Postoperative Pain Management after Spinal Fusion Surgery: An Analysis of the Efficacy of Continuous Infusion of Local Anesthetics

Richard A. K. Reynolds[1]   Julie E. Legakis[1]   Jillian Tweedie[2]   YoungKey Chung[3]   Emily J. Ren[4]
Patricia A. BeVier[2]   Ronald L. Thomas[5]   Suresh T. Thomas[2]

[1] Department of Orthopaedic Surgery, Children's Hospital of Michigan, Detroit Medical Center, Detroit, Michigan
[2] Department of Anesthesiology, Children's Hospital of Michigan, Detroit Medical Center, Detroit, Michigan
[3] Wayne State University School of Medicine, Richard J. Mazurek Medical Education Commons, Detroit, Michigan
[4] Department of Orthopaedic Surgery, University of Minnesota, Minneapolis
[5] Department of Clinical Pharmacology, Children's Hospital of Michigan, Detroit Medical Center, Detroit, Michigan

Address for correspondence Julie E. Legakis, PhD, Department of Orthopaedic Surgery, Children's Hospital of Michigan, Detroit Medical Center, 3901 Beaubien Blvd., Detroit, MI (e-mail: jlegakis@dmc.org).

Abstract

Spinal fusion surgery is a major surgery that results in severe postoperative pain, therefore pain reduction is a primary concern. New strategies for pain management are currently under investigation and include multimodal treatment. A 3-year retrospective analysis of patients with idiopathic scoliosis undergoing spinal fusion surgery was performed at our hospital, assessing patient pain scores, opioid use, and recovery. We evaluated the effect of adding continuous infusion of local anesthetics (CILA) to a postoperative pain management protocol that includes intraoperative intrathecal morphine, as well as postoperative patient-controlled analgesia and oral opioid/acetaminophen combination. The study compared 25 patients treated according to the standard protocol, with 62 patients treated with CILA in addition to the pain management protocol. Patients in the CILA group used nearly 0.5 mg/kg less opioid analgesics during the first 24 hours after surgery.

Keywords
► spinal fusion
► idiopathic scoliosis
► continuous infusion of local anesthetics
► post-operative pain management

Adolescent idiopathic scoliosis (IS) is a condition of unclear etiology that occurs in 1 to 3% of otherwise healthy children and adolescents and when severe can result in respiratory and cardiovascular deterioration.[1–3] When the curvature exceeds a certain severity, spinal fusion surgery is indicated, with a goal of correcting the existing curve and preventing further progression while preserving pulmonary function.[4,5] However, spinal fusion surgery can result in severe postoperative pain,[5–7] and when it is the chosen treatment, pain management is a primary concern.

The standard of care for pain management for spine surgery in children consists of continuous infusion of intravenous (IV) morphine supplemented with patient-controlled analgesia (PCA). However, to achieve satisfactory pain control with this method, high doses of opioids must be administered. Unfortunately, use of opioids is associated with serious adverse effects, including nausea, vomiting, pruritus, sedation, and respiratory depression, which often delay patient recovery.[8] Moreover, patient recovery times are also delayed by high postoperative pain levels, potentially leading to poorer patient outcomes.[9] To reduce postoperative pain levels, decrease recovery time, and increase patient satisfaction, a balance between analgesia and adverse effects of the medication should be achieved.

Recent studies of pediatric patients have evaluated the efficacy of different types and combinations of anesthetics and routes of delivery in an attempt to achieve adequate pain control while limiting side effects caused by opioid use.[10] These investigations include those comparing continuous epidural analgesia of a combination of opioids and local anesthetics to PCA or IV morphine alone.[11–17] Other studies involve comparisons of different epidural anesthetics[18,19] as well as optimization of dose of intrathecal morphine,[20–23] with variable results. Still another investigation examined the efficacy of the combination of intrathecal morphine and continuous infusion of IV morphine without PCA, under strict protocol guidelines, as a postoperative pain management strategy for spinal fusion surgery.[24] These studies suggest that use of combinations of different types of analgesia along with different routes of administration maximizes pain relief while minimizing the adverse effects. Some studies show that supplementing the pain management regimen with continuous infusion of local anesthetics (CILA) into the surgical site with an elastomeric pain pump significantly improves pain control, particularly for orthopedic surgeries[25,26] and adult spinal fusion surgeries.[27] It has been shown that CILA is effective in reducing postoperative pain in children,[28,29] and to our knowledge its use for pediatric spinal fusion surgery has been described in one other publication, with promising results.[30]

