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Masterthesis

Role of epidural analgesia in the perioperative pain management of scoliosis surgery in adolescents: a narrative review

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Abstract

This review attempts to provide a comprehensive evaluation of the scientific literature on epidural analgesia in comparison with other analgesia regimen for postoperative pain management in paediatric and adolescent posterior thoraco-lumbar spine surgery. Epidural anaesthesia is said to be associated with better pain control compared to traditional intravenous analgesia alone, as it targets pain at the site of surgery, potentially reducing the need for systemic opioids and their associated side effects. However, its use in children remains bringing controversy and presents unique challenges. A comprehensive literature search was conducted through the databases of PubMed, Cochrane Library and Web of science. We focused on studies and trials that examined the efficacy and safety of epidural analgesia compared to other analgesia regimens in adolescents and children. Epidural analgesia has been shown to provide effective postoperative pain relief in patients undergoing thoraco-lumbar spine surgery, offering benefits such as reduced opioid use, improved patient satisfaction and a faster return of gastrointestinal function. Complications related to epidural analgesia, such as catheter related complications, adverse events and severe complications were reported but are very rare. Despite these risks, epidural analgesia was generally associated with better outcomes compared to intravenous analgesia, with improved pain control and beginning to earn its place in enhanced recovery protocols. The evidence quality was low and there were significant variations in the methods and pain regimens used across studies. We can conclude that epidural analgesia is a valuable technique for managing postoperative pain in paediatric thoraco-lumbar spine surgery. While it offers certain advantages over intravenous analgesia, its implementation must be carefully managed to avoid potential complications. This review highlights the need for further research to refine the optimal use and implementation of epidural anaesthesia protocols in paediatric and adolescent populations for posterior spinal fusions (PSF).

Keywords: **Epidural analgesia, epidural anaesthesia, spinal fusion, adolescent and young adult.**

Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity characterized by a lateral curvature exceeding 10° in the coronal plane, with no identifiable cause. Surgical intervention is recommended for adolescent idiopathic scoliosis cases where the Cobb angle exceeds 45°, as such deformities can impair lung function and hinder daily activities[1]. Idiopathic scoliosis is the most frequently observed type, accounting for around 70% to 80% of all scoliosis cases[2,3]. The prevalence of idiopathic scoliosis is estimated to be between 0.9% and 12% of the general population, with up to 0.1% at risk of requiring a surgical intervention[3]. A PSF involves the permanent fusion of two or more vertebrae to prevent further curvature progression. This surgery requires extensive tissue dissection, including the skin, subcutaneous layers, bones, and ligaments and is often lengthy and complex which results in significant postoperative pain emphasizing the need for effective pain management strategies to optimize the postoperative recovery period[4,5]. Major spinal surgery is associated with severe postoperative pain and stress response, bowel dysfunction, and a potential for chronic pain development[6,7]. Pain management strategies following PSF for

AIS have evolved in recent years. Different multimodal regimens for effective pain control are being implemented which can enhance patient satisfaction, facilitate early mobilization, improve oral intake, and reduce both pain levels and hospital stays[8-10]. Multimodal pain management approaches have been widely studied in adult orthopaedic surgeries, demonstrating reduced opioid usage, better pain relief, and shorter hospital stays[11]. Kurd et al reviewed literature highlighting increasing evidence supporting multimodal analgesia in adult spinal surgeries[12]. In adult surgical literature, epidural analgesia has already been associated with enhanced postoperative recovery. However, its role in paediatric and adolescent spinal surgeries remains less established and results remain inconclusive[14,15]. The three most used analgesic options include intravenous opioids via patient-controlled analgesia (PCA), patient controlled epidural analgesia (PCEA) and intrathecal analgesia (IT)[13]. Historically, opioids have been the primary approach for managing postoperative pain, but their use is associated with some adverse effects[8,16]. Systemic opioids for acute postoperative pain may increase postoperative nausea and vomiting, gastrointestinal ileus and may prolong hospitalization, potentially increase hospital costs[17]. Pulmonary function may also be affected in children with scoliosis deformity, particularly among children with non-idiopathic scoliosis or those with idiopathic scoliosis and a thoracic deformity, making them more susceptible to respiratory depression from systemic opioids[18,19]. Compared with systemic analgesia alone, epidural analgesia may offer better pain control but practitioners are often inhibited by possible complications. However, epidural analgesia has been associated with rare but serious complications, it is critical to quantify the real benefits of epidural analgesia over other modes of pain treatment[17]. Different epidural solution and protocols where being used in the literature, no standardised protocols where found. Most use a local anaesthetic alone, an opioid alone, or local anaesthetic plus opioid. In scoliosis surgery, thoracic epidural catheters are often placed intraoperatively by surgeons due to challenges associated with percutaneous insertion, including the risk of spinal cord injury. Preoperative placement is frequently avoided due to technical difficulties and potential risks, especially for less experienced practitioners[21,22]. Additionally, concerns exist regarding delayed recovery due to reduced mobility and inadequate guidance in the tapering process of the epidural catheter. Despite the popularity of epidural analgesia in other major surgeries, uncertainty remains about its optimal application in scoliosis fusion, especially in comparison to other pain management methods such as intravenous opioids or multimodal analgesia, including methadone[23]. Findings across studies are conflicting regarding the effectiveness and safety of epidural analgesia in this context, highlighting the need for a comprehensive review of the available data. The goal is to provide a clear overview of the benefits, risks, and clinical outcomes associated with the use of epidural analgesia during PSF in adolescents and children. The findings of this review will contribute to the further optimization of pain management strategies for PSF patients and may serve as a basis for future guidelines and research.

Methodology

This narrative review was not eligible for registry in a review database. The recommendations and checklist of the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Metanalysis) were used as a guideline to conduct this review[24]. The primary objective of this narrative review is to evaluate the effectiveness of epidural analgesia on pain management in children and adolescents aged 6-24 years, without significant medical history, undergoing PSF. This will be done by comparing postoperative pain scores, time to first mobilization and patient satisfaction. The secondary objective of this narrative review was to examine the safety true application and complications of epidural anaesthesia specifically for PSF in children and adolescents aged 6-24 years and its use in multimodal pain regimens and rapid recovery pathways. This includes both common complications such as the number of attempts required for correct catheter placement, dislodged catheters, post-operative nausea and vomiting, postoperative enteral recovery, urinary retention as well as rarer but serious side effects such as neurological complications, hypotension or respiratory depression. Exclusion criteria were studies with no use or comparison with epidural analgesia, studies with adults (>24j), individuals with neuromuscular, congenital, or non-idiopathic scoliosis, anterior spinal fusions and research about surgery other than PSF, also studies with no free text where excluded. If the study had both inclusion and exclusion criteria, studies where examined to be of any added value for the paper. For example in a paper with healthy, and individuals with neuromuscular/congenital scoliosis, only the results of the healthy patients were used. This approach aims to prevent data dispersion and focus solely on the effectiveness of epidural analgesia.

If future research yields positive results regarding epidural analgesia in scoliosis fusions, subsequent reviews can be conducted to investigate different subtypes in more detail. These analyses could help identify epidural analgesia regimens or alternative methods that may be safer or more effective. The goal of this review will be to focus on gathering info about the current posterior scoliosis fusion epidural analgesia protocols and identifying gaps in the current knowledge base that require further study. To achieve a comprehensive overview of the subject matter, we devised a focused search strategy that would enable us to gather the most relevant and informative literature on the topic. To ensure the relevance and completeness of this narrative review, a comprehensive search strategy across multiple databases, including PubMed, Cochrane Library and Web of science was performed between January 2025 and March 2025. No language restrictions where used to select articles. An AI translator app was used to translate and read the articles if necessary. The keywords used, selected through the MeSH tools, were the following: epidural analgesia, epidural anaesthesia, spinal fusion, adolescent and young adult. For an overview of the included studies see Table I. The following search string was employed for the searches, adapted for each search engine: ("Scoliosis surger*" OR "Spinal fusion*"[Mesh] OR "spinal fusion*" OR "Posterior spinal fusion*" OR "Corrective spinal surger*" OR "spine deformity surger*" OR "spine surger*") AND ("Anesthesia, Epidural"[Mesh] OR "epidural anesthes*" OR "Analgesia, Epidural"[Mesh] OR "epidural analges*" OR "Continuous epidural infusion*" OR "Patient-controlled epidural analges*" OR "epidural catheter technique*") AND ("adolescent"[Mesh] OR "adolesc*" OR "Young adult"[Mesh] OR "young adult*" OR "Teenager*" OR "Pediatric patient*" OR "Young patient*" OR "Children*" OR "pediatric*" OR "pediatric" OR "young adult"[Mesh] OR "young adult*"). This strategy yielded a total of 190 articles. Duplicate articles were subsequently removed, resulting in 157 unique articles. These were screened based on title and abstract, resulting in the removing of 104 articles leaving 53 articles for further review. After removing 17 articles because full text wasn't available, 36 reports remained for assessment for eligibility. The search results will be evaluated by a single researcher, who will determine which studies qualify based on predefined inclusion and exclusion criteria as above. These criteria will include all studies focusing on the use of epidural analgesia in posterior scoliosis fusions for children and adolescents. Including randomized controlled trials, cohort studies, systematic/narrative reviews and retrospective analyses that give answers for our primary and secondary objectives. Studies that are still ongoing, do not meet methodological standards, lack qualitative standards or lack full-text availability will be excluded. After thorough examination, 11 articles remained. 5 articles were included regarding the objective 'epidural compared to intravenous analgesia', 1 article were included regarding 'continuous compared to intermittent epidural', 1 article was included regarding 'epidural efficacy and safety', 2 narrative reviews were included about pain management in paediatric spine surgery and 2 articles were included regarding 'intrathecal vs epidural analgesia'. In order to maximize fluent legibility and to provide depth, further database searches for articles containing keywords relevant to the initially selected articles were performed when necessary, in order to expand on the subject matter. Figure 1 displays a schematic overview of the selection process. An overview of the included studies, regarding the intervention, outcome measures and results of epidural analgesia in comparison to intravenous analgesia is presented in Table I.

