REGIONAL ANESTHESIA / ANALGESIA FOR CARDIAC SURGERY

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No conflict of interest represented in this presentation.
OBJECTIVES

- Understand the indications and contraindications for regional anesthesia and analgesia for pediatric cardiac surgeries.
- Describe the regional anesthesia and analgesia techniques for pediatric patients with congenital heart disease.
- Provide complementary medical therapies to ease pain for pediatric patients after cardiac surgeries.
WHAT IS SPECIAL ABOUT THORACIC PAIN?

- One of the most painful procedures.
- Increased central sensitization.
- Confounding effects of WAN.
- Post operative complex pain syndromes.
ANALGESIC GOALS

- Pain score less than 4 for 48 hours.
  - Important to assess with movement/cough.
- Aggressively treat nausea and vomiting.
  - Only 1 dose of 5-HT3 receptor antagonist if it does not work.
- Minimize pruritus.
- Own the discomfort.
Neurologic complications are seen with pediatric cardiothoracic procedures without regional techniques.

- Cerebral events.
- Spinal cord events.

ADVANTAGES OF EPIDURAL FOR CARDIAC SURGERY

- Early extubation.
- Improved pulmonary toilet.
- Decreased arrhythmias.
- Decreased oxygen consumption.
- Increased thyroid hormone.
- Increased free radical scavenging.
- Decreased neurologic events.
CONTRAINDICATION TO EPIDURAL

- Parent/patient refusal
- Infection at insertion site
- Coagulopathy
  - INR >1.4, Platelet count < 100k
  - Therapeutic on anticoagulant
    - Failure to stop lovinox
PRE-OP MEDICATION

- Topical anesthetic
- Analgesic
- Amnestic
- Antihistamine
- Anti seizure
- Antiemetic
REGIONAL TECHNIQUES

- Spinal
- Epidural
- Paravertebral
POST THORACOTOMY PAIN SYNDROME (PTPS)

- Thoracic pain which persists more than 2 months after surgery, alldynia and temperature disturbances
- Increased incidence in those with poorly controlled acute postoperative pain
  - 39 vs. 48% (Bong)
- Minimized by preemptive analgesia?
- We see it less than 1% in non-pectus
- 50% of pectus pain 6 months or more
Schematic of Epidural Space

SACRUM

L5  L4  L3  L2  L1
Bleeding from Caudal Epidural
Bleeding from Lumbar Epidural
Bleeding from High Epidural

L5 L4 L3 L2 L1

SACRUM
MEDICATION AND INDICATION

- Local anesthetics
- Narcotics
- Central alpha agonists
- Magnesium
- Others
24 GAUGE CATHETER
20 GAUGE NEEDLES
RISK FACTORS FOR DEVELOPMENT EPIDURAL HEMATOMA

- Difficulty in identifying the epidural space.
- Coagulation abnormalities (all 3).
- Advanced age.
- Female Gender.
- Bony spinal pathology.

Christie IW, McCabe Anaesthesia 2007;62:335-41
Onset is usually within 24 hours of placement or removal and 8 hour window for resolution.

- Radicular pain.
- Progressive sensorimotor deficit.
- Sphincter dysfunction.
PARAVERTEBRAL BLOCK
ADVANTAGES

- Can be bilateral or unilateral.
- Ultrasound guided or directed.
- Can be done with coagulopathy?
- Can be done with anatomic abnormalities.
- Fewer side effects than epidural.
Paravertebral block
Epidural vs. Paravertebral

Figure 1.—Postoperative pain: cumulative morphine at arrival in recovery room, 6 hours later, and on the first, second, and third postoperative days. Data are reported as median (25th-75th percentiles).

Messina M. Minerva Anestesiol 2009;75(1):616-21
- Yearly IRB renewal.
  - 1 surgeon 1 anesthesiologist.
  - Only peds heart program in the state.
  - Personal visits and electronic records.
  - 1 year, 5 year, 10 year, 10 year plus.
  - Neurologic events.
DATA COLLECTED PROSPECTIVELY

- Date / weight / Age (months).
- Insertion site / how far it was inserted.
- Blood / clear fluid on insertion.
- Presence of a membrane.
- Surgical procedure / time to heparin.
- Medicines given in epidural.
- 2676 patients over 20 plus years.
- Incidence of blood 9%.
- Incidence of clear fluid 0.1%.
- Membrane 34%.
- Coarctation 114.
<table>
<thead>
<tr>
<th>AGE</th>
<th>OPERATION</th>
<th>PLACEMENT</th>
<th>COLDS</th>
<th>LESION</th>
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<tbody>
<tr>
<td>18</td>
<td>PVR</td>
<td>THORACIC</td>
<td>+</td>
<td>C5-7 INFRACT PARTIAL</td>
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<tr>
<td>18</td>
<td>AVR</td>
<td>THORACIC</td>
<td>-</td>
<td>T8-10 EPIDURAL HEMATOMA</td>
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<tr>
<td>12</td>
<td>PVR</td>
<td>THORACIC</td>
<td>+</td>
<td>T-10 SPINAL INFARCT COMPLETE</td>
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<tr>
<td>15</td>
<td>PVR</td>
<td>THORACIC</td>
<td>-</td>
<td>CEREBRAL STROKE</td>
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</table>
COMPLEMENTARY TECHNIQUES