Given the evidence outlined above, there is no conclusive answer as to the best pain management protocol for pediatric spinal fusion surgery patients. However, there is evidence that a multimodal approach to pain management is most effective, utilizing different therapeutic classes of analgesics administered through distinct routes of administration.[10] The purpose of this investigation is to determine whether the addition of CILA to our pain management regimen for spinal fusion surgery reduced opioid use or pain levels during the first 3 postoperative days.

Materials and Methods

Patient Enrollment

After approval by the Academic Medical Center Institutional Review Board, a retrospective cohort study was conducted of patients with IS who underwent spinal fusion surgery. All patients with a diagnosis of IS and who underwent spinal fusion surgery by one of three attending surgeons between November 1, 2006, and October 31, 2009, were considered for inclusion. Patients meeting the following criteria were eligible for inclusion: (1) diagnosed with IS, (2) age 6 to 17, (3) elective spinal fusion surgery performed, (4) ability to use PCA, and (5) ability to self-report pain. Patients were excluded if they had a diagnosis of neuromuscular or congenital scoliosis, did not use postoperative PCA, or were hypersensitive to local anesthetics or opioid analgesics.

Intra- and Postoperative Pain Management

A standard protocol for anesthesia was used for all patients. Patients received fentanyl for IV induction and continuous IV infusion of propofol, fentanyl, or remifentanil, throughout the

surgery for maintenance and inhaled isoflurane, one-half minimum alveolar capacity, also throughout the surgery. A standard pain management protocol was also used for all patients and began with administration of one intraoperative dose of intrathecal morphine, 5 to 8 μg/kg, 0.6 mg maximum, with an average dose of 4.8 μg/kg. At our institution, use of a pain pump that enables CILA at the incision site (ON-Q® Painbuster® system, I-Flow Corporation, Lake Forest, California, USA) is performed at the discretion of the senior attending orthopedic surgeon, although use of the pain pump was more common during the later part of the study period. When CILA is used, the device's two catheters are inserted into the subcutaneous tissue on either side of the incision site, just before wound closure. The system provided continuous wound infusion with 0.25% bupivacaine in sterile saline at a rate of 4 mL/h (2 mL/h for each catheter), with a total volume of 410 mL. This infusion lasted ∼102 hours, through postoperative day 4 and into postoperative day 5, although the catheters were sometimes passively or actively removed before infusion of the full volume was complete. The average dose of bupivacaine was 0.17 mg/kg·hour; however, because the device has a set rate of infusion and the weight of our patients was varied, the dose range was 0.5 to 0.09 mg/kg·hour. Once in the postanesthesia recovery unit, the patients received PCA consisting of morphine or hydromorphone (if there was a history of adverse reaction to morphine), which was continued through postoperative day 2 or 3, according to the discretion of the attending surgeon, along with the pain management service. Additional pain medications were given as needed according to the discretion of the attending surgeon and the pain management service, including other opioid analgesics, as well as nonsteroidal anti-inflammatory drugs. The additional opioid medications included IV morphine, IV hydromorphone, oral hydrocodone, oral codeine, IV meperidine, and IV fentanyl.