Results

Pain

Pain is not only a distressing sensation, it increases the complication rate as well as the length of hospitalization. In children and adults it is difficult to evaluate postoperative pain therapy by the amount of pain or the need for pain medication. Children have various individual ways to communicate discomfort, depending on a variety of factors, including expectation, education, cognitive capacity, anxiety and assistance by caregivers. Pain is measured mostly by visual analogue scale (VAS) pain scores (choices ranging from 0 (no pain) to 10 (worst imaginable pain)) and were mostly obtained from patients in the recovery after transport from the operating room and at subsequent time intervals for the first hours postoperatively and every so many hours thereafter, until CEA or PCA was discontinued[17,26,30]. In other retrospective studies assessment of pain was expressed through the number of times the patients administered drugs via the PC(E)A or demanded additional pain medication (rescue medication), such as opioids and non-opioids[29]. It has already been proven that after spinal fusion in adults, the addition of continuous postoperative infusion of levobupivacaine through an epidural catheter placed intraoperatively by an orthopaedic surgeon significantly reduces the pain, opioid and non-
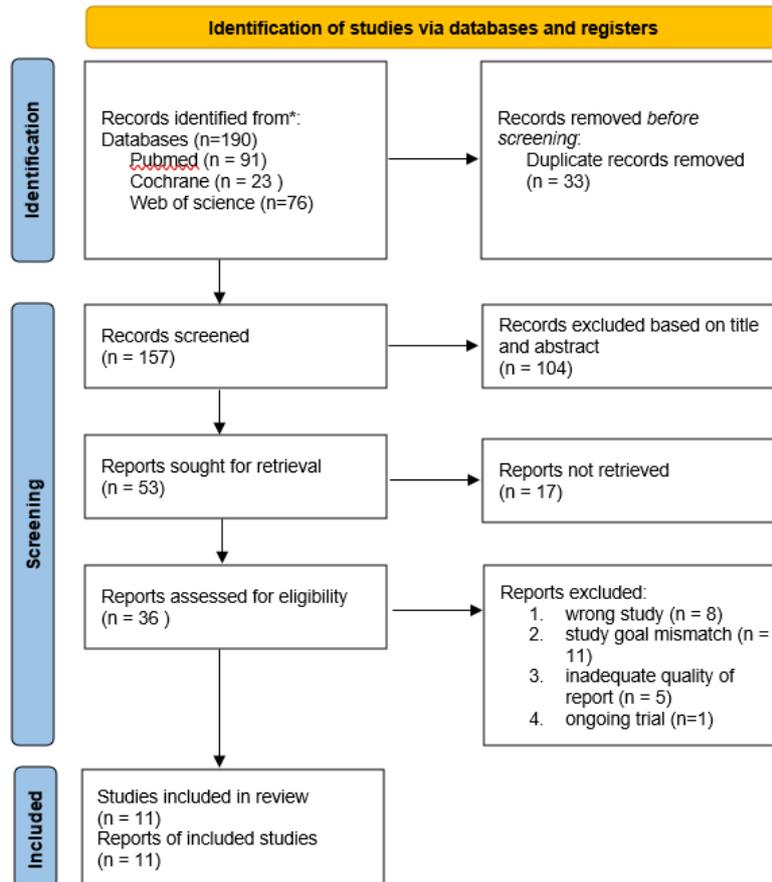
Identification of studies via databases and registers

Identification

Records identified from*:
Databases (n=190)
Pubmed (n = 91)
Cochrane (n = 23)
Web of science (n=76)

Records removed *before screening*:
Duplicate records removed (n = 33)

Screening

Records screened (n = 157)

Records excluded based on title and abstract (n = 104)

Reports sought for retrieval (n = 53)

Reports not retrieved (n = 17)

Reports assessed for eligibility (n = 36)

Reports excluded:
1. wrong study (n = 8)
2. study goal mismatch (n = 11)
3. inadequate quality of report (n = 5)
4. ongoing trial (n=1)

Included

Studies included in review (n = 11)
Reports of included studies (n = 11)

Fig. 1 — Prisma flow diagram of study identification, screening and inclusion.

opioid analgesic consumption[6]. It seems to be clear and logical is that epidural analgesia also reduces the amount of opioid use and post-operative pain which was confirmed by our largest studies. This was firstly conformed by a systematic review by Guay at al. that showed that pain at rest and on movement is reduced to 72 hours after surgery and thereby reduces opioid-induced side effects[17,29,31,32]. An improvement in pain control after surgery was found with the use of epidural analgesia compared with systemic analgesia and was in accordance with results found in adults for various surgeries including abdominal surgery[17]. In another study from the systematic review, Gauger et al found that on the first three postoperative days, pain control with PCEA was excellent as reflected by the low maximal pain scores at rest and high satisfaction rates. Maximal pain during mobilization was also relatively low after this extensive surgery and decreased further over the next few days. Nevertheless, when PCEA was changed to PCA because of the absence of pain and to minimize the risk of infection, the number of rescue analgetic doses greatly increased in response to the increase in pain scores at rest after the change of analgesic technique. Introduction of the PCA regimen was also accompanied by a significant increase in post-operative pain and vomiting (PONV) 7–20%, and

by a decrease of satisfaction scores 98–83%[17,33]. In a meta-analysis by Taenzer et al, four relevant randomized controlled trials (RCTs) were identified (n=129, ranged 30 to 36 participants) with withdrawals ranged from 0% to 14%. Postoperative pain scores were significantly lower in the epidural group than in the intravenous morphine group after 24 hours (WMD -12.59, 95% CI -24.40 to -0.78, I2=0%; four studies), after 48 hours (WMD -10.13, 95% CI -19.11 to -1.16, I2=0%; four studies) and after 72 hours (WMD -11.53, 95% CI -20.85 to -2.21, I2=0%; three studies). Rescue analgesic use (four studies) was significantly lower in epidural groups than intravenous morphine groups in two studies (WMD -7.5mg morphine per patient, 95% CI -11.26 to -3.69). Furthermore, three studies evaluating CEA with a local anaesthetic mixture via two simultaneous epidural catheters confirmed a reduction in pain scores compared to opioid based analgesia[30,32,34]. Halpern at al also confirmed in a small single-centre, retrospective study with 57 participants that CEA with a local anaesthetic mixture via a single epidural catheter for PSF can provide profound analgesia. When assessing the analgesic effect of regional anaesthesia on acute post-operative pain, it is important to consider both pain scores and opioid usage. In this study, we found no significant change in pain scores

Table I. — Overview of the selected articles regarding epidural anaesthesia in adolescent and children for PSF.