- Music
- Point specific therapies.
  - Acupuncture
  - Acupressure
  - Electro acupuncture
  - Electro-stimulation
- Non-specific point therapy.
ACUPUNCTURE POINTS BENEFICIAL FOR CARDIAC SURGERY

- Lung 1, Lung 7, Pericardium 4
- Lung 1, Lung 5, Pericardium 4
- Lung 1, Lung 2, Lung 7, Pericardium 6
- Pericardium 6, Pericardium 4
- Pericardium 6
ZhongFU Lung point 1: Location 6 cun lateral to the midline level with the first intercostal space.

Chize Lung point 5: On the elbow crease, 1 cun lateral to the biceps tendon in the depression.

Kongzui: Lung point 6: Location 7 cun above wrist crease

LieQue: Lung point 7: Location 1.5 cun above the wrist crease superior to the styloid process
XiMen Pericardium 4 (P4): Location 5 cun above wrist crease

Neiguan (P6) Location 2 cun above the transverse crease
ELECTRO ACU-STIMULATION DEVICE
ELECTRO-ACUPUNCTURE AT P6 AND P4
ACU-STIMULATION WAVES

- Analgesia: Continuous and Dense-disperse.
- Blood circulation: Dense-disperse.
- Absorption of tissue fluid: Disperse and Respiration.
Stimulation of Pericardium 6 and 4

Fig. 3 Plasma β-EP levels were significantly increased immediately after the surgery in all groups, but elevated only in group C at 24 and 48 h postoperatively (△P<0.05 vs. group A/B; #P<0.05 vs. T1).

Group A: control group; group B: sham EA group; group C: EAS group

Table 2. Clinical outcome in two groups

<table>
<thead>
<tr>
<th>Postvariables</th>
<th>Control group ( (n = 36) )</th>
<th>TEAS group ( (n = 34) )</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Data are median with interquartile range. ICU, intensive care unit; TEAS, transcutaneous electrical acupoint stimulation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation (h)</td>
<td>10 (8.5–20)</td>
<td>6 (5.5–10)</td>
<td>0.004</td>
</tr>
<tr>
<td>Urine output (ml·kg·h(^{-1}))</td>
<td>3.4 (2.3–5.5)</td>
<td>3.6 (2.5–5)</td>
<td>0.915</td>
</tr>
<tr>
<td>ICU stay (h)</td>
<td>46 (24–50)</td>
<td>41 (23–47)</td>
<td>0.032</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>8 (7–9)</td>
<td>8 (7–9)</td>
<td>0.673</td>
</tr>
</tbody>
</table>
Transport blood to the heart.
Balance Yin and Yang in the thorax.
Regulation of the cardiovascular physiology.
Decreases myocardial metabolism.
Slows energy consumption during aortic occlusion.
First 2 post-op days are most critical.
The advantages of regional and complementary techniques continue to be demonstrated.
The risks of regional techniques can be minimized.
Regional Anesthesia /Analgesia for Pediatric Cardiac Surgery
David A Rosen MD , FAAP

As a pediatric cardiac anesthesiologist the management of chest pain in the pediatric patient is vital to my daily practice. Chest pain in pediatric patients is rarely an isolated problem. Total comfort of the child presenting with chest pain needs to be considered. The apparent offending source of the pain must be dealt with but also the associated comfort issues of sedation and psychological impact of the part of the body that hurts. This paper will address pain techniques, but one must be cognizant of the fact that failure to address all of the issues often produces a child that is still uncomfortable. The issue of which of these three areas is truly the problem becomes more difficult to solve.

The approach to the pain in this comfort model is often times the easiest. There is no doubt that intravenous narcotics can be used to provide analgesia for the chest. Since the 1980’s we have known that the presence of pain the neonate undergoing chest procedures increases the mortality. The studies from Boston clearly showed that high dose narcotic technique for the first 48 hours in neonates undergoing complex cardiothoracic repair improved survival. (1). What is critical is not the use of a specific narcotic, but analgesic techniques to totally control the pain and stress response in the neonatal cardiothoracic patient.

Pain management strategies that target the specific area in pain can be more advantageous than those techniques which provide analgesia throughout the body including the area in pain. Management of thoracic pain is complicated by the fact that a functioning chest cavity is critical to daily functioning. It becomes even more complex when we try to provide the pain relief while functioning at peak efficiency. Additionally, comfort at rest is only part of the problem, the child needs to be able to be comfortable with activity such as coughing in order to optimize pulmonary toilet.