Data Collection and Analysis

The patients' medical records were examined for demographics, medical history and diagnosis, intraoperative information including blood loss and number of vertebrae fused, and postoperative opioid and analgesic use, as well as pain scores. Use of opioid analgesics, including morphine, hydromorphone, hydrocodone, codeine, meperidine, and fentanyl was recorded. Data on postoperative opioid use was gathered from the end of the surgery as follows: total PCA opioid use in the first 24 hours, total PCA opioid use in the first 48 hours, total PCA opioid use in the first 72 hours, total opioid use in the first 24 hours, total opioid use in the first 48 hours, and total opioid use in the first 72 hours. Opioid use was calculated as morphine equivalents, according to published equianalgesic opioid doses.[31–33] To normalize opioid dose equivalents between patients, doses are expressed as milligram opioid equivalent per kilogram of body weight. Patient pain levels were assessed approximately every 1 to 2 hours using one of three 10-point pain scales: a modified Wong-Baker Faces scale[34]; Face, Legs, Activity, Cry, Consolability; or a visual analog scale. Pain scores were recorded every hour, if available, for 72 hours after surgery. Patients were divided

into two groups based on whether the pain pump for CILA was utilized, the protocol group, and the CILA group.

Statistical Analysis

SPSS Version 17.0 was utilized to perform all statistical procedures. To examine proportional differences between study groups, nonparametric Fisher exact chi-square tests were performed. Similarly, to examine mean differences between study groups, parametric independent sample t tests were performed. In the cases that assumptions of normality and/or homogeneity of variance were violated, nonparametric Mann-Whitney U tests were substituted. Univariate analysis of variance was performed to compare all pain scores over a 24-hour period. Statistically significant differences were considered achieved at a p value ≤ 0.05, two-tailed. Standard deviations, when shown, are noted in parentheses after the mean value of the variable being discussed. Sample Power Version 2.0 was employed to calculate sample size and power. Using a 10-point pain rating scale we positioned that a clinically and substantive effect, which would be important to detect, would be a movement of 2 units or more on the scale. We further hypothesized that 60% of patients treated with CILA would improve 2 or more units on the pain scale, in comparison with 40% patients treated according to the standard protocol. With a proportional difference of 20% (40% versus 60%), the study will have power of 80.1% with a proposed sample size of 97 and 97 for the two groups.

Results

Patient Enrollment and Demographics

During the 3-year study period, a total of 104 patients were identified who underwent spinal fusion surgery with a diagnosis of IS. Of these, 17 patients were excluded: 3 because the surgery was performed by one of the surgeons from the previous orthopedic group, 9 because they did not use PCA for pain control, 3 due to inadequate documentation in the medical record, and 2 because they had conditions that prevented them from using PCA. Of the remaining 87 patients,

68 (78.2%) were female, the average age was 13.7 years, the mean weight was 59.1 kg, 55 (64%) of patients were black, and 19 (22.1%) were white. Interestingly, 12 (13.8%) patients reported a family history of scoliosis, and an average of 20.5 months elapsed between the diagnosis of scoliosis and the surgical procedure to correct the curvature. When divided into groups according to use of the pain pump, there were no statistically significant differences between the groups regarding age, gender, weight, race, family history of scoliosis or time from diagnosis to surgery (►**Table 1**).

Surgical Information

We next examined surgical information for the two groups and found that the majority (75.9%) of all spinal fusion patients had a thoracic curve as their primary curve and similar results when grouped according to use of the pain pump (protocol versus CILA), with 68% of the protocol group and 79% of the CILA group with a thoracic primary curve (►**Table 2**). The average Cobb angle for patients in the protocol group was 56.4 degrees, and the average Cobb angle for patients in the CILA group was 62.3 degrees, which was a statistically significant difference ($p = 0.023$). The two groups had a similar time between diagnosis and surgery, with 17.7 months for the protocol group and 21.5 months for the CILA group. When we compared the percent of patients who received blood transfusions, this was also similar for the two groups, with 20% for the protocol group and 33.9% for the CILA group. The protocol group lost an average of 587 mL of blood intraoperatively, and the CILA group had an average blood loss of 612 mL. The average length of stay was also similar for the two groups.

