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Intercostal nerve cryoablation as part of an opioid-sparing protocol reduces opioid and epidural use after lung transplant

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BACKGROUND: Inadequate pain control after lung transplantation increases perioperative complications. Standard opioid-based regimens are associated with adverse effects and epidural catheters that reduce opioid use are limited by contraindications and technical challenges. We report the use of intercostal nerve cryoablation to enhance perioperative pain control as part of an opioid-sparing protocol for lung transplant recipients (LTR).

METHODS: We conducted a retrospective cohort study of LTRs from January 1, 2016 to December 31, 2021, before (precryo) and after (postcryo) initiation of an opioid-sparing protocol utilizing intraoperative intercostal nerve cryoablation. The precryo cohort included consecutive patients treated with opioids and selective use of epidural catheters. The postcryo cohort received intercostal nerve cryoablation at levels 3 to 7, scheduled acetaminophen, gabapentin, and tramadol. Additional opioids or epidural catheters were used for breakthrough pain.

RESULTS: In total, 49 precryo and 40 postcryo patients were analyzed. Baseline demographics were similar aside from a shift to performing more bilateral lung transplants in the postcryo cohort (57% vs 95%, $p < 0.0001$). Total opioid usage during the index hospitalization decreased by 24% (1110 vs 841 morphine milligram equivalents [MME], $p = 0.027$), and 28% in the bilateral LTR subgroup analysis (1168 vs 846 MME, $p = 0.007$). Epidural use declined from 61% to 3% ($p < 0.0001$). Median opioids prescribed at discharge decreased by 66% (450 vs 154 MME, $p < 0.0001$).

CONCLUSIONS: The implementation of a perioperative pain management protocol that included intercostal nerve cryoablation was associated with a significant reduction in epidural utilization and opioid use during index hospitalization and upon discharge. Further research is needed to understand the impact on outcomes.

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Background

Pain is a major source of morbidity following lung transplantation and adequate pain control is an important aspect of patient-centered care and promotion of postoperative recovery.[1,2] Optimizing the pain management strategy in the lung transplant population is challenging and has been the subject of increased focus among those who care for these complex patients.[3-7]

Opioid-based approaches to the management of surgical pain are plagued not just by issues with patients developing dependency and chronic pain issues, but also by surgeons lacking appropriate training in judicious and proper prescribing of opioids in the perioperative setting.[8-12] Up to one-third of lung transplant recipients use opioids in a chronic setting, and opioid dependency has been associated with reduced lung function, poor quality of life, and increased mortality.[1,3,8] Thoracic epidurals and paravertebral blocks are utilized in many thoracic procedures but are less useful in the lung transplant setting due to issues with hemodynamic compromise, infection, coagulopathy, and analgesic durability.[5] Liposomal bupivacaine injection offers an attractive alternative but is limited by duration of action.[4,13]

The advent of intercostal nerve cryoablation as a non-pharmacologic approach to reducing pain after open thoracic procedures sparked interest that has increased dramatically following US Food and Drug Administration approval in 2014 of the cryoICE Cryoablation Probe (Atricure Inc, Mason, OH). Though data in the thoracic literature are limited, the weaknesses of current pain regimens have prompted recent integration of the technique into many high-volume lung transplant centers' approach to pain control after thoracotomy with mixed results individually, but promising results cumulatively.[3,5-7,14-17] Herein we describe our experience with intercostal nerve cryoablation as part of an opioid-sparing protocol for lung transplant patients.

