

**Microdose Intrathecal Morphine Injection in Teenagers Undergoing Scoliosis Surgery
Decreases Length of Stay, Pain Scores, and Opioid Consumption**

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Key Points

1. ITM-RRP has allowed for a 70% reduction in opioid consumption in this large sample of AIS patients undergoing PSF.
2. Further beneficial outcomes are seen such as earlier discharge, ambulation, and time to first stool.
3. Between the years 2017 and 2018, the first year ITM-RRP was implemented, there were significant cost-savings observed.
4. The micro-dose intrathecal morphine injection did not increase the frequency of respiratory complications, arachnoiditis, cerebrospinal fluid leaks, headaches, or pruritus.

Abstract

Study Design Retrospective Cohort Study

Objective This study aimed to investigate outcomes in Adolescent Idiopathic Scoliosis (AIS) patients undergoing posterior spinal fusion (PSF) with our institution's rapid recovery pathway (RRP) protocol that utilizes a micro-dose of ITM.

Summary of Background Data Reducing opioid exposure among the adolescent population is extremely desirable. Micro-dose intrathecal morphine (ITM) has become common in labor and delivery surgery, among other sub-specialties, because of the long-lasting analgesic properties. We hypothesized that this ITM-RRP protocol will reduce opioid consumption in this large sample.

Methods Retrospective cohort study of pediatric patients with spinal deformity who underwent posterior spinal fusion (PSF) between the years 2015-2023 were included. Patients prior to the implementation of RRP in 2018 were in the PCA group (2015-2017) and patients who underwent

the procedure after the implementation of RRP (2018-2023) were in the ITM-RRP group. Outcomes measured include intraoperative, postoperative, and total opioid consumption, as well as length of stay, VAS pain scores, rate of emesis, and 90-day complications.

Results ITM-RRP patients had lower VAS pain scores at activity ($p<0.001$), were out of bed earlier ($p<0.001$), were discharged earlier ($p<0.001$), had lower rate of emesis ($p<0.001$), and had their first stool earlier ($p<0.001$) when compared to PCA patients. ITM-RRP patients consumed significantly less opioids intraoperatively ($p<0.001$), postoperatively ($p<0.001$), and overall ($p<0.001$). ITM-RRP and PCA group had similar rates of 90-day complications ($p=0.28$) and respiratory complications ($p=0.94$).

Conclusion ITM-RRP, which utilizes a micro-dose of morphine, is effective in managing postoperative pain after PSF. This is valuable because it allows for a reduction in not only the dosage of opioid exposure in adolescents but the duration as well, reducing the likelihood of opioid dependence in the future.

Introduction

In recent years, rapid recovery protocols have become popular in scoliosis surgery. However, these protocols utilize patient-controlled analgesia (PCA) for at least one day postoperatively.¹⁻³ PCA at 1mg morphine per hour-- over two days can result in patients consuming 48mg of morphine. In 2018, our institution implemented a rapid recovery protocol (RRP) which eliminated PCA, and was published by Sarwahi et al in 2021, demonstrating a significant reduction in opioid consumption.⁴ Opioid reduction decreases itching, constipation, grogginess, and possibly dependence, while allowing earlier food intake. Yule et al reported that adolescent receiving prescription opioids increases the risk of opioid dependence by 33%.⁵

Our institution's RRP utilizes a micro-dose of intrathecal morphine (ITM) injected intraoperatively. ITM at higher doses can cause respiratory depression.⁶⁻¹¹ Micro-dose ITM, in comparison, does not have this major adverse effect, while having effective pain control and has been safely used in labor and delivery and in pediatric surgery.^{10,12-16} Its effectiveness has also been analyzed in adult lumbar spinal surgeries by Wang et al. and in adolescent idiopathic scoliosis (AIS) patients by Sarwahi et al.^{4,16,18} The objective of this study is to analyze the effectiveness of a microdose ITM based RRP in a large population of AIS patients undergoing posterior spinal fusion (PSF). (Figure 1)

Methods

Study Design

Retrospective cohort study of 650 patients with AIS who underwent PSF between the years 2015-2023. Non-idiopathic scoliosis patients and revision surgeries were excluded.