Opioid Use and Pain Scores

We next examined postoperative opioid use, pain scores, and untoward effects for patients in both groups. We found that in the first 24 hours after surgery, patients in the protocol group used significantly more PCA opioid equivalents, on average, 0.4 mg/kg, or 36% more than those in the CILA group ($p = 0.007$), shown in ►**Fig. 1**. Furthermore, patients in the protocol group used an average of 1.2 mg/kg of total opioids in

Table 1 Demographic characteristics of scoliosis surgery patients

	Protocol group ($n = 25$)	CILA group ($n = 62$)	p
Age, mean (SD), y	13.2 (2.2)	13.9 (2.2)	0.231[a]
Female gender, n (%)	20 (80)	48 (77.4)	n.s.[b]
Weight, mean (SD), kg	58.5 (21.4)	59.3 (16.5)	0.878[a]
Family history of scoliosis, n (%)	5 (20)	7 (11.3)	0.314[b]
Race, n (%)			
Black	17 (70.8)	38 (61.3)	n/a
White	4 (16.7)	15 (24.2)	n/a
Hispanic	0 (0)	2 (3.2)	n/a
Other	3 (12.5)	7 (11.3)	n/a
Time from diagnosis to surgery, mean (SD), mo	17.7 (13.8)	21.5 (21.1)	0.370[a]

Abbreviations: CILA, continuous infusion of local anesthetics; n/a, not available; SD, standard deviation; n.s., not significant.
[a]Student's t test.
[b]Pearson χ^2 test.

Table 2 Surgical information for scoliosis surgery patients

	Protocol group ($n = 25$)	CILA group ($n = 62$)	p
Area of primary curvature, n (%)			
Thoracic	17 (68.0)	49 (79.0)	0.411[a]
Thoracolumbar	7 (28.0)	13 (21.0)	0.411[a]
Lumbar	1 (4.0)	0 (0)	n/a
Cobb angle, mean (SD), degree	56.4 (9.2)	62.3 (13.1)	0.023[b]
Number of vertebrae fused, mean (SD)	9.6 (3.5)	10.0 (2.4)	0.537[b]
Time from diagnosis to surgery, mean (SD), mo	17.7 (13.8)	21.5 (21.1)	0.370[b]
Received transfused blood, n (%)	5 (20)	21 (33.9)	0.301[a]
Intraoperative blood loss, mean (SD), mL	587 (282)	612 (383)	0.738[b]

Abbreviations: CILA, continuous infusion of local anesthetics; n/a, not available; SD, standard deviation.
[a]Pearson χ^2 test.
[b]Student's t test.

the first 24 hours postoperatively, and those in the CILA group used an average of 0.74 mg/kg total opioids, 38% less than the protocol group, a statistically significant difference ($p = 0.006$, ►**Fig. 1**). Total opioid use for the second and third days after surgery was not significantly different for the two groups (data not shown).

When we compared pain scores for the two groups, we found that the immediate postoperative pain scores were 38% lower for patients in the CILA group (1.3), when compared with pain scores for patients in the protocol group (2.1), as shown in ►**Fig. 2**. In addition, average pain scores for the first 24 hours after surgery were 2.7 for the CILA group and 3.1 for the protocol group (►**Fig. 2**). These differences, however, were not statistically significant. Similarly, average pain scores for the second and third postoperative days were higher for the protocol group than for the CILA group, but these were not statistically significant differences (data not shown). The pain scores were noted hourly for the first 24 hours after surgery. When we examined the median pain scores over time for the first 24 hours after surgery, as illustrated in ►**Fig. 3**, the pain

scores for the protocol group were generally higher and have a greater variability from one hour to the next, and the pain scores for the CILA group followed a more consistent pattern, with more gradual changes in pain scores (►**Fig. 3**).