Author	study aim	participants	study design	intervention	outcome measures	results
Epidural analgesia compared to intravenous analgesia						
Cassady et al. (2000)	A randomized comparison of the effects of continuous thoracic epidural analgesia and intravenous patient-controlled analgesia after posterior spinal fusion in adolescents	n = 33	randomized controlled trial	continuous thoracic epidural analgesia with bupivacaine-fentanyl (CEA) and intravenous patient-controlled analgesia with morphine	*VAS pain scores *Hypotension, PONV, pruritus, respiratory depression, wound infection, recovery times, bowel sounds and resumption of liquid intake	*There were no significant differences between groups in VAS pain scores, side effects, or time to resumption of liquid intake. *There was a significant difference (P = .0089) between groups in return of bowel sounds, which occurred earlier in patients receiving CEA
Dinter et al. (2023)	Continuous epidural and intravenous patient-controlled analgesia	* n=175 (children between 8 and 18) years * two sub-cohorts: those who were mentally and/ or physically impaired (H; n = 93 vs. n = 30) and those who were impaired (I; n = 26 vs. n =26).	retrospective cohort study	CEA with local anesthetic and opioids and IV-PCA with opioids	* Pain (administered drugs via the catheter or IV-PCA or demanded additional pain medication) *First defecation *First mobilization *Length of hospitalization and on Intensive Care Unit	*There was no difference in additional demand for pain medication *Healthy children who received CEA started mobilization 1 day earlier than children with IV-PCA *First postsurgical defecation was seen earlier in all children who received CEA in both groups *Healthy children who received CEA were discharged from hospital 4 days earlier than their IVPCA counterparts (p < 0.001). *Transient neurological irritations were seen in 9.7% of the patients in the CEA group.

Table I. — Overview of the selected articles regarding epidural anaesthesia in adolescent and children for PSF (Continued).

Author	study aim	participants	study design	intervention	outcome measures	results
Guay et al. (2019)	epidural analgesia vs systemic analgesia	included 11 trials (559 participants), 249 participants in the analysis	systematic review	effectiveness and safety of epidural analgesia compared with systemic analgesia for acute postoperative pain control after thoraco-lumbar spine surgery in children	PRIM:* Pain (at rest and on movement up to 72 hours after surgery) * Return of gastrointestinal function measured as time to first: * Vomiting up to 48 hours after surgery a. flatus (hours); b. bowel movement (hours); c. liquid ingestion (hours); d. solid food ingestion (hours). SEC: *Time to first mobilization (days). *Hospital length of stay (days). *Satisfaction with postoperative analgesia regimen (participant and parent satisfaction *Complications and neurological complications.	*There is moderate- and low-quality evidence that there may be a small additional reduction in pain up to 72 hours after surgery with epidural analgesia compared with systemic analgesia. *Two very small studies showed epidural analgesia with local anaesthetic alone may accelerate the return of gastrointestinal function. *The safety of this technique in children undergoing thoraco-lumbar surgery is uncertain due to the very low-quality of the evidence.
Halpern et al. (2023)	To see if the tip in the upper thorax can provide adequate analgesia for PSF	n = 57	single-center, retrospective study	Effects of epidural analgesia before and after removal	*The primary outcome is the comparison of opioid usage while the epidural was in place and after epidural removal. *Secondary outcomes include the number of patients not requiring opioids with the epidural in place and after epidural removal, pain scores in the two group, the number of patients reporting severe pain (VAS >7) all three PODs, and complications associated with the epidural catheter.	* Opioid usage was 4.5 times greater in the 19 hours following removal of the epidural catheter when compared to the entire period (mean 65 hours) the epidural was in place (Group Epi 0.154 OME/kg vs Group No Epi 0.690 OME/kg, p<0.001). * 51% (29/57) of patients did not require opioids (intravenous or oral) while the epidural was in place, all patients required opioids after epidural removal. * Mean opioid usage while the epidural was in place was 9.3 OME, equivalent to approximately 6 mg of oxycodone. * Mean and maximum pain scores increased significantly after removal of the epidural of the epidural catheter.
Taenzer et al. (2010)	To evaluate the efficacy of postoperative epidural anaesthesia in adolescent scoliosis surgery.	n=129	Meta-analysis	compared use of a continuous infusion of epidural local anaesthetics plus intravenous opioids versus intravenous opioids alone for postoperative pain management	*postoperative pain score measured with a visual analogue scale. *Secondary outcomes were: nausea; pruritus; rescue analgesics or total opioid usage; return of bowel function; and patient satisfaction.	postoperative epidural anaesthesia significantly improved pain control compared to intravenous opioids alone in the first three days after adolescent scoliosis surgery and had a beneficial effect for patient satisfaction and side effects (such as nausea, pruritus, rescue analgesics).

Table I. — Overview of the selected articles regarding epidural anaesthesia in adolescent and children for PSF (Continued).

Author	study aim	participants	study design	intervention	outcome measures	results
Intrathecal analgesia compared to epidural analgesia						
Cohen et al. (2017)	To evaluate if extended-release epidural morphine (EREM) would provide better pain control and less adverse effects compared to intrathecal (IT) morphine	n = 71	randomized controlled double-blinded trial	randomly allocated to IT morphine 7.5 mcg/kg or extended-release epidural morphine (EREM) 150 mcg/kg. Post-operative pain was treated with morphine patient controlled analgesia (PCA), ketorolac, oral oxycodone and acetaminophen.	*The primary outcome was total IV morphine consumption during 0–48 hours post-operatively. *Secondary outcomes included time until first PCA demand, pain scores and adverse opioid effects.	*There was no difference in total morphine consumption over the first 48 hours between subjects in the EREM and IT morphine groups: median (range) 42.2 (5.5–123.0) and 34.0 (4.5–128.8) mg, respectively (p=0.27). *EREM and IT morphine groups had no difference in time until first PCA demand. *Pain scores were no different between the groups from 8–24 hours after surgery. Compared to IT morphine, EREM subjects had lower pain scores from 28–36 hours after surgery. *The reported incidence of pruritus was lower in the EREM subjects.
Hong et al. (2017)	to examine the efficacy of our intrathecal morphine protocol vs epidural hydromorphone for postoperative analgesia after posterior spinal fusion.	n=40	retrospective cohort study	*Intrathecal morphine 12 µg·kg-1 (max 1000 µg) prior to incision. Postoperatively, order to receive oral oxycodone (0.1 mg·kg-1, max 5 mg) at 18 h postintrathecal injection. * Epidural hydromorphone group, catheters were placed by the surgeon and bolused with 5 µg·kg-1 hydromorphone (max 200 µg) and 1 µg·kg-1 fentanyl (max 50 µg), followed by a continuous infusion of 40-60 µg·h-1, patient-controlled bolus doses of 5 µg with a lockout interval of 30 min.	*Pain scores, sedation scores, episodes of nausea, vomiting, and pruritus; administration of antiemetics and antipruritics; *Use of supplemental oxygen; time of first oral intake; time of hospital discharge (LOS) *Evidence of any other adverse events, including admission to the intensive care unit.	*Compared to the epidural hydromorphone group, the intrathecal morphine group reported lower pain scores in the postanesthesia care unit and first 8 h after surgery and higher pain scores on the 2nd postoperative day *The documented time to ambulation and time of Foley catheter removal were statistically earlier in the intrathecal morphine group, and the hospital length of stay was significantly shorter (3.0 ± 0.5 days vs 3.5 ± 0.7 days; P = 0.03). *Adverse events did not significantly differ between the groups.

Table I. — Overview of the selected articles regarding epidural anaesthesia in adolescent and children for PSF (Continued).

Author	study aim	participants	study design	intervention	outcome measures	results
Intermittent epidural analgesia compared to patient controlled continuous epidural analgesia						
Erdogan et al. (2016)	compare the efficacy and side effects of patient-controlled intermittent bolus epidural analgesia (PCIEA) and patient-controlled continuous epidural analgesia (PCCEA) for postoperative pain control in adolescent idiopathic scoliosis.	n=47	a prospective, randomized, double blinded study	PCIEA group: 0.2 mg/mL of morphine, 0.25 mL/kg of morphine bolus, additional doses of 0.25 mL/kg morphine with a 1-hour lockout given by patient-controlled demand, and no infusion. PCCEA group: 0.2 mg/ mL morphine, an initial morphine loading set at 0.1 mL/kg, followed by a 0.05 mL/ kg/h continuous infusion of morphine, and a 0.025 mL/kg bolus dose of morphine. There was a 30-minute lockout interval.	The primary outcome was morphine usage. The secondary outcomes were pain score, postoperative nausea and vomiting, and pruritus.	Cumulative morphine consumption was lower in the PCIEA group than in the PCCEA group. Both methods provided effective pain control. There were no differences in pain scores between the groups. Postoperative nausea, vomiting, and prur-itus were lower in the PCIEA group
Narrative reviews about perioperative pain regimens and rapid recovery in pediatric posterior spine surgery						
Shah et al. (2020)	review of the literature assessing the efficacy of opioid alternatives, multimodal pain regimens, and rapid recovery in pediatric spine surgery.	9 studies reviewed (2 RCT, 1 cohort, 3 RR, 2 prospective DB RCT and 1 case serie)	Narrative re-view	Comparing literature about the efficacy of neuraxial blockade for postoperative pain control after adult spine surgery IT vs DCEA vs PCA vs SCEA	visual analogue scale (VAS), postoperative resumption of bowel sounds, liquid intake, and adverse effects	*They concluded that epidural analgesia was a safe and effective way to control postoperative pain after AIS surgery. *They found that there was no significant difference in VAS scores, liquid intake, or adverse effects; however, return of bowel sounds was significantly faster in the CEA group. The authors concluded that both CEA and PCA are comparable in terms of efficacy and safety. *They concluded that there was no difference in in outcomes when using epidural or intravenous analgesia after PSF in adolescents.

