Combined erector spinae plane block with surgical intercostal nerve cryoablation for Nuss procedure is associated with decreased opioid use and length of stay

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ABSTRACT

Background and objectives Pain management for patients undergoing the Nuss procedure for treatment of pectus excavatum can be challenging. In an effort to improve pain management, our institution added bilateral single injection erector spinae plane (ESP) blocks to surgeon placed intercostal nerve cryoablation. We aimed to assess the efficacy of this practice change.

Methods Retrospective clinical data from a single academic medical center were evaluated. Due to an institutional change in clinical management, we were able to perform a before and after study. Twenty patients undergoing Nuss procedure who received bilateral ultrasound-guided single-shot T6 level ESP blocks and intercostal nerve cryoablation were compared with a historical control cohort of 20 patients who underwent Nuss procedure with intercostal nerve cryoablation alone. The primary outcome variables included postoperative pain scores, total hospital opioid use, and hospital length of stay.

Results Median total hospital intravenous morphine milligram equivalents was lower for the ESP group than for the control group (0.60 (IQR 0.35–0.88) vs 1.15 mg/kg (IQR 0.74–1.68), p<0.01). There was no difference in postoperative pain scores between the two groups. Mean hospital length of stay was 2.45 (SD 0.69) days for the control group and 1.95 (SD 0.69) days for the ESP group (p=0.03). No adverse events related to block placement were identified.

Conclusions In a single-center academic practice, the addition of bilateral single injection ESP blocks at T6 to surgeon performed cryoablation reduced opioid consumption without a change in subjectively reported pain scores. The results from this pilot study can provide effect size estimates to guide the design of future randomized trials.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Both erector spinae plane (ESP) blocks and surgical intercostal nerve cryoablation have been shown to independently decrease opioid use and hospital length of stay for patients with pectus excavatum undergoing the Nuss procedure.

WHAT THIS STUDY ADDS

⇒ The combination of ESP blocks with surgeon performed intercostal nerve cryoablation is associated with decreased total hospital opioid use.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our results can provide effect size estimates to guide the design of future randomized trials.

INTRODUCTION

Pectus excavatum (PE) is the most common anterior chest wall deformity, with an incidence of one in every 1000 individuals per year.[1] Severe sternal depression may cause compression of intrathoracic structures, affect cardiopulmonary function, and is an indication for surgical repair.[2] Early repair in childhood has positive physiological and psychological impacts and is associated with better outcomes than repair in adulthood.[3]

The Nuss procedure is a minimally invasive procedure now considered to be the standard of care for pediatric PE repair;[4] it consists of placing and rotating curved metal bars behind the sternum to advance the chest wall into correct position.[5] Despite its safety and efficacy, the surgery is associated with severe postoperative pain; current techniques for pain control include multimodal intravenous analgesia, neuraxial and regional anesthesia (including paravertebral and intercostal nerve blocks), and cryoablation.[6]

The erector spinae plane (ESP) block is a relatively novel technique developed for the management of thoracic neuropathic pain and consists of injecting local anesthetic deep to the erector spinae muscle to achieve a multi-dermatomal sensory block.[7] While initially thought to block the ventral and dorsal rami of thoracic and abdominal spinal nerves, recent studies have questioned the extent of anterior coverage conferred by the ESP block; diffusion into the paravertebral space (with subsequent anterior spread) remains controversial and the evidence is mixed.[8 9] Nevertheless, recent studies have reported a reduction in opioid use with bilateral ESP blocks for Nuss procedure compared with opioid-based patient-controlled analgesia (PCA) or neuraxial anesthesia, as well as a decrease in length of stay (LOS).[10–12]

Surgical intercostal nerve cryoablation is another technique increasingly employed for analgesia after Nuss procedure. Temperatures between −60 and −70°C are applied to intercostal nerve bundles and cause Wallerian degeneration of nerve axons to induce a period of paresthesia.[13 14] In both retrospective and randomized controlled trials, cryoablation has been associated with decreased hospital LOS as well as with a reduction in both direct variable and indirect fixed costs.[13 15] Additionally, cryoablation is associated with decreased perioperative opioid and non-opioid analgesic requirements.[15] While the onset time of analgesia from intercostal nerve cyroablation is not fully known, studies suggest that patients likely begin to experience the effects in the first 24 hours.[15–19] Opioids, thoracic epidural catheters, and intercostal nerve blocks have been used to provide analgesic coverage until cryoablation takes full effect.