Methods

Experimental design

Following local institutional review board approval, a retrospective analysis was performed of adult patients undergoing primary lung transplantation at a single institution between January 1, 2016 and December 31, 2021. The precryo (before initiation of an opioid-sparing protocol utilizing intraoperative intercostal nerve cryoablation) cohort was transplanted before December 31, 2018; the postcryo (after initiation of an opioid-sparing protocol utilizing intraoperative intercostal nerve cryoablation) cohort was transplanted after January 1, 2019. Of note, the decision to utilize intercostal nerve cryoablation as part of an opioid-sparing protocol was deferred to the primary attending surgeon, and only select surgeons performing lung transplant surgeries at our institution were utilizing intercostal nerve cryoablation during the study window. Surgeons were also screened for absolute and relative contraindications to intercostal nerve cryoablation. Patients were excluded if they remained intubated for more than 48 hours after transplant, were re-intubated post-transplant, had less than 8 weeks of post-transplant follow-up, or did not receive intercostal nerve cryoablation, and were transplanted after January 1, 2019. Patients were typically requested to wean off opioids before transplant, though if unable this was not a contraindication for listing. All data were manually extracted by individual chart review from the electronic health record. Morphine milligram equivalents (MME) were calculated and analyzed at 1, 2, 3, and 4 weeks after transplantation during the index hospitalization. Sources of opioids captured during hospital stay included opioids administered by parenteral, enteral, and epidural routes. MME were calculated using standard conversion factors cited in the literature[18,19]; in the case of epidural opioid administration, this conversion factor accounted for the estimated systemic absorption.[20] Conversion factors utilized can be found in the Appendix. MME were also collected and analyzed at the time of discharge from index hospitalization and within 8 weeks after transplant. Outpatient use was approximated based on prescriptions and included all opioids prescribed at discharge and any additional outpatient prescriptions written by provider(s) practicing at our center within 8 weeks of transplant. This study was conducted in accordance with the local Institutional Review Board and compliance with the ISHLT Ethics Statement.

Operative procedure and post-transplant management

All lung transplants were performed via bilateral thoracosternotomy (for bilateral lung transplants) or anterolateral thoracotomy (for single lung transplants). Intraoperative hemodynamic and respiratory support was provided with centrally-cannulated venoarterial extracorporeal membrane oxygenation or cardiopulmonary bypass. For patients in whom intercostal nerve cryoablation was performed, this typically occurred immediately following recipient pneumonectomy and was performed by a member of the surgical team during simultaneous backbench preparation of the donor lung allograft before implantation. In rare circumstances, intercostal nerve cryoablation was performed following reperfusion of the lungs during a period of hemostasis before initiation of chest closure. Cryoablation was performed at −60°C to −80°C for 120 seconds per nerve level using the AtriCure cryoICE cryoablation system (AtriCure, Inc, Mason, OH). Under direct visualization, the surgeon identified the intercostal nerves and ablated at levels T3 through T7 several centimeters lateral to the sympathetic chain. These spaces were selected to cover the thoracosternotomy space (typically at the fourth interspace), with a space above, and several spaces inferior to include the tunneled chest tube entry sites.

All patients received standard induction immunosuppression with basiliximab and standard post-transplant immunosuppressive management which included tacrolimus, mycophenolate, and corticosteroids. Mechanical ventilation was discontinued when patients were awake and demonstrated hemodynamic and respiratory stability in minimal ventilator settings. Patients were managed by a multidisciplinary team, including

thoracic surgeons, pulmonologists, cardiothoracic intensivists, transplant pharmacists, nurses, respiratory therapists, physical therapists, and occupational therapists.

Pain management protocol

Postoperatively while intubated, patients were sedated with dexmedetomidine or propofol with the addition of continuous opioid infusions if deemed necessary by the multidisciplinary team managing the patient. While patients were intubated, sedation was titrated to a Richmond Agitation and Sedation Scale score of −1 to +1. After extubation, the precryo cohort was managed with opioids as needed; nonopioid adjuncts were rarely used. Multimodal analgesia (including acetaminophen and gabapentin) could be initiated at the clinician's discretion, though there was no protocol in place for systematic initiation. In the postcryo cohort, cryoablation was complemented by a standardized pain control regimen designed to minimize opioid use. The postcryo protocol included scheduled acetaminophen, gabapentin, and tramadol. The acetaminophen dose was typically initiated at 650 to 1,000 mg 4 times daily to a maximum of 4,000 mg per day. The gabapentin dose was typically initiated at 100 mg 3 times daily and titrated based on tolerance and patient-reported pain; the gabapentin dose was adjusted in the setting of reduced renal function or adverse effects. The tramadol dose was typically initiated at 50 mg up to 4 times daily as needed; the tramadol dose was adjusted in the setting of reduced renal function or adverse effects. Oral oxycodone and intravenous hydromorphone were also available as needed for breakthrough pain, per our institutional pain management algorithm for the selection of as-needed analgesics. Upon administration of as-needed analgesics, bedside nurses assessed the patient's reported pain using the Numeric Rating Scale with a range of 0 (absence of pain) to 10 (worst possible pain). At discharge, the type and quantity of pain medications prescribed were based on pain medication utilization during the index hospitalization. All patients in the postcryo cohort were discharged with acetaminophen (scheduled or as needed) as well as gabapentin, tramadol, and oxycodone as clinically appropriate. In the precryo cohort, some patients were discharged with extended-release oxycodone based on the clinical assessment of the attending transplant pulmonologist.