Table I. — Overview of the selected articles regarding epidural anaesthesia in adolescent and children for PSF (Continued).

Author	study aim	participants	study design	intervention	outcome measures	results
Seki et al. (2018)	to provide detailed information of each analgesic technique so that clinicians can make appropriate choices regarding pain management in patients with adolescent idiopathic scoliosis undergoing posterior spinal fusion.	31 studies were included in the review. (8 about epidural analgesia)	Narrative review	The focus was on postoperative pain management in patients undergoing PSF for AIS	*short-term outcomes: i.e., postoperative morphine use, pain scores, and side effects *the long-term outcome: i.e., incidence of pain after discharge from hospital *Complications	* epidural analgesia is superior in analgesic effect when compared with IV PCA * epidural analgesia has a lower incidence of these adverse effects than IV PCA, while others have found no difference between the two techniques. * epidural analgesia is effective as a postoperative analgesia strategy and may provide better analgesia than IV PCA in patients undergoing PSF for AIS.
Safety and efficacy of epidural analgesia						
Saudan et al. (2008)	Safety and efficacy of patient controlled epidural analgesia following pediatric spinal surgery	n=100	Prospective cohort study	One or two epidural catheters were positioned under direct vision by the surgeon based on the number of vertebral segments operated upon. The epidural solution consisted of bupivacaine 0.0625%, fentanyl 1 µg·ml−1 and clonidine 0.6 µg·ml−1, delivered at a basal rate of 0.2 ml·kg−1·h−1 and a PCEA dose of 0.1 ml·kg−1·h−1(max. 2 h−1).	* Pain scores, patient satisfaction and motor blockade * Adverse avents: hypotension, convulsion, leakage into spinal space, technical problems, insufficient analgesia, PCEA displaced	*The present study demonstrates that PCEA provides excellent pain relief following extensive spinal surgery and is associated with a low incidence of adverse events. *The use of PCEA should be encouraged in children and adolescents following extensive spinal surgery.

between post-operative day (POD) 1 and POD 2[28]. Some small randomized controlled trials show that CEA and PCA provide comparable analgesia after PSF[27,29]. In a study with 29 participants, no significant differences in VAS pain scores were shown within subjects, between subjects within a group, or between groups. There were 8.7 +/- 5.1 and 6.9 + 3.7 VAS in the CEA and PCA groups, respectively, which was not statistically significant. Mean number of rescue ketorolac doses given by treatment groups was not significantly different between groups (3.7 + 2.1 CEA; 3.2 + 2.0 PCA)[27]. As so Dinter et could not demonstrate the superiority of CEA over IV-PCA in pain management in our study. Yet, it was shown in several other trials. There was no difference in additional demand for pain medication in children, regardless of the type of postoperative pain management[29]. In one prospective, randomized, double blinded study with 47 participants, the effects of patient-controlled intermittent bolus epidural analgesia (PCIEA) and patient-controlled continuous epidural analgesia (PCCEA) for postoperative pain control in adolescent idiopathic scoliosis was examined. Both groups were provided effective pain control. There were no significant differences in the VAS between the groups, Compared with the continuous PCEA, at all-time points, morphine usage was significantly less in the group with intermittent PCEA, and total morphine usage was significantly decreased in intermittent PCEA. Additionally, compared with PCCEA infusion morphine, PCIEA with morphine was associated with less nausea/ vomiting and pruritus, and lower morphine usage. They emphasized that intermittent boluses of anaesthetic solution may be more successful than continuous infusion to produce uniform block. It has been shown in labour anaesthesia studies that the administration of bolus epidural analgesia, in comparison to continuous infusion, that there is decreased anaesthetic agent consumption, provided greater sensory block and patient satisfaction[35-37]. Side effects, including nausea, vomiting, and pruritus, were considerably higher in the continuous epidural infusion group. In addition, the side effects associated with epidural opioids can be avoided by an intermittent bolus with a relatively lower amount of opioid[26].

Intrathecal analgesia compared to epidural analgesia

A third commonly used pain relief is intrathecal morphine. However, this technique is known to possibly result in rostral spread provoking delayed respiratory depression and has a limited duration of pain relief of a maximum of 18–24h[22]. Two studies were selected regarding the efficacy of intrathecal morphine in comparison to epidural analgesia for postoperative analgesia after PSF in children and adolescent. Low-dose intrathecal morphine is known to provide better analgesia than intravenous morphine alone after spinal fusion in children[65,66]. A single injection of epidural morphine has also been used successfully for analgesia after spinal fusion for scoliosis in children[67]. Disadvantages of intrathecal morphine are the short duration of action as it analgesic benefit wears off early in the morning on post-operative day one. The increase in pain often coincides with the first physical therapy session and at it is known to cause multiple adverse effects like pruritus, nausea, sedation, and respiratory depression[13]. Although these studies have shown reduction in pain on the first day following intrathecal injection, one of the biggest challenges associated with using intrathecal morphine for PSF is anticipating and managing the substantial increase in pain scores that occurs when the analgesic effect of intrathecal morphine wears off on the first postoperative day[60]. There are some advantages compared to epidural analgesia, including the diminished concern for infection related to presence of a foreign body in the surgical site, the technical difficulties with the epidural pumps which remain a frustration for the bedside nurses, and the common occurrence of serous fluid leaking around the epidural site. A single, intraoperative opioid dose administered via the intrathecal route obviates these problems and offers an alternative strategy for pain relief following spinal fusion[60]. Cohen et al. a randomized controlled double-blinded trial with 71 participants noted that intrathecal morphine was given preservative-free morphine at a dose of 7.5 mcg/kg and the extended release epidural morphine group received a dose of 0.15 mg/kg. All intrathecal/epidural injections were performed by the anaesthesiologist before surgical incision. A 24 gauge spinal needle was placed through the dura between levels L3–L5 to deliver the intrathecal morphine at a concentration of 7.5 mcg/kg. For the group extended release epidural morphine (EREM), an 18 gauge Tuohy needle was used with standard loss of resistance technique to administer 0.15 mg/kg of EREM between levels L2–L5. All subjects had the same regimen for postoperative pain management[13]. In another retrospective cohort study by Hong et al. intrathecal morphine was administered in a dose of 12 µg·kg−1 by or under the supervision of the anaesthesiologist immediately after induction of anaesthesia and prior to incision. This dose was based on data from Tripi et al. where their moderate dose group (mean 14 µg·kg−1, range 9–19 µg·kg−1