There has been no study to date analyzing the efficacy of combining surgical nerve cryoablation with single-shot ESP blocks as a technique to further reduce perioperative opioid consumption and hospital LOS. Our primary aim was to compare total hospital opioid use and hospital LOS between patients who received an ESP block and cryoablation and those who received cryoablation alone. Secondary aims included comparing pain scores as well as surgical and total operating room times between these two groups. We hypothesized that single-shot ESP blocks could be used as an analgesic bridge in the immediate postoperative period while surgical intercostal nerve cryoablation took effect, resulting in overall decreased opioid use and facilitating earlier hospital discharge.

METHODS

This observational retrospective study was conducted at The Johns Hopkins Children's Center. The Johns Hopkins Medicine Institutional Review Board (#00345348) approved this study in adherence to the Declaration of Helsinki. The requirement for written informed consent was waived by the IRB.

This study included patients with PE undergoing the Nuss procedure with video-assisted surgical cryoablation of the third through seventh intercostal nerves at −70°C for 2 min at each level, bilaterally. Twenty (20) patients undergoing Nuss procedure who received bilateral preincision ultrasound-guided single-shot ESP blocks under general anesthesia between April and September 2022 were retrospectively compared with a control cohort of 20 patients who received cryoablation alone between May 2021 and February 2022. The control cohort comprised the 20 patients who underwent the Nuss procedure immediately prior to the introduction of ESP blocks as part of the perioperative pathway at this institution. The ESP blocks were placed with ultrasound guidance using a paramedian sagittal approach at the T6 level and contained 20 mL of ropivacaine 0.35% with 0.5 mcg/kg clonidine on each side which is the standard local anesthetic mixture for regional nerve blocks at this institution. Postoperatively, patients in both groups followed a pre-existing enhanced recovery after surgery pathway which included patient-controlled bolus-only intravenous opioid analgesia, low-dose adjunctive ketamine infusion (0.1 mg/kg/hour), gabapentin, scheduled acetaminophen and ketorolac, and diazepam as needed. Once patients were tolerating a diet without nausea or vomiting, they were converted to oral oxycodone or hydromorphone.

Perioperative and demographic data were extracted from the electronic medical record. Perioperative information included intraoperative, postanesthesia care unit (PACU), and inpatient unit opioid use; nurse-elicited interval numeric pain scores obtained in the PACU and on the inpatient unit; hospital LOS; total surgical time; and total operating room time. Intravenous and oral opioids were converted to intravenous morphine milligram equivalents (MME) using standard conversion factors.[20 21] Opioid use was calculated for 24-hour intervals; postoperative day (POD) 0 comprised the periods in both the PACU and on the inpatient floor. Pain scores were evaluated using pain intensity rating tools consistent with patient's age, condition, and ability to understand. For this particular cohort of patients, pain was assessed every 4 hours by bedside nursing via the Numerical Pain Rating Scale, where 0 indicates no pain and 10 indicates the worst possible pain. In addition to standard postoperative nursing assessments, pain scores and characteristics, including incisional and neuropathic pain as well as chest pressure/tightness, were evaluated daily by the pediatric acute pain team. As pain is a very subjective and personal experience, we define pain intensity rating as mild (1–3), moderate (4–6), and severe (7–10). Postoperative pain scores were calculated using median pain scores for each patient in the PACU and on PODs 0 through day of discharge. Total surgical time was defined as the number of minutes between incision and endotracheal extubation, and total operating room time was defined as the number of minutes between entering the operating room and endotracheal extubation. For patients who received an ESP block, time needed for ESP block placement, medications used for the block, and adverse events related to block placement were recorded. Demographic data obtained from the perioperative record included age, weight, sex, race/ethnicity, and American Society of Anesthesiologists physical status (ASA-PS).

