Spinal Anesthesia in Preterm Infants Undergoing Herniorrhaphy

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Inguinal hernias are the most common diagnosis requiring surgical repair in children of all ages. Anesthetic management of premature infants is often difficult due to their comorbidities and propensity for apnea and bradycardia. General anesthesia has been shown to be associated with an increased incidence of postoperative adverse events.

The purpose of this review is to determine the benefits and risks of spinal anesthesia in preterm infants undergoing herniorrhaphy. The use of spinal anesthesia in this population has been shown to decrease the incidence of postoperative adverse events.

Keywords: Herniorrhaphy, preterm infants, spinal anesthesia.

Advances in the care of premature newborns have created a greater incidence of neonates and infants undergoing surgical repair. Because the likelihood of developing an inguinal hernia (IH) is inversely proportional to birth weight, the number of low-birth-weight neonates and infants with IH has increased significantly.[1] In premature infants, the incidence ranges from 14% to greater than 30%, occurring with increased frequency in infants born at less than 32 weeks' gestation or weighing less than 1,250 g at birth.[2] The incidence of IH in children of all ages is 2%, making it the most common diagnosis requiring surgical repair during childhood.[3]

Prematurity is considered to occur when an infant is born before 37 weeks' gestation,[4] although in the research reviewed for this article, prematurity was defined broadly as an infant born earlier than 36 to 38 weeks[1,5-12] or as an infant weighing less than 2,000 g at birth[2]; some researchers did not specify. The preterm birth rate reportedly increased 2% in 2004 to 12.5% of all births; subsequently, more than one-half million infants were born prematurely in 2004.[13]

It is generally accepted that IH in infants should be repaired as soon as possible because the incidence of incarceration of the hernia is higher in infants than in children, and the complication rate of herniotomy for an incarcerated hernia is high.[3] The decision for planning surgical repair creates a dilemma for pediatric surgeons due to the surgical and anesthetic risks that accompany a neonate's size and comorbidities. Conditions such as bronchopulmonary dysplasia, apnea, bradycardia, patent ductus arteriosus, intraventricular hemorrhage, and cardiac and other congenital malformations must be managed before repair is scheduled.[1,14]

Anesthetic management of premature infants is often difficult and frequently debated because of their propensity for apnea and bradycardia. There are a variety of anesthetic choices for this patient population, including a general anesthetic with endotracheal intubation or laryngeal mask airway and caudal, local, or other regional anesthesia. The high incidence of apnea following general anesthesia has led to routine postoperative hospital admissions to monitor the infants following minor surgical procedures.[5,6] Caudal anesthesia has been documented as an alternative to general anesthesia; however, it is technically more challenging than other anesthetic techniques and is often administered after anesthesia has been induced with a general anesthetic.[15] Spinal anesthesia has become extensively researched in the last 2 decades and seems to offer a safer and quicker recovery for high-risk infants following minor infra-abdominal surgical procedures.

Regional anesthesia may be contraindicated if preoperative laboratory data reveal coagulopathy or septicemia. Nevertheless, a comprehensive preoperative assessment may lead an anesthetist to choose a regional anesthetic based on the documented decreased risk of intraoperative and postoperative complications.[7-9,16-19]

Abdominal surgery requires anesthetic blockade from mid to high thoracic levels. Hyperbaric tetracaine and bupivacaine are the most commonly used agents reported in the literature.[7,10,19] Dosing regimens for local anesthetics are different in infants, particularly in premature infants, than in children and adults due to significant pharmacokinetic differences.[19]

Regional anesthesia requires meticulous observation and technique to avoid complications such as postdural puncture headache, an epidural hematoma, a total spinal, and an inadequate block. However, if a spinal anesthetic is chosen for a "former" premature infant (born earlier than 36 to 38 weeks or weighing less than 2,000 g at birth), these risks are minimal, and often these complications are more frequent as the child matures.[20]

The high incidence of apnea in this population has resulted in routine overnight monitoring for most premature infants undergoing surgery.[11] Recent reports suggest that spinal anesthesia for former premature infants undergoing herniorrhaphy may lessen the need for routine postoperative hospital admission in the outpatient setting.[7]

The purpose of this review is to describe the benefits and risks of spinal anesthesia in former premature infants undergoing herniorrhaphy. The use of spinal anesthesia in this population may decrease the incidence of many postoperative adverse events, thereby allowing for a less complicated surgical course and decreasing the overall length of hospital stay.