Statistical analysis

Our primary objective was to evaluate total MME utilization for pain management during the index hospitalization. Secondary objectives included evaluating MME administered during weeks 1, 2, 3, and 4 of index hospitalization; MME administered during the index hospitalization (excluding that administered via epidural catheters); epidural catheter use; MME prescribed at discharge from index hospitalization; additional MME prescribed within 8 weeks of transplant; and total MME administered during the first 8 weeks post-transplant (including index admission, upon discharge and within 8 weeks of transplant). The primary outcome of total MME utilized during index hospitalization was compared between the groups using the Mann-Whitney U test. MME at other time points, age, length of stay, and lung allocation score were also compared using Mann-Whitney U tests. Categorical data, such as gender, type of transplant, and indication for transplant, were compared using chi-square tests. Multivariate regression was used to identify the most relevant variables associated with opioid use during index hospitalization. We included any variable that had a p-value < 0.1 in a bivariate analysis.

Results

During the study period, 186 patients underwent lung transplantation at our center. The precryo cohort underwent lung transplantation before December 31, 2018, and the postcryo cohort patients were transplanted after January 1, 2019. Forty-nine patients met the inclusion criteria in the precryo cohort, and 40 patients met the inclusion criteria in the postcryo cohort. Of note, 26 patients were excluded from the precryo cohort and 71 patients were excluded from the postcryo cohort. Patient demographics are detailed in Table 1. Overall, the populations were predominantly male (precryo, 67.35%; postcryo, 72.50%; $p = 0.62$) and of similar age (precryo, median 62 years; postcryo, median 60 years; $p = 0.287$) with comparable lung allocation scores at time of transplant (precryo, median 37.67; postcryo, median 36.60; $p = 0.598$). Bilateral lung transplant procedures were significantly more common in the postcryo cohort (precryo, 57.14%; postcryo, 95%; $p < 0.0001$). There was a significant difference in the indication for lung transplant between the cohorts ($p = 0.029$), with fewer cystic fibrosis patients undergoing lung transplant in the postcryo cohort (precryo, 22.45%; postcryo, 2.50%).

Pain management and opioid administration during the index hospitalization are detailed in Table 2. Patients in the postcryo cohort received significantly fewer opioids during the index hospitalization (precryo, median 1110 MME; postcryo, median 841.0 MME; $p = 0.027$, Figure 1). The postcryo cohort received significantly fewer opioids during post-transplant week 2 (precryo, median 195 MME; postcryo, median 139 MME; $p = 0.042$) and was decreased at all time-points, but did not reach statistical significance at weeks 1, 3, and 4 (Figure 2); to note, epidural analgesia is not included in these calculations. Patients in the postcryo cohort also had significantly fewer epidurals placed during the index hospitalization (precryo, 61.2%; postcryo, 2.5%; $p < 0.0001$).

As shown in Table 3, because there was a marked shift in the percentage of bilateral lung transplants vs single lung transplants in the postcryo period, we further examined opioid use when stratified by transplant type. The above-mentioned trends were maintained when patients who underwent bilateral lung transplant in the precryo and postcryo cohorts were compared. Patients in the postcryo cohort had significantly reduced opioid usage for the index hospitalization (precryo, median 1168 MME; postcryo, median 846 MME; $p = 0.007$). The postcryo cohort also had significantly reduced opioid usage during post-transplant week 2 (precryo, median 243 MME; postcryo, median 147 MME; $p = 0.024$), with similar though nonsignificant decreases observed at weeks 1, 3, and 4.

Table 1 Baseline Demographics

Demographics	Precryoablation $n = 49$	Postcryoablation $n = 40$	p
Age at transplant, years – median (IQR)	62 (48-65)	60 (56-65)	0.287
Gender – n (%)			
Female	16 (32.7%)	11 (27.5%)	0.62
Male	33 (67.3%)	29 (72.5%)	
Indication for transplant – n (%)			0.029
IIP	17 (34.7%)	19 (47.5%)	
COPD	10 (20.4%)	6 (15%)	
CF	11 (22.5%)	1 (2.5%)	
Other	11 (22.4%)	14 (35%)	
Procedure type – n (%)			< 0.0001
Single	21 (42.9%)	2 (5%)	
Bilateral	28 (57.1%)	38 (95%)	
LAS at transplant – median (IQR)	37.7 (34.6-47.3)	36.6 (33.6-42.2)	0.598
LOS from transplant date, days – median (IQR)	14 (11-17)	15 (12-22)	0.059

Abbreviations: CF, cystic fibrosis; COPD, chronic obstructive pulmonary disease; IIP, idiopathic interstitial pneumonias; IQR, interquartile range; LAS, lung allocation score; LOS, length of stay.