Discharge readiness, determined by the surgical team, included ambulating unassisted, tolerating a regular diet without antiemetics, and adequate pain control with a numeric pain score less than 4/10.

Statistical analysis

Demographic and clinical characteristics of patients were assessed for normality using Shapiro-Wilk tests. We compared demographic and clinical characteristics of patients who received the ESP block to those who did not using Student's t-tests for normally distributed continuous variables, Wilcoxon rank-sum tests for non-normally distributed continuous variables, and Fisher's exact tests for categorical variables.

As LOS was assessed with days using discrete categories, an ordinal logistic regression model was used to compare hospital LOS between the two groups, with and without adjusting for age, sex, ASA-PS status, weight, and race/ethnicity. A likelihood-ratio test was used to assess the proportional hazards assumptions of the ordinal logistic model. Opioid use (MME/kg) was converted to a log scale and assessed for normality using Shapiro-Wilk tests prior to being used as an outcome in a linear regression model. A mixed effects linear regression with an independent covariance structure was used to compare opioid use (logged, MME/kg) by intervention group, fitting a random intercept for each patient and a random slope by POD, with and without adjusting for POD, age, sex, ASA-PS status, weight, and race/ethnicity. This structure of the mixed effects model was determined using clinical insight and statistical diagnostics from the likelihood-ratio test.

Total opioid consumption was analyzed using statistical process control charts for special cause variation, where the total opioid consumption of 20 patients in the ESP group was analyzed against the expected natural variation of opioid consumption, determined with the mean and SD of opioid consumption

Table 1 Sociodemographic characteristics

	Cryo	ESP+Cryo	P value*†
Sample size	20	20	
Mean age (SD) in years	15.4 (1.7)	15.3 (1.3)	0.76
Sex, n (%)			1
Male	18 (90)	17 (85)	
Female	2 (10)	3 (15)	
Mean weight (SD) in kg	56.5 (7.4)	57.3 (7.7)	0.72
Race/Ethnicity, n (%)			1
Asian	2 (10)	2 (10)	
Black	1 (5)	0	
Hispanic/Latino	1 (5)	1 (5)	
White	16 (80)	16 (80)	
Other	0	1 (5)	
ASA-PS, n (%)			0.1
1	10 (50)	4 (20)	
2	10 (50)	15 (75)	
3	0	1 (5)	

*P value compares cryoablation alone vs cryoablation and ESP block.
†t-Test used to compare means and Fisher's exact test used to compare proportions.
ASA-PS, American Society of Anesthesiologists physical status; Cryo, cryotherapy; ESP, erector spinae plane.

among controls. Among patients who received the ESP block, special cause variation was defined as having either four out of five successive points more than 1 SD from the mean on the same side of the center line or having 8 successive points on the same side of the center line. All analyses were performed using Stata V.17.0 (Stata, College Station, Texas, USA).

RESULTS

Table 1 reveals patient characteristics. There was no significant difference in opioid consumption for either the intraoperative or PACU phases of care between the two groups (table 2, figure 1), but median opioid use on the inpatient floor was significantly lower for the ESP group on POD1 and POD2 than for the control group (POD1 0.17 (IQR 0.03–0.27) mg/kg vs 0.45 (IQR 0.16–0.68) mg/kg, p=0.01; POD2 0.03 (IQR 0.00–0.05) mg/kg vs 0.09 (IQR 0.05–0.24) mg/kg, p<0.01). Median opioid use for the entire hospitalization was significantly less for the ESP group than for the control group (0.60 (IQR 0.35–0.88) mg/kg vs 1.15 (IQR 0.74–1.68) mg/kg, p<0.01, figure 2). Multiple mixed effects linear regression models were developed to compare opioid use across hospital stay among ESP and control groups (table 3). Compared with control patients, patients who received an ESP block had an expected opioid use that was 0.52 units lower with each logged-unit increase in opioid use per MME/kg when adjusting for POD and patient demographics and allowing for patient-specific intercepts and POD-specific intercepts (Opioid model 4: Coefficient −0.52 (95% CI −0.83 to −0.22), p<0.01).