• *Anesthetic Options*. Pain relief was previously thought to be of little importance in the treatment of neonates. However, physiologic responses to painful stimuli are reflected in hormonal, metabolic, and cardiorespiratory changes and have been well documented in neonates born at various gestational ages.[21] These findings suggest that neonates do perceive pain, and effective pain relief is considered an essential part of their anesthetic plan and an important factor in their postoperative outcome.[21]

• *General Anesthesia*. Former premature infants are at risk of respiratory and cardiovascular complications at any time throughout a surgical course. Use of intraoperative opioids, neuromuscular relaxants, and volatile anesthetics may cause residual postoperative effects, such as respiratory depression and skeletal muscle weakness, increasing the incidence of adverse events in a premature infant. Even in infants without a history of apnea, general anesthesia may contribute to the development of apnea postoperatively by decreasing upper airway muscle tone, leading to upper airway obstruction and apnea.[22] Despite the reported adverse effects of general anesthesia, many surgeons and pediatric anesthetists have reservations regarding the use of spinal anesthesia due to the reliability of general anesthesia and the technical difficulty of regional anesthesia in this specific population.[7,23]

• *Spinal Anesthesia*. Spinal anesthesia may be selected to avoid potential respiratory and neurologic effects in certain patient populations. Spinal anesthesia allows infants to be managed throughout the surgical procedure with minimal anesthetic medication, thereby avoiding intravenous opioids and volatile agents and their respiratory depressing effects.

• *Administration Times*. It is a common misperception that a spinal anesthetic may take longer to administer in a premature infant and, consequently, prolong the anesthesia and surgical times. Data regarding the anesthesia time, operating room time, nonoperating room time, and surgical time between 2 groups of infants receiving general and spinal anesthesia revealed no significant difference in one clinical setting.[18] Another study concluded that there was no significant difference in median anesthetic times between a group of infants administered a general anesthetic with sevoflurane and a group receiving spinal anesthesia.[9] Other investigators found that if there was a delay in the start of the surgical procedure due to placement of a spinal anesthetic, there was less time spent at the end of the procedure because there was no need to wait for the infant to emerge from anesthesia before transferring to the postanesthesia care unit (PACU).[7]

Preoperative Assessment

Before selecting an anesthetic technique, it is vital that the patient is thoroughly assessed and the medical history reviewed. Contraindications for spinal anesthesia include coagulopathy, sepsis, local infection at the site of lumbar puncture, intracranial hypertension, preexisting neurologic disease, and hypovolemia. Coagulopathies are more difficult to detect in pediatric patients because hemorrhagic symptoms are often rare before a child begins walking, even if the child has a congenital hemostatic deficiency.[21] Because the hemostatic system is an age-dependent evolving process, at birth, the hemostatic system has not fully matured.[24] Plasma concentrations of vitamin K–dependent factors (II, VII, IX, and X) are decreased at birth, and factor levels may be even lower in premature infants because there is an increase in factor levels that occurs after 34 weeks' gestation.[12] Despite these reported depressed levels of coagulation factors, infants usually have minimal incidence of hemorrhage or bleeding tendencies[24]; however, laboratory coagulation tests are preferably obtained before administration of a neuraxial blockade.

With most practitioners obtaining coagulation studies before administering a neuraxial blockade in an infant, a study assessed the reliability of preoperative laboratory coagulation tests performed in former premature infants.[24] The authors reported that the mean values for activated partial thromboplastin time are frequently high, especially in infants with a postconceptual age of less than 45 weeks. Even though these levels were elevated, none of the infants showed any sign, evidence, or risk of bleeding.[24]

Preoperative Management

The greatest advantage to using a spinal anesthetic in this high-risk population is the avoidance of sedative, volatile, and opioid medications. Therefore, it is ideal to avoid preoperative medication that may increase the risk of intraoperative and postoperative adverse events. Lumbar puncture can be particularly difficult in this population of patients because of the responses that may be encountered to the pain of the needle insertion. Many of the studies reviewed applied eutectic mixture of local anesthetics (EMLA) to the infant's lumbosacral region 60 to 90 minutes before the procedure to alleviate discomfort associated with the lumbar puncture.[10,19,25,26] Excluding Vilà et al,[10] who applied 50% nitrous oxide during lumbar puncture on all patients studied, the EMLA application provided the infants with enough comfort for ease of the local anesthetic placement within all of the studies.[19,25,26] Therefore, superficial dermal analgesia may eliminate or decrease the need for intravenous sedation.

