Intensive Care in Digestive Surgery

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5.1 Introduction

Postoperative admission to the pediatric intensive care unit (PICU) is foreseen for all pediatric patients undergoing major digestive surgery and all children with a basic critical illness, often unrelated to the abdominal problem that leads to surgery, which requires monitoring and/or intensive treatment. Hospitalization in intensive care increases the security of critical patients in the delicate phase that follows the surgery, characterized by the need to maintain a proper respiratory, cardiovascular, and metabolic function and stabilization of these features, together with the need for analgesia and sedation, appropriate fluid therapy and electrolyte compensation, neurological monitoring, and prevention/treatment of infections.

It should also be pointed out that for some diseases, often typical of the neonatal age, such as esophageal atresia, abdominal wall defects, and necrotizing enterocolitis, the surgery is part of an intensive treatment, which begins at birth and which also involves an important phase of preoperative treatment and stabilization. For these clinical conditions, the more correct term is perioperative intensive care [1].

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5.2 Intensive Monitoring

Monitoring is one of the main prerogatives of intensive perioperative hospitalization, which may involve pathologies with clinical controls and rapid autonomization or others requiring long and complex assistance.

Particular importance is given to respiratory monitoring, with attention to the type of mechanical ventilation, the respiratory weaning, and the techniques of noninvasive respiratory assistance, and to the cardiovascular, metabolic and electrolyte, temperature, and neurological monitoring carefully tailored to the level of consciousness and sedation of the patient.

The respiratory monitoring involves simple and noninvasive instrumentation ranging from pulse oximetry and capnography to the reading of volumes, pressures, and compliance curves present during mechanical ventilation. An important control is that of the arterial blood gases, which offers the opportunity to further monitor oxygenation parameters such as alveolar-arterial gradient oxygen ($A\text{-}aDO_2$), oxygenation index (OI), arterial-alveolar ratio (a/AO_2), and PaO_2/FiO_2 ratio, useful in the evaluation of the postoperative alveolar recruitment in many challenging diseases such as esophageal atresia, omphalocele, and gastroschisis. The traditional control of the chest with imaging through X-ray until the computed tomography is now usefully supplemented by the use of ultrasound lung, easily repeatable and usable in the control/treatment of conditions

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such as pneumothorax, pleural effusion, and pulmonary atelectasis [2, 3].

Hemodynamic monitoring focuses on parameters of the conventional type such as ECG, invasive or noninvasive blood pressure, and central venous pressure as well as on parameters obtained through the method of pulse contour analysis and transpulmonary thermodilution, which allow the continuous evaluation of cardiac output, peripheral vascular resistance, and stroke volume, in addition to the measurement of preload in volumetric terms and the estimation of the intrathoracic blood volume (ITBV) and the amount of extravascular lung water (EVLW).

Furthermore, it is possible to obtain the evaluation of the perfusion of tissues such as the brain, renal, and splanchnic through the "near-infrared spectroscopy" (NIRS). Finally, again through ultrasound method, the monitoring of the filling fluid challenge can be obtained through the measurement of the size of the vena cava.

Monitoring in PICU includes control of the main laboratory tests and evaluation at regular intervals of daily input and output of fluid in order to accurately assess the volume status of the patient.

The children admitted require careful monitoring to prevent infectious complications. The monitoring follows a strict protocol of surveillance involving culture tests such as throat swabs, rectal samples, biological tracheobronchial secretions, gastric and urinary content, and material conducted by any drainage. The surveillance begins at the induction of anesthesia in the operating room or at the time of admission to the PICU. It should also examine all the types of principal invasive devices and drainage at the time of their removal. Blood cultures are programmed if the patient's clinical condition and the biohumoral markers suggest severe sepsis.

5.3 Respiratory Treatment

After major digestive surgery, often the main treatment in PICU is instrumental support of the respiratory function, which provides a gradation of interventions depending on the severity of the respiratory failure. Early respiratory weaning and extubation are safe and feasible in many patients, but in a significant minority, this might not be possible. A number of factors have been shown to contribute to delayed weaning from the ventilator. These include perioperative factors such as known chromosomal and neurological abnormalities, the age of the patients, the presence of airway problems and pulmonary disease, the complexity of the operation, postsurgical complications, and myocardial dysfunction.

The main objectives of such support are the insurance of an adequate alveolar ventilation, with CO_2 removal associated with a satisfactory oxygenation, improving the relationship of ventilation/perfusion (VA/Q), encouraging alveolar recruitment, and reducing the work of breathing (Table 5.1).

The first measures are constituted by methods of noninvasive ventilatory (NIV) assistance, combining oxygen therapy with the possible application of positive airway pressure and/or of a ventilatory support (high-flow nasal oxygen, NIV equipment), with the use of different interfaces depending on the age of the patient (nasal prong, masks, or helmets) (Figs. 5.1 and 5.2) [4].

If the newborn and children require intubation, the possibilities of ventilatory assistance can range from techniques of controlled ventilation (mainly controlled pressure) to assisted methods, used in the weaning of patients such as synchronized intermittent mandatory ventilation (SIMV), pressure support (PS), and continuous positive airway pressure (CPAP) [5, 6].