The occurrence of untoward effects was also evaluated and is summarized in ►**Table 3**, noting number of times the patients experienced nausea, vomiting, and pruritus during the 3-day postoperative period. The number of patients who experienced sedation or respiratory depression during 72 hours after surgery was also recorded. The occurrence of all of these untoward effects was low for all patients and was statistically similar. Specifically, the protocol group experienced nausea an average of 1.4 times, vomiting an average of 0.6 times, and pruritus 1 time during the first 3 postoperative days. Similarly, patients in the CILA group experienced nausea an average of 0.8 times, vomiting an average of 0.7 times, and pruritus an average of 1.9 times. The incidence of sedation was low, with none of the protocol group and 3.2% of the CILA group experiencing this effect. Finally, only 4% of the protocol group and 3.2% of the CILA group suffered from respiratory
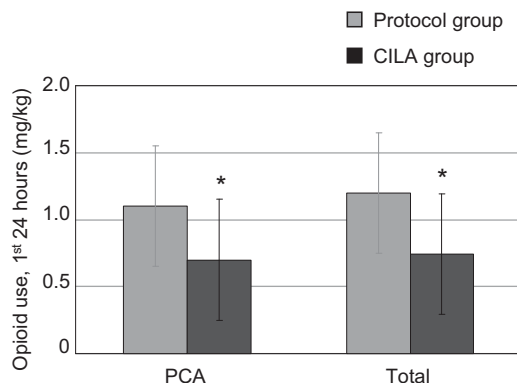

Fig. 1 Opioid use for first 24 hours after surgery. Graph illustrating the mean patient-controlled analgesia (PCA) and total opioid use during the first postoperative day for patients treated according to protocol (light gray) and patients additionally treated with continuous infusion of local anesthetics (CILA; dark gray). Bars indicate standard deviations. *Statistically significant difference ($p \leq 0.05$).
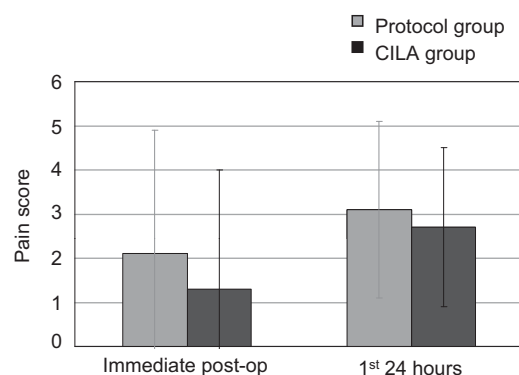

Fig. 2 Pain scores for the immediate postoperative period and the first 24 hours after surgery. Graph showing mean pain scores taken both immediately after the surgery, and the mean pain scores for the first 24 hours after surgery for the protocol (light gray) and continuous infusion of local anesthetics (CILA; dark gray) groups. Bars indicate standard deviations.
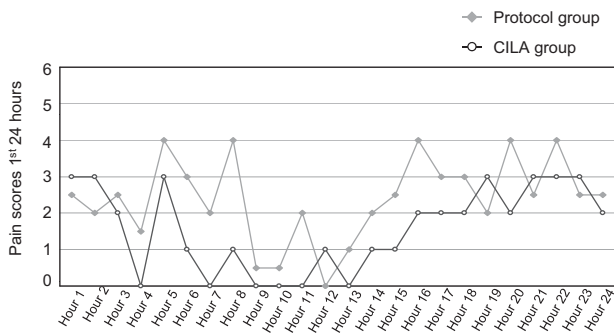
Fig. 3 Pain scores for the first 24 hours after surgery. Graph illustrating median pain scores for each hour, hours 1 to 24, after surgery, for the protocol (light gray diamonds) and continuous infusion of local anesthetics (CILA; black open circles) groups.

depression (►**Table 3**). There were no signs or symptoms of local anesthetic toxicity noted (data not shown).

Discussion

Pediatric spinal fusion surgery is a major surgery that results in severe postoperative pain. Recent investigations have demonstrated that multimodal pain management techniques can maximize alleviation of pain for pediatric spinal fusion surgeries while minimizing untoward effects of opioid analgesics, with studies examining the efficacy of utilizing ketorolac, dextromethorphan, or gabapentin to reduce postoperative pain and opioid use, with good results.[35–37] We believe that opioid analgesics are an important part of a successful pain management treatment strategy but that we can better control pain and opioid use while limiting the occurrence of side effects by adding local anesthetics to the pain management protocol. In fact, one investigation showed that use of continuous infusion of bupivacaine reduces opioid use in the early postoperative period; however, pain management was not standardized throughout the study period.[30] Furthermore, the previous study did not include analysis of opioid use and pain scores after discharge from the intensive care unit, nor did it evaluate PCA opioid use.[30] In contrast, our investigation examined PCA and total opioid use, pain scores, and untoward effects for 3 days after spinal fusion surgery.