Patients were compared based upon which recovery protocol was utilized at the time of their procedure. Patients operated on between 2015-2017 utilized a traditional protocol including PCA (PCA group) (n=250). Patients operated on between 2018-2023 were in the ITM-RRP group (n=400).

Demographic characteristics were collected. Pre-and post-operative Cobb Angles, levels fused, and fixation points were measured on radiographs. Surgical variables included estimated blood loss (EBL), operative time, and anesthesia time. Clinical variables include maximum patient-reported Visual Analog Scale (VAS) pain scores during activity, time to ambulation (OOB), length of stay (LOS), transfusions, narcotic refill frequency, 90-day complications, time to stool, and rate of emesis. Pruritus was recorded based on self-reporting or on administered intervening medication. Maximum VAS pain scores were observed by postoperative day and overall stay. Total hospital-stay cost was collected, a sum of intraoperative anesthesia, postoperative anesthesia, operating room, ICU stay, and hospital room cost. Intraoperative and postoperative opioid consumption was collected as morphine milligram equivalents (MME). Total hospital-stay and grand total opioid consumption, which includes hospital stay opioid consumption and the patient's initial take-home opioid prescription, were collected. In a contemporary sub-analysis, 2017 PCA patients were compared to 2018 ITM-RRP patients.

Rapid Recovery Pathway Protocol

⁴ Pre-operation, patients and families are educated regarding intrathecal morphine and problems with prolonged and increased opioid use. Protocol recommendations include increasing physical activity, laxatives for 7-days, a high-fiber diet pre-surgically, and avoid a heavy meal the night before surgery. Postoperative recovery expectations and the benefits of ITM on pain

management are discussed. A clear carbohydrate drink (Ensure Pre-surgery) is given 2 hours prior to surgery.⁴ ITM is intraoperatively administered as 1.5 µg/kg diluted in 1 to 1.5cc of saline by anesthesiologists at the beginning of the case or by the orthopedic surgeon at the end of the procedure through the interlaminar space (L3–L4 or L4–L5). At induction, IV fentanyl (0.5–2 µg/kg) is given, followed by remifentanyl (0.05–0.5 µg/kg/min) or fentanyl (0.5–2.0 µg/kg/h) infusion. Immediate postoperative IV ketorolac (0.5 mg/kg; max 30 mg), oral Tylenol (15 mg/kg; max 650 mg), and oral Diazepam (0.05 mg/kg) Q6H are administered for the initial 48 hours. PO oxycodone (0.1 mg/kg) is given Q4H for 72 hours post-surgery.⁴ IV hydromorphone (15mcg/kg) Q4H is given for breakthrough pain in the first 24 hours. Patients are given acetaminophen and non-steroidal anti-inflammatory drugs (NSAIDs) every 2 hours. Acetaminophen is given at hour 8, 12, 16, while an NSAID is staggered at hour 10, 14 and 18.⁴

The foley catheter is removed on POD 0, and patients sit up in bed as tolerated alongside physical and occupational therapy (PT/OT). On POD 1, the patient is out of bed to chair and ambulate as tolerated. On POD 2, patients ambulate in the hallway 2–3x/day. On POD 3, the patient utilizes the stairs with a physical therapist and pain is managed with acetaminophen and diazepam, while oxycodone is changed to PRN. Patients are typically discharged by POD 3 with diazepam, PO oxycodone PRN, and acetaminophen. A standard dose of 3–5 days of opioids are prescribed to the patient.

The adherence to the protocol is stressed including timing of regular diet, ambulation, and pain medications with occasional modifications based on patient requirements. The ITM-RRP protocol is intended to improve patients' pain management and their recovery throughout their hospital stay.

Traditional Protocol

This traditional protocol was utilized prior to 2018. There are similarities to the ITM-RRP protocol with preoperative education regarding: constipation, OOB, nursing assistance, and diet administration. However, opioid reduction strategies and drawbacks of opioid use were not highlighted.