Numeric pain rating scores by POD are detailed in table 2. There was no difference in pain scores in the PACU or on the inpatient floor. Mean hospital LOS was 2.45 (SD 0.69) days for the control group and 1.95 (SD 0.69) days for the ESP group (p=0.03). Twenty-five per cent of patients in the ESP group were discharged on POD1 (figure 3), compared with 100% of patients in the control group who were discharged on POD2 or later (p=0.047). Ordinal logistic regression results, assuming proportional odds, showed that patients who received an ESP block had 75% increased odds of being discharged for each additional day stayed, compared with patients who did not receive a block (OR 0.25 (95% CI 0.06 to 0.96), p=0.04) (table 3). When adjusted for age, sex, ASA-PS status, race/ethnicity, and weight, patients who received an ESP block had 85% increased odds of being discharged for each additional day stayed (OR 0.15 (95% CI 0.03 to 0.75), p=0.02).

Mean time for ESP block placement was 12.5±3.2 min. Mean surgical time was 145 (SD 27.10) min for the control group and 136 (SD 28.48) min for the ESP group (p=0.16), and mean operating room time was 188 (SD 30.33) min for the control group and 191 (SD 31.10) min for the ESP group (p=0.71). There were no documented adverse events related to ESP block placement.

Table 2 Perioperative opioid use, pain scores, and length of stay after Nuss procedure

	Cryo	ESP+Cryo	P value*†
Sample size, n	20	20	
Median opioid use (IQR) by phase of care, MME/kg			
Intraoperative	0.21 (0.12, 0.34) (n=20)	0.14 (0.10, 0.23) (n=20)	0.08
Postoperative			
Day 0	0.30 (0.12, 0.45) (n=20)	0.19 (0.10, 0.40) (n=20)	0.42
PACU	0.09 (0.03, 0.17) (n=20)	0.06 (0.05, 0.10) (n=20)	0.68
Floor	0.15 (0.08, 0.31) (n=20)	0.14 (0.04, 0.21) (n=20)	0.36
Day 1	0.45 (0.16, 0.68) (n=20)	0.17 (0.03,0.27) (n=20)	0.01
Day 2	0.09 (0.05, 0.24) (n=20)	0.03 (0.00, 0.05) (n=15)	<0.01
Day 3	0.09 (0.05, 0.21) (n=7)	0.04 (0.01, 0.09) (n=4)	0.3
Day 4	0.10 (0.08, 0.12) (n=2)	--	
Total hospitalization	1.15 (0.74, 1.68) (n=20)	0.60 (0.35, 0.88) (n=20)	<0.01
Mean pain score (SD)			
PACU	5.39 (1.96) (n=20)	4.17 (2.17) (n=20)	0.08
Inpatient floor	4.16 (1.56) (n=20)	3.77 (1.75) (n=20)	0.48
POD0	4.45 (1.58) (n=20)	3.67 (2.15) (n=20)	0.21
POD1	3.95 (1.66) (n=20)	3.85 (1.82) (n=20)	0.86
POD2	4.00 (1.69) (n=20)	3.61 (2.15) (n=15)	0.56
POD3	4.57 (1.69) (n=7)	2.63 (2.66) (n=4)	0.17
POD4	4.50 (0.71) (n=2)	--	
Mean length of stay (SD) in days	2.45 (0.69)	1.95 (0.69)	0.03
Mean time for block placement (SD), in min	--	12.5 (3.20)	
Mean surgical time (SD), in min	145 (27.10)	136 (28.48)	0.16
Mean operating room time (SD), in min	188 (30.33)	191 (31.10)	0.71

*P value compares cryoablation alone vs cryoablation and ESP block.
†t-Test used to compare means and Wilcoxon rank-sum test used to compare medians.
Cryo, cryotherapy; ESP, erector spinae plane; MME, morphine milligram equivalents; PACU, post anesthesia care unit.