Table 2 Pain Management During Index Hospitalization

Pain management requirement	Precryoablation $n = 49$	Postcryoablation $n = 40$	p
Epidural placed – n (%)	30 (61.2%)	1 (2.5%)	< 0.0001
MME from epidural opioid administration – median (IQR)	82 (0-200)	206	–
MME from nonepidural pain medications – median (IQR)			
Week 1	690 (476-995)	629 (552-762)	0.170
Week 2	195 (120-465)	139 (59-263)	0.042
Week 3	48 (23-218)	62 (26-151)	0.777
Week 4	75 (0-357)	3 (0-30)	0.328
Total MME of hospitalization – median (IQR)	1008 (680-1585)	841 (634-1123)	0.142
Total MME of hospitalization including epidural opioid administration – median (IQR)	1110 (692-1638)	841 (634-1123)	0.027

Abbreviations: IQR, interquartile range; MME, morphine milligram equivalent.

Opioids prescribed at the time of discharge from index hospitalization and within 8 weeks of transplant were also analyzed (Table 4). Patients in the postcryo cohort had significantly fewer opioids prescribed at discharge (precryo, median 450 MME; postcryo, median 154 MME; $p = < 0.0001$) and fewer opioids prescribed within 8 weeks of transplant ($p = 0.206$, Figure 3).

Increasing age at transplant was significantly correlated with decreasing MME among the patients who had cryoablation (correlation coefficient –0.48; $p = 0.002$; Spearman). Length of stay, gender, and lung allocation score were not correlated with MME between cohorts.

Intercostal nerve cryoablation was not associated with adverse effects or complications.

Discussion

Appropriate pain control after lung transplantation is an essential part of recovery, and the mitigation of pain and its associated impact on mobility, deep breathing, and overall activity warrants increased attention from the lung transplant community. In this retrospective single-center cohort investigation, we showed that transitioning to a multimodal opioid-sparing pain control regimen with the addition of intraoperative intercostal nerve cryoablation resulted in decreased opioid usage in both the inpatient and outpatient settings and decreased need for thoracic epidural catheter placement despite a higher rate of bilateral vs single lung transplants.

A growing body of literature demonstrates that shifting to a nonopioid-based pain control regimen after lung transplant provides satisfactory pain control while attenuating the short- and long-term effects of opioid usage.[3-7] While recently published papers have demonstrated similar outcomes using intraoperative intercostal nerve cryoablation during lung transplant surgeries, this study presents a more comprehensive assessment of perioperative opioid use in both cohorts, including opioids administered by parenteral, enteral, and epidural routes during index hospitalization and in the outpatient setting for 8 weeks after transplant.[3,5] Potential adverse effects of intercostal nerve cryoablation include pneumothorax, hypo- or hyperalgesia, allodynia, and numbness persisting longer than 3 months. In alignment with other available literature, intercostal nerve