At induction, 0.5-2 $\mu\text{g}/\text{kg}$ of IV fentanyl was given, followed by 0.05-0.5 $\mu\text{g}/\text{kg}/\text{min}$ of a remifentanyl infusion.⁴ PCA morphine or hydromorphone, started on POD 0. Demand boluses were delivered every 10 minutes, with a 4-hour maximum of 0.3 mg/kg of morphine or 0.06 mg/kg of hydromorphone.⁴ Patients were administered diazepam PRN with 30mg of IV Toradol. On POD 2, PCA was stopped, and 10mg of PO Oxycodone was started, along with IV hydromorphone injections as necessary. Patients were given either Tylenol or NSAIDs every 2 hours and discharged on diazepam, PO oxycodone, and PO Tylenol for 14 days.⁴

The patients' foley catheter was removed between POD 1 and POD 2. On POD 1, patients began on a clear liquid diet, progressed to a regular diet as tolerated, and were OOB to chair with further advancement to ambulation under PT supervision but without standardized timepoints.⁴

In both cohorts, patients were maintained on total intravenous anesthesia (TIVA) using remifentanyl and propofol infusions intraoperatively.⁴ Dilaudid is also given to both groups to cover the initial stimulation of surgery. Ultimately, the intraoperative administration of ITM with significant protocol changes creates a major difference between the two cohorts.

Statistical Analysis

Differences in variables were compared using Wilcoxon rank-sum tests for continuous variables and Fisher's exact or Chi-squared for categorical variables. An independent biostatistician performed all statistical analyses using SAS software version 9.4 (SAS Institute Inc., Cary, NC). All p-values were two-tailed, with $p < 0.05$ considered significant. Continuous data is presented in the tables as median and interquartile range (IQR). Categorical data is presented in the tables as frequency and percentages.

Results

There were no differences in demographic or radiographic variables, excluding age ($p = 0.002$). The PCA group had a significantly higher median EBL compared to the ITM-RRP group (500.0mL vs. 400.0mL, $p < 0.001$). Operative and anesthesia time were also significantly higher in the PCA group than the ITM-RRP ($p < 0.001$ and $p = 0.03$, respectively). Maximum VAS pain scores at activity were lower in the ITM-RRP group ($p < 0.05$). ITM-RRP patients were OOB significantly earlier than PCA patients ($p < 0.001$). 81.5% of patients in ITM-RRP had their first stool by POD 3, as opposed to only 23.4% PCA patients ($p < 0.001$). LOS was shorter for ITM-RRP patients (4.0 vs 5.0 days, $p < 0.001$). 16.4% of PCA patients required a narcotic refill, compared to 8.3% of ITM-RRP patients ($p < 0.001$). 1.7% of patients in ITM-RRP experienced emesis, while 8.8% in PCA did ($p < 0.001$). There was no difference in transfusion rates ($p = 0.56$). (Table 1). Figures 2 and 3 illustrate length of stay and maximum VAS pain scores at activity each year from 2015-2023, respectively.

Complications

A similar rate of 90-day complications was observed between the PCA and ITM-RRP patients (4.0% vs. 2.5%, $p=0.28$). In the PCA group, 5 patients developed a surgical site infection (SSI). 2 patients required a revision procedure: one due to rod dislodgement and the other developed paraparesis 12-hours later. Additional complications include: 1 cerebrospinal fluid (CSF) leak and 2 respiratory complications. In the ITM-RRP group, 5 (1%) patients developed a SSI and 3 (0.75%) developed respiratory complications ($p=0.94$): 2 pleural effusions and 1 respiratory distress. This respiratory distress patient had history of mitral valve repair and on POD1, chest X-Ray showed lung opacities. Patient was switched to BiPAP on POD1 and weaned off on POD2. No patients self-reported pruritus or experienced arachnoiditis or headaches.

Opioid Consumption

PCA patients had significantly higher intraoperative opioid consumption than ITM-RRP (47.0 MME vs. 35.5 MME, $p<0.001$). PCA patients had higher opioid consumption at every postoperative stage ($p<0.05$). The PCA group consumed a median of 437.0 MME of opioids during their hospital stay, while the ITM-RRP group had a median consumption of 125.9 MME ($p<0.001$). PCA patients' grand total opioid consumption was significantly higher compared to ITM-RRP (616.0 MME vs. 184.6 MME, $p<0.001$) (Table 2). Figure 4 illustrates the median grand total opioid consumption from 2015-2023.