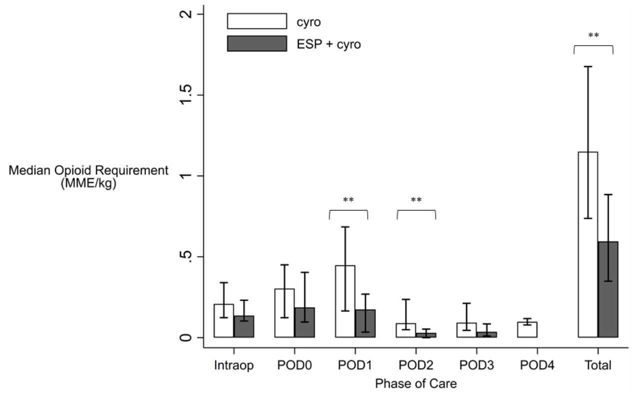

Figure 1 Median opioid requirements for intraoperative and postoperative phases of care with error bars showing IQRs. Cryo, cryotherapy; ESP, erector spinae plane; MME, morphine milligram equivalents; POD, postoperative day.

Table 3 Regression modeling of length of stay and opioid use by intervention group

Model	OR/Coefficient*†	P value	95% CI
LOS model 1	−0.25	0.04	0.06 to 0.97
LOS model 2	−0.15	0.02	0.03 to 0.75
Opioid model 1	−0.5	<0.01	−0.85 to −0.16
Opioid model 2	−0.68	<0.001	−1.04 to −0.32
Opioid model 3	−0.62	<0.001	−0.94 to −0.31
Opioid model 4	−0.52	<0.01	−0.83 to −0.22

LOS model 1: ordinal logistic regression of LOS (days) by intervention group.
LOS model 2: ordinal logistic regression of LOS (days) by intervention group, adjusting for age, sex, ASA-PS status, weight, and race/ethnicity.
Opioid model 1: mixed effects linear regression of opioid use (logged, MME/kg) by intervention group, fitting random intercepts for each individual.
Opioid model 2: mixed effects linear regression of opioid use (logged, MME/kg) by intervention group, fitting random intercepts for each patient, and adjusting for postoperative day.
Opioid model 3: mixed effects linear regression of opioid use (logged, MME/kg) by intervention group, fitting a random intercept for each patient and a random slope by postoperative day, and adjusting for postoperative day.
Opioid model 4: mixed effects linear regression of opioid use (logged, MME/kg) by intervention group, fitting random intercepts for each patient and a random slope by postoperative day, and adjusting for postoperative day, age, sex, ASA-PS status, weight, and race/ethnicity.
*OR compares LOS among cryoablation alone vs cryoablation with ESP block
†Regression coefficient compares opioid consumption among cryoablation alone vs cryoablation with ESP block.
LOS, length of stay.

DISCUSSION

This study adds to a growing body of literature demonstrating decreased opioid use and length of hospital stay when bilateral ESP blocks are placed as part of a perioperative analgesic regimen for Nuss procedures.[10–12 22 23] Importantly, total hospital opioid use was significantly lower for the ESP cohort than for the control group. Additionally, mean pain scores were not statistically different between the two groups despite reduction in overall opioid consumption in the ESP cohort, underscoring that ESP blocks effectively make up for the analgesic coverage previously conferred by opioids. However, the fact that patients in the ESP group had a shorter LOS despite similar pain scores suggests that higher opioid use (without ESP block) may incur associated side effects which may delay discharge.

In both retrospective studies and a randomized clinical trial, surgical intercostal nerve cryoablation has been shown to decrease hospital LOS and opioid requirements when compared with paravertebral blocks, thoracic epidural analgesia and opioid PCA.[13–15] However, no study to date has directly compared cryoablation alone to cryoablation preceded by a regional anesthetic technique. But, when cryoablation has been bundled with surgical intercostal nerve blocks, median LOS in those studies was reported between 1 and 1.1 days and median inpatient opioid utilization was 0.4 mg/kg.[14 15 19] Our study, which directly compares cryoablation alone to cryoablation with ESP blocks, is proof-of-concept that ESP blocks can be used to provide a bridging source of non-opioid analgesia while waiting for surgical intercostal nerve cryoablation to take full effect.