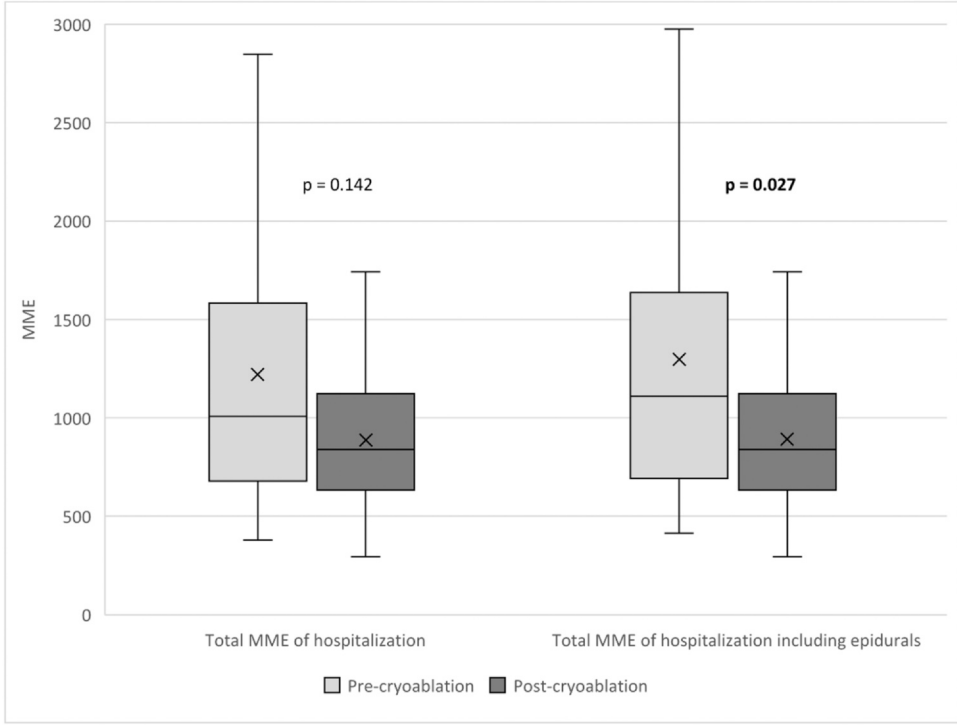

Figure 1 Total MME prescribed during index hospitalization. Horizontal line represents the median and the ends of the box represent the interquartile range. X represents the mean. Whiskers represent the range. Medians compared using Mann-Whitney U test. MME, morphine milligram equivalent.

cryoablation was found to be safe in this patient population and was not associated with adverse effects or complications in this study.

Identified predictors of increased pain levels post-transplant include pretransplant history of depression and anxiety, lower 6-minute walk distance, and bilateral lung transplant.[1] Given this association of bilateral lung transplant procedures with increased pain, we performed a stratified subgroup analysis of bilateral lung transplant recipients precryoablation and postcryoablation which demonstrated an even greater decrease in opioid usage during index hospitalization. Overall, this shift toward a higher frequency of bilateral transplant was multifactorial, including national allocation trends, surgeon and pulmonologist preferences, and changes in the diagnoses and indications for transplant.

Immediately after lung transplant, pain ratings have been shown to peak in the first 24 to 48 hours after transplant and decrease over time during index hospitalization, with a slight increase reported at the time of transition from the use of parenteral opioids and epidurals to oral opioid use.[1,2] It is well-recognized that the first days and weeks after lung transplantation cover several important clinical milestones that portend the long-term outcomes of these patients. To that end, it is important to consider both short- and long-term effects when comparing pain control strategies. Our study was largely consistent with these trends, with opioid usage decreasing over time during the index hospitalization across cohorts. Importantly, we found that intercostal nerve cryoablation along with an opioid-sparing multimodal approach to pain management in the early post-transplant period had an effect not just on inpatient opioid usage but also in the outpatient setting in terms of opioids prescribed within the first 8 weeks after transplant.

The balance between improving bronchopulmonary hygiene in the short term while decreasing the reliance on pharmacologic methods to make bronchopulmonary hygiene comfortable is essential for lung transplant patients. Gerber et al found that intercostal nerve cryoablation was strongly associated with functional improvements in patient recovery and pain control, specifically showing a decreased rate of postoperative pneumonia in patients who underwent intercostal nerve cryoablation during bilateral lung transplant.[7] While inadequate pain control can hinder recovery, overprescribing opioid pain medication can lead to issues with chronic pain or opioid dependence. Chronic pain is a common complication after lung transplant with reported incidences ranging from 10% to 58%,[1,9,10,21] with 9.4% of patients reporting moderate to severe pain.[10] Chronic opioid use is well-known to increase the risk of respiratory and cardiovascular complications in advanced pulmonary disease.[22] Notably, a dose-dependent association between prescription fills of opioids and adjusted mortality risk has been observed in lung transplant recipients.[23]

Given the negative impacts of acute and chronic pain after lung transplant, and the limitations of neuraxial catheters as a means to intensify pain management regimens, alternative strategies are needed within multimodal opioid-sparing analgesic regimens and intercostal nerve cryoablation is not the only technique with increasingly widespread adoption. A recent publication described the use of a multimodal opioid-sparing protocol with the incorporation of