Table 5.1 Objectives of mechanical ventilation

Support or manipulate pulmonary gas exchange
Normalize alveolar ventilation (PaO_2, $PaCO_2$, and pH)
Achieve and maintain $PaO_2 > 90$ mmHg and peripheral Sat $O_2 > 95\,\%$
Increase lung volume and maintain adequate functional residual capacity (FRC)
Obtain lung expansion and prevent or treat atelectasis
Improve oxygenation and lung compliance
Reduce the work of breathing in the presence of high airway resistance and/or reduced compliance, when spontaneous breathing becomes ineffective

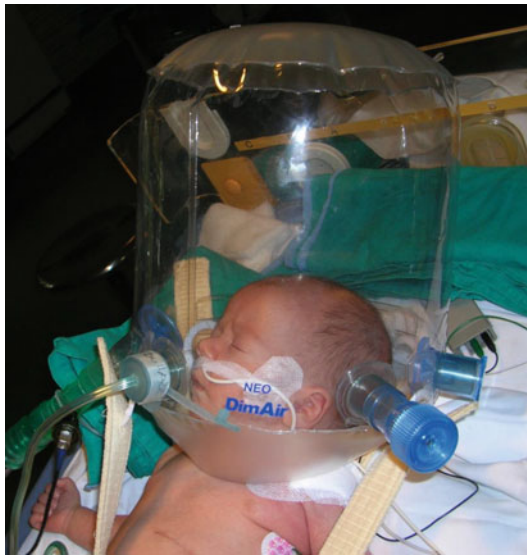

Fig. 5.1 Noninvasive ventilatory (NIV) assistance with helmet in neonatal age

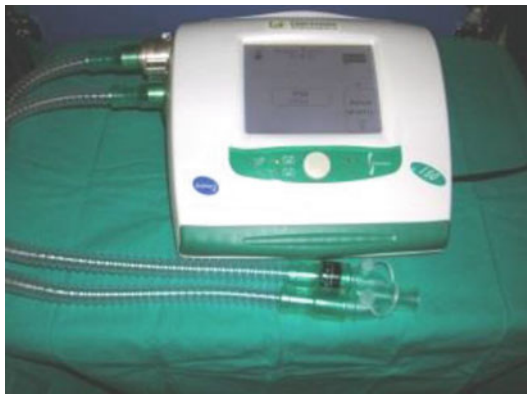

Fig. 5.2 Ventilator for noninvasive ventilatory (NIV) assistance

A particular method of ventilation is controlled high-frequency oscillatory ventilation (HFOV) characterized by very small volumes (less than the dead space) and extremely high respiratory rates between 5 and 15 Hz (300 and 900 breaths/min). Oscillatory ventilation produces a series of oscillations (positive and negative) in the airways, with an active expiratory phase, and during the entire respiratory cycle, lung volume is maintained almost constant (Fig. 5.3).

An interesting ventilatory approach, very useful for the weaning of patients, is the neurally

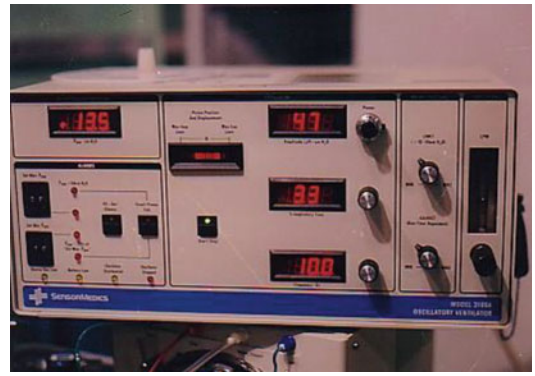

Fig. 5.3 Parameters of respiratory assistance with high-frequency oscillatory ventilation (HFOV)

adjusted ventilatory assistance (NAVA) based on neural respiratory control [7, 8]. By NAVA, the electrical activity of the diaphragm (Edi) is captured with an appropriate catheter, equipped with an array of nine miniaturized electrodes, which must interface in the lower esophagus at the level of the diaphragm, in order to obtain the best electrical signal from diaphragmatic fibers. The catheter sends the signals to the ventilator and is used to assist the patient's breathing [9, 10]. Since the mechanical ventilator and the diaphragm work with the same signal, the mechanical coupling between the diaphragm and the mechanical ventilation is virtually instantaneous (Fig. 5.4).

The ventilation in neonatal and pediatric age during the postoperative course after surgery requires a solid basic understanding of respiratory system mechanics (pressure-volume relationship of the respiratory system and the concept of its time constants) and cardiopulmonary physiology. Furthermore, careful attention has to be paid to avoid damaging the lungs by potentially injurious mechanical ventilation. Optimizing ventilator settings during controlled and assisted ventilation must lead to a progressive and gentle lung recruitment, avoiding the damage caused by strong and repetitive opening/collapse of distal airways and excessive alveolar hyperinflation.