The plan for post operative pain control for cardiothoracic procedures needs to be initiated before the actual procedure. Good communication between all members of the team is an essential part of the care that is delivered to these patients. All members of the team need to know the analgesic history and the coagulation status of the patient so that appropriate plans can be made. After understanding this preoperative information the anesthetic/analgesic options that are available need to be discussed with the parents and the risk benefit ratio presented in a way that is understandable to them. The risk of complications from regional techniques is low but not zero. Horlocker reports the incidence of 1:10,000 as the risk of a serious unexpected complication from an epidural.(2) While Rupen reports a worst-case incidence of 1:1700 for thoracic epidurals for adult cardiac anesthesia. (3) The benefits are statistics and harder to assign a specific ratio to. Regional techniques for cardiac surgery have always been a contentious topic. Those that don’t do regional for cardiac on a regular basis have a difficult time understanding the increased benefit for something that they see as adding risk, even though it is small, with little benefit. Those of us that perform regional anesthetics for these patients, and the nurses that take care of them post op, see the difficult to quantify
advantages in the child At our center where regional is the norm, when a regional technique is not used we are face with the stark contrast of a child who has had a cardiothoracic procedure with regional and then without and how uncomfortable they are. The development of paravertebral blocks now provides a viable option to the epidural in children where the coagulation profile is not normal. Despite our best efforts to prevent it some pediatric cardiac patient will become tolerant to narcotics. In this setting the ability to provide anesthesia and analgesia with a regional technique for repeat cardiothoracic anesthesia is even more advantageous. We have to examine both pediatric and adult studies to come up with what conclusions may be made. The Cochrane collaboration reviewed this topic of epidural analgesia for cardiac surgery in 2013. (4) It was a review of the past 30 years of thoracic epidural analgesia (TEA). Their meta-analysis showed that TEA produced results similar to findings in 1998 as well as 2006 with regards to statistically significant reductions in postoperative respiratory complications compared to cardiac surgery without TEA. This has consistently been attributed to the superior analgesia after TEA. The 2013 Cochrane review found as others that TEA facilitates earlier spontaneous respiration in the intensive care unit and faster tracheal extubation. Another benefit of TEA that the 2013 Cochrane analysis demonstrated was reduced risk of postoperative supraventricular arrhythmias. The final conclusion of this 2013 review was that patients with TEA also had a reduced risk of postoperative neurological complications. Unfortunately, the 2013 Cochrane review was still unable to quantify the real risk of an epidural hematoma caused by a regional technique and therefore it remains a major reason for the opposition to this technique.

As noted before the analgesic process typically starts prior to the onset of pain. Premedication is a common practice in children undergoing pediatric cardiothoracic procedures. The premedication also has the advantage of decreasing the amount of anesthetic agent which must be administered to induce anesthesia. The induction agents are well recognized for their effects on vascular resistance and cardiac performance, two areas which disruption of can have disastrous effects on the sick pediatric cardiac patient. We use topical local anesthetics in most patients to facilitate IM injections or intravenous access. Narcotics are another good choice because of their ready reversibility as are benzodiazepines. Anti-seizure drugs as well as antiemetics are often included as part of the premedication.

I started using a caudal technique for pediatric cardiothoracic surgery in 1985. (5) The group that was first studied were children old enough to do use a self reporting pain scoring system that were extubated at the end of the surgery so that they could report their pain score and ask for narcotics. The caudal injection was done at the end of the surgical procedure after the coagulation system had been normalized as a single shot. Small epidural catheters did not exist, so a continuous infusion was not an option. That first study documented the pain relief of a distally applied epidural technique to provide analgesia for post op cardiac pain. The pain relief was not the 24 hours that had been predicted from adult studies but closer to 8 hours. Still the analgesic effects persisted so that smaller doses of morphine (0.025mg/kg) could be used to reestablish comfort. As the anesthesiologist and intensivist caring for these patients the data was clear to me, and I did most of my cardiac cases that way. I also realized that the analgesic advantages
would be enhanced if I did the caudal epidural block before the surgery instead of after. When catheters became available they were placed at the beginning of surgery and dosed every 8 hours with 0.75 mg/kg of morphine. When infusion pumps became available that could deliver precise quantities through small catheters morphine was infused at 7.5 mcg/kg/hr. (0.125 mcg/kg/min). A double blinded study where half the patients got the bolus of morphine at the beginning of the case followed by a continuous infusion and half got only saline till the end of the case and then received epidural morphine showed that the perfusionist was able to see decreased oxygen consumption on the bypass machine in those patients that received pre-incision morphine. It also demonstrated that T3 and free radical scavenging were also preserved compared to those that received a saline epidural bolus and saline epidural infusion for the case. Since 1992 when I moved to West Virginia University with IRB approval I have been able to set up an ongoing database. Since WVU is the only pediatric cardiac hospital in the state, and I am the only anesthesiologist that does these cases, I see all the patients and discuss the possibilities of utilizing regional techniques for their pediatric cardiac care. As WVU is an electronic hospital and has had electronic records for years I have been able to do the procedure and then follow up on my patients. My earliest patients still return to WVU so I have the advantage of having over 20 years of follow-up on my original patients. Every year I submit a proposal to our IRB allowing for the continued long-term follow-up of these children.