Procedural Techniques

The techniques involved in placing a subarachnoid block in a premature infant are of great importance to effectively provide anesthesia to this patient population and avoid complications. In a study conducted by Vilà et al,[10] 30 preterm infants undergoing inguinal herniorrhaphy were randomized to receive a subarachnoid block in the sitting or lateral position to determine the differences in heart rate, blood pressure, oxygen saturation, and average block time (onset and duration). During this study, isobaric bupivacaine was used to avoid the variables in relation to the baricity, patient positioning, and dermatomal height of the block. Investigators found no median difference in terms of dermatomal height between the 2 groups, and both techniques provided equal effectiveness with minimal side effects.[10] Vilà et al[10] also compared the effects of lumbar puncture in this population in the lateral and sitting positions and found that the position of the patient during the injection had no effect on the eventual dermatomal height of the block.

Identifying accurate anatomical landmarks is critical in the care of an infant before administering a subarachnoid block due to caudal extension of the spinal cord to the L3 level compared with the L1 level in adults. Shenkman et al[19] reported that placing infants in the sitting position facilitated recognition of anatomical landmarks.[19] The use of nitrous oxide during the administration of subarachnoid blockade is another technique that is described in the current literature. Vilà et al[10] administered sedation with 50% nitrous oxide in oxygen before lumbar puncture and found that the sedative effects of nitrous oxide wore off shortly after the cessation of administration, with none of their subjects experiencing apnea during or after surgery.

Local Anesthetics

Throughout the literature various dosing regimens are suggested, with tetracaine and bupivacaine reported to be used most often. The concentration and doses of tetracaine, range from a 0.5% solution dosed at 1 mg/kg to a 1% solution dosed at 0.5 to 0.6 mg/kg.[7,8,16,18,19] All of these authors report mixing the tetracaine anesthetic with 10% dextrose to make a hyperbaric solution. In addition, Shenkman et al[19] reported that they decreased the dose from 1 mg/kg to 0.8 mg/kg if the infant was receiving diuretics to compensate for a potential contraction of the cerebrospinal fluid volume.

Bupivacaine, an amino amide local anesthetic, is the other anesthetic frequently discussed in the literature. The concentration and doses of bupivacaine range from a 0.5% solution dosed at 0.6 to 1 mg/kg, with 1 mg/kg used by 4 of the 5 groups.[9,10,17,19,27] Of the 5 groups, 3 used isobaric bupivacaine[10,17,27]; Shenkman et al[19] reported the use of a hyperbaric solution, and Williams et al[9] did not specify the baricity used in their study. Typically, 1 mg/kg of tetracaine or bupivacaine usually results in a sensory block to the T2 to T4 level; however, higher levels may be observed.[16]

Epinephrine is frequently added to local anesthetic solutions to prolong the duration of spinal anesthesia. Vasoconstrictors decrease the uptake and clearance of local anesthetics from the cerebrospinal fluid and may have weak spinal analgesic properties. Frumiento et al[7] added epinephrine to the tetracaine solution if the surgical procedure was expected to last longer than 30 minutes (0.02 mL of a 1:1,000 epinephrine solution), while the other researchers routinely added epinephrine to the local anesthetic solution.[8,10,19] Abajian et al[28] reported that the addition of epinephrine to tetracaine increased the duration of the block by an average of 32% ($P < .01$). I have observed that the addition of epinephrine to bupivacaine only modestly increased the duration of block and also increased the risk of cardiac toxicity.

The pharmacokinetics of local anesthetics in infants compared with adults is extensively discussed in the literature. Higher doses of local anesthetics per kilogram of body weight are required in infants in comparison with adults.[29] It is speculated that this increased requirement may be related to the larger volume of distribution of cerebrospinal fluid in infants than in adults, 4 vs 2 mg/kg, respectively. In addition, the relatively increased surface area of the spinal cord and nerve roots and an infant's increased cardiac output may all be determining factors.[29] It is also speculated that there is proportionally greater blood flow to an infant's spinal cord, leading to faster drug uptake in the subarachnoid space.[7] With faster drug distribution, uptake, and elimination of the drug, an infant's motor level regression is approximately 5 times faster than that in adults.[19] Thus, there is a great deal of debate regarding how to prolong the duration of the anesthetic blockade, which limits the amount of anesthetic supplementation that may need to be given intraoperatively.