Especially in neonatal age, in the presence of a still immature lung, and in association with problems such as pulmonary infections, sepsis, aspiration of saliva or gastric juice, and severe heart diseases, excessive mechanical ventilation

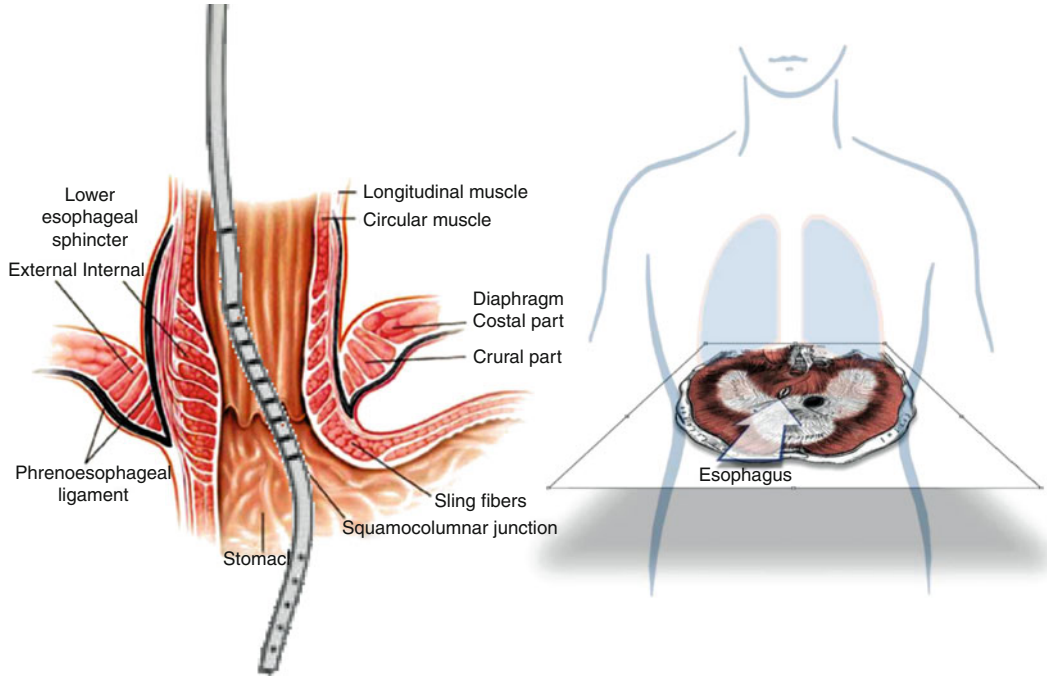

Fig. 5.4 The electrical discharge of the diaphragm captured through the introduction in the lower esophagus, at the level of the diaphragm, of a NAVA catheter equipped with an array of nine miniaturized electrodes

can lead to lung injury, emphasizing phenomena of volutrauma and barotrauma, which can result in a biotrauma, characterized by alveolar damage, with increased microvascular and epithelial permeability, fluid filtration, and pulmonary edema.

This clinical condition can approach an acute respiratory distress syndrome (ARDS), characterized by the absence of secretion or abnormalities in the action of surfactant, resulting in decreased lung compliance and significant hypoxemia. Administration of surfactant, associated with HFOV, may represent an effective method of lung recruitment and alveolar recovery in acute pulmonary injury and in ARDS. Bronchoscopic instillation offers the theoretical advantages that the surfactant may be distributed directly to the desired regions of the lung, with a more economical use of the drug and with the opportunity to lavage leaked serum proteins prior to instillation.

5.4 Cardiocirculatory Treatment

The cardiac output (CO) is the result of the heart rate multiplied by the stroke volume; it undergoes changes according to the variation of the two parameters.

Modifications of the heart rate are able to result in major reductions in cardiac output: bradycardia in children, especially at an early age, causes an important reduction of CO, as the systolic ejection volume does not increase in proportion to the decrease of the heart rate, because of poor ventricular compliance, due to the immaturity of the cardiac muscles.

Tachycardia, up to 200 beats/min, seems better tolerated, as it is accompanied by a proportional increase in CO.

Likewise, limitations in stroke volume also involve a significant lowering of cardiac output. Supporting cardiovascular disease in young patients with digestive surgery must include both

principal actions for the overall improvement in stroke volume and specific interventions with antiarrhythmic therapy.

5.4.1 Increase of Stroke Volume

The increase of the CO is achieved, thanks to an increase in the volume of systolic ejection. It depends on and is influenced substantially by three mechanisms:

- Increase in the preload
- Increase in myocardial contractility
- Reduction of the afterload (vascular resistance against which the ventricle pumps the blood volume)

The volume expansion contributes to the increase in preload; it should benefit from the use of crystalloid, colloid, and blood and its derivatives. At first contributions of 10–20 ml/kg isotonic polyelectrolyte solutions are likely to improve the clinical condition with the recovery of peripheral perfusion, decreased heart rate, and the recovery of a viable diuresis. These quantities are usually well tolerated hemodynamically.

Secondly, volume resuscitation of a patient with hypovolemic or septic shock is an essential component of initial patient care. Massive amounts of intravenous fluid are usually administered to replace intravascular volume deficit and to minimize complications attributed to hypovolemia such as tachycardia, hypotension, acute kidney injury, and multiorgan failure. Goal-directed therapies focused on the restoration of normal blood pressure and organ perfusion have been advocated in the management of critically ill patients. Early goal-directed therapy, which is instituted in the initial phase of management of patients with severe sepsis or septic shock, has been shown to improve overall survival [11, 12].

In contrast to the notion of aggressive and liberal volume resuscitation, a growing body of evidence strongly suggests that fluid overload may be detrimental to critically ill patients. Relatively, little attention has been paid to the consequences of fluid overload such as respiratory failure, increased cardiac demand, and peripheral edema. Recent studies on patients with acute lung or kidney injury have reported that fluid overload has been associated with adverse outcomes [13, 14].

The treatment of choice for the optimization of myocardial contractility appears to be the correction of all unfavorable factors (hypoxia, acidosis, hypoglycemia, hypocalcemia, drugs, and toxic substances). Positive inotropic agents, pressor drugs, and vasodilators are indicated as appropriate [15]. Sympathomimetic amines are compounds used in optimizing hemodynamics.