Guideline for placement of epidural catheters:
The guidelines we use are more conservative than the current ASRA guidelines. Children must have an INR less than 1.40. The ASRA guidelines for the specific anticoagulants are closely followed. Sterile prep with chlorhexidine, gowns, hats, mask, and gloves as well as a wide surgical field are followed for indwelling catheters. The decision on where to place the epidural is based upon time till heparinization. (6) If the time is predicted to be less than 3 hours the catheter is inserted in the caudal space and only passed a maximum of three cm. If there it is anticipated that there will be more than three hours between placement or heparinization or the patient will not be receiving heparin the catheter can be inserted in the caudal space and then guided to thoracic dermatome, or placed directly in the thoracic region. The majority of our catheters are placed in children asleep. Teenagers that can tolerate awake thoracic placement are lightly sedated for placement. A Synera® patch is used in these patients to initiate topical anesthesia before the placement of the local infiltration wheel. Caudal catheters tend to be placed asleep in the lateral decubitus position. Preferably, as soon as possible to allow analgesics to take effect before skin incision. Muscle relaxants are avoided where possible in the hopes that if the catheter were pushed against a nerve route on insertion there might be some muscle movement to demonstrate this. The current practice in children less than 25 kg is to insert a 22 gauge Jelco® catheter into the caudal space and then insert the 24 gauge caudal catheter 3 cm into the canal. Catheter placement is confirmed with ultrasound or an X-ray when one of the new wire reinforced catheters are used. In children larger than 25 kg an 18-gauge needle (Jelco®, Crawford or Touhy) is used and then the 20 gauge catheter is passed. Catheters are continuously infused for up to 5 days. It is critical that the sterile dressing be applied after the procedure so that in the event the patient stools the catheter does not become contaminated. For this purpose a
sterile dressing is placed below the catheter followed by a dressing on top of the catheter with some overlap so as to seal the catheters to minimize contamination. The catheters are then attached to a stopcock. A yellow stopcock is used to differentiate epidural administration from intravenous. This is secured to a tongue blade to minimize the chance of separation. The stopcock not only allows for easy checking of patency, but facilitates the addition of a second or potentially a third medication if needed to maintain comfort in the child. When the 24 gauge catheters are used it is important to maintain them as straight as possible to avoid coiling and kinking, but the most common place for occlusion to occur with these catheters is at the point of skin insertion when the awake child scoots around. Pulling down on the gluteal muscles will usually eliminate this problem. Kinking is rarely a problem with the 20 gauge catheter, and less of a problem with the new wire reinforced 24 gauge catheters.

Catheters are removed after 5 days, if they are contaminated, or 3 hours before starting heparin. They are typically left in at least 48 hours to optimize pain control and minimize chance of chronic pain syndromes. Patients with epidurals narcotics must be monitored for late respiratory depression. They remain on continuous pulse oximetry for at least the first 8 hours after initiation of the epidural narcotic infusion. They can go to routine care with the provision that no additional narcotics are given postoperatively with the catheter in place.

Findings of the D Rosen Cardiothoracic Epidural Database:
Over 2750 cases have been entered into this database. The cardiopulmonary database includes cardiac bypass cases, off pump cardiac cases and pectus excavatum repair. 82% of the catheters were placed caudally, 18% were thoracically placed and less than 1% were lumbar. Clear fluid has been seen 0.1% and blood through the insertion needle or catheter has been seen 9%. Blood on placement of the epidural technique has not been a risk factor for the development of neurologic sequellae. Epidural techniques are only done in patients with an INR of 1.3 or less. The protocol also states that the catheter be placed caudally and left in the caudal space if there will be less than three hours between placement and the catheter and heparinization. In those patients where a thoracic catheter could be placed, but are too small for me to try and place a needle in the thoracic region (<15 kg) a caudally inserted catheter fed into the thoracic space is tried. The incidence of finding an epidural membrane which prevents the passage of the catheter to the thoracic region has been 34%.