2017 PCA versus 2018 ITM-RRP Analysis

Maximum VAS Pain Score for 2017 PCA patients was 8 (7,10) when compared to 7 (6,9) for 2018 ITM-RRP ($p=0.021$). OOB by POD 1 as well as first stool by POD 3 both found

significant differences between groups ($p < 0.001$). 2017 median total cost was significantly higher than 2018 (\$68,850.00 vs. \$44,216.00, $p < 0.001$). Comparable outcomes were seen in this sub-analysis as in the overall group (Table 3 and Table 4).

Discussion

Our institution's micro-dose ITM has shown to be effective and safe in scoliosis surgery; and has allowed for the complete elimination of PCA and a significant reduction in opioid consumption.⁴ ITM-RRP protocol resulted in a 70% reduction in total opioid consumption compared to the PCA group. Intraoperative, postoperative, and post-discharge opioid consumption all decreased. The standard for intraoperative anesthesia is a continuous infusion of propofol and remifentanyl. Since propofol and remifentanyl are titratable, ITM-RRP's increased education and awareness encourages the anesthesia team to reduce morphine administration by continuously adjusting the dosage, depending on the level of surgical stimulus and physiological indicators from the patient. This focus on opioid reduction intraoperatively, based on surgical and patient demand, has resulted in lowering of intraoperative opioids. It is likely an effect of opioid awareness rather than of ITM.

Furthermore, postoperative opioid consumption was significantly lower in the ITM-RRP group at every timepoint. PCA patients experienced significantly more pain and reported higher pain scores, and as a result required more opioids each day. Finally, the post-discharge opioid consumption was also lower in ITM-RRP. ITM-RRP protocol, patients are discharged with a 3-5-day supply of opioids.⁴ PCA, patients were discharged with 2-3 weeks supply. Despite fewer opioids at discharge, ITM-RRP patients still request fewer refills (8.3% vs 16.4% of PCA patients). These reductions are ultimately reflected in the grand total opioid consumption, which decreased 431.4 MME in the ITM-RRP patients.

The micro-dose of morphine has decreased many of the concerns surrounding an ITM injection, such as increased respiratory depression, pruritus complaints, and constipation.^{6-8,11,17,19-21} Urban et al investigated the effect of varying ITM doses, 10µg/kg, 20µg/kg, or none. They found that an increased incidence of pruritus was present in both groups who received this dosage of ITM.²² The risk of increased respiratory depression is usually dose dependent and often results in a longer ICU stay for patients.¹¹ Duad et al. conducted a study concluding that AIS patients who received a high dose of ITM were associated with the risk of developing respiratory depression, while patients receiving a low to moderate dose of ITM experienced complications that were comparable to those in the control group.²³ Similarly, Baxter et al in 2023 studied low-dose ITM following lumbar fusion surgery in 180 patients, 65 patients received ITM and 115 did not.²⁴ Baxter et al reported that there was no increase in respiratory depression or nausea in patients treated with low-dose ITM.²⁴ Our study administers a micro-dose of ITM to minimize the risk of adverse effects while still achieving analgesic effects. While complications can still occur, there is a decreased likelihood when compared to patients receiving a higher dose.

ITM-RRP protocol allows for gastrointestinal (GI) normalcy in patients sooner after surgery. In the ITM-RRP, patients experienced less emesis (1.7% vs. 8.8%) and had earlier bowel movements, 81.5% of ITM-RRP patients had their first stool by POD3, compared to only 23.4% of PCA patients. Furthermore, as patients are not on PCA, we allow patients to eat an hour postop and take PO analgesics; an advantage over IV medications in terms of cost and potential increased opioid exposure. Decreased opioid use and exposure have important short and long-term implications such as reduced constipation, nausea, and earlier bowel movements²⁵. Additionally, an alert patient is more cooperative in their postoperative recovery, putting less

burden on the nursing team. These benefits facilitate earlier mobilization, oral intake, and discharge. Long-term benefits are decreased risk of opioids dependence. The likelihood of long-term opioid use increases after 5 days of opioids have been prescribed.²³ Teenagers exposed to prescription opioids are more likely to utilize non-prescription opioids later in life and develop an opioid use disorder.²⁴ Deyo et al reported that even one refill after the initial prescription was associated with 2.25 greater odds of long-term opioid use.²⁷ Thus, the number of patients requiring a narcotic refill in the ITM-RRP group being half that of the PCA group is promising. Reducing both the dosage and duration of exposure is beneficial in the long-term as well.