Dopamine is a catecholamine most used in neonatal and pediatric age. Its action takes place on both beta and alpha receptors at a dose of 5–10 mcg/kg/min, respectively. The positive inotropic effect is still mainly due to the release of endogenous norepinephrine. Its positive inotropic effect is modest overall. In patients with renal impairment, it is the drug of choice because at a dose of 3–2 mcg/kg/min, in continuous administration, it ensures a vasodilatation of the splanchnic and renal vascular system. Such action however is discussed for renal and intestinal protection.

Dobutamine increases myocardial contractility, systolic ejection volume, and cardiac output; it decreases the systemic and pulmonary resistance when used in cardiac failure. Even at high doses, it has little effect on heart rate and does not cause an increase in peripheral resistance. It is therefore particularly indicated for patients with severe heart failure. Its action is predominantly beta-adrenergic. This drug is normally used in continuous infusion at a dose of 5–10 mcg/kg/min. It has no specific action on renal and mesenteric circulation and is therefore often used jointly with low-dose dopamine.

Epinephrine is the drug of choice in cardiopulmonary resuscitation (CPR). It possesses potent inotropic and chronotropic effects, associated with action on the alpha and beta receptors of the systemic vascular resistance. In moderate doses it proves to be a real inotropic support in critically ill patients, even when other medicines have not been fruitful; the risk of a response in generalized vasoconstriction is real only at high doses.

In other cases, it is necessary to resort to a reduction in the afterload; the decrease in systemic vascular resistance decreases afterload and increases the volume of systolic ejection, without being accompanied by increased myocardial oxygen demand.

Sodium nitroprusside is a vasodilator with effects on vascular resistance (arteries) and capacitance (veins). Arteriolar dilation produced by this drug reduces the afterload; increased vascular capacitance requires proper support of the preload. It is normally used at a dosage of 0.5–10 mcg/kg/min; its administration requires continuous monitoring of cyanide and thiocyanate metabolites [16].

Nitroglycerin dosage of 1–20 mcg/kg/min has an action prevailing on vascular capacitance with an effective reduction of the preload.

Amrinone is an inhibitor of phosphodiesterase, which has positive inotropic action and is a powerful vasodilator. It is administered slowly in boluses of 0.75–1 mg/kg, followed by continuous infusion of 5–10 mcg/kg/min.

5.4.2 Heart Rate and Rhythm Normalization

Tachyarrhythmias have recently been reported in childhood but can be related to the increased presence of circulating catecholamines, electrolyte abnormalities, metabolic acidosis, hypoxia, and hypercapnia. Pheochromocytoma and hyperthyroidism are the endocrine disorders that most frequently are associated with tachyarrhythmias. Often beta-blocker drugs, especially propranolol at a dose of 0.01–0.1 mg/kg/day, constitute the drugs mainly used, even only to reduce an excessive increase in heart rate.

Supraventricular tachycardia (SVT) is the most common rhythm disturbance in children. Adenosine is considered the drug of choice to correct the SVT. If administered quickly, at a dose of 0.1 mg/kg through a central venous catheter, it causes an immediate reduction in the frequency of the sinoatrial node and the conduction velocity of the atrioventricular node. The doses may be repeated and the dosage increased up to 0.2–0.3 mg/kg, with a maximum total dose of 12 mg.

Ventricular tachycardia, fortunately infrequent in children, requires immediate treatment. In the acute phase lidocaine (1 mg/kg), amiodarone (5 mg/kg) and procainamide (5–15 mg/kg) intravenous are recommended. Electrical cardioversion is indicated when the patient remains unstable despite drug treatment.

5.5 Fluid Management

Fluid management of the pediatric surgical patient represents an important aspect of clinical care, particularly for the initial treatment of the sick child. An understanding of the physiology of fluid requirements is essential for care of these children. Infants and children are sensitive to small degrees of dehydration, and commonly used protocols for pediatric fluid therapy do not consider the rapidly changing perioperative physiology in this patient population. Standard formulas for fluid therapy can be modified to account for these rapid changes in physiology (Table 5.2).

Control and distribution of body fluids in neonates, infants, and children are carried out in large part through the kidney and vary according to the different age groups: the total water of a premature infant represents approximately 85 % of body

Table 5.2 Postoperative fluid management

Patient weight	Daily fluid intake
<10 kg	85–100 ml/kg
10–20 kg	1000 ml + 50 ml every kg > 10 kg
>20 kg	1500 ml + 20 ml every kg > 20 kg

weight, with a redistribution percentage between the extracellular fluid volume (ECV) and intracellular fluid volume (ICV) of 55% and 30%, respectively; in term infant the total water constitutes 78% with an ECV equals to 45% and an ICV to 33%. Only at 1-year-old (total H_2O = 65%) is the reversal of the percentages of the two compartments witnessed (ICV = 40% and ECV = 25%), which is the characteristic of adults (total H_2O 60%, ICV 40%, and ECV 20%).