of intrathecal morphine) had significantly less respiratory complications and intensive care unit admissions compared to the high-dose group (mean 24 μg·kg−1, 20 μg·kg−1 minimum of intrathecal morphine)[60]. In the epidural group, catheters were placed by the surgeon at the end of the operation and bolused with 5 μg·kg−1 hydromorphone (maximum dose 200 μg) and 1 μg·kg−1 of fentanyl (max 50 μg), followed by a continuous infusion of 40–60 μg·h−1, and patient-controlled bolus doses of 5 μg with a lockout interval of 30 min. Cohen et al. a randomized controlled double-blinded trial with 71 participants found that the subjects who received extended release epidural morphine had similar total morphine consumption over the first 48 hours compared to intrathecal morphine: median (range) 42.2 (5.5–123.0) and 34.0 (4.5–128.8) mg, respectively (p=0.27). The pain scores reported immediately after surgery, and then 4 hours later, were significantly higher in subjects who received EREM compared with ITM. From 8–24 hours after surgery, the pain scores were similar in both groups, with the exception of 16 hours. At the 16 hour time point, EREM showed significantly lower pain scores[13]. Not surprisingly, intrathecal morphine appeared to be most effective in controlling pain during the first 16 h postoperatively. After this point, pain scores significantly increased for the ITM group compared to the EPI group, which had relatively stable pain scores over time. When corrected for multiple comparisons, the IT group reported pain scores that were significantly lower only in the post-operative care unit (PACU; P = 0.001) and higher during the 24–48 h postoperative period (P = 0.037). All patients who received intrathecal morphine were successfully and directly transitioned to oral oxycodone on the first postoperative day without the need for IV opioid rescue. In addition, the hospital length of stay was significantly shorter in the ITM group (3.0 ± 0.5 days vs 3.5 ± 0.7 days; P = 0.03)[60]. In terms of secondary outcomes, the incidence of any type of adverse opioid effect was not statistically significant between the two treatment groups, EREM vs. IT morphine: nausea (26% vs. 46%, p = 0.08, difference (95% CI): 19% (−2.4% to 41.3%), emesis (15% vs. 24%, p = 0.30, Difference (95% CI):9.6% (−8.6% to 27.9%), pruritus (62% vs. 81%, p = 0.07, Difference (95% CI): 19% (−1.3% to 40.0%)), and respiratory depression (15% vs. 24%, p = 0.31, difference (95% CI): 19% (−8.6% to 27.9%). There was no difference in the number of post-operative days until subjects were discharged from the hospital. Parent questionnaire results showed similar overall satisfaction with each pain control modality[13].

Intrathecal morphine can cause high concentrations of morphine in the plasma and CSF, which can lead to opioid induced adverse effects. Because EREM releases morphine gradually, the maximum plasma morphine concentration is approximately 30% the concentration seen after an injection of IT morphine. Due to the lower plasma concentration, EREM might cause less opioid adverse reactions. In this study, parental reports of less itching with EREM were statistically significant. There was a trend towards less adverse effects (nausea and vomiting, itching, respiratory depression) in the EREM group. There was no difference in length of stay[13]. Both groups experienced similarly high rates of nausea/vomiting and pruritus. Two patients were admitted to the paediatric intensive care unit for closer neurological and blood pressure monitoring following transient loss of transcranial electric motor-evoked potentials (MEPs) intraoperatively. Despite this, based on rates of administration of antiemetics, the incidence of postoperative nausea and vomiting was 90% in the ITM group and 80% in the EPI group (P = 0.661). One patient from the EPI group required straight catheterization for urinary retention after the epidural was removed. No incidence of post dural puncture headache was noted for either group. While our rates of nausea and vomiting were high in the ITM group, they were nearly as high in our EPI group, suggesting that both routes of opioid administration are similarly associated with this adverse effect. it is clear that management of this very troublesome side effect in this high-risk patient population could be improved. Nonetheless, it remains important to recognize, monitor for, and intervene to prevent or treat hypotension when intrathecal morphine is used during PSF[60]. In conclusion, no serious adverse outcomes were noted in terms of persistent neurologic deficits or respiratory depression requiring intervention beyond nasal cannula oxygen[60].

Patient satisfaction

Only two studies in meta-analysis assessed patient satisfaction using a zero to 10 scale and found a higher satisfaction rate in the epidural group than the intravenous morphine group (WMD 1.62, 95% CI 1.26 to 1.97)[30]. Also Saudan et al concluded in a prospective cohort study with 100 participants that the use of epidural analgesia is a feasible and safe method to provide postoperative analgesia for extensive spinal surgery in children and adolescents. The satisfaction rate was excellent with this epidural analgesia technique (>90%)[22]. There were no differences found in patient satisfaction between the intermittent and continuous PCEA[26].

Compared intrathecal to epidural analgesia, parent questionnaire results showed similar overall satisfaction with each pain control modality[13].

Safety and complications

Epidural placement

Despite concerns about feasibility, different studies have shown that preoperative epidural catheter insertion can be performed without raising significant concerns and a high success rate of 96%, corresponding to that reported in the non-scoliotic spine. PCEA was acknowledged in multiple studies to be a feasible and safe method to provide postoperative analgesia for extensive spinal surgery in children and adolescents[17,27,53,54]. Obstacles to trans epidural catheter placement in the scoliotic spine are most often caused by the axial rotation of the vertebral bodies and angulation of the spinal processes[21]. However, no standard methods have been established. An epidural catheter is mostly always placed by the surgeon prior to the closure of the surgical wound, the numbers and positions of the catheters inserted, the types and amounts of agents used, and the mode of administration vary widely in the literature[22,25,26]. In one study, the epidural catheter was introduced 4 to 5 cm into the thoracic 6-7 interspace under direct visualization[27]. In another study in between Th8 and Th9[28]. One study gave an epidural catheter for every eight corrected vertebral segments before wound closure under direct vision of the surgeon using the loss-of-resistance technique via an 18-gauge Tuohy needle. The placement of the catheter tip with a single catheter was in the centre of the surgical site. In the case of two catheters, the cranial catheter was set between the thoracic levels T4 and T6 and the lower catheter between T10 and L1. These catheters were mostly all tunnelled laterally, which would reduce infection and pressure ulcers[22]. The evidence for a single thoracic epidural catheter providing adequate analgesia with a local anaesthetic mixture has been inconclusive. Data from one study suggested that the spread of radiopaque dye in the thoracic epidural space could be insufficient to spread local anaesthetic to cover the length of the surgical procedure[28]. One study by Wenk et al, mentioned something about the ideal place for epidural puncture in a magnetic resonance imaging study. They examined 307 vertebrae in patients where spinal fusion was used for thoracic scoliosis which found an average Cobb angle of 66° (range, 50–108°) and that the width of the epidural space was less than 1 mm on the concave side at the thoracic apical vertebral level and 1 mm at the lumbar level. However, on the convex side, the horizontal width of the epidural space measured between 3 and 5 mm. A shift of the dural sac toward the concavity resulted in the width of the epidural space on the concave side being significantly less than that on the convex side at nearly all vertebral levels. The amount of dural sac shift diminished farther away from the apex vertebra toward the neutral vertebral levels, leaving symmetrical epidural spaces at the neutral level[21]. We found one small study giving suggestive evidence about which catheter could give the best results. They found a decrease in the incidence of breakthrough pain in the Theracath group with 63% (17/27) not requiring opioids while the epidural was in place compared to 40% (12/30) in the Perifix group (p = 0.08)[28].

Technical problems

Technical problems caused the most frequently encountered complications (7%)[22,33]. First of all, it is likely that the efficacy and safety of epidural analgesia depend on the experience of health care providers. Guay et al. noted that one trial reported a high rate of primary catheter failure (37%)[33]. None of these trials mentioned any precautions taken to prevent catheter dislodgment or leakage, or both[51]. Sucato et al. reported 13% of their epidural catheter cohort had their epidural prematurely removed. One study showed that inadequate analgesia was the reason 61% of cases had to be terminated[55]. They speculated that incorrect epidural position was the reason for epidural failure[28]. Dinter et al., a study with 93 epidurals placed, showed no epidural leakage was found postoperatively. A small number of CEA patients needed additional IV-PCA-support to ease the pain. Yet, this transfer was already seen in other trials[33,44]. Klatt et al described epidural leakage as a reason for inadequate pain control in 10 cases (out of 21 participants with a single catheter and 18 participants with two catheters[30,56]. Besides malposition, this might be a reason for inadequate pain control and the need for additional pain medication. But even though some patients received CEA and opioids, we could show that this group had a better outcome as patients only receiving opioids[17]. To a conclusion, the use of epidural analgesia may be associated with some technical problems, but as the catheter is most often inserted by the surgeon at the end of surgery under direct vision, one would normally expect that most catheters would be placed in an optimal position. However, this might not be the case for surgeons unfamiliar with the technique[29].