In our study, the mean LOS in the ESP cohort was 1.95 days, and 25% of patients were discharged on POD 1. Previous studies comparing PE patients receiving ESP blocks for Nuss procedure to those receiving thoracic epidurals or PCA opioid analgesia have demonstrated LOS for ESP cohorts ranging from 2 to 3.3 days (Abbasian *et al* 2.3 days; Walter *et al* 2 days; Santana *et*

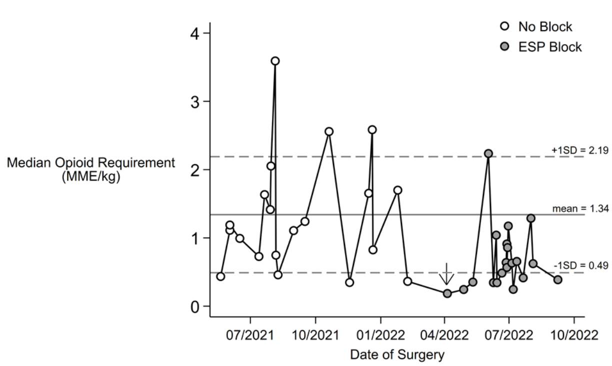

Figure 2 Statistical process control chart showing total opioid consumption following Nuss procedure. Total median opioid consumption (mg/kg) is depicted along the y-axis; individual patients along x-axis; solid line is mean opioid consumption and dashed lines represent upper/lower control limits (±1 SD above and below mean) from before implementation of single-shot ESP protocol. Implementation of ESP protocol is indicated by solid arrow. Special cause variation was determined if four out of five successive points were more than 1 SD from the mean on the same side of the center line or if eight successive points were on the same side of the center line. ESP, erector spinae plane; MME, morphine milligram equivalents.

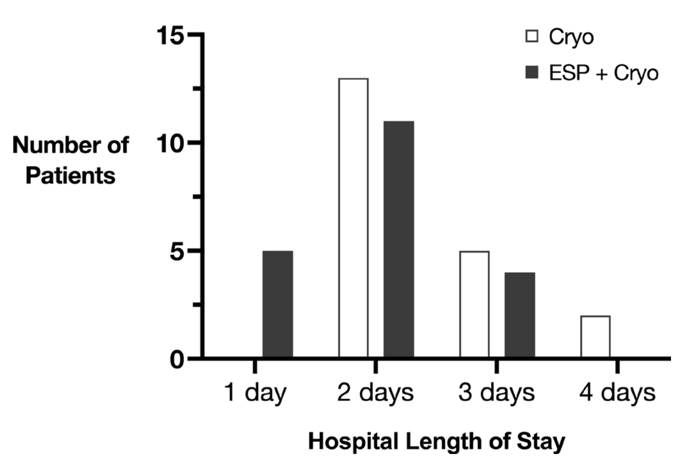

Figure 3 Hospital length of stay for patients receiving ESP block and cryotherapy compared with those receiving cryotherapy alone. Cryo, cryotherapy; ESP, erector spinae plane.

al 3.3 days; Bliss *et al* 2.90).[10–12 23] We posit that the combination of ESP blocks with surgical intercostal nerve cryoablation may be responsible for this additional decrease in LOS.

Unexpectedly, during the first 24 hours postoperatively when the ESP block would presumably have greatest effect, we observed no significant difference in opioid consumption between the two groups. However, on PODs 1 and 2, we did observe a 60% reduction in opioid use. This might suggest that the block has a priming effect on opioid mitigation which is clinically apparent throughout the entire hospitalization but achieves statistical significance after the first POD. Additionally, it is possible that the block is insufficient to relieve all of the pain in the immediate 24-hour period postoperatively during which pain may be most severe. Alternatively, because our institutional perioperative multimodal analgesia regimen is designed to be opioid sparing, there may be a lower initial burden of postoperative pain that a regional technique can be used to cover.