Two aspects are most relevant in designing a fluid therapy in all ages: fluid intake and volume replacement. Intravascular fluid guarantees tissue perfusion; therefore, paying attention to it must have the highest priority. Fluid replacement is necessary to maintain the hydroelectrolytic homeostasis and acid-base balance. Fluid distribution is regulated by osmotic pressure: hypothalamic nucleus is sensitive and responds to very low variations, and this condition causes a hormonal response, involving the secretion of ADH and aldosterone. The dehydrated patient produces more ADH to preserve the H_2O. It should be taken into account that during the intraoperative period, ADH secretions may increase due to factors other than the osmotic ones (pain, stress, drugs). For a correct fluid postoperative planning, consideration must be given to the metabolic requirements, intraoperative administration, "third-space" sequestration, blood loss related to surgery, and particular conditions such as the use of radiant lamps for neonates/preterms [17].

Fluid requirements depend on the metabolic expenditure, which is higher in neonatal age. Under normal conditions, 100 ml is required to metabolize 100 Kcal, according to the calculation of Holliday and Segar.

5.6 Analgosedation Management

Effective and adequate therapy to control pain and stress is essential in the management of children in perioperative digestive surgery treatment.

Analgosedation must meet different requirements: adequacy, appropriateness, effectiveness, and safety.

Much evidence confirms that pain and stress must be treated in order to prevent short- and long-term adverse outcomes [18–20].

Not rarely a correct analgosedation management is hard to achieve and overtreatment and undertreatment are both harmful. The complexity and the clinical difficulties due to the age of the patients sometimes induce therapeutic priorities to preserve cardiocirculatory stability or to ensure neurological evaluation, giving up analgesic and sedative drugs and underestimating the consequences of an inadequate pain control and prolonged stress.

Therapeutic necessities of a patient should be set up in advance on dedicated and shared internal protocols, integrated into local context and appropriate to the needs of specific situations, in order to prepare later and progressively an efficient and personalized analgosedation therapeutic plan, according to real needs of the patient.

5.6.1 Pain and Sedation Measurement

Analgesia must be regularly assessed and documented using validated age-related scales.

Self-report scales are preferred instruments for pain assessment in patients with adequate cognitive development. There are several proposals for different ages: the Faces Pain Scale (>3 years), the visual analog scale (VAS), and the numerical rating scale (NRS) (>7 years).

Observational scales must be applied in patients aged less than 3 years or unable to communicate and therefore are the most used in intensive care; some of them, multidimensional, also include the registration of physiological parameters such as heart rate, blood pressure, and SpO_2.

Observational scales recommended for neonatal age are the Premature Infant Pain Profile (PIPP) and the Crying, Requires increased oxygen administration, Increased vital signs, Expression, and Sleeplessness (CRIES) scale; for children the Face, Legs, Activity, Cry, and Consolability (FLACC) and the Children's

Hospital of Eastern Ontario Pain Scale (CHEOPS) are used.

Pain measurement must be carried out at regular intervals like other vital signs to monitor changes in pain intensity over time and the effectiveness of the treatment. Intervals of 4–6 h may be sufficient if pain control is adequate.

Sedation must be regularly assessed and documented using adequate monitoring scales. The COMFORT scale, validated also for the neonatal age, is the most utilized tool [21].

5.6.2 Drugs for Analgosedation

Measurement of pain and the identification of its underlying causes lead to the choice of analgesic drug, which must be of adequate power and targeted to causal mechanisms.

Acute pain is the form most frequently met in PICU, but complex patients with prolonged stay in intensive care may present with persistent, chronic forms of pain, for which a multimodality approach may be necessary (Table 5.3).

Acetaminophen in neonates and acetaminophen and nonsteroidal anti-inflammatory drugs in children above 3 months of age are recommended for treating mild pain (Table 5.4).

Opioids are the drugs recommended for treating moderate-to-severe pain (Table 5.5).

In some patients, adding nonsteroidal anti-inflammatory drugs or acetaminophen to opioids is useful.

Fentanyl is indicated in the presence of cardiocirculatory instability and in neonates with persistent pulmonary hypertension.

Table 5.3 Postoperative pain management. Multimodality approach

Acetaminophen
Nonsteroidal anti-inflammatory
Opioids
Regional anesthesia
Local infiltration of the trocar insertion in laparo- and thoracoscopy
Local wound infiltration
Nonpharmacological techniques

Regional techniques must always be considered in cases of localized pain such as procedures and surgery. Epidural analgesia is effective for acute pain after surgery or trauma to the chest, abdomen, pelvis, or lower limbs, although its safe management requires expertise and good skill level.

The aims of sedation are reduction of distress, fear, and agitation, improvement of patient-ventilator synchrony, and decrease in self-removing of invasive devices. Sedation cannot be pursued without an adequate analgesic treatment, since persistent not treated pain hampers the sedation strategy.

Midazolam is the most frequent benzodiazepine used for sedation in pediatric intensive care. Its administration by continuous intravenous infusion varies between 0.5 and 4 mcg/kg/min. Midazolam is not recommended in premature infants because of the high incidence of neurological adverse events related to continuous infusions.

Propofol is a sedative/amnestic agent with no analgesic properties. Although initially introduced into anesthesia practice, its rapid onset, rapid recovery time, and lack of active metabolites led to its evaluation as a drug for intensive care sedation. Its use for prolonged periods of time may cause adverse effects such as hyperlipidemia, hypercarbia, and the "propofol infusion syndrome," characterized by metabolic acidosis, rhabdomyolysis, arrhythmias, and cardiac failure [22].

5.6.3 Tolerance and Withdrawal Syndrome

Long-term treatments can be complicated by tolerance. Drugs and patient-related factors take part in developing tolerance, defined as the pharmacodynamic reduction of the secondary effects to long-term therapy.