Epidural pain regimens

The types and amounts of agents used, and the mode of administration vary widely in the literature. It has been suggested that epidural analgesia after spinal

surgery should only be commenced after normal neurological function has been confirmed[22]. In most institutions, intraoperative spinal cord monitoring is used and in the absence of any signs for surgically induced neurological lesions, local anaesthetics with or without opioids are administered to ensure optimal pain relief before extubation. Cassady et al and Halpern et al, both first used a bolus of bupivacaine 0.25% with epinephrine 1:200,000 or 0.1% bupivacaine with 5 mcg/mL hydromorphone or 0.1 % ropivicaine with 5 mcg/mL of fentanyl for the epidural group. Within 30 minutes of arrival in the post anaesthesia care unit (PACU), continuous epidural infusion was begun. The intravenous (IV) group got PCA within 30 minutes of arrival in the PACU, a morphine sulfate bolus dose of 0.02 mg/kg, 4-hour limit of 0.2 mg/kg, and an 8-minute lockout[27]. In another study, continuous epidural analgesia (CEA) was delivered by a continuous and patient-triggered application of Ropivacaine $0.2\% + 0.5$ µg/ml sufentanil. IV-PCA for postoperative pain management were able to self-administer weight-adjusted boluses of piritramide when feeling pain (bolus volume 2–4 ml). In this system, no continuous application was established. Weaning off the epidural catheter was started 3–4 days post-surgery by reducing the continuous rate and followed by removal of the catheter on the fifth day. During CEA—and IV-PCA weaning, as well as rescue medication, various drugs were used (Piritramide, Metamizole, and Nonsteroidal anti-inflammatory drugs)[28,29]. In a big meta-analysis, two studies were included with 0.3% ropivacaine where two epidural catheters were used. Interventions in the other two included studies were bupivacaine (0.065% or 0.1%) and bupivacaine (0.125%) plus fentanyl 2.5mcg/ml. These two studies used one epidural catheter. All of the included studies allowed intravenous opioids in addition to epidural anaesthesia. The included controls all used intravenous morphine[30]. In a prospective, randomized, double-blinded study by Erdogan et al, looking at comparing the efficacy and side effects of patient-controlled intermittent bolus epidural analgesia (PCIEA) and patient-controlled continuous epidural analgesia (PCCEA) for postoperative pain control in adolescent idiopathic scoliosis. Patients in the PCIEA group received intra epidural morphine after extubation and a neurological examination[26]. In a study by Saudan et al, an epidural mixture of bupivacaine 0.0625%, fentanyl 1 µg·ml−1 and clonidine 0.6 µg·ml−1 was used at a basal rate of 0.2 ml·kg−1·h−1 and a PCEA dose of 0.1 ml·kg−1·h−1(max. 2 h−1). On the fourth postoperative day, PCEA was stopped

and analgesia was continued with PCA with morphine[22]. Mostly patients received an additional multi-modal analgesia regimen with scheduled acetaminophen (15 mg/kg oral/intravenous q6 hours), a non-steroidal anti-inflammatory drug (ketorolac 0.5 mg/kg intravenous or ibuprofen 10 mg/kg oral q6 hours), and gabapentin (5 mg/kg oral q8 hours, no loading dose). Also diazepam or methocarbamol were available in some studies as needed for the treatment of muscle spasm. Oxycodone and morphine were mostly used as needed after discharge from the PACU for breakthrough pain of four or greater. Patients who could not tolerate morphine or oxycodone were given intravenous or oral hydromorphone[28].

Postoperative enteral recovery

The physiologic stress of surgery and parenteral opioid therapy are well-known causes of postoperative gastrointestinal dysfunction, including ileus[38-42]. Postoperative unsuccessful restoration of oral intake is a primary limiting factor in discontinuation of removal of vascular access catheters, restoration of nutrition, and discharge from the hospital. A group of parameters, e.g., return of flatus and faeces, restoration of bowel sounds, and reappearance of thirst and hunger, may be collectively assessed as indications for postoperative restoration of oral intake[27]. Acceleration of return of gastrointestinal function with an epidural containing a local anaesthetic is also consistent with results found on other type of surgeries[17]. Epidural analgesia may promote a faster return of intestinal transit through various mechanisms including a reduction in opioid administration, a blockade of sympathetic gut innervation (creating a relative parasympathetic predominance), a direct effect of systemic local anaesthetics, or a combination of these[43]. However, as opposed to findings in abdominal surgery, for spine surgery there was a faster return of gastrointestinal function clearly demonstrated only in trials using local anaesthetic without the addition of opioids[31,32]. One author reported that when an epidural was used, bowel sounds were present in a higher percentage of participants on the day of surgery (20% for epidural analgesia versus 0% for systemic analgesia) and at postoperative day one (80% versus 43.75%) while using a mixture of local anaesthetic and an opioid. Although, this did not result in faster resumption of liquid oral intake[27]. Two trials infused local anaesthetic alone through two catheters and reported on the number of participants with or without bowel movement within 48 hours, which they found that epidural analgesia increased the possibility of having first

bowel movement within 48 hours (RR 11.52, 95% CI 2.36 to 56.26; NNTB 3, 95% CI 2 to 10)[32]. One trial infused a mixture of local anaesthetic and an opioid, and reported no significant reduce in time to first bowel movement (mean ± SD; participants with one catheter: 3.82 ± 0.85 days; 22 participants; participants with two catheters: 3.75 ± 0.68 days; 16 participants; participants with IV patient-controlled analgesia: 3.70 ± 0.73 days; 20 participants)[34,17]. Although some measurements concerning a faster return of gastrointestinal transit were contradictory and present only when local anaesthetics alone were infused, we consider that being able to increase the number of children who can tolerate solid food within 48 hours is also highly clinically relevant[17]. Guay et al. also showed that first postsurgical defecation and bowel sounds was seen earlier in all patients who received epidural anaesthetics, compared to those who received IV-PCA, speeding up bowel movement for 1 day in healthy children (p = 0.011). Van Boerum et al. showed that patients in the epidural group tolerated a full diet earlier (p = 0.03) than patients in the IV-PCA group[28,44]. This was also confirmed by one study in the systematic review. One trial with 30 participants provided data for first flatus within 48 hours and first solid food intake[31]. Using a double catheter technique with ropivacaine alone, Blumenthal et al. reported that 15/15 participants with epidural analgesia had their first flatus within 48 hours compared with 9/15 participants for those who had systemic analgesia (RR 1.63, 95% CI 1.08 to 2.47)[31]. Participants with epidural analgesia were more likely to have their first solid foods ingested within 48 hours (RR 7.00, 95% CI 1.91 to 25.62). Based on a 13.3% incidence of solid food intake within 48 hours in the control group. Contradictory, for return of bowel function, in a meta-analysis, two studies showed no significant differences between groups for resumption of liquid intake (one RCT), time to liquid or solid intake, return of bowel sounds and nasogastric tube removal (one RCT). And two other small studies found that the epidural group had more rapid return to bowel sounds, first flatus, first tolerated meal and first bowel movement[17,30]. Conclusive, it is shown that CEA can have a positive impact on early bowel movement.45 Early mobilization and early bowel movement have a positive impact on length of hospitalization after PSIF and the overall complication rate in spinal surgeries[29,46,47]. Delaying the introduction of epidural local anaesthetics to postoperative day one such as done in two trials did not seem to impede the beneficial effect of epidural local anaesthetic to influence the accelerative return of gastrointestinal function[17,31,32].

Nausea and vomiting

As mentioned earlier, the high incidence of opioid-related adverse effects, particularly PONV and pruritus, is problematic in the management of postoperative pain in patients undergoing PSF for adolescent idiopathic scoliosis. There are several measures that can minimize these complications. Prophylactic administration of antiemetics is the mainstay for the prevention of PONV. For patients at high risk for PONV, several antiemetics with different mechanisms of action may be needed to receive adequate prophylactic potency[25,49]. Our systematic review showed no difference for the risk of nausea and vomiting (RR 0.87, 95% CI 0.58 to 1.30). Six trials with 215 participants reported on nausea and vomiting after surgery[27,31-34,50,51]. During use of epidural or IV patient-controlled analgesia which was discontinued upon successful restoration of oral fluid intake and this occurred at a mean time of 39.3 hours for epidural analgesia and 41.7 hours for systemic analgesia[17]. Other small studies showed no significant relationship between the groups and incidence of nausea/vomiting[27-29]. So did twelve of the 14 patients (85.7%) receiving CEA experienced nausea and vomiting, with a mean of 1.7 +/- 1.4 episodes. Twelve of the fifteen patients (80.0%) receiving PCA experienced nausea and vomiting, with a mean of 1.7 +/- 1.3 episodes[27]. In a single-centre retrospective cohort study of 57 participants, 67% patients (38/57) had a side effect that required treatment while the epidural was infusing. The most common adverse events were nausea or vomiting in 51% and pruritus in 16% of patients[28]. However, some small studies in our meta-analysis showed that nausea rates (three studies) were significantly lower in epidural groups (0% versus 38%) than intravenous morphine groups (0% versus 20%) in two studies after 24 hours; there was no significant difference between groups in a third study[30]. Also, Erdogan et al. showed that with intermittent PCEA, postoperative nausea/vomiting and pruritus were significantly decreased in comparison to intravenous analgesia. In this study, the rates of nausea, vomiting, and pruritus were 56%, 40% ,and 50%, respectively, in patients who received continuous epidural morphine administration. The prevalence of these side effects was similar to reported findings in the literature using IV morphine. The rates of nausea, vomiting, and pruritus were 21%, 13%, and 17%, respectively, in the PCIEA group[26]. Despite the use of a morphine sparing analgesia regimen with epidural anaesthesia, we observed a surprisingly high incidence of PONV. This high incidence (35%) after surgery might be attributed to the

intraoperative administration of opioids and the lack of a routine PONV prophylaxis. Accordingly, PONV consecutively decreased over the first postoperative days[22].