The patients included in our study were demographically similar. However, incidence of family history of scoliosis was

higher for the protocol group, but the reason for this difference is unknown. We found that patients who were given continuous infusion of bupivacaine using an elastomeric pump (the CILA group) used 36% less PCA opioids and significantly less total opioids than those who did not in the first 24 hours after surgery. In addition, patient pain scores were 38% lower for the immediate postoperative measurement and 13% lower for the first 24 hours after surgery for patients in the CILA group. Although the differences in pain scores were not statistically significant, these differences are relevant given that the pain score for the protocol group ranged between 2 and 3.7, and it would be difficult to achieve a 2- to 3-point reduction in pain score by any intervention. Unfortunately, the study was underpowered to detect a statistically significant difference in pain scores between these groups. We believe that pain control during the first 24 hours after surgery is an integral part of the pain management strategy because the pain levels experienced by patients upon emergence from anesthesia establish a precedent for pain control throughout the entire postoperative recovery period. If pain is not well managed during the early postoperative period, it is difficult to regain adequate pain control.

Although opioid use was significantly less for patients in the CILA group for the first 24 hours, the untoward effects were not significantly different. However, there was a trend toward reduced incidence of nausea in the CILA group. Interestingly, there were no differences between the two groups in opioid use and pain scores for the second 24 hours after surgery. Our postoperative protocol involves ambulation on postoperative day 2, and if local anesthetics are not effective against this type of dynamic pain, this would explain the similarity in pain scores and opioid use for postoperative day 2. We conclude from this that CILA into the surgical incision site is effective for reducing postoperative pain and opioid use for the first 24 hours after surgery but does not reduce pain or narcotic use once patients begin ambulating. In addition, pain management practices are more variable on postoperative day 2 and after, making comparisons between groups for this period problematic.

The limitations of this study include that it is not randomized but is a retrospective study and therefore has inherent uncontrolled variables. However, although there are several uncontrolled variables in this study, the goal of this investigation was to evaluate the impact of changing the pain

Table 3 Side effects of opioid use for scoliosis surgery patients

Side effects	Protocol group (n = 25)	CILA group (n = 62)	p
Nausea, no. of times, mean (SD)	1.4 (2.0)	0.8 (1.3)	0.125[a]
Vomiting, no. of times, mean (SD)	0.6 (1.3)	0.7 (2.9)	0.694[a]
Pruritus, no. of times, mean (SD)	1.0 (2.6)	1.9 (3.7)	0.188[a]
Sedation, occurrence, n (%)	0 (0)	2 (3.2)	n.s.[b]
Respiratory depression, occurrence, n (%)	1 (4.0)	2 (3.2)	n.s.[b]

Abbreviations: CILA, continuous infusion of local anesthetics; n/a, not available; SD, standard deviation; n.s., not significant.
[a]Student's t test.
[b]Pearson χ^2 test.

management protocol in a real-world environment, in the presence of uncontrolled variables. In addition, in general, the operative procedure and postoperative care, although following the pain management protocol, was under the supervision of the attending surgeon and may have varied slightly from one patient to the next. Finally, although opioid analgesic use is evaluated for this study, the effect of other analgesics is not examined, and therefore the effects of these medications on pain scores and opioid use is unknown.

Given these data, it seems that we are controlling our patients' postoperative pain and opioid use well for the first 24 hours after surgery, and we have been able to improve patients' pain scores, opioid use, and recovery during the early postoperative period through implementation of a standardized pain management protocol for spinal fusion patients. Given that CILA is not enhancing pain control after postoperative day 1, we recommend use of CILA for a shorter time period and have implemented this change at our institution. We believe that our patients' pain during the later postoperative period (days 2 and 3) can be better managed. This study is part of an ongoing effort to improve pain control for pediatric spinal fusion patients. Future studies will be needed to test and identify additional treatments that can be added to the pain management protocol to better control pain levels for pediatric spinal fusion patients during the late postoperative period.