Symptoms of withdrawal may develop during therapy discontinuation: hypersympathetic activity, neuroexcitability, and gastrointestinal impairment. Symptoms are not specific, and withdrawal syndrome may pass underdiagnosed

Table 5.4 Doses and method of postoperative administration of acetaminophen, main nonsteroidal anti-inflammatory drugs (NSAIDs), and tramadol used in children

Drugs	Administration	Dose (kg/day)	N° times (day)	Continuous
Acetaminophen	Oral, rectal	60–90 mg	4–6	
Acetaminophen	Intravenous	60–90 mg	4–6	
Ibuprofen	Oral, intravenous	20–40 mg	3–4	
Ketoprofen	Oral, intravenous	5–7.5 mg	3	
Ketorolac	Oral, intravenous	1–1.5 mg	3	
Naproxen	Oral, intravenous	10–20 mg	2	
Acetylsalicylic acid	Oral, intravenous	40–80 mg	4	
Tramadol	Oral, intravenous	2–3 mg	2–3	0.1–0.25 mg/kg/h

Table 5.5 Postoperative pain management. Drug doses, onset, duration, and potency of opioid narcotics

Drug	Potency	Doses (mcg/kg/h)	Onset (min)	Duration (h)	Respiratory depression
Morphine	1	10–50	20–30	3–4	+++
Fentanyl	100	0.5–4	3–5	0.5–1	+++
Alfentanil	20	3–15	1.5–3	0.2–0.3	+
Remifentanil	250	0.05–1 (mg/kg/min)	1–2	0.1–0.2	+

or not recognized, since such symptoms may be frequently ascribed to other pathologic conditions seen in PICU.

Risk factors have long been identified and must always be evaluated: length of the therapy (>5 days) and cumulative dose (fentanyl in neonates > 1.6 mg/kg, in infants > 2.5 mg/kg, midazolam > 60 mg/kg). Even if the incidence of the withdrawal syndrome is variable in different epidemiological studies, it seems clear that the syndrome develops mainly when analgosedation drugs are too rapidly reduced or abruptly withheld [23–25].

5.7 Nutritional Support

Clinical nutrition is a therapeutic act that helps meet the nutritional needs of patients unable to feed adequately in a natural way. Objectives of clinical nutrition are reduction of the damage produced by pain and surgical stress, preventing the onset of a condition of malnutrition, and/or the reduction of its implications if they were already present.

The quantitative and qualitative composition of the nutrition begins with the identification of needs in normal terms and assesses the changes related to the clinical status. Almost always it is good to take as a reference point the actual weight, considering the ideal weight only in cases that deviate significantly from normality.

Enteral and/or parenteral nutrition should aim at covering the nutritional needs of the patient in terms of basal metabolic rate and physical activity and correction of preexisting malnutrition, growth, and disease states.

Excessive nutritional intake can cause hyperglycemia, increased fat, fatty liver disease, disorders of the lipid, and protein metabolism. By contrast, a reduced intake can cause weight loss, malnutrition, impaired immune response, delayed tissue repair, and growth retardation.

The World Health Organization (WHO) indicates the adequate daily intake in pediatric age.

Tolerance of caloric intake is limited by the capacity to metabolize substrate calories, depending on the route of administration, the activity, the age, and the pathology of the patient.

A newborn subjected to parenteral nutrition (PN) requires a lower caloric intake compared to a similar neonate subjected to enteral nutrition (EN), since the consumption determined by the

dynamic-specific action, related to intestinal absorption, is absent.

Early nutritional support is always necessary in newborns, especially in premature with reduced gestational age, such as very-low-birth-weight (VLBW) infants, whose birth weight is below 1500 g and that, because of their limited nutritional reserves, need a higher protein and calorie intake than a normal-weight newborn.

An important aspect of postoperative stress in pediatric surgery is that, after surgery, energy expenditure reaches a maximum value of 2–4 h after operation, returning to baseline within 24 h. The amount of energy expenditure is related to the severity of the surgery and remains higher in premature infants and in the first 48 h of life.

Pain, stress, and trauma surgery greatly influence a correct nutrition through hormonal imbalance initially characterized by reduced insulin secretion and increased release of the hormones with opposite action, such as catecholamines and glucagon. This early phase is characterized by a reduced utilization of metabolic nutrients. Subsequently, it develops into a tendency toward a hypermetabolic state, with an increased demand for protein and calories, which are drawn from the energy reserves of the organism, with a redistribution among deposit tissues, such as fat, toward organs with high metabolic needs such as the nervous tissue and viscera, including the liver and kidney. This altered nutritional, metabolic, and hormonal condition, if not supported by a gradual and controlled administration of nutrient intake, can lead to a state of catabolism and protein/caloric malnutrition, which in turn is responsible for:

- Increased susceptibility to infection
- Hypoprotidemia
- Slowing the healing of surgical wounds (gastrointestinal anastomosis)
- Increase of decubitus ulcers
- Increased presence of altered gastrointestinal bacteria
- Reduced intestinal absorption and nutrient loss with feces

After a major surgery, necessitating a state of starvation, it is mandatory to intervene through artificial feeding, of which there are two modes of administration: enteral and parenteral nutrition. On the basis of the age and the presence of endogenous reserves of nutrients, which are scarcer the lower the age of patients, it is necessary to program an artificial nutrition plan, which should not be delayed beyond 24 h in neonates and infants and beyond 48–72 h in later age bands. In the postoperative period following digestive surgery, parenteral nutrition is most frequently adopted.