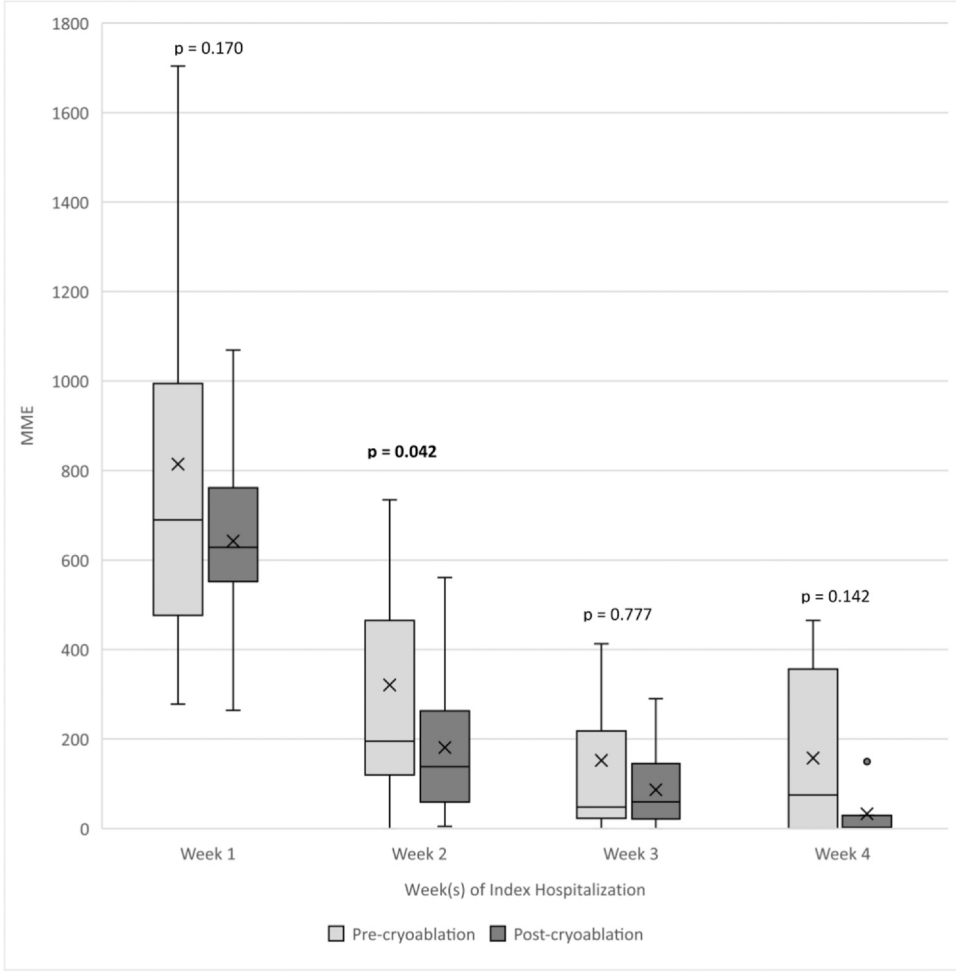

Figure 2 Total MME prescribed during index hospitalization by week. Epidural analgesia is not included in these calculations. Horizontal line represents the median and the ends of the box represent the interquartile range. X represents the mean. Whiskers represent the range. Medians compared using Mann-Whitney U test. MME, morphine milligram equivalent.

Table 3 Pain Management During Index Hospitalization by Procedure Type

Pain management requirement	Precryoablation $n = 49$	Postcryoablation $n = 40$	p
Single lung transplant	$n = 28$	$n = 2$	
MME from nonepidural pain medications – median (IQR)			
Week 1	673 (419-960)	341, 448 (n/a)	0.198
Week 2	165 (68-471)	75, 105 (n/a)	0.400
Week 3	48 (5-109)	n/a	–
Week 4	n/a	n/a	–
Total MME of hospitalization – median (IQR)	786 (531-1,311)	446, 523 (n/a)	0.198
Total MME of hospitalization including epidural opioid administration – median (IQR)	805 (660-1,311)	446, 523 (n/a)	0.095
Bilateral lung transplant	$n = 21$	$n = 38$	
MME from nonepidural pain medications – median (IQR)			
Week 1	702 (569-1,200)	642 (554-763)	0.109
Week 2	243 (139-460)	147 (57-276)	0.024
Week 3	48 (23-250)	62 (26-151)	0.839
Week 4	162 (19-411)	3 (0-30)	0.133
Total MME of hospitalization – median (IQR)	1,049 (716-2,023)	846 (676-1,126)	0.055
Total MME of hospitalization including epidural opioid administration – median (IQR)	1,168 (820-2,112)	846 (676-1,126)	0.007

Abbreviations: IQR, interquartile range; MME, morphine milligram equivalent.