Ultimately, there are multiple ways to provide bridging analgesia until cryoablation takes effect, including intravenous opioids, paravertebral blocks, and neuraxial techniques. The ESP block is a technically simpler and lower risk block to perform compared with paravertebral and neuraxial blocks and thus may be more accessible to a wider range of anesthesia providers. Opioids are associated with multiple systemic side effects which a targeted block such as the ESP circumvents.

Our study has several strengths. It represents a large, pediatric tertiary care surgical center, and provides external generalizability to the pediatric anesthesia community. Additionally, the ESP and control cohorts are demographically similar in terms of age, sex, ASA-PS status, and race/ethnicity. Finally, our subset analysis comparing both surgical time and operating room time between the two groups revealed no statistically significant difference, underscoring the minimal impact bilateral ESP block placement has on operating room throughput and efficiency.

While this is the first report of its kind, we acknowledge several limitations. This was a retrospective study and therefore limited by data available in the chart and not subject to randomization. While our sample size is modest at 40 patients, it nevertheless offers a first look at some of the important trends that exist in this population. Future trials would benefit from prospective randomization and larger sample sizes to evaluate the effect of combining ESP blocks with cryoablation on secondary outcomes such as the incidence of postoperative nausea, vomiting and constipation as well as time to ambulation and resumption of functional status. Second, the perioperative opioid regimen, particularly during the intraoperative period, was non-standard in both the ESP and control groups, with providers using a range of opioids for surgical analgesia. While we attempted to mitigate this limitation by converting all opioids to MMEs, these conversions are imperfect given the complex pharmacodynamics of opioids, and future studies would benefit from a standardized intraoperative opioid regimen. Third, our study does not account for the block-prolonging effects of intravenous dexamethasone as well as the systemic effects of perineural clonidine, two medications which could have impacted the analgesia in the ESP group.[24] Finally, we were unable to perform long-term follow-up of either the control or ESP cohorts to determine if patients developed any long-term complications such as neuropathic pain-related symptoms. Future studies would benefit from close follow-up to determine if multiple insults to the same nerve in the form of ESP block with subsequent cryoablation increases the risk for postoperative neuralgias.

CONCLUSION

In summary, this pilot study suggests that combining bilateral single-shot preincision ESP blocks with intraoperative intercostal nerve cryoablation in patients undergoing the Nuss procedure is associated with decreased total hospital opioid use and may facilitate earlier hospital discharge. These findings can help guide the design of future randomized control trials investigating novel analgesic strategies, when coupled with continued refinement of perioperative pathways, that can be used to optimize the care of children with PE.

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Patient consent for publication Not applicable.

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REFERENCES

1 Frawley G, Frawley J, Crameri J. A review of anesthetic techniques and outcomes following minimally invasive repair of pectus excavatum (Nuss procedure). *Paediatr Anaesth* 2016;26:1082–90.
2 Lawson ML, Mellins RB, Paulson JF, *et al*. Increasing severity of pectus excavatum is associated with reduced pulmonary function. *J Pediatr* 2011;159:256–61.
3 Mack SJ, Till BM, Huang C, *et al*. National trends in pectus excavatum repair: patient age, facility volume, and outcomes. *J Thorac Dis* 2022;14:952–61.
4 Kelly RE, Goretsky MJ, Obermeyer R, *et al*. Twenty-one years of experience with minimally invasive repair of pectus excavatum by the Nuss procedure in 1215 patients. *Ann Surg* 2010;252:1072–81.
5 Nuss D, Kelly RE, Croitoru DP, *et al*. A 10-year review of a minimally invasive technique for the correction of pectus excavatum. *J Pediatr Surg* 1998;33:545–52.
6 Futagawa K, Suwa I, Okuda T, *et al*. Anesthetic management for the minimally invasive Nuss procedure in 21 patients with pectus excavatum. *J Anesth* 2006;20:48–50.
7 Forero M, Adhikary SD, Lopez H, *et al*. The Erector Spinae plane block: a novel analgesic technique in Thoracic neuropathic pain. *Reg Anesth Pain Med* 2016;41:621–7.
8 Lonnqvist PA, Karmakar MK, Richardson J, *et al*. Daring discourse: should the ESP block be renamed RIP II block *Reg Anesth Pain Med* 2021;46:57–60.
9 Zhang J, He Y, Wang S, *et al*. The Erector Spinae plane block causes only cutaneous sensory loss on ipsilateral posterior Thorax: a prospective observational volunteer study. *BMC Anesthesiol* 2020;20.
10 Santana L, Driggers J, Carvalho NF. Pain management for the Nuss procedure: comparison between erector spinae plane block, Thoracic epidural, and control. *World J Pediatr Surg* 2022;5:e000418.
11 Abbasian N, Clay SJ, Batra M, *et al*. Multimodal continuous ambulatory erector spinae catheter pain protocol for early recovery following Nuss procedure: a retrospective cohort study. *Reg Anesth Pain Med* 2022;47:421–3.
12 Bliss DP, Strandness TB, Derderian SC, *et al*. Ultrasound-guided erector spinae plane block versus thoracic epidural analgesia: postoperative pain management after Nuss repair for pectus excavatum. *J Pediatr Surg* 2022;57:207–12.