The start and progressive increase of nutrients up to the desired values is called the induction phase of the parenteral nutrition (PN). Nutrients must be administered with well-calibrated increments, respecting a constant relationship between protein intake and energy intake (provided by nonprotein calories which are the sum between calories of carbohydrates and lipids). This ratio has to be carefully balanced (nitrogen grams/nonprotein calories = 1/150–250). In this phase the metabolic indexes should be checked frequently to test the tolerance of the patient to PN. In the following days, with the PN at a stability condition, if well tolerated by the patient, the biochemical controls may be weekly. With the achievement of the phase of stabilization, monitoring of the auxological parameters, such as nitrogen balance, visceral protein (retinol, prealbumin, transferrin), weight, height, and head circumference, is particularly useful [26].

As soon as bowel function is recovered, the PN can be suspended with a gradual reduction of the volume and amount of nutrients (weaning phase).

Table 5.6 shows the nutritional needs during total parenteral nutrition.

5.8 Abdominal Compartment Syndrome

5.8.1 Introduction

Abdominal compartment syndrome (ACS) is defined as the adverse physiologic consequences resulting from an increased intra-abdominal pressure (IAP). The organ systems most affected include the cardiovascular, renal, and pulmonary

Table 5.6 Nutritional needs during total parenteral nutrition

Age and weight	Protein (g/kg/day)	Carbohydrates (g/kg/day)	Lipids (g/kg/day)*
Premature	3–4	12–14–16	2–3
Neonate	3	18	2–3
3–10 kg	2.5–3	16–18	2
10–15 kg	2.5	12–14	2
15–20 kg	2	10–12	1.5
20–30 kg	1.5–2	<12	1.5
>30 kg	1.5	<10	1
Critically ill children	1.5–3	7.5	1–2

*Lipids in TPN
Lipid intake 25–35 % of nonprotein calories
Minimum 0.25 g/kg/day to prevent EFA deficiency
Maximum 2–3 g/kg/day in neonates and infants
Administration continuously over about 24 h

systems. If untreated, ACS can cause clinical deterioration and rapidly lead to crucial organ failure and death. On the other hand, abdominal decompression usually leads to a prompt reversal of the adverse pathophysiologic modifications.

5.8.2 Etiology and Pathophysiology

In pediatric age, ACS has been associated with several etiologies including abdominal injury with postoperative bleeding, abdominal hemangioma, trauma, bowel necrosis, mesenteric vein thrombosis, omphalocele, gastroschisis, intestinal graft-versus-host disease, intestinal perforation, peritonitis, necrotizing enterocolitis, hepatic veno-occlusive disease, shock, and burns requiring massive fluid resuscitation.

Intra-abdominal pressure under normal condition is usually 0 mmHg and is slightly positive in patients submitted to mechanical ventilation, because of transmission of intrathoracic pressure in the abdomen. Initially, IAP rises slowly as abdominal contents and girth increase. However, at a certain critical level, compliance of the abdominal wall reaches its limits, and any further distension results in a rapid rise in abdominal pressure, decreased organ perfusion, and development of clinical ACS.

As intestinal ischemia leads to bowel distension, bowel wall edema, and capillary leak, it can set up a vicious cycle by further increasing IAP and may eventually lead to both bowel necrosis and ACS [27].

5.8.3 Clinical Presentation

5.8.3.1 Cardiovascular

With advancing ACS, the patient presents a profound shock often unresponsive to fluid resuscitation and vasoactive drugs. Reduced cardiac output results primarily from decreased venous return because of compression of the inferior vena cava and the portal vein as well as from increased intrathoracic pressure, which markedly reduces cardiac preload.

Increased thoracic pressure, related to diaphragmatic elevation, was shown to decrease left ventricular compliance and a very high IAP to decrease myocardial contractility. Hemodynamic function is further impaired by increased systemic vascular resistances induced by increased IAP.

5.8.3.2 Respiratory

Respiratory failure is a major component of the ACS and is characterized by elevated peak ventilatory pressure, hypoxemia, and hypercarbia. The elevated IAP causes upward displacement of the diaphragm and compresses the lungs, resulting in progressively stiffer chest with extremely low compliance.

5.8.3.3 Renal

Oliguria progressing to anuria, both of which can be unresponsive to fluid therapy and diuretics, is the hallmark of the ACS. Elevated IAP results in markedly increased renal venous pressure and impaired renal venous drainage: this is thought to be the most important mechanism of renal dysfunction.

5.8.3.4 Gastrointestinal

Increased IAP was shown to significantly reduce splanchnic perfusion. At an IAP of 20 mmHg, significant decreases in blood flow to all segments of the bowel, the liver, the kidneys, and the spleen were demonstrated. Impaired intestinal perfusion results in anaerobic metabolism, lactic acidosis, and free radical production.

5.8.3.5 Cerebral

Increased intracranial pressure (ICP) is a recognized component of ACS. In recent years several case reports described prompt reductions in elevated ICP following abdominal decompression.

5.8.4 Intra-abdominal Pressure Determination

Intra-abdominal pressure can be determined by measuring intragastric pressure, inferior vena cava pressure through a long femoral venous catheter, or urinary bladder pressure. This last procedure is simple and practical in which an age-adjusted amount of saline is injected through a urinary catheter connected to a pressure transducer (Table 5.7).