Pruritus

Pruritus is also known to be one of the most common minor adverse effects of opioids. It remains unclear if epidural opioids have the same negative effects. Three studies in the meta-analysis from Saudan et al. showed that pruritus rates were significantly lower in the epidural groups (0% versus 38%) than the intravenous morphine groups (7% versus 33%) in two studies after 24 hours; there was no significant difference between groups in a third study[30]. Cassady et al. described that six of the fourteen patients (42.9%) receiving CEA with infusion consisting of bupivacaine 0.125 % and fentanyl 0.0025 mg/mL, experienced pruritus, with a mean of 1.3 +/- 1.9 episodes. Seven of the 15 patients (46.7%) receiving PCA (morphine) experienced pruritus, with a mean of 0.7 +/- 1.7 episodes. Thus, in this study, no significant relationship was identified between the groups and the incidence of pruritus[28].

Neurological complications

Neurological irritations, such as numbness or tingling sensations and transient motor blockage, are a well-known concomitant feature of epidural analgesia and are well described in the literature[31-33,57,58]. Two studies by Blumenthal et al. reported no complications/problems associated with the catheters. Based on four trials with 151 participants, there was no difference in the risk of neurological complications (RD 0.01, 95% CI −0.04 to 0.06; I2 = 0%)[17,31,32]. Dinter et al. noted that there were 9 catheter-associated neurological irritations in group with epidural analgesia (9.7%). Sensory disturbances (upper or lower extremities) were seen in 6 cases. In 3 cases, patients described a hypoesthesia (chest, upper extremities, lower extremities), and in 1 case, a paresis was found (upper extremities). The irritations were either treated through a change of therapy (pause of therapy or catheter removal) or it resolved independently, without any change in therapy. In one case, an MRI was performed without any further therapeutic implications. All neurological deficits resolved completely during the hospital stay[29]. Halpern et al, a retrospective study with 57 participants described that one patient developed Horner's syndrome and two patients developed numbness (one of an arm, one in both legs). The rare occurrence of numbness did not adversely affect any patient outcome and all symptoms

resolved quickly with discontinuing the infusion. No persistent neurologic complications were noted in any patient[28]. Thoraco-lumbar spine surgery is associated with a risk of neurological damage. Therefore, being able to proceed to a neurological examination after the surgery is critical. Despite concerns about feasibility, multiple studies have shown that perioperative epidural catheter insertion can be performed without raising significant concerns and a high success rate, corresponding to that reported in the non-scoliotic spine[21,53,56,57]. Extensive motor block could mask postoperative neurological deficits related to surgery and is counterproductive for all mobilization strategies. Blumenthal et al. showed that there was transient partial lower limb motor blockade after the initial loading dose using ropivacaine alone for 4/30 participants and for 2/30 participants with another study by Blumenthal et al. Motor strength normalized within 180 minutes for all participants. Three other trials noted that 12 out of 62 participants developed paranaesthesia of the lower limbs[17,31,33,34,58]. The use of a low concentration of bupivacaine is associated with a lower incidence of motor block[22,26]. There is one study mentioning that convulsions can be a sign of local anaesthetic toxicity that is more frequently observed during continuous regional anaesthesia. The risk for convulsions might be increased by a potentially diminished epileptic threshold in epileptic patients, as seen in the adolescent presenting with a focal convulsion on the first postoperative day[22]. In one randomized controlled trial that compared epidural analgesia and IV PCA, urinary retention was observed in 3 of 22 patients in the epidural group. Although the incidence of urinary retention was not different between the two analgesic techniques, postoperative epidural analgesia has been reported to be associated with a higher incidence of urinary retention than IV PCA[25,59].

Major complications

Issues with local anaesthetic include cardiovascular changes related to sympathetic blockade and the potential for vascular uptake and systemic toxicity[52]. The use of CEA might be associated with major complications, such as hypotension or bronchoconstriction[29,33,45]. In a prospective cohort study by Saudan at. with 100 participants showed that a PCEA regimen including bupivacaine at low concentrations with fentanyl and clonidine resulted in a low incidence of adverse events. The overall rate of severe complications was low (2%)[22]. The adverse reaction might be caused by a lack of sympathetic reaction to an acute volume distribution. Guay et al. described that one participant had respiratory depression (oxygen desaturation less than 90%)[33].

One finding of vegetative decompensation is described by Dinter et al. within 119 epidural participants , presenting as hypotension and respiratory arrest after first commissioning of the epidural catheter[29]. Halpern et al. described seven patients that required a rate reduction for excessive sedation or mild hypotension. There were no episodes of hypotension that required pharmacologic treatment. One single episode (2%) of respiratory depression requiring naloxone is lower than previously reported (7.3%), likely due to our reduced concentration of opioid in the epidural infusion (5 mcg/mL) compared to earlier studies (up to 20 mcg/mL)[28]. Saudan et al finally noted that although epidural analgesia can lead to hypotension, especially after extensive surgery with a high risk of haemorrhage and the epidural administration of clonidine, none of the previous studies on epidural analgesia for spinal surgery reported this potentially severe side-effect. All episodes were easily relieved by the administration of a crystalloid solution and the discontinuation of the PCEA solution[22]. There were also small studies that noted no incidents of clinically significant hypotension in either group of neuraxial analgesia in comparison with intravenous analgesia[22,27,29]. Guay et al also noted some complications of hypotension and respiratory depression that was possibly related to systemic analgesia. In one study, two of 19 participants remained intubated and ventilated for several hours[33]. Three participants had respiratory depression (oxygen desaturation less than 90%) in Gauger et al and one participant had increased partial pressure of carbon dioxide and decreased respiratory rate. Four trials with 126 participants reported on the number of participants with clinically significant respiratory depression for the two modes of treatment, which showed no clinical difference(RD –0.05, 95% CI –0.16 to 0.05)[17]. It is possible that the use of intrathecal morphine increases the risk for hypotension compared to other methods of analgesia. Adequate fluid resuscitation for these patients is difficult, given the relatively high blood loss associated with PSF concurrent with the desire to avoid high-volume crystalloid resuscitation as it is associated with increased risk for postoperative visual loss in these surgeries[60,61]. Nonetheless, it remains important to recognize, monitor for, and intervene to prevent or treat hypotension when intrathecal or epidural analgesia is used during PSF[13].

Wound infection

The outcome after spinal surgery can also be jeopardized by infection of the epidural catheter or develop an epidural abces, as it remains in place for 4–5 days. Saudan et al presented one study were there was no clinical signs of infection or development of epidural abscesses related to epidural anaesthesia. Another study, based on three trials with 120 participants also confirms this finding (RD 0.00, 95% CI –0.05 to 0.05; I2 = 0%). The absence of infections might have been associated with the use of tunnelled catheters and antibiotic prophylaxis with cefuroxime for the duration of PCEA[22]. Through the systematic review by Guay et al. we found one study by Cassady et al. that reported one wound infection in the epidural group versus none in the systemic analgesia group. Other studies reported no wound infection in either group. Therefore, based on two trials with 93 participants, we also did not find a significant difference for wound infection (RD 0.01, 95% CI –0.05 to 0.08; I2 = 0%)[17,27,34]. We can conclude that the occurrence of wound infection caused by the catheter is a rarely described complication in literature[29,31,32]. Hematomas are possible even with epidural catheter being placed under direct vision. Be aware that some patients may have congenital haemostasis abnormalities contributing or not to increased risk of bleeding. For instance, idiopathic scoliosis is associated with abnormal collagen and platelet function[62,63].