Disclosures
Richard A. K. Reynolds, None
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Suresh T. Thomas, None

References
1 Weinstein SL, Dolan LA, Cheng JCY, Danielsson A, Morcuende JA. Adolescent idiopathic scoliosis. Lancet 2008;371:1527–1537
2 Miller NH. Genetics of familial idiopathic scoliosis. Clin Orthop Relat Res 2007;462:6–10
3 Raw DA, Beattie JK, Hunter JM. Anaesthesia for spinal surgery in adults. Br J Anaesth 2003;91:886–904
4 Hawes MC, O'Brien JP. A century of spine surgery: what can patients expect? Disabil Rehabil 2008;30:808–817
5 Weiss H-R. Adolescent idiopathic scoliosis (AIS)—an indication for surgery? A systematic review of the literature. Disabil Rehabil 2008;30:799–807
6 Negrini S. Approach to scoliosis changed due to causes other than evidence: patients call for conservative (rehabilitation) experts to join in team orthopedic surgeons. Disabil Rehabil 2008;30:731–741
7 Dolan LA, Weinstein SL. Surgical rates after observation and bracing for adolescent idiopathic scoliosis: an evidence-based review. Spine 2007;32(19, Suppl):S91–S100

8 Tobias JD. A review of intrathecal and epidural analgesia after spinal surgery in children. Anesth Analg 2004;98:956–965
9 Viscusi ER. Patient-controlled drug delivery for acute postoperative pain management: a review of current and emerging technologies. Reg Anesth Pain Med 2008;33:146–158
10 Borgeat A, Blumenthal S. Postoperative pain management following scoliosis surgery. Curr Opin Anaesthesiol 2008;21:313–316
11 Sucato DJ, Duey-Holtz A, Elerson E, Safavi F. Postoperative analgesia following surgical correction for adolescent idiopathic scoliosis: a comparison of continuous epidural analgesia and patient-controlled analgesia. Spine 2005;30:211–217
12 Cassady JF Jr, Lederhaas G, Cancel DD, Cummings RJ, Loveless EA. A randomized comparison of the effects of continuous thoracic epidural analgesia and intravenous patient-controlled analgesia after posterior spinal fusion in adolescents. Reg Anesth Pain Med 2000;25:246–253
13 Van Boerum DH, Smith JT, Curtin MJ. A comparison of the effects of patient-controlled analgesia with intravenous opioids versus epidural analgesia on recovery after surgery for idiopathic scoliosis. Spine 2000;25:2355–2357
14 Gauger VT, Voepel-Lewis TD, Burke CN, et al. Epidural analgesia compared with intravenous analgesia after pediatric posterior spinal fusion. J Pediatr Orthop 2009;29:588–593
15 Milbrandt TA, Singhal M, Minter C, et al. A comparison of three methods of pain control for posterior spinal fusions in adolescent idiopathic scoliosis. Spine 2009;34:1499–1503
16 O'Hara JF Jr, Cywinski JB, Tetzlaff JE, Xu M, Gurd AR, Andrish JT. The effect of epidural vs intravenous analgesia for posterior spinal fusion surgery. Paediatr Anaesth 2004;14:1009–1015
17 Blumenthal S, Borgeat A, Nadig M, Min K. Postoperative analgesia after anterior correction of thoracic scoliosis: a prospective randomized study comparing continuous double epidural catheter technique with intravenous morphine. Spine 2006;31:1646–1651
18 Karmakar MK, Booker PD, Franks R. Bilateral continuous paravertebral block used for postoperative analgesia in an infant having bilateral thoracotomy. Paediatr Anaesth 1997;7:469–471
19 Pham Dang C, Delécrin J, Péréon Y, et al. Epidural analgesia after scoliosis surgery: electrophysiologic and clinical assessment of the effects of bupivacaine 0.125% plus morphine versus ropivacaine 0.2% plus morphine. J Clin Anesth 2008;20:17–24
20 Gall O, Aubineau J-V, Bernière J, Desjeux L, Murat I. Analgesic effect of low-dose intrathecal morphine after spinal fusion in children. Anesthesiology 2001;94:447–452
21 Eschertzhuber S, Hohlrieder M, Keller C, Oswald E, Kuehbacher G, Innerhofer P. Comparison of high- and low-dose intrathecal morphine for spinal fusion in children. Br J Anaesth 2008;100:538–543
22 Tripi PA, Poe-Kochert C, Potzman J, Son-Hing JP, Thompson GH. Intrathecal morphine for postoperative analgesia in patients with idiopathic scoliosis undergoing posterior spinal fusion. Spine 2008;33:2248–2251
23 Goodarzi M. The advantages of intrathecal opioids for spinal fusion in children. Paediatr Anaesth 1998;8:131–134
24 Poe-Kochert C, Tripi PA, Potzman J, Son-Hing JP, Thompson GH. Continuous intravenous morphine infusion for postoperative analgesia following posterior spinal fusion for idiopathic scoliosis. Spine 2010;35:754–757
25 Liu SS, Richman JM, Thirlby RC, Wu CL. Efficacy of continuous wound catheters delivering local anesthetic for postoperative analgesia: a quantitative and qualitative systematic review of randomized controlled trials. J Am Coll Surg 2006;203:914–932
26 Parvizi J, Miller AG, Gandhi K. Multimodal pain management after total joint arthroplasty. J Bone Joint Surg Am 2011;93:1075–1084
27 Elder JB, Hoh DJ, Wang MY. Postoperative continuous paravertebral anesthetic infusion for pain control in lumbar spinal fusion surgery. Spine 2008;33:210–218
28 Baig MK, Zmora O, Derdemezi J, Weiss EG, Nogueras JJ, Wexner SD. Use of the ON-Q pain management system is associated with