5.8.5 Management

5.8.5.1 Medical Care

Critical care management of the patient with ACS consists of supporting the failing organ system until definitive therapy is instituted and the basic problem can be brought under control.

Volume resuscitation with repeated fluid challenges is the mainstay of cardiovascular support, aiming and improving the decreased preload that causes the reduced cardiac output. This should be increased by inotropic support (dopamine, dobutamine, epinephrine) if response is inadequate.

Most patients will require mechanical ventilation, and, as abdominal pressure rises, higher airway pressures and FiO_2 will be required to maintain gas exchange.

These measures, however, will at best result in temporary improvement, because they do not alleviate the underlying problem and may actually result in further deterioration as more fluids leak into the abdominal third space.

5.8.5.2 Surgical Care

The key to successful management of ACS is an early diagnosis and prompt surgical decompression of the abdomen.

In patients whose ACS is caused by intra-abdominal accumulation of fluid, such as ascites, peritoneal tap and continuous drainage may resolve the problem.

Following decompression, primary abdominal closure without excessive pressure is usually impossible, and the abdominal cavity is left open with the use of various temporary abdominal wall closure techniques.

Several techniques are described depending on the underlying disease, age, and severity of the clinical condition: the use of "only-skin" closure, the Dacron mesh, and the external sterile plastic pack (vacuum pack) or of sterile 2-L intravenous fluid bag ("Bogota" bag).

Table 5.7 Grading of abdominal compartment syndrome by intra-abdominal pressure and percentage of organ failures, with recommendation for treatment

Grade	Bladder pressure (mmHg)	Urine output <0.5 ml/kg/h	PIP >45 mmHg	SVR >1000 dyn/s/cm^{-5}	DO_2I >600 O_2/min/m^2	Recommendations
I	10–15	0 %	0 %	0 %	0 %	Maintain normovolemia
II	16–25	0 %	40 %	20 %	20 %	Hypervolemic resuscitation
III	26–35	65 %	78 %	65 %	57 %	Decompression
IV	>35	100 %	100 %	100 %	100 %	Decompression and re-exploration

PIP peak inspiratory pressure, *SVR* systemic vascular resistances, *DO_2I* oxygen delivery index

5.9 Necrotizing Enterocolitis

Necrotizing enterocolitis (NEC), which typically occurs in the second to third week of life in preterms, is characterized by variable damage to the intestinal tract, ranging from mucosal injury to full-thickness necrosis and perforation. NEC affects close to 10% of infants who weigh less than 1500 g, with mortality rates of 50%.

In surgical NEC, the anesthesia is carried out in a clinical condition characterized by a drastic and rapid deterioration, frequently involving complications such as acidosis, electrolyte imbalances, lethargy, abdominal compartment syndrome, acute renal failure, coagulopathy, RDS, and cardiocirculatory failure. Often the clinical picture is further complicated by the occurrence of toxic-septic shock with multiple organ dysfunction syndrome (MODS) which is triggered in an infant weighing <1000 g.

Often, especially in extremely low-birthweight (ELBW) infants, the anesthesiological and intensive approach may become difficult [28–30].

Some points, almost always interdependent, need to be raised [31]:

- The choice of surgical option. This is between peritoneal drainage and laparotomy, depending on the clinical condition of the infant and the extent of the disease. However, the optimum choice remains controversial. Peritoneal drainage is a short procedure, requires a less risky anesthesia, but only offers a temporary decompression for the purposes of stabilizing the patient in expectancy of a more invasive surgical intervention. Laparotomy foresees an anesthesia with very high risk, its principal objective being the removal of gangrenous bowel in order to check sepsis while preserving as much bowel length as possible. The surgical options of laparotomy include enterostomy alone or intestinal resection with enterostomy.
- The decision about where to operate. This question is still open to debate, also considering that every hospital has its own logistic and organizational characteristics. The NICU may not be the optimal setting for a surgical procedure, but moving an infant weighing <1000 g in a serious and unstable condition to the operating theater entails very high risks. In a short space of time, various events may occur that could irreversibly precipitate their condition: the loss of body temperature, the discontinuation of the mechanical ventilation instituted, the modifications in posture during transfer, which could lead to serious cardiocirculatory complications such as bradycardia and hypotension.
- The decision as to whether, and for how long, it is possible to wait before undertaking the urgent intervention. The goal should be to obtain, in a brief space of time, the best possible clinical stabilization before undertaking surgery (optimization of the fluid resuscitation and inotropic and vasopressor drugs, correction of possible acidosis, anemia, or coagulopathy) without further compromising the general condition of the patient.
- The choice of which anesthetic drugs to use. Even though the pharmacokinetics is not fully understood, smaller doses of anesthetic are usually required, and their effects last longer due to low clearance and prolonged elimination half-lives. The literature is currently still discussing the neurotoxic effect of anesthetic drugs on the developing brain. It therefore remains unclear what role anesthesia exposure during infancy actually plays in determining neurobehavioral outcome. This could have very worrying implications in ELBW. Moreover, no important differences in neurodevelopmental outcomes were observed between the surgical and medical NEC.
- The choice of which intraoperative monitoring might constitute an additional aid in such small preterms in whom the scarce feasibility of monitoring is well known during high-risk interventions. Capillary blood-gas analysis could be useful. Other possibilities to be investigated in ELBW could be the reliability of central venous pressure in a peripherally inserted central catheter of extremely small caliber and the role of abdominal as well as cerebral near-infrared spectrometry (NIRS).

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