Headaches in general are common in children. The literature reports approximately 67% of females and 58% of males. In younger children headaches show no gender difference while above 14 they are more common in females (7) Kokki et al. report an incidence of spinal headaches of <1/1000 in children and only 2-3/1000 in adolescents undergoing dural punctures (8). They found the problem to be rare, and usually resolves with conservative treatment. If a blood patch were needed 0.25ml/kg was given. There have been no spinal headaches in the database. There have been 4 critical neurologic incidences only one was related to the epidural catheter when a teenage boy 2 days post operative received anticoagulation with a heparin infusion and TPA while ambulating that suddenly developed an epidural hematoma. (9) The paralysis resolved quickly with decompression of the hematoma within the 8 hour window. The other 3 events where an
epidural hematoma was ruled out when a neurologic event occurred in proximity to the epidural. A teenage boy woke up from his first cardiac surgery neurologically intact but the next day had to undergo emergent surgery. He was placed into a medically induced coma and upon awakening had a cord infarct below T-9. An MRI revealed no evidence of an epidural hematoma. Another teenage patient developed right arm sensory and motor loss on the second post-operative day. His brain MRI revealed a stroke with a normal spine MRI. His loss resolved rapidly. A third teenage girl developed weakness in her left arm 24 hours after the epidural catheter was removed. She had been started on heparin 3 hours later following removal of the epidural catheter. When her weakness developed she was taken to the MRI which revealed a localized cord infarct with no evidence of an epidural hematoma. Her epidural catheter had been placed at T-9. All 4 patients with neurological events have been valve patients (3 pulmonary and 1 aortic) that have a known increase risks of strokes. Another group with a recognized incidence of cord strokes are coarctation of the aorta patients. We have not seen any spinal cord strokes in over 100 coarctation patients receiving epidural narcotics. Paralysis is a well recognize complication of coarctation repairs. Do epidural narcotics offer some protection?

Paravertebral blocks
The block was described in the 50s and Lonnqvist brought it to pediatrics in the early 90s, then by Berta et al. in 2008, and revived again by Boretsky. The advent of ultrasound has made the block much more available to practitioners. Some studies have shown intraoperative paravertebral placed by the surgeon appear to be no better than control even when doses of ropivacaine as high as 0.5 mg/kg/hr. were used. Other studies have found the intraoperative placement to be successful. Messina et al., found the epidural to reduce the need for supplemental morphine as well as better pulmonary status compared to the paravertebral block. (11) The FVC on day 3 was 83% of the preoperative value in the epidural group while it was 31% in the paravertebral group. While others have found the paravertebral block to be superior to Epidural techniques. (12)

We still have additional information to learn about paravertebral blocks that we all ready know about epidural techniques. Which local anesthetic are best, how much is needed, what adjuvants can be used are just a few of the questions. Yoshida 2014 study addressed the concentration issue. Yoshida found that the concentration of ropivacaine did not effect the number of dermatomes of analgesia when comparing ropivacaine 0.2 or 0.5%. (13) The paravertebral block does not presently have the same limitations with regards to coagulopathy or anatomical limitations (spinal fusions, vertebral issues, etc.) that the thoracic epidural has. Still its proximity to the epidural space does make epidural complication a potential issue. The paravertebral block also has the advantage that it can be placed preoperative, post operative or intraoperative using the ‘de visu’ technique. The key to using the intraoperative technique is to ensure that he drug is delivered to the paravertebral space and does not leak out to the intercostal or pleural spaces.

Our practice is to use paravertebral blocks for unilateral surgeries, those where we are unable to place an epidural or those with coagulation abnormalities. We take special
efforts to try and maintain pleural integrity when the procedure is done open as this enhances effectiveness. In our most difficult patients we often place both a paravertebral block and a caudal. Preservative free morphine is administered in the caudal and local anesthetics in the paravertebral. We continuously infuse ropivacaine at doses as high as 0.35mcg/kg/hr.

Timing of the regional procedure and chronic post thoracotomy pain:

The question of preemptive analgesia in children remains, but adult studies continue to support its use. Many studies examining preemptive analgesia use the thoracotomy model. A number of papers have suggested that the patients undergoing thoracotomies are more prone to the development of central sensitization than with other surgical approaches. Whether an epidural will prevent chronic post thoracotomy syndrome is another issue. Bong’s meta analysis paper found acute pain statistically improved with preemptive analgesia and a trend 39.6% in the group getting preemptive TEA and 48.6% in the control group but this was not statistically significant. The prevalence of Post Thoracotomy Pain Syndrome (PTPS) defined as still having significant pain 2 months post operative has been reported to be as high as 50% in adults. Patients also have increased threshold to tactile detection as well as temperature disturbances in the operated vs non-operated site. PTPS is reported to be able to be reduced to 21% with modern techniques which focus on this problem. A recent adult study has shown that controlled release oxycodone could produce similar results to epidural analgesia. (14) Another issue which may be important to the development of PTPS that this paper suggests is that this pain syndrome may be more common in posterolateral thoracotomies compared to anteroaxillary approaches.