One of the main restrictive factors to using spinal anesthesia, besides failure of lumbar puncture, is the short duration of action of intrathecal bupivacaine in infants, which is reported to be approximately 60 to 70 minutes.[26] In earlier studies by Webster et al[29] and Welborn et al,[6] up to 45% of patients required sedative or anesthetic supplementation for the procedure to be completed. Rather than increase the dose of the local anesthetic and increase the risk of toxic effects, especially with the potential cardiotoxic effects of bupivacaine, Rochette et al[26] proposed the addition of clonidine to prolong the duration of the subarachnoid block in infants.

Rochette et al[26] conducted a prospective study to investigate the duration of surgical blockade provided by various doses of clonidine (0.25, 0.5, 1, and 2 μg/kg) added to bupivacaine for spinal anesthesia in infants. In addition, the researchers monitored the short-term hemodynamic, respiratory, and sedative consequences of spinal clonidine. At a dose of 1 μg/kg, the duration of the block was increased 2-fold in comparison with isobaric bupivacaine, exceeding 100 minutes in preterm and term infants.[26] This dose of clonidine was not associated with clinically significant hemodynamic or respiratory alterations, whereas 2 μg/kg provided the same duration of blockade and was associated with more serious side effects such as hypotension, bradycardia, and sedation.[26] However, a key limiting factor to this study is that clonidine has a long half-life; thus, a study that monitors the hemodynamic effects for a 24-hour period may provide more sufficient data for applicable use in the pediatric setting.

In 2005, Rochette et al[25] investigated the delayed respiratory events after a combined bupivacaine and clonidine spinal anesthetic. Using 1 mg/kg of 0.5% isobaric bupivacaine and 1 μg/kg of clonidine significantly increased the risk of apnea in full-term (P = .003) and preterm infants (P = .011); however, desaturation, sustained bradycardia, and hypotension were not observed in the 24-hour period following the procedure.[25] One problem in comparing the incidence of apnea in these studies is that apnea is defined and measured differently in the literature. Rochette et al[25] defined *apnea* as a 10-second respiratory pause, while 15 and 20 seconds are commonly used by other researchers.[19,22] Therefore, even though Rochette et al[25] found an increase in the apnea incidents in their study population, it is difficult to compare their results with those of other studies that defined apnea differently.

Rochette et al[25] found that deep sedation occurred in a few patients on admission to the PACU. However, cardiorespiratory conditions were not altered and the patients responded quickly and adequately to stimulation outside the blocked area.[25] The authors also found that as infants became less sedated, their anesthetic recovery and length of stay in the PACU were not prolonged. In fact, the researchers proposed that there may have been such a decrease in nociceptive inputs that the infants may have fallen asleep during the procedure, leading to higher sedation scores when the infants were admitted to the PACU.[25]

Intraoperative Management

There are a variety of techniques discussed in the literature regarding intraoperative management of infants receiving a subarachnoid block for herniorrhaphy. There are concerns regarding operating on an awake, high-risk infant while providing relief from discomfort during surgical repair. However, it is important to avoid putting infants at risk for postoperative apnea and bradycardia by supplementing their anesthesia with opioids, benzodiazepines, or volatile anesthetics. Nitrous oxide is the agent that is most frequently discussed in the literature for providing relief of discomfort[8,19] or for using throughout the procedure and surgical repair.[10] Other researchers reported the use of a pacifier dipped in 10% dextrose to soothe the infants during the herniorrhaphy, and for some infants, the upper arms were restrained.[17]

Vilà et al[10] reported that they used nitrous oxide to decrease the infant's response to the spinal and surgical procedure. The authors found that none of their subjects experienced an apneic event during or after surgery when 50% nitrous oxide was administered via face mask, which may be because the effects of nitrous oxide wear off shortly after the cessation of administration.[10]