Table 4 Pain Management in the Outpatient Setting After Index Hospitalization

Pain management requirement	Precryoablation $n = 49$	Postcryoablation $n = 40$	p
MME prescribed at discharge – median (IQR)	450 (338-582)	154 (90-300)	< 0.0001
Additional MME prescribed in first 8 weeks post-transplant – median (IQR)	0 (0-619)	0 (0-300)	0.206

Abbreviations: IQR, interquartile range; MME, morphine milligram equivalent.

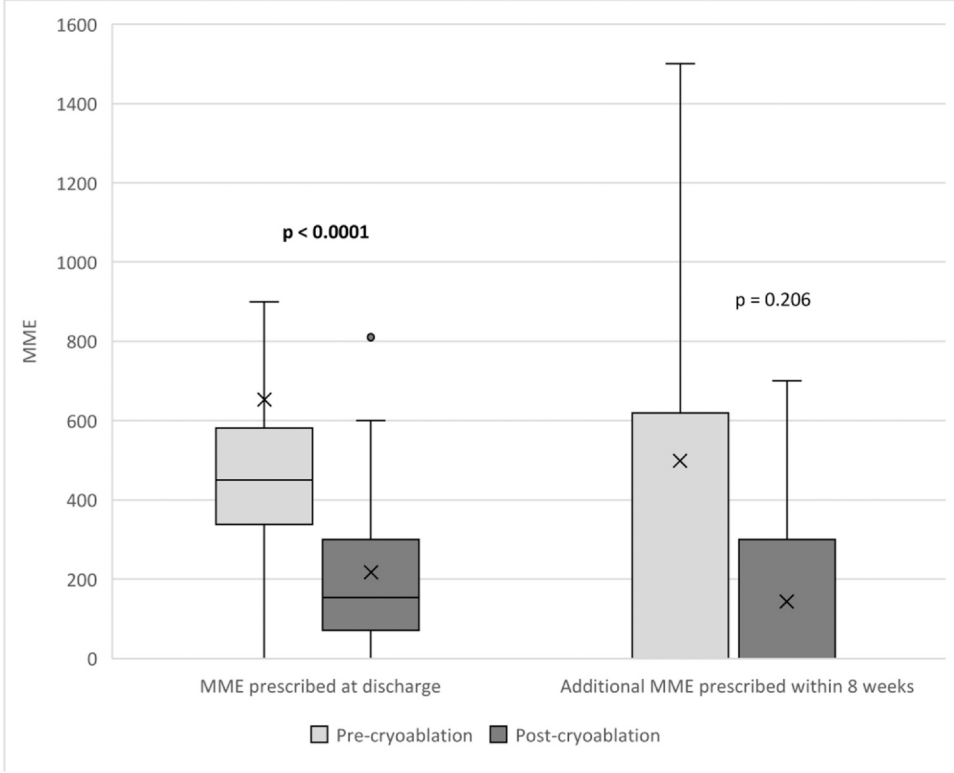

Figure 3 Total MME prescribed after discharge from index hospitalization. Horizontal line represents the median and the ends of the box represent the interquartile range. X represents the mean. Whiskers represent the range. Medians compared using Mann-Whitney U test. MME, morphine milligram equivalent.

liposomal bupivacaine intercostal nerve block after lung transplant that significantly reduced opioid consumption through postoperative day 4.[4] Additionally, this group found that patients who received a liposomal bupivacaine intercostal nerve block were not discharged home on opioids unless the patient was on opioids before transplant.[4] The results from this study suggest that liposomal bupivacaine intercostal nerve blocks may be a viable strategy for improved pain management after lung transplant and warrants further investigation as it is not without its disadvantages. In addition to issues with cost and hospital pharmacy regulations, all local anesthetic-based pain control strategies have much shorter duration of effect compared to cryoanalgesia. It can take several months for sensory nerves to regain function after cryoablation, thus this strategy may better address the long-term pain driving the persistent opioid usage seen in these patients at up to 8 weeks after transplant in our study (Figure 3).