Role of epidural analgesia in multimodal pain regimens and rapid recovery pathways

Refining perioperative pain management to lessen opioid consumption with multimodal regimens may be useful to decrease recovery time, pain, and complications. Nonsteroidal anti-inflammatory drugs, acetaminophen, gabapentin, neuraxial blockades, and local anaesthesia are known to offer benefits for postoperative pain management. Their combination in multimodal regimens and rapid recovery pathways may contribute to faster recovery time, improved pain levels, and lower reduction in total opioid consumption[68]. In recent years, the immediate postoperative period has been a primary focus of change in pain management for patients undergoing orthopaedic surgery, including PSF for AIS. Traditional postoperative regimens often involved 24 hours of bed rest or limited activity; however, there have been studies reporting early mobilization in combination with multimodal analgesia may decrease hospital stay. Our results show that non-impaired patients who received epidural anaesthesia after PSF in adolescent scoliosis are able to ambulate earlier than patients receiving IV-PCA[29,31]. An other study by Dinter et al, showed that healthy patients who had received epidural anaesthetics could be mobilized 1 day

earlier than IV-PCA-treated patients (median day 1 vs. 2 post-surgery, p = 0.002).29 In one adult study by Shah et al. they concluded that implementing a rapid recovery pathway reduced time to functional recovery and maintained effective analgesia postoperatively following PSF for AIS[68]. Yet, we haven't found any literature that could prove this statement in adolescents or children. These findings are contradictory to other publications that could not find any difference in the time until independent ambulation or hospital length of stay when using epidural analgesia. (MD –0.29 days, 95% CI –0.69 to 010)[17,27,29,44,57]. Apart from an effective pain-management through CEA (as was shown by other studies), this could also be due to the rising awareness of the importance of early mobilization after major surgery[68]. Recent guidelines recommend consideration of IV ketamine as a component of multimodal analgesia[72]. However, the postoperative analgesic effect of adjuvant ketamine in patients undergoing scoliosis correction surgery for AIS is controversial. Intraoperative low-dose ketamine failed to decrease the cumulative morphine consumption, the pain scores, or the frequency of PONV and pruritus at 72 h after PSF when compared with the saline-treated group[73,74]. One study however showed that perioperative low-dose ketamine (a bolus dose of 0.5 mg/kg, followed by 48 h of continuous infusion of 0.12 mg/kg/h, n = 17) decreased the cumulative morphine consumption by 20% when compared with a control group (n = 19) at 24 and 48 h after surgery[25]. One recent meta-analyses about gabapentin shows that these agents are useful as adjuvant analgesia for reducing postoperative pain, including after spine surgery[75,76]. However, only the analgesic effect of gabapentin has been studied in scoliosis correction surgery, and the results are inconsistent. Different meta-analyses suggest that several techniques, including regional anaesthesia, intravenous infusion of local anaesthetics, and perioperative pregabalin and ketamine, may reduce persistent postoperative pain, but no promising results have been obtained as yet[76-78]. The development of persistent postoperative pain appears to be multifactorial, so a multimodal approach might afford the best chance of favourable results[25].

Discussion

Epidural analgesia and intravenous analgesia were compared in five studies on postoperative pain control after thoraco-lumbar PSF in children. Despite challenges, epidural catheter placement showed a high success rate, especially when placed by an experience practitioner. Pain regimens varied widely, with different local anaesthetics, opioids and other multi-modal analgesia commonly used. There is a lack of uniform guidelines and studies within this matter. Epidural anaesthesia was often initiated postoperatively after neurological assessment or before extubation with close neurological examination every hour. Evaluating postoperative pain in children remains challenging due to interpersonal differences in expression and how pain is scored by clinicians. Pain management is known to be crucial in reducing hospital stay and uplifting satisfaction rates. Multiple studies showed that epidural analgesia may reduce overall pain and opioid use compared to intravenous analgesia, with benefits lasting until removal of the epidural catheter. Additionally, we found small evidence supporting reduced breakthrough pain with epidural anaesthesia. However, some small trials could not find significant difference between PCA and PCEA. One study showed that intermittent bolus epidural analgesia may be more effective than continuous infusion in reducing opioid-related side effects. Despite mixed findings in low grade studies, epidural techniques also seem to improve patient satisfaction postoperatively. Additionally, epidural analgesia is believed to accelerate gastrointestinal recovery by reducing opioid use and enhancing intestinal blood flow. Though these findings are from low grade studies and are very inconsistent. Some studies show faster bowel movement and food tolerance, while others report no significant differences. Multiple studies found that epidural analgesia does not have a significantly impact on reducing postoperative nausea and vomiting compared to IV analgesia. On the other hand, one study showed that intermittent PCEA has signs of lower PONV and pruritus rates. Despite opioid-sparing effects, PONV incidence remains high, likely due to other causes like intraoperative opioid use and inadequate prophylaxis. Two small studies show that intrathecal and epidural analgesia are both effective ways of management post-operative pain after spinal fusion. Yet, intrathecal morphine only seems to provides effective pain relief in the first 16 hours post-surgery, often resulting in a significant increase in pain by the next day. It is associated with more adverse effects such as pruritus, nausea, and respiratory depression. On the other hand, epidural analgesia could offer a more stable pain control over a longer period but is technically more challenging and carries higher technical risk of infection and fluid leakage. Regional anaesthesia in children may cause side effects related to the infused solution, catheter problems, cardiovascular changes, infection or neurological risks. Overall,

PCEA is believed to be safe, with some severe complications reported in only a number of cases. Technical issues, such as catheter dislodgement and leakage, are relatively uncommon. Catheter failure may result from incorrect positioning, inadequate fixation, or leakage. Despite some requiring additional intravenous pain relief while epidural catheter is in place, studies show better outcomes with epidural analgesia compared to opioids alone. This emphasizing the additional analgetic capacity of epidural analgesia. Most common neurological complications of continuous epidural analgesia include transient motor blockage, numbness, and tingling. Studies report low incidence, with most symptoms resolving independently or after therapy adjustment. Severe complications are rare. Hypotension and respiratory issues may occur in rare occasions. However they were all manageable with fluid resuscitation and dosage adjustments. Epidural-related infections and hematomas are uncommon but cannot be totally excluded. Provider experience must be ensured for optimal placement and efficacy to minimize the risk of adverse effect. Despite the benefits, monitoring remains essential to prevent complications and ensuring safety. Particularly in major spinal fusion where loss of motor function is a known complication of surgery. Further studies are needed to optimize and confirm current findings about the efficacy and safety of epidural anaesthesia in PSF.

More emphasis should be laid on utilizing neuraxial analgesia in multimodal practices to yield the best result. Multimodal analgesic regimens may be used as part of a rapid recovery pathway to facilitate faster recovery in patients undergoing PSF for scoliosis.

Limitations

Our study's limitations stem from several factors, including the reliance on some adult-based or other surgery based research due to a lack of well-conducted paediatric trials on the subject. This highlights an ongoing need for more large high-quality studies focusing specifically on children. One of the key limitations was the variability in pain score assessments and the absence of standardized epidural and analgetic rescue protocols across studies. The retrospective design of some studies further complicated the accurate evaluation of pain levels and medication use, as even in prospective settings, pain measurement remains inherently difficult. Additionally, in certain studies, bowel recovery assessment was overly simplistic, relying solely on an all-or-nothing auscultatory method rather than incorporating more detailed indicators such as the return of flatus, signs of hunger, or

intestinal motility. Future research should adopt more comprehensive measures of postoperative recovery, including the resumption of normal oral intake, the onset of functional recovery, overall patient satisfaction, and hospital length of stay to better evaluate the impact of enhanced recovery pathways.

Conclusion

This review highlights the effectiveness of epidural analgesia in perioperative pain management for children and adolescents undergoing posterior thoraco-lumbar spine surgery. Our findings suggests that epidural analgesia, especially when combined with other multimodal analgesia, can provide superior pain control compared to intravenous analgesia alone. It is proven by some small studies that both pain at rest and on movement are reduced. On the other hand, the findings for gastrointestinal recovery are mixed. So has epidural anaesthesia been linked with faster bowel movement and food tolerance. The overall safety of epidural analgesia in paediatric and adolescent patients is reassuring, but remains uncertain due to inconsistent quality across studies and needs to be investigated more thoroughly. The technique is associated with fewer opioid-related side effects, such as nausea and pruritus, and can improve patient satisfaction. Catheter-related and other complications should be carefully monitored. We suggest that further high-quality trials are necessary to further assess the safety, efficacy and impact of epidural analgesia in children and adolescents undergoing PSF. More specifically, in investigating a standardized guideline that provides the best effect and induces the fewest complications. Future research should focus on refining existing multimodal epidural pain protocols for postoperative pain management to improve outcomes, particularly in terms of pain, early mobilization and gastrointestinal function. For now, the use of epidural analgesia should be consider individually by the patient needs and surgical contexts. We would like to remark the importance of knowing the benefits and potential risks of epidural anaesthesia.

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