The most efficient method of maintaining a reduced risk of postoperative apnea and bradycardia in this patient population is determining the most effective dose of local anesthetic suitable for the procedure without having to supplement the anesthetic intraoperatively. Shenkman et al[19] revealed a 90% satisfactory spinal anesthetic, defined by a lack of sensation to pinch at the desired sensory level and paralysis of the lower limbs, with no need for anesthetic or analgesic supplementation, which in comparison with reports by Frumiento et al[7] (79%) and Krane et al[8] (67%) is significantly higher. In the study by Shenkman et al,[19] the decreased need for supplementation during the intraoperative period may allude to the higher dose of local anesthetic, 1 mg/kg, in comparison with the studies by Frumiento et al[7] and Krane et al,[8] who used 0.5 and 0.6 mg/kg, respectively.

Hemodynamic Effects

The hemodynamic changes in response to a subarachnoid block in patients younger than 1 year are unlike those in adults. In adults, there is a preganglionic sympathetic blockade that results from high levels of spinal anesthesia.[16] The adverse effects that are observed in adults are suggested to be the result of sympathetic withdrawal in combination with an increase in vagal outflow; however, most important, this phenomenon is not typically observed in subjects younger than 1 year.[30] This dramatic difference in hemodynamic effects between infants and adults has been observed even in the absence of intravascular fluid administration before the administration of a spinal anesthetic.[16]

Oberlander et al[16] examined the potential autonomic regulatory mechanisms that account for the minimal changes in heart rate and blood pressure in response to a subarachnoid blockade in infants. It has been speculated that cardiovascular stability in infants is due to smaller venous capacitance in the lower extremities, leading to less pooling of blood, or a relative immaturity of the sympathetic nervous system, resulting in less dependence on sympathetic control of vascular tone.[30]

The researchers report that even though a sensory block was achieved to a dermatomal level of C7 to T4, there were no reported complications in any of the former premature infants in their study.[16] The data collected in this study support the previous suggestions that infants differ from adults in their response to spinal anesthesia. Oberlander et al[16] report that despite the absence of volume loading before anesthetic administration, neither the heart rate nor arterial pressure changed. In addition, because the researchers measured the respiratory activity of the infants, they were able to evaluate the infants' cardiac vagal and sympathetic modulation more accurately. With the use of spectral analysis of heart rate, transfer function of heart rate, and respiratory activity, the researchers were able to conclude that the spinal anesthetic had a predominant effect on parasympathetic modulation of the heart rate.[16] Therefore, a decrease in heart rate and blood pressure, which may occur with a high spinal anesthetic, may be offset by decreased cardiac vagal activity in this population.[16]

With the overwhelming recommendations in the literature to use spinal anesthesia in former preterm infants to reduce the incidence of postoperative apnea, Bonnet et al[27] conducted a prospective study to assess the effects that spinal anesthesia may have on cerebral hemodynamics. The authors found that the spinal anesthetic proved successful for all of the infants; in addition, no complications were observed in the postoperative period. However, their hemodynamic data revealed a significant increase in cerebrovascular resistance in association with a decrease in the mean arterial blood pressure.[27] However, it is notable that these reported significant decreases in cerebral blood flow may be due in part to the greater dose of isobaric bupivacaine used in this study. Bonnet et al[27] dosed the subarachnoid block with 1 mg/kg of bupivacaine, which may explain the greater decrease in arterial blood pressure in comparison with other studies that used 0.3 to 1 mg/kg of tetracaine.[16,30]

Wolf et al[31] demonstrated that another advantage of neuraxial blockade may be its modification of the surgical stress response. These authors reported a decrease in adrenaline levels in addition to a more controlled heart rate and blood pressure in infants receiving neuraxial blockade (spinal or epidural) in addition to general anesthetic vs infants receiving only general anesthesia.[31] Thus, supporting the use of a neuraxial block to effectively blunt the sympathetic nervous system may improve the outcome for infants undergoing surgical procedures.

Potential Complications

Postdural puncture headache is a well-recognized potential complication of lumbar puncture following spinal anesthesia.[20] It is thought to be rare in children younger than 10 years when a 22-gauge spinal needle is used; subsequently, there have been no reported cases in infants.[20] However, one may argue that the incidence of postdural puncture headache is difficult to accurately assess and diagnose in this age group. Therefore, as with adults, the most likely effective preventive measure is the use of smaller-gauge, pencil-point needles for any lumbar puncture.