Our sub-analysis of 2017 vs 2018 patients found that 2018 ITM-RRP patients consumed approximately 80% less opioids than the 2017 PCA patients. This reduction was in presence of lower pain scores with ITM-RRP; evidence of its effectiveness in decreasing opioids with adequate pain control. Other recovery measures also highlight the efficacy of the ITM-RRP protocol: significantly quicker bowel movement (91.9% vs. 38.0% by POD3), lower VAS pain scores at activity throughout hospital stay, and OOB by POD 1 significantly quicker, which reflects accelerated mobilization. ITM patients' LOS was significantly shorter and had significantly fewer narcotic refills. We also found that the institution's total cost significantly decreased between 2017-2018. These consecutive years were selected for accurate comparison and to help to control inflation. Thus, the benefits of ITM-RRP extend beyond patient outcomes; however, further, more comprehensive analysis should be conducted.

The limitations of our study are that patients were not specifically asked about pruritus, headaches and pain score were recorded at the start of nursing shift or when pain medications were given. Pruritus, for example, if not self-reported, was not recorded. The nursing records,

while accurate, may not reflect the complete picture. It is also possible that patients may have refused PT due to pain but this was not recorded. These limitations are true for any study, especially retrospective. The strength is its large number of patients, a standardized unmodified protocol, and length of study duration.

Conclusion

The RRP protocol, centrally utilizing a micro-dose of ITM (ITM-RRP), is effective in pain control and management in pediatric patients after a thoracolumbar spinal fusion procedure. This ITM-RRP pathway has allowed for the complete elimination of patient-controlled analgesia (PCA) at our institution, significantly reducing opioid consumption in pediatric patients. This procedural change has allowed for beneficial outcomes which ultimately result in quicker recovery and discharge with no untoward side effects of the intrathecal morphine.

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Figure 1. Breakdown and further description of the RRP protocol.



Figure 2. Median length of hospital stay for patients over the years 2015-2023.

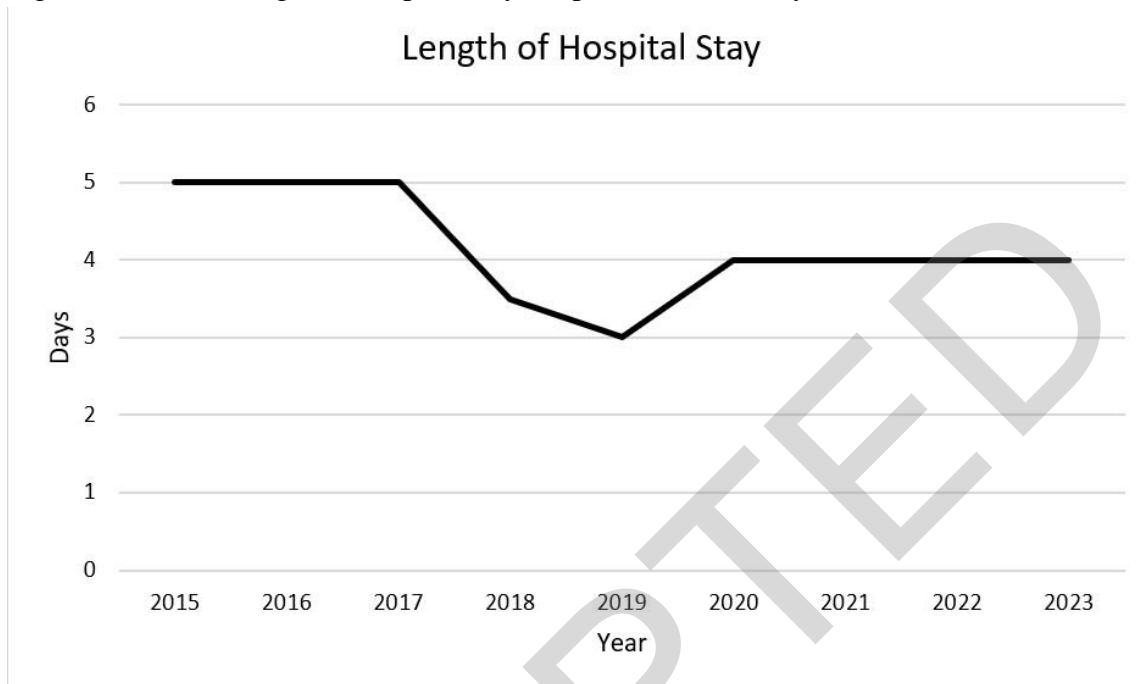


Figure 3. Median maximum VAS pain scores for patients' total hospital stay over the years 2015-2023.

