Controversial issues in pediatric regional anesthesia
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Introduction
Pediatric regional anesthesia (PRA) is today a standardized and universally applied technique in the daily clinical practice. However, there are still some aspects that are debatable and continue to be a source of long discussions or comments at meetings and also in published scientific papers.

This review represents an update on some of these issues, trying if not to solve, at least to clarify some of them.

Compartment syndrome
Acute compartment syndrome (ACS) of the extremities is a well-known complication in adults but reports in children of symptoms, diagnostic procedures, and treatment of ACS are scarce (1,2).

The compartment syndrome is a pathology that can occur after even relative minor trauma of the extremities and is characterized by an increased pressure in a closed muscle compartment. If severe enough, the increased pressure may even compromise the circulation and function of tissues within the noncompliant muscle compartment and can ultimately lead to motor and sensory impairment, amputation, and even death. A direct relation exists between the time elapsed and the performance of a fasciotomy and the final functional result. An untreated compartment syndrome will lead to loss of muscle tissue, hyperkalemia, metabolic acidosis, renal insufficiency, amputation of extremities, and outright mortality.

The incidence in children is still largely unknown. The peak incidence is in the 10- to 14-year-old age group and is more common in boys (78%). The most frequent region of ACS is the lower leg, followed by the feet. In most cases, ACS of the lower leg is seen in combination with a fracture (40%), although other causes (minor trauma or vascular surgery) are other known causes (3–7).

The incidence of ACS is lower in children than in adults, but children may be at greater risk of developing ACS because the normal compartment pressures in the lower leg (13–16 mmHg) are significantly higher than those of adults (0–10 mmHg). This discrepancy between adults and children may be explained by the fact that children are in a stage of muscle growth and, hence, the increasing volume owing to muscle hypertrophy may cause a higher intracompartamental baseline pressure (8; Figure 1).

The prompt diagnosis of ACS is the key for adequate treatment of this syndrome, but no gold stan-
standard currently exists for diagnosing ACS. The classic warning signs of limb ischemia (e.g., pain, pallor, paresthesia, paralysis, and pulselessness) are relatively unreliable, and in children, particularly in preverbal children, the diagnosis is not easy. Patient history (pain out of proportion to the associated injury) and physical examination are central to the diagnosis. The degree of pain experienced and, particularly, the discrepancy between the seriousness of pain in comparison with the extent of the trauma can indicate an existing or developing ACS.

Despite the lack of a general consensus, an absolute intramuscular pressure measurement of >30 mmHg in the compartment is commonly viewed as an absolute indication to perform a fasciotomy (Figure 2).

The existing controversy is whether regional blocks may mask the signs and symptoms of a developing ACS. Some published adult case reports infer that the presence of a central or peripheral block may have delayed the appropriate diagnosis of ACS. However, in all these case reports, the regional blocks did result in dense sensory and motor block that masked the symptoms of compartment syndrome (9–12).

In the pediatric literature, 12 cases of ACS have been reviewed without any clear evidence that the presence of an epidural delayed the diagnosis (13–15). In many of these reported cases, it is apparent that the clinicians have failed to consider the possibility of an ACS in the situation of severe breakthrough pain and instead focused on the failure of the analgesic technique and administered additional analgesia.

Thus, regional anesthetic techniques can be safely used in children, without the risk of masking an ACS, if strictly adhering to some precautions:

The concentration of local anesthetic should be kept as low as possible to avoid causing dense sensory and motor blockade. The use of 0.2–0.25% of ropivacaine or levo-bupivacaine will provide good intraoperative analgesia and is still associated with valid postoperative analgesia without any significant motor block. The intense pain of a compartment syndrome is unlikely to be masked by analgesia produced by low concentrations of local anesthetic.

The use of ultrasound-guided regional anesthesia can reduce not only the amount of local anesthetic but also, as the drug is administered just around the nerve and thus more effective, the concentration of the drug itself.

The key to identify the development of an ACS is not to refrain from regional anesthetic technique but to provide adequate continuous postoperative monitoring of the patient. When pain reoccurs despite previously adequate postoperative analgesia and is not controlled by normal pain killers (e.g., paracetamol), especially if accompanied by recurring motor block combined with loss of sensitivity, then a compartment syndrome must be suspected and the compartment pressure should be immediately measured.