In our patient population we have found less than 1% of patients developing post thoracotomy syndrome after cardiac or thoracic procedures. However approximately 50% of our pectus patients still report discomfort 6 months post repair.

Medication Dosing:

The following medications are regularly used. All the drugs injected spinally need to be preservative free. They should also have under gone testing to ensure that they are not neurotoxic. I use epinephrine in my test doses or in bolus dosing but not in continuous infusions (theoretic argument presented in legal case that the epinephrine induced vasoconstriction which produced a cord stroke).

Epidural:
All drugs are infused into the epidural space by their own infusion pump. They are attached to the catheter at a stopcock. In acute pain patients I don’t mix anything together so that I can titrate the various drugs individually to optimize their effect and minimize side effects.
Local Anesthetics:
I used the formula 0.056 cc/kg/segment to determine the volume of local anesthetic needed. When local anesthetics are used the level is checked using an ice cube at least every 24 hours when possible. Local anesthetics are used cautiously because of their ability to cause sympathetic alterations.

Bupivacaine:
Bolus as high as 1.25 mg/kg followed by a continuous infusion of 0.2 mg/kg/hr in neonates. In non-neonates the dose can safely been increased to 0.25 mg/kg/hr.
Ropivacaine: For children less than 2 I start with 0.1% ropivacaine and go to 0.2% ropivacaine for children older. I keep the dose less than 0.37 mg/kg/hr.
A Lidocaine bolus up to 1.5 mg/kg followed by an infusion at 10 mcg/kg/min to 40 mcg/kg/min. Lidocaine is used when there are ventricular arrhythmias as this infusion rate will provide a blood level potentially treating the pain and the ventricular arrhythmia at the same time. The concentration used for the continuous infusion is usually 0.75%.
Chloroprocaine 2% (10-15 mg/kg) as a bolus drug may be used with minimal risk of toxicity.

Narcotics:
Narcotics are the predominant drugs in children undergoing cardiac procedures because of their ability to produce analgesia without producing hemodynamic changes. The majority of the catheters are placed caudally. Morphine is used because of its lack of lypophilicrity which allows the drug effect to provide analgesia in the thoracic region. Morphine caudals are loaded with 0.04 mg/kg and then infused at a maximum of 7.5 mcg/kg/hr. It is started at half this rate when the catheter is placed in the thoracic region. In clinical practice if I am inserting a catheter in the caudal region and then hoping to thread into the thoracic region I prepare the caudal morphine bolus which is changed to hydromorphone if the catheter can be threaded to the thoracic space but given as morphine continuous infusion if it cannot. Increasing the morphine to greater than 7.5 mcg/kg/hr in acute pain patients produces more side effects and not analgesia. The pruritus that can occur with morphine makes some non-verbal children look agitated as though they are in pain. Decreasing the dose instead of giving supplemental narcotics fixes the problem. A small dose of nalbuphine 0.025 mg/kg can sometimes help sort this out.
Hydromorphone is used with the catheter tip near the dermatomes where the pain process is taking place. The starting dose is 0.5 mcg/kg/hr and usually this is the appropriate dose. The maximum dose I have ever found to be effective without significant side effects is 3.5 mcg/kg/hr. Typically the high dose child will only need 1.5 mcg/kg/hr.

Central alpha agonists:
Clonidine is the only approved drug in this class though various reports in the literature demonstrate that dexmedetomidine is being more widely used. Clonidine is usually started as a continuous at 0.5 mcg/kg/hr. It may be initiated as a bolus at up to 1 mcg/kg. The maximum dose I have found effective is 5 mcg/kg/hr, but usually 1 mcg/kg/hr is all that is needed. Clonidine is effective when combined with morphine given in the caudal
space. Hypotension has been seen in some patients which requires decreasing or stopping the clonidine dosage. Sedation may also be seen in patients receiving this drug.

Dexmedetomidine: Epidural dosing of dexmedetomidine is not FDA approved, but is being used. Garg et al dosed a caudal mixture with PF Morphine 100 mcg/kg and dexmedetomidine 1 mcg/kg diluted in PF NS 1 ml/kg and gave this as a single bolus at least 60 min before heparinization, and found it effective. A recent meta analysis in 2014 done by Wu et al. found that the recommended dose of epidural clonidine was 1.5-4 times greater than Dexmedetomidine. (15) Caudal Dexmedetomidine was found to prolong analgesic duration longer than other epidural sites or even intrathecal but he was comparing pediatric caudal to adult non caudal administration. This was felt to be due to the fact that dexmedetomidine has an 8-10 times greater affinity for the spinal alpha 2 AR site than clonidine does. Wu et al.’s analysis concluded that short term neurotoxicity of dexmedetomidine is favorable, but information about delayed neurological impairment from this drug is lacking.

