An empathic approach should be used to prepare the child. Small children who are crying during venipuncture can often be calmed by telling them, "*We will put on a Band-Aid in a minute*."
16. Tell the child what to expect during the recovery, where recovery will take place, what discomfort they may experience, and for how long. Carefully explain such items as eye patches, nasogastric tubes, and catheters as necessary and that they will be inserted while the child is anesthetized. A urinary catheter may look like a giant worm to an unprepared child! Assure the child that any pain will be treated.
17. Discuss in detail the plan for postoperative pain relief with both the family and the child.

Postoperative Care

The parents should be reunited with their child as soon as it is practical—before the child awakens, if possible. It is imperative that the parents are cautioned that if an emergency occurs in the recovery room, they will be returned to the parent waiting room until it is appropriate for them to return. Every effort should be made to provide good, but safe, analgesia. Regional nerve blocks, opioid infusions, patient-controlled analgesia, epidural opioids, and all ancillary techniques used in adults should be considered, discussed with the parents, and provided for infants and children when appropriate. A discussion of what the parents can expect postoperatively at home and the need for postoperative oral analgesics is also important.

In the intensive care unit (ICU), the child's problems are similar to those for adults: pain, lack of sleep, and, later, boredom. In addition, children have their own special concerns, such as separation from the family. Special attention should be directed to pain relief, regular visitation by the parents, and provision of toys, games, and other distractions (e.g., television, computer games) as the child's condition improves. Parents of children in the ICU benefit by being kept very well informed of their child's condition and progress, and they must also be continuously updated on the treatment plans for their child.

Suggested Reading

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For Parents: The Society for Pediatric Anesthesia has information for parents at its website: http://www.pedsanesthesia.org/frequently-asked-questions/

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CHAPTER 2

Anatomy and Physiology

CENTRAL NERVOUS SYSTEM

The central nervous system in the neonate differs from that in the older child: the myelination of nerve fibers is incomplete, and the cerebral cortex is less developed; its cellular elements continue to increase during the first years of life. Reflexes not seen in older children may be elicited. Neonatal spinal reflexes are more generalized and the threshold is lower. In the preterm, brainstem-evoked potentials are prolonged, and the normalization of these coincides with maturation of respiratory control mechanisms.

Anesthesia-induced developmental neurotoxicity has been demonstrated in some neonatal animal models, but the significance of this to humans remains uncertain and will be difficult to fully determine. Meanwhile, appropriate anesthesia and analgesia should be provided to all young children.

Sensitivity to Pain

Until quite recently, little was understood of the ability of infants and small children to appreciate pain. As a result, there was an unfortunate tendency to ignore the need for analgesia during painful procedures, even during and after surgical operations. It is now well established that neonates, including those born prematurely, may have increased sensitivity to pain and will react to it with tachycardia, hypertension, increased intracranial pressure, and a neuroendocrine response that exceeds that reported in adults. Infants demonstrate measurable behavioral responses to pain (e.g., crying, grimacing, restlessness); these responses have been used as a basis for pain scoring systems. Evidence suggests that infants who are subjected to painful procedures (e.g., circumcision) without adequate analgesia may experience an increased sensitivity to pain as older children. This has been attributed to the persistence of alterations in the infant's central processing of painful stimuli. Control of intraoperative and postoperative pain, by modifying stress responses, may possibly even improve survival in infants with critical illness. It is for these reasons that we provide optimal analgesia or anesthesia for all infants and children during and after *any* painful

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procedure with the same care as we do for adults. As children grow from infancy into early childhood, their pain threshold remains reduced compared with that of older children or adults.

CRANIUM AND INTRACRANIAL PRESSURE

The skull is less rigid in infants than in adults. As a result, an increase in the volume of its contents—blood, cerebral spinal fluid (CSF), and brain tissue—can be accommodated to some extent by expansion of the fontanelles and separation of the suture lines. Palpation of the fontanelles can be used to assess intracranial pressure in infants. Intracranial pressure (ICP) increases with age ranging from 0–6 mmHg in infants to 13–15 mmHg in adolescents.

CEREBRAL BLOOD FLOW AND INTRAVENTRICULAR HEMORRHAGE

Autoregulation of cerebral blood flow (CBF) is impaired in sick neonates, rendering CBF pressure dependent. The threshold below which autoregulation of CBF is impaired is unknown, although some hold that this threshold (mean BP) is the gestational age in mmHg. Hypotension may lead to cerebral ischemia, and pressure fluctuations are transmitted to the capillary circulation. In the preterm infant, the cerebral vessels are very fragile, especially in the region of the germinal matrix overlying the caudate nucleus. Rupture of these vessels leads to intracerebral hemorrhage, which often extends into the ventricular system as an intraventricular hemorrhage (IVH).

Small preterm infants are very prone to IVH, which usually occurs during the first few days after birth and is a leading cause of mortality and morbidity; survivors have a high incidence of cerebral palsy, mental retardation, hydrocephalus, and psychiatric disorders. Potential predisposing factors to IVH include hypoxia, hypercarbia, hypernatremia, fluctuations in arterial or venous pressure, low hematocrit, overtransfusion, and rapid administration of hypertonic fluids (e.g., sodium bicarbonate, dextrose).