Another potential complication associated with a lumbar puncture is a neuraxial hematoma. The greatest risk factor for incidence of a spinal hematoma in this population is repeated attempts at lumbar puncture or administration of a subarachnoid block in a patient with an unrecognized coagulopathy.[32] There are 2 reports of a neuraxial hematoma developing in an infant: one case was attributed to multiple attempts at inserting an epidural catheter,[33] and the other occurred during a routine lumbar puncture in an infant with unrecognized hemophilia.[32]

Blocking the cardioaccelerator fibers is a third potential adverse complication related to administration of a subarachnoid block. However, as previously discussed, it has been shown that infants tolerate a high thoracic spinal anesthetic to a greater degree in comparison with adults.[16,30] Therefore, unless a child is significantly hypovolemic before administration, even without a preoperative intravascular fluid bolus, there is little risk of a significant sympathectomy.

The risk of an inadequate block is an area of great concern with this anesthetic technique. The advantages that are gained with administration of a subarachnoid block in former premature infants are reduced once an infant requires supplemental medication for sedation or analgesia. The need for supplemental medication may be due in part to the infant's inability to tolerate the wakefulness, an inadequate block, or the procedure lasting longer than the duration of the local anesthetic.

Shenkman et al[19] reported that 3 of 55 spinal attempts required general anesthesia, 1 due to technical problems with operating room equipment and the other 2 because of failure of the block to set up adequately. Similarly, Somri et al[17] reported that supplemental anesthesia was given to 6 infants despite successful subarachnoid block, while 14 infants were restrained and given a pacifier dipped in 10% dextrose to ease their discomfort. Krane et al[8] stated that 3 of their subjects were given 50% nitrous oxide via face mask when they began crying during surgical manipulation. Even though some of the subjects of these studies required alternative interventions for completion of the procedure after a spinal anesthetic was administered, most of the interventions were minimal, making these findings insignificant.

In a large study, Frumiento et al[7] found that the spinal anesthetic was sufficient after the first dose in 246 of 269 cases, while a second dose was successfully administered to 17 of 23 cases. In addition, they reported that supplemental anesthesia was administered to 56 (21.4%) of 262 patients intraoperatively. With concern about increasing the risk of postoperative complications, the researchers administered intravenous medication (fentanyl, diazepam, or midazolam) for 34 patients, while 12 patients were given supplemental local infiltration, 4 were given additional regional blockade, and only 6 required conversion of the anesthetic to general anesthesia.[7] Even though Frumiento et al[7] reported more need for interventions, they had a larger sample, making their results similar to those previously discussed.

Postoperative Outcomes

Postoperative apnea is one of the greatest and most prevalent risks of anesthetizing a former premature infant. It has been speculated that apnea results from the combination of prematurity, exposure to anesthetic agents, and an increased endogenous opioid production in the first 72 hours following surgical repair.[5,6,19] Therefore, the infants already at risk for postoperative apnea, due to their history of apnea of prematurity, anemia, and low gestational or postconceptual age, may benefit from the use of spinal anesthesia.[19]

In a study by Shenkman et al,[19] 55 premature patients underwent inguinal herniorrhaphy, and all had 2 of 3 of the aforementioned previous risk factors. Even though all of the premature patients were at risk for intraoperative respiratory complications, only 5 patients in their study required an intervention for a respiratory event intraoperatively (9%).[19] In addition, postoperative apnea was diagnosed in 5 patients, which was reported to occur during transport or on arrival to the neonatal intensive care unit.[19]

Krane et al[8] conducted a prospective study to compare the incidence of postoperative apnea, bradycardia, and oxygen desaturation in former premature infants randomized to general or spinal anesthesia. They found that infants who had received general anesthesia had lower minimum hemoglobin-oxygen saturation and heart rate and a tendency to experience more episodes of severe desaturation in comparison with infants who had received spinal anesthesia. However, contrary to the author's hypothesis, Krane et al found the incidence of postoperative apnea to be 22% and did not increase from baseline after the administration of general anesthesia.[8] This was a significant finding in this study because it seemed that general anesthesia increased the risk of postoperative oxygen desaturation and bradycardia in comparison with spinal anesthesia, but spinal anesthesia did not completely eliminate the risk of postoperative apnea or oxygen desaturation in this population.[8] Even though these authors did not find that spinal anesthesia would have no effect on postoperative respirations, their findings supported the generalization that general anesthesia accentuates desaturation and bradycardia events in this notably high-risk patient population.