The impact of improved nonopioid pain control on lung transplant allograft function and long-term survival is not well studied. Koons et al found similar trends in forced expiratory volume in 1 second between patients who underwent intercostal nerve cryoablation and those who did not, but their data did suggest small albeit superior survival at both 30 days and 1 year after transplant for the cryoablation group. Further study of long-term post-transplant outcomes for patients who undergo intercostal nerve cryoablation is needed and will be forthcoming as this therapy becomes more widespread in the transplant population.

Limitations

Our study is inherently limited by its single-center, retrospective design. Another potential limitation involves the exclusion criteria of intubation longer than 48 hours or reintubation post-transplant that was utilized. The study team determined it was most appropriate to exclude these patients to avoid conflating analgesia for analgosedation (or

analgesia-first sedation) while intubated and pain related to the lung transplant surgery. Additionally, patients with prolonged intubation or reintubation may have additional sources of pain, including added procedures; higher numbers of intravenous lines and drains; and complications related to prolonged periods of critical illness such as skin breakdown wounds. However, this exclusion criteria may have been selected for lung transplant recipients with reduced complications during the index hospitalization and therefore the findings regarding intercostal nerve cryoablation may not be as applicable to or have the same magnitude of benefit in lung transplant recipients with more complications during the index hospitalization.

The reduction in patients transplanted for cystic fibrosis in the postcryo cohort compared to the precryo cohort may also confound the reduction in opioid use observed as patients with cystic fibrosis have an increased prevalence of chronic and undertreated pain related to the disease state.[24,25] This shift in indication for lung transplant does align with nationally observed trends, postulated to correspond with stabilization or improvement of lung function in patients with cystic fibrosis due to cystic fibrosis transmembrane conductance regulator modulator therapy.[26] Furthermore, multimodal analgesia was protocolized in addition to the utilization of intercostal nerve cryoablation for the postcryo cohort, which could confound differences in opioid utilization seen between cohorts.

Additionally, the study included patients who were transplanted from 2016 to 2021 and during this time there were significant changes to both lung transplantation and opioid prescribing practices. Specifically, changes in outpatient opioid prescribing confound the outpatient opioid usage reported throughout our study, and the significant reduction in opioids prescribed at discharge from index hospitalization is likely indicative of an overall shifting culture in addition to the efficacy of intercostal nerve cryoablation. Our ability to capture outpatient opioid prescribing was limited to prescriptions written by prescribers within our institution, as these records are available in the electronic health record system. The use of prescriptions as a surrogate for actual opioid use is practical although does not quantify actual opioid use. Furthermore, it is possible we did not capture prescription refills ordered outside our system, although it is quite rare that an outside provider would make medication changes to these patients in the early post-transplant period. Lastly, interindividual variability between different providers and different eras could confound opioid utilization, especially as our cohorts were transplanted over a period of 6 years.

Conclusions

In this retrospective cohort study of carefully selected lung transplant recipients, intercostal nerve cryoablation as part of a multimodal opioid-sparing pain regimen was associated with a significant reduction in total opioid usage during the index hospitalization, epidural usage during the index hospitalization, and opioids prescribed at discharge from index hospitalization. While the findings in this study demonstrate that a multimodal opioid-sparing pain regimen, which includes intercostal nerve cryoablation, may reduce physicians' reliance on opioids as the first-line therapy for pain control after lung transplantation, potential confounders may exist in assessing this complex, multifactorial area of clinical practice. Future randomized studies are needed to definitively evaluate the impact of this strategy on pain management and other clinical outcomes after lung transplant, as well as assess the efficacy of the intervention in special populations such as patients with chronic pain pretransplant or more complex index hospitalizations (including prolonged intubation or reintubation).

Author Contributions

D.J.H., J.D.M., M.M.D., and D.P.M. performed the surgical interventions discussed in the study. E.M.L., H.L.K., M.S.H., and D.P.M. collected data relevant to the study and performed statistical analysis. H.L.K., M.S.H., and D.J.H. wrote the initial manuscript. All authors contributed to the editing of the manuscript and approved the final version prior to publication.

Disclosure statement

D.P.M. serves as a consultant for Atricure; the company was not involved in the funding, design, or conduct of this study. All other authors state that they have no financial conflict of interest with regard to this work.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jhlto.2024.100084.

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