The anesthesiologist should avoid precipitating these factors in the small preterm infant: airway manipulations, including awake tracheal intubation, and suctioning have been shown to increase blood pressure and anterior fontanelle pressure to similar extents, similar to coughing as well. “Awake” intubation should be avoided whenever possible (even though a definite relationship between “awake” tracheal intubation and IVH has never been established). If the airway is known or appears to be difficult to secure or maintain by facemask, then an “awake” or preferably sedated tracheal intubation is a reasonable choice.

If an awake tracheal intubation is planned, topical analgesia to the mouth and palate (using weight-appropriate doses of local anesthetic [see p. 142]) may attenuate the infant's physiologic responses.

To further prevent blood pressure fluctuations during surgery or painful procedures, adequate anesthesia and analgesia should be provided. Rapid injections of undiluted hypertonic solutions, such as dextrose or sodium bicarbonate, should be avoided. Care should be taken to replace blood losses accurately. Severe anemia and/or coagulopathy should be corrected promptly. Periventricular leukomalacia is a major feature of persistent brain damage in small preterm infants and may follow IVH or may be a direct consequence of prematurity, hypoxia, ischemia, inflammation, and chronic persistent hypotension. Indomethacin therapy may reduce the incidence of severe IVH.

CEREBROSPINAL FLUID AND HYDROCEPHALUS

The CSF, which occupies the cerebral ventricles and the subarachnoid spaces surrounding the brain and spinal cord, is formed by choroid plexuses in the temporal horns of the lateral ventricles, the posterior portion of the third ventricle, and the roof of the fourth ventricle. Meningeal and ependymal vessels and blood vessels of the brain and spinal cord also contribute small volumes of CSF.

The choroid plexuses are cauliflower-like structures consisting of blood vessels covered by thin epithelium through which CSF continuously exudes. The rate of CSF formation is variable, increasing in the first two years to ~0.13 mL/min. Except for the active secretion of a few substances by the choroid plexus, CSF is similar in composition to interstitial fluid.

CSF flow is initiated by pulsations in the choroid plexus. From the lateral ventricles, CSF passes into the third ventricle via the foramen of Monro and along the aqueduct of Sylvius into the fourth ventricle, each ventricle contributing more fluid by secretion from its choroid plexus. CSF then flows through the two lateral foramina of Luschka and the midline foramen of Magendie into the cisterna magna and throughout the subarachnoid spaces. CSF is reabsorbed into the blood by hydrostatic filtration through the arachnoid villi, which project from the subarachnoid space into the venous sinuses. Hydrocephalus is an abnormal accumulation of CSF within the cranium that may be either obstructive or nonobstructive.

Obstructive hydrocephalus is caused by a blockage in the flow of CSF. It may be communicating (e.g., when the CSF pathway into the subarachnoid space is open, as after chronic arachnoiditis) or noncommunicating (e.g., when the fluid's pathway proximal to the subarachnoid space is obstructed, as in aqueductal stenosis or Arnold-Chiari malformation).

Nonobstructive hydrocephalus is caused by a reduction in the volume of brain substance, with secondary dilation of the ventricles; by overproduction of CSF (e.g., in choroid plexus papilloma); or by diminished reabsorption of CSF due to scarring.

EYES

Retinopathy of Prematurity

Retinopathy of prematurity (ROP), which is caused by retinal vessel proliferation and retinal detachment, is a leading cause of blindness. Improved survival of very-low-birth-weight infants increased the incidence of this condition. ROP is most common in neonates weighing less than 1500 g. The role of increased oxygen levels in the blood in the etiology of ROP has long been recognized. Limiting the inspired oxygen concentration reduces ROP but, if excessive, may increase both mortality and the incidence of necrotizing enterocolitis. The development of ROP is now considered to progress in stages. Preterm birth exposes the retina to oxygen levels in the blood that are greater than those during intrauterine development, which decreases local vascular growth factors, interrupting the orderly vascularization to the retinal periphery. In the second phase, the peripheral retina becomes metabolically active but with inadequate perfusion. Hypoxic ischemic damage ensues. Inspired oxygen levels in the blood accelerate this process and compound the situation by high levels of damaging "reactive oxygen species."

The clinical factors associated with ROP include hyperoxia, hypoxia, hypercarbia, or hypocarbia, blood transfusion, recurrent apnea, sepsis, and other systemic illness. Occasionally, ROP occurs in infants who have never been given supplemental oxygen and even in infants with cyanotic congenital heart disease. A major multi-institutional study of tight control of oxygen administration failed to reduce the incidence of ROP. Nevertheless, the inspired oxygen concentration should be carefully controlled in all preterm infants to prevent unnecessary hyperoxia. Large fluctuations in inspired oxygen concentrations should be avoided. The safe level of PaO_2 is now considered to be 50–70 mmHg. Monitoring oxygen saturation at a preductal site (right hand or earlobe), maintaining the arterial oxygen saturation (SaO_2) at 90–95 %, and avoiding large fluctuations in oxygen levels are recommended. On occasion, it may still be necessary to err on the side of safety and administer greater inspired oxygen concentrations. Major surgical procedures do not appear to predispose infants to ROP.