Somri et al[17] also compared the postoperative effects of general and spinal anesthesia in premature infants undergoing elective hernia repair. Their study recorded the incidence not only of postoperative apnea and bradycardia but also periodic breathing and of continued mechanical ventilation. Among the infants who received a spinal anesthetic, 2 of 20 were reported to have an apneic event ($P = .4$). However, both of these events occurred well after the immediate postoperative period (10 and 14 hours) and were also associated with infant feeding, thus decreasing the significance of these events in relation to the spinal anesthetic.[17] In addition, none of the infants who received a spinal anesthetic required assisted ventilation or experienced a bradycardic event. The general anesthetic group had 4 of 20 subjects who required continued mechanical ventilation; 7 infants experienced prolonged apnea ($P = .05$), longer than 15 seconds, and 2 of the 7 infants required intervention for a sustained bradycardic event ($P = .4$). In addition, the authors reported that in 2 infants in this group, several episodes of short apnea developed throughout postoperative monitoring ($P = .4$).[17]

Spinal anesthesia was also performed by Huang and Hirshberg[18] to determine whether its use would decrease the need for postoperative mechanical ventilation in former premature infants.[18] These authors specifically recruited infants who were born with a very low birth weight (mean, 860 g); the mean weight at surgery was 2,400 g. Their study revealed that 7 patients in the general anesthesia group required postoperative mechanical ventilation in comparison with 1 patient in the spinal anesthesia group ($P < .05$). However, the need in the infant who required postoperative mechanical ventilation in the spinal group occurred on the first postoperative day when the infant had respiratory distress and severe bradycardia.[18] This result is similar to the findings reported by Somri et al,[17] in which the adverse respiratory events associated with spinal anesthesia occurred well after the immediate postoperative period. Thus, these adverse events most likely have little to do with the spinal anesthetic and are probably due to preexisting conditions.

Postoperative Monitoring

With all of the research that has been conducted on this high-risk patient population, there is yet to be a consensus on the exact incidence of apnea in preterm infants who receive general anesthesia. In addition, there have been numerous factors that have been identified as the cause of apnea in preterm infants.[8] These factors have led to routine postoperative admission after herniorrhaphy.[20]

Frumiento et al[7] conducted a large-scale study to determine whether it is safe and effective to perform spinal anesthesia in an outpatient population of preterm infants undergoing IH repair. There were 103 outpatients included in the study; 39 of these patients had a history of apnea and 7 had a history of congenital heart problems. There were no reported apneic events and only 2 bradycardic events, one that was treated with atropine and the other resolving spontaneously. Following the procedure, all of the outpatients were discharged home following a 1-hour to 6-hour stay in the PACU. Infants were then followed up in the attending surgeon's office within 1 week.

During this period, none of the patients were reported to experience an apneic event per the parent's monitoring.[7] The results from this study suggest that preterm infants who are in medically stable condition and ready for discharge may be discharged following a hernia repair if a spinal anesthetic is used, assuming that anesthetic supplementation was not required during the procedure.[8]

Frumiento et al[7] also reported that the use of spinal anesthesia in comparison with general anesthesia resulted in a reduction in charges of $64,890 for the 103 outpatients studied. Therefore, the ability to eliminate postoperative admission for apnea monitoring would greatly reduce not only financial charges but also the emotional stress for families of premature infants.

Conclusion

Spinal anesthesia has begun to gain acceptance as an alternative to general anesthesia for repair of an IH in preterm infants. The objectives of a spinal anesthetic are to provide analgesia, relaxation, minimal physiological changes, and rapid recovery. The clinical data clearly support the efficacy of spinal anesthesia for this high-risk population and procedure, making it an ideal anesthetic for former premature infants.

Unfortunately, there are a limited number of institutions that are studying the use of spinal anesthesia in premature infants; thus, there are few overall data in comparison with the number of infants who undergo hernia repair. For a spinal anesthetic to be successful in this population, it is crucial that anesthesia providers be proficient at administering subarachnoid blocks, especially in this population, and pay particular attention to details because the margin of error is limited with this anesthetic technique. Therefore, more education and training are needed to advance the skills of practitioners caring for this high-risk population.

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