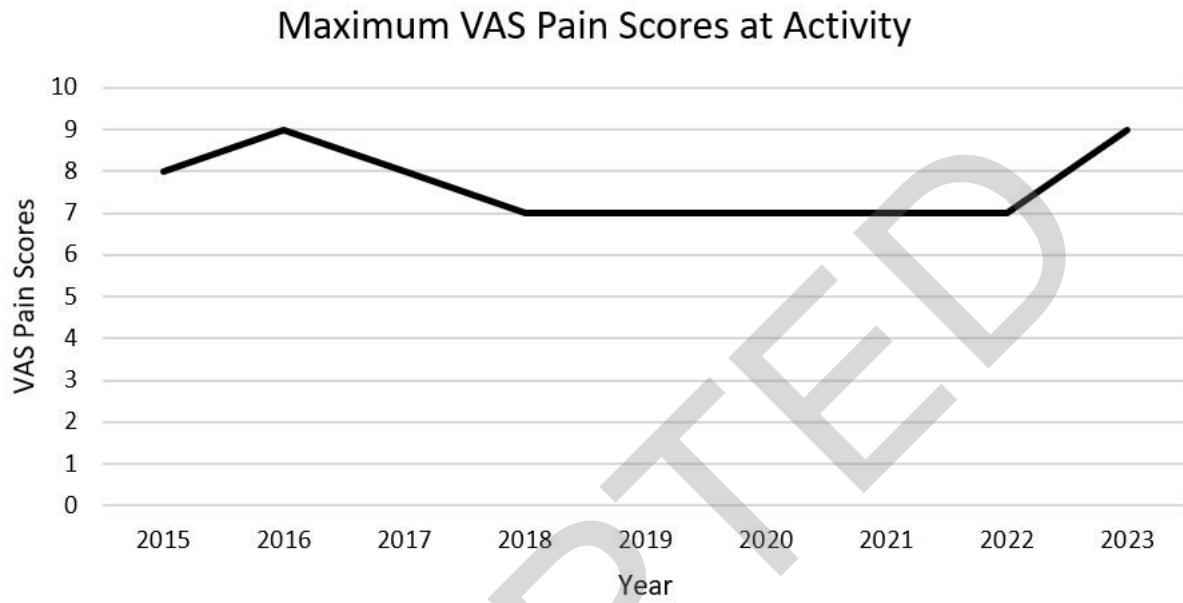


Figure 4. Median Grand Total Opioid Consumption for patients over the years 2015-2023.