decreased postoperative analgesic requirement: double blind randomized placebo pilot study. J Am Coll Surg 2006;202:297–305

29 Dadure C, Pirat P, Raux O, et al. Perioperative continuous peripheral nerve blocks with disposable infusion pumps in children: a prospective descriptive study. Anesth Analg 2003;97:687–690

30 Ross PA, Smith BM, Tolo VT, Khemani RG. Continuous infusion of bupivacaine reduces postoperative morphine use in adolescent idiopathic scoliosis after posterior spine fusion. Spine 2011;36: 1478–1483

31 Yaster M, Lenke LG, Maxwell LG. Opioid agonists and antagonists. In: Schecter NL, Berde CB, Yastor M, eds. Pain in Infants, Children and Adolescents. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2003:181–224

32 McPherson MM. Introduction to opioid conversion calculations. In: Demystifying Opioid Conversion Calculations. A Guide for Effective Dosing. Bethesda, MD: American Society of Health System Pharmacists; 2010:1–16

33 Dosage tables for adult and pediatric patients. In: Acute pain management: operative or medical procedures and trauma. AHCPR Clinical practice guidelines. Rockville, MD: Agency for Health Care Policy and Research; 1992:C112–C113

34 Wong DL, Hockenberry-Eaton M, Wilson D, Winkelstein ML, Scwartz P. Wong's Essentials of Pediatric Nursing. 6th ed. St. Louis, MO; 2001:1301

35 Horn PL, Wrona S, Beebe AC, Klamar JE. A retrospective quality improvement study of ketorolac use following spinal fusion in pediatric patients. Orthop Nurs 2010;29:342–343

36 Suski M, Bujak-Gizycka B, Madej J, et al. Co-administration of dextromethorphan and morphine: reduction of post-operative pain and lack of influence on morphine metabolism. Basic Clin Pharmacol Toxicol 2010;107:680–684

37 Rusy LM, Hainsworth KR, Nelson TJ, et al. Gabapentin use in pediatric spinal fusion patients: a randomized, double-blind, controlled trial. Anesth Analg 2010;110:1393–1398