13 Graves CE, Moyer J, Zobel MJ, *et al*. Intraoperative Intercostal nerve Cryoablation during the Nuss procedure reduces length of stay and opioid requirement: A randomized clinical trial. *J Pediatr Surg* 2019;54:2250–6.
14 Zeineddin S, Goldstein SD, Linton S, *et al*. Effectiveness of one minute per level Intercostal nerve Cryoablation for postoperative analgesia after surgical correction of Pectus Excavatum. *J Pediatr Surg* 2023;58:34–40.
15 Aiken TJ, Stahl CC, Lemaster D, *et al*. Intercostal nerve cryoablation is associated with lower hospital cost during minimally invasive Nuss procedure for pectus excavatum. *J Pediatr Surg* 2021;56:1841–5.
16 Mustola ST, Lempinen J, Saimanen E, *et al*. Efficacy of thoracic epidural analgesia with or without intercostal nerve cryoanalgesia for postthoracotomy pain. *Ann Thorac Surg* 2011;91:869–73.
17 Whittaker DK. Degeneration and regeneration of nerves following cryosurgery. *Br J Exp Pathol* 1974;55:595–600.
18 Harbaugh CM, Johnson KN, Kein CE, *et al*. Comparing outcomes with Thoracic epidural and Intercostal nerve cryoablation after Nuss procedure. *J Surg Res* 2018;231:217–23.
19 DiFiore JW, Robertson JO, Chhabada S, *et al*. Next day discharge after the Nuss procedure using Intercostal nerve cryoablation, Intercostal nerve blocks, and a perioperative ERAS pain protocol. *J Pediatr Surg* 2022;57:213–8.
20 Pereira J, Lawlor P, Vigano A, *et al*. Equianalgesic dose ratios for opioids. a critical review and proposals for long-term dosing. *J Pain Symptom Manage* 2001;22:672–87.
21 Anderson R, Saiers JH, Abram S, *et al*. Accuracy in equianalgesic dosing. conversion dilemmas. *J Pain Symptom Manage* 2001;21:397–406.
22 Fiorelli S, Menna C, Andreetti C, *et al*. Bilateral ultrasound-guided erector Spinae plane block for pectus excavatum surgery: a retrospective propensity-score study. *J Cardiothorac Vasc Anesth* 2022;36:4327–32.
23 Walter CM, Lee CS, Moore DL, *et al*. Retrospective study comparing outcomes of multimodal epidural and erector spinae catheter pain protocols after pectus surgery. *J Pediatr Surg* 2023;58:397–404.
24 Sehmbi H, Brull R, Ceballos KR, *et al*. Perineural and intravenous dexamethasone and dexmedetomidine: network meta-analysis of adjunctive effects on supraclavicular brachial plexus block. *Anaesthesia* 2021;76:974–90.