Magnesium

Magnesium is reported to have NMDA properties and has been used intravenously as well as epidurally to enhance analgesia. I have found epidural magnesium 1-2 mg/kg augments epidural clonidine and epidural morphine for 12-24 hours when given via the epidural route. Kim et al added 50 mg of magnesium to ropivacaine in their 2-6 year old patients undergoing herniorrhaphy and found significant improvement up to 72 hours post op. (16) They felt that it works at the spinal NMDA site and that intravenous magnesium would not cross the blood brain barrier to reach this site. When examining a variety of other studies looking at epidural magnesium it can be concluded that it is an adjuvant that needs time to bind to the receptor and that studies looking at durations shorter than 6 hours failed to show advantage when adding epidural ropivacaine to epidural magnesium. There are other studies where magnesium potentiates analgesic effects of opiates and its onset effects are rapid in that setting. A number of human and animal studies that have shown it to not be neurotoxic. However, one rabbit study suggested that more than 1 mg/kg of intrathecal magnesium might be neurotoxic. (17)

Paravertebral dosing:

Boretsky reports a bolus 0.5% ropivacaine up to a maximum of 3 ml/kg. She recommends 10 ml on a side if it does not exceed the toxic threshold. Continuous infusion 0.2% ropivacaine starts at 7 ml/hr up to a total dose of 0.25 mg/kg/hr of ropivacaine. (18) In an earlier article Boretsky gave ropivacaine 0.5 ml/kg/side to a maximum of 15 ml per side using 0.5 % ropivacaine, and then an infusion 0.2% ropivacaine at 0.5 mg/kg/hr. For children less than 50 Kg she felt that 0.1% ropivacaine might also be used. (19) Turkoz et al used 0.5 ml per kg of 0.25% bupivacaine with 1:200,000 epinephrine on 15 infants undergoing coarctation of the aorta repair. (20) As the technique continues to be relatively new in children optimal dosing of the analgesic medications particularly the local anesthetic has not been confirmed. When I use this technique I have limited it to a single side and have kept my ropivacaine max at 0.35
mg/kg/hr. Often I will use lidocaine and bolus with 1.5 mg/kg and then infuse 10-40 mcg/kg/min.

Contraindication to regional techniques:

Parent refusal. It’s informed consent and if parents refuse my description and presentation of risk benefits a different approach to analgesia is taken. Infection is controversial, KotzeA et al., looked at complications from thoracic epidural analgesia in children undergoing decortications with epidural analgesia and found no complications related to placing these catheters in infected patients. Further they found that their patients who received only IV narcotics had increased complications.(21) A local infection typically can be dealt with by moving to a different location and explains most of the lumbar epidurals in our database.

Complementary techniques:

Placing needles in proper locations to enhance patient comfort are techniques commonly employed by the anesthesiologist that utilize regional techniques. Acupuncture is a natural progression of this skill set. In pediatric cardiothoracic anesthesia the use of acupuncture compliments other anesthetic techniques but particularly regional techniques. Pediatric patient’s difficulties in cooperating with regional techniques means that very little can be done prior to the induction of anesthesia. Presurgical time must be optimized to provide a secure airway, techniques for maximal comfort during and after surgery, and the placement of monitoring lines. There is an unspecified but limited amount of time between entering the surgical suite and making skin incision. Conventional acupuncture techniques may be difficult to use in the OR because of time constraints. Electro-acupuncture can achieve the results of standard acupuncture with less time or can utilize current instead of needle manipulation to achieve results. Electrical stimulation can be provided through an acupuncture needle or a small electrode. A continuous and/or a dense-disperse wave are used for stimulation because of its analgesic properties. Blood circulation is also enhanced by a dense-disperse wave. The disperse and respiration waves are good for absorption of tissue fluid. A lower frequency (2 Hz) is used when dealing with damaged tissue like surgery. Use 8 Hz for maintenance and higher frequency, 10Hz when dealing with spasm. The intensity is just below the threshold where things move or mid range (4-14mA). When obtaining anesthesia consents always review risks and benefits of general anesthesia, regional techniques and alternative techniques (Acupuncture).

My acupuncture experience is limited. I copy techniques of those who are more familiar with designing which points are most effective for cardiothoracic surgical pain issues. Below are my extractions of some recent acupuncture studies from the literature. I utilize a variety of points similar to those described below. My only caveats is that there can be no more than 11 different (bilateral) points at a session. Most of the acupuncture points are measured from specific anatomic landmarks and are described as “cun”. The cun is a measurement of the width of the child’s thumb. Making ruler with the width of the child’s thumb can be helpful in determining where to find the various acupuncture points.
A point finder is also needed to help you determine the precise locations of these acupuncture points. Zhou et al. studied 200 patients. 100 patients with standard GA and 100 with combined Acupuncture plus midazolam. Those in the acupuncture group had significantly less narcotic use lower pulmonary infections, shorter ICU stays and lower cost. In their acupuncture group they taught abdominal breathing for three days prior to the surgery. This would have obviously had a benefit in and of itself. They stimulated ZhongFU (Lung 1) LieQue (Lung 7) and Ximen (PC 4).(22)

ZhongFU Lung point 1: Location 6 cun lateral to the midline level with the first intercostal space.