In summary, epidural catheters should be sited as close as possible to the dermatomes associated with the surgical procedure, and the concentration of long-acting local anesthetics should preferably be kept ≤0.25% to avoid dense sensory and motor blockade. Unnecessary sensory blockade of anatomical areas remote to the surgical site should be avoided, if possible, in order not to put such areas at risk. Furthermore, the distribution and density of the block should be repeatedly checked during the postoperative period, and it is vital that reappearance of dense sensory and motor blockade is immediately detected. It is imperative that the early signs and symptoms of compartment
syndrome are recognized and not erroneously attributed to inadequate analgesia.

Test dose

One of the major controversies in PRA still remains the use of a test dose of local anesthetics mixed with adrenaline to potentially identify inadvertent intravascular injection, thereby avoiding the risk of severe systemic local anesthetic toxicity.

Early symptoms of systemic local anesthetic toxicity cannot be detected in children because the vast majority of blocks are performed in children under general anesthesia or heavy sedation. Thus, the identification of an inadvertent intravascular injection can be made by either aspiration or spontaneous back-flow of blood through the block needle or on cardiovascular signs secondary to the small dose of adrenaline incorporated in the test dose injection. However, the aspiration test for blood in children is associated with poor sensitivity, as is the use of a simulated test dose (16–19). Furthermore, the best hemodynamic predictor of intravascular injection of a test dose in anesthetized children will differ depending on the type of general anesthetic that is used (e.g., different volatile anesthetic agents or total intravenous anesthesia; 20–23).

Other means of identifying inadvertent systemic injection of local anesthetic solutions are therefore necessary. One suggested option is the use of the ‘fractional test dose’. This suggests to inject the local anesthetic solution in fractionated volumes while simultaneously observing the ECG. In fact, T-wave amplitude or ST segment changes can be considered as more sensitive means of identifying inadvertent systemic injection. Additionally, HR slowing or the development of nodal or sinus bradycardia is uncommon but specific signs of systemic injection. Changes in T-wave amplitude occur first, subsequently followed by changes in HR and later also changes in systolic blood pressure. The mechanisms responsible for the ECG changes have not been clearly delineated, but T-wave changes have been described, when only the local anesthetic is given, and when both agents are administered together (24–26). More recently, experimental studies on neonatal pigs showed that propofol anesthesia does not suppress ECG changes during inadvertent intravascular injection of local anesthetics and it seems that the T-wave changes and increases in heart rate are epinephrine-related, not owing to bupivacaine injection (27–29).

The indicators of inadvertent systemic injection may be delayed for up to 60–90 s after the fractional test dose, suggesting an appropriate observation period of 90 s after the test dose before delivery of the remaining local anesthetic solution. Even after a negative test dose, the remaining volume of local anesthetic should be administered in incremental volumes of 0.1–0.2 ml kg⁻¹.

To add further safety to the technique, the block should if possible be performed maintaining spontaneous ventilation. Such a practice will allow the possibility to detect the cessation of spontaneous respiration as a sign on inadvertent injection of the local anesthetic (Figure 3).

Loss of resistance (LOR) technique to air or saline

The LOR technique was first described in 1933 by Dogliotti (30) and still remains the most widely used technique for detecting entrance into the epidural space. Recently, LOR to normal saline (LORNS) has been advocated to be the technique of choice in adult anesthesia (31,32).

In the pediatric population, there is still a controversy in the literature as to which medium is the most appropriate for the identification of the epidural space (31,33). LORNS has been advocated by certain experts (34), but LORNS may have limitations in infants and young children because of their particular anatomy (35). In direct contrast to adult patients in whom the continuous pressure of the saline technique pushes the dura away and so reduces the risk of dural puncture, in children air may permit easier detection of a dural tap compared to saline and the actual incidence of dural puncture in pediatric patients has been reported to be greater with LORNS (36,37). Furthermore, air is readily available and cannot be confused for another substance.