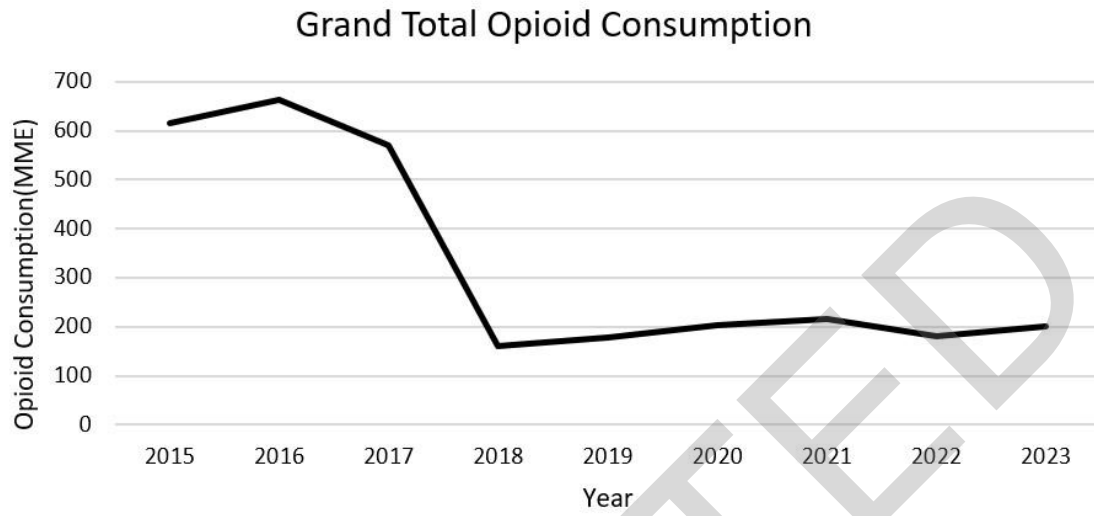


Table 1. Comparison of demographic, radiographic, and perioperative variables between AIS patients that received either PCA or ITM-RRP. Continuous data is presented as median and interquartile range. Categorical is represented as frequency and percentages. Statistical values with $p < 0.05$ are considered statistically significant and bolded.

	PCA (n=250)	ITM (n =400)	P
Age (years)	14.9 (13.3, 16.2)	15.3 (13.8, 17.0)	0.002
BMI (kg/m ²)	21.1 (18.7, 24.8)	21.2 (19.2, 25.3)	0.33
Female	164 (76.3%)	282 (70.5%)	0.13
Preop Cobb (°)	54.0 (48.0, 62.1)	54.0 (50.0, 61.8)	0.98
Postop Cobb (°)	17.4 (11.4, 24.0)	17.0 (9.9, 22.1)	0.20
Cobb Correction (%)	68.5 (57.7, 78.7)	69.7 (61.2, 80.0)	0.22
Levels Fused	11.0 (9.0, 12.0)	12.0 (11.0, 14.0)	< 0.001
Fixation Points	22.0 (20.0, 25.0)	25.0 (22.0, 26.0)	< 0.001
EBL (mL)	500.0 (400.0, 700.0)	400.0 (300.0, 600.0)	< 0.001
Operative Time (mins)	267.0 (235.0, 324.0)	248.0 (217.0, 295.0)	< 0.001
Anesthesia Time (mins)	401.0 (356.0, 452.0)	386.0 (347.0, 439.0)	0.03
Transfusion, n (%)	40 (16.0%)	71 (17.8%)	0.56
Max Pain Score at Activity			
<i>POD 0</i>	7.5 (5.0, 9.0)	5.0 (4.0, 7.0)	
<i>POD 1</i>	7.0 (5.0, 9.0)	6.0 (4.0, 8.0)	
<i>POD 2</i>	7.0 (6.0, 8.0)	6.0 (5.0, 8.0)	
<i>Overall</i>	8.0 (7.0, 10.0)	7.0 (6.0, 9.0)	< 0.001
OOB by POD 1	34 (14.5%)	359 (98.6%)	< 0.001
OOB after POD 1	201 (85.5%)	5 (1.4%)	
First Stool by POD 3	54/231 (23.4%)	264/324 (81.5%)	<0.001
LOS (days)	5.0 (4.0, 5.0)	4.0 (3.0, 5.0)	< 0.001
Narcotic refill, n(%)	41 (16.4%)	32 (8.3%)	<0.001
Complication within 90 days, n (%)	10 (4.0%)	10 (2.5%)	0.28
<i>Respiratory complications, n (%)</i>	2 (0.8%)	3 (0.75%)	0.94

<i>CSF leaks, n (%)</i>	1 (0.4%)	0 (0.0%)	0.39
<i>Pruritus, n(%)</i>	0	0	-
<i>Arachnoiditis, n(%)</i>	0	0	-
<i>Headaches, n(%)</i>	0	0	-
<i>Emesis, n(%)</i>	22 (8.8%)	7 (1.7%)	< 0.001

P values were obtained from Wilcoxon rank-sum tests for continuous variables and Chi-Squared or Fisher's exact tests for categorical variables.

Table 2. Comparison of morphine milligram equivalents (MME) of opioids consumed between AIS patients that received either PCA or ITM-RRP. Data is presented as median and interquartile range. Statistical values with $p < 0.05$ are considered statistically significant and bolded.