Kongzui: Lung point 6: Location 7 cun above wrist crease

LieQue: Lung point 7: Location 1.5 cun above the wrist crease superior to the styloid process
XiMen Pericardium 4 (P4): Location 5 cun above wrist crease between tendons of palmaris longus and flexor carpi radialis

Neiguan (P6) Location 2 cun above the transverse crease of the wrist between the tendons of the palmaris longus and the flexor carpi radialis.

Chi et al. used electrical acupuncture compared to GA alone. They studied 80 patients in each group and found advantages of significantly fewer blood transfusion, need for antibiotics pulmonary infections, duration of hospitalization, ICU stays and medical costs. The points that they stimulated (3-4 Hz at 2.0-2.2 mA) for 20 minutes were Zhongfu (Lung 1), Chize (LU 5) Ximen (PC 4). Tang et al. used Electroacupuncture (EA) at Yunmen (LU 2), Zhongfu (LU1), Lieque (LU7) and Neiguan (PC6). They were studying whether Dexmedetomidine or Midazolam was a better adjuvant to their electro acupuncture. They found dexmedetomidine superior to midazolam in analgesia, improving respiration and circulation functions in their patients undergoing open-heart surgery patients under acupuncture-assisted general anesthesia. Xie et al. used electro acupuncture at P 6 and P 4 consisting of a disperse-dense wave with a low
frequency of 2 Hz and a high frequency of 20 Hz. It was performed 30 minutes prior to induction of general anesthesia and continued through the surgery. The points they used were P6 and P4. (25) The only recent pediatric cardiac acupuncture study was done by Ni X et al. It was a randomized control trial. They enrolled 70 non-complex congenital heart patients age 2-12 that would be undergoing CPB with aortic cross clamp. After inducing anesthesia with IM ketamine 4-6 mg/kg, they stimulated the P6 point bilaterally with a 1.5cm diameter electrode for 30 min. They found lower troponin and c-reactive proteins in children receiving stimulation. They also noted shorter ventilation times and PICU stays. They stimulated P6 with a disperse-dense wave at a frequency of 2 Hz for 30 min. They reported that they adjusted their amplitude to maintain a slight twitch during their treatment. Their mean amplitude was 14 ± 3 mA. Anesthesia maintenance was fentanyl and midazolam. They found higher B endorphin levels and lower 5-HT in patients undergoing thoracotomies under electro stimulation. They did not find an advantage of this technique with regards to inflammatory markers IL-6, TNF-alpha or IL-10. Additionally, they did not find any advantages with regards to inotropic needs or urinary output. Their results are similar to those found with other regional approaches to cardiothoracic procedures. The point they used (P-6) has been widely used in a variety of pediatric studies. The advantage of this approach is that they don’t need to place a needle, but the disadvantage is that the energy is not directly focused on the P6 point. The P6 point makes sense because it supposed to provide blood flow to the heart and balance in the thorax.

The techniques described in this paper are familiar to us, and we appreciate the whys how’s and whens of these techniques. Most of the rest of the population does not appreciate what, how when’s of what we do. Therefore, if there is a problem which can be related in some way to what we did it is not unlikely that there may be some type of legal action directed towards us. In my PICU at WVU when a regional technique is not done the nurses and physicians regularly ask why and comment on how much more difficult it is to keep the patient comfortable. The answer to this problem is not to avoid doing the procedures, this places the child at unnecessary risk for lack of comfort, but to take a proactive approach. Anything that looks like a problem needs to be actively investigated, document carefully every time. If a problem does happen leaving a catheter in to help locate where a problem may exist can help if it can be seen on imagining studies (MRI, CT, and ultrasound) Remove it as quickly as possible if you think it is causing the problem. Open lines of communication need to be maintained and surround yourself with regional experts that will be able to serve as your experts when an unscrupulous lawyer convinces your patient to take actions against you for something you are not responsible.

In order to optimize care for the children undergoing cardiothoracic procedures we have to be concerned with more than just the intraoperative delivery of a high dose narcotic technique for all our children. Techniques which provide comfort throughout the entire hospital period are critical to achieve this goal. (27) The literature continues to support the development of regional and complimentary techniques to meet this need. There are situations where one technique may have certain advantages over another. Being familiar
with multiple techniques will allow optimization of comfort in the child undergoing cardiothoracic procedures.

References:

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