However, LORA has been reported to be associated with significant complications, such as nerve root compression, pneumocephalus, a greater incidence of
incomplete analgesia, a higher incidence of paresthesia, and venous air embolism, as described in the published case reports (31,38,39).

Despite the potential for serious complications, it has been suggested that LOR to air (LORA) is safer than saline for the identification of the epidural space in children <2 years of age (33,35). Owing to the inherent risks of LORA, every effort should be made to limit the injection of air into the epidural space. Thus, the amount of air in the syringe should be limited to a maximum of 1–2 ml and used only to detect the change of resistance, releasing the pressure on the plunger immediately upon entry into the epidural space.

The use of other less common media has been used to detect the epidural space. From a theoretical point of view, carbon dioxide may offer some theoretical advantages. First, CO₂ is extremely soluble in blood and therefore will limit the risk of air embolism, and second, CO₂ may possess bactericidal properties (35). However, as the availability of CO₂ usually is limited, it may be perceived as impractical compared to the use of either air or saline.

More recently, the combination of air and saline has been suggested as the best technique because this allows improved feeling while reducing the risk of injecting air when the epidural space is entered. This technique is also associated with less saline being injected, thereby making the diagnosis of an accidental epidural tap easier and will also minimize the possible dilution of local anesthetic (40).

In summary, the use of both LORA and LORNS are supported by different international experts, and as long as the two techniques are used appropriately, they can both be safely used in infants and children.

Regional anesthesia in sedated/anesthetized children (‘Double anesthetics, double the risk’)

In 1998, Bromage and Benumof published a case report on a severe complication (permanent paraplegia) in a woman who received a central block performed under general anesthesia (41). They stated that ‘this case reinforces the admonition against attempting epidural puncture above the termination of the cord in unconscious, areflexic patients, and the opinion that risk of such gravity is only justified as a life-saving measure under exceptional circumstances’.

This case report immediately created reactions from pediatric anesthesiologists who were used to perform PRA under general anesthesia. The criticism of the case report was linked to the conception that an awake patient can indicate that something is going wrong during the performance of a block while in an anesthetized patient there is no alarm of a harmful procedure.

Quite contrary to the situation in adults, it may be impossible or dangerous to perform a block in an awake child because the child can have uncontrolled movements during the block performance. Hence, in the same year as the case report quoted elsewhere, two replies to the statement of Bromage and Benumof were published (42,43). The first was signed by 53 well-known pediatric anesthesiologists from all over the world and concluded: ‘The performance of a block during anesthesia is safer than when performed in an awake child’. The second reply by Bosenberg and Ivani pointed to current literature indicating the safety of PRA in anesthetized children and questioned: ‘Is self report of early symptoms of toxicity likely to be any more reliable in the frightened young child?’ Furthermore, two major studies from the French Speaking Society of Pediatric Anesthesia (ADARPEF) (17,18) have clearly demonstrated the safety of performing PRA under general anesthesia or during deep sedation.

The recently published consensus guidelines of the American Society of Regional Anesthesia also underline the necessary link between general anesthesia and performance of regional blocks in children (44):

1. Without heavy sedation or general anesthesia, regional blocks would be all but impossible in pediatric anesthesia.
2. Based on the available literature, it is our recommendation that anesthesia or heavy sedation should not be considered an absolute contraindication in children. This recommendation is based on human data and general agreement of expert opinion.

Thus, according to current worldwide consensus, PRA should in the vast majority of cases be performed under general anesthesia or heavy sedation to ensure maximum safety against potential complications.

Conclusions

The value of regional anesthesia in children is now widely accepted, the safety of its performance in anesthetized infants and children is confirmed, and the use of PRA is now considered standard practice in most parts of the world.

Pediatric regional anesthesia, when performed following strict guidelines, is a procedure at least as safe as general anesthesia alone, and we do hope that old prejudices will now finally be eradicated (45).

Therefore, we like to conclude with the words of Krane et al.: ‘Children must continue to be the beneficiaries of this important tool when it is in the hands of an experienced anesthesiologist with the appropriate training, skill, and sound judgment to practice it safely’.
References


42 Krane E, Dalens B, Murat I et al. The safety of epiduals placed during general