	PCA (n=250)	ITM (n =400)	P
Intraoperative (MME)	47.0 (28.0, 115.0)	35.5 (19.4, 47.8)	< 0.001
0 – 24H (MME)	155.0 (99.5, 213.5)	41.5 (27.7, 61.5)	< 0.001
24 – 48H (MME)	80.0 (35.0, 120.0)	30.8 (19.2, 46.2)	< 0.001
48-72 H (MME)	34.0 (18.0, 55.0)	18.5 (11.5, 26.9)	< 0.001
72 – 96 H (MME)	30.0 (20.0, 50.0)	15.4 (11.4, 23.1)	< 0.001
96 H+ (MME)	30.0 (20.0, 48.0)	15.4 (15.4, 18.5)	< 0.001
Total Hospital Stay Opioid Consumption (MME)	437.0 (328.0, 526.0)	125.9 (96.3, 173.9)	< 0.001
Grand Total Opioid Consumption (MME)	616.0 (45.0, 791.5)	184.6 (140.5, 250.1)	< 0.001

P values were obtained from Wilcoxon rank-sum tests.

Table 3. Comparison of demographic, radiographic, and perioperative variables between AIS patients that received either PCA in 2017 or ITM-RRP in 2018. Continuous data is presented as median and interquartile range. Categorical is represented as frequency and percentages. Statistical values with $p < 0.05$ are considered statistically significant and bolded.

	2017 PCA (n= 58)	2018 ITM-RRP (n = 71)	P
Age (years)	15.0 (13.3, 16.3)	15.3 (13.7, 16.9)	0.495
BMI (kg/m ²)	21.2 (18.8, 27.1)	20.2 (18.5, 25.1)	0.268
Female, n(%)	42 (72.4%)	54 (76.1%)	0.637
Preop Cobb (°)	52.0 (45.0, 61.0)	54.0 (51.0, 60.0)	0.092
Postop Cobb (°)	18.0 (12.9, 23.6)	17.0 (11.0, 22.0)	0.248
Cobb Correction (%)	65.5 (56.8, 76.7)	68.4 (63.5, 79.4)	0.085
Levels Fused	11 (9, 12)	12 (10, 13)	0.003
Operative Time (mins)	275.5 (232.0, 321.0)	237.5 (211.0, 304.5)	0.065
Max Pain Score at Activity			
<i>POD 0</i>	8 (7, 9)	6 (4, 7.5)	
<i>POD 1</i>	8 (5, 9.5)	6 (4, 8)	
<i>POD 2</i>	7 (6, 8)	6 (5, 7)	
<i>Overall</i>	8 (7, 10)	7 (6, 9)	0.021
OOB by POD 1, n(%)	7 (12.1%)	67 (100%)	< 0.001
OOB after POD 1, n(%)	51 (87.9%)	0	
First Stool by POD 3, n(%)	19/ 50 (38.0%)	57/ 62 (91.9%)	<0.001
LOS (days)	5 (4, 5)	3 (3, 5)	< 0.001
Narcotic refill, n(%)	16 (27.6%)	7 (10%)	0.010
Complication within 90 days, n (%)	2 (3.5%)	2 (2.8%)	1.0
Total Hospital-Stay Cost (\$)	68,850.0 (60,137.0, 79,048.0)	44,216.0 (36,260.0, 54,376.0)	< 0.001

P values were obtained from Wilcoxon rank-sum tests for continuous variables and chi-square or Fisher's exact tests for categorical variables.

Table 4. Comparison of morphine milligram equivalents (MME) of opioids consumed between AIS patients that received either PCA in 2017 or ITM-RRP in 2018. Data is presented as median and interquartile range. Statistical values with $p < 0.05$ are considered statistically significant and bolded.

	2017 PCA (n= 58)	2018 ITM-RRP (n = 71)	P
Intraoperative (MME)	33.0 (19.0, 62.5)	29.4 (19.4, 47.7)	0.402
0 – 24H (MME)	180.0 (120.0, 210.0)	34.6 (25.4, 54.6)	< 0.001
24 – 48H (MME)	84.0 (45.0, 110.0)	21.5 (14.6, 30.8)	< 0.001
48-72 H (MME)	39.0 (24.0, 60.0)	15.4 (7.3, 18.9)	< 0.001
Total Hospital Stay Opioid Consumption (MME)	446.5 (361.5, 577.8)	100.9 (75.5, 146.2)	< 0.001
Grand Total Opioid Consumption (MME)	596.5 (428.5, 814.5)	160.9 (111.7, 214.7)	< 0.001

P values were obtained from Wilcoxon rank-sum tests.