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Long-Term Neurologic Effects of Cryoablation in Thoracic Surgery in Children and Teenagers

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Research Article

Keywords: Cryoablation, Chest wall surgery, Neuropathic pain, TE, Sensory outcomes

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11414358/v1

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Additional Declarations: No competing interests reported.

TITLE: Long-Term Neurologic Effects of Cryoablation in Thoracic Surgery in Children and Teenagers

CONFLICT OF INTEREST:

The authors declare no conflicts of interest related to this study.

FUNDING:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ABSTRACT

Purpose: To evaluate long-term sensory outcomes (pain, loss of sensation, paresthesia, and allodynia) associated with cryoablation compared with thoracic epidural (TE) and general anesthesia (GA) alone in children undergoing thoracic surgery.

Methods: A retrospective cohort study included 101 patients under 18 years who underwent chest wall surgery at five hospitals within a single healthcare system between 2013 and 2023. Participants completed standardized telephone interviews at least one year postoperatively. Patients were categorized by analgesic technique: cryoablation (n=49), TE (n=35), or GA only (n=17). The primary outcome was the presence of sensory symptoms at the time of interview.

Results: At the time of interview, most patients did not report ongoing sensory symptoms. There were no statistically significant differences in the proportion of all patients reporting pain, allodynia, paresthesia, or loss of sensation at any time postoperatively or at the time of interview between anesthesia groups.

Conclusions: Cryoablation provides effective postoperative analgesia without increasing long-term sensory complications compared with TE or GA alone. Chest wall sensory changes are common but generally resolve over time.

KEYWORDS:

Cryoablation, Chest wall surgery, Neuropathic pain, TE, Sensory outcomes

MANUSCRIPT BODY

Introduction

Pectus excavatum and pectus carinatum are congenital chest wall deformities characterized by inward collapse or outward protrusion of the sternum, respectively. Pectus excavatum affects approximately 1 in 400 children, while pectus carinatum affects about 1 in 1,000 in the United States [1,2]. The most common methods of surgical repair include the minimally invasive Nuss procedure and the more invasive modified Ravitch procedure. Reported benefits of these interventions include improved exercise capacity, functional vital capacity, total lung capacity, cardiac function, and most importantly, cosmetic and psychosocial benefits [3-5].

Despite their benefits, these procedures are associated with long-lasting postoperative chest wall pain [6-8]. Various pain management strategies have been used, including thoracic epidural (TE) analgesia, intravenous opioids, benzodiazepines, non-steroidal anti-inflammatory drugs, neuromuscular blocks, and more recently, cryoablation of the intercostal nerves [9, 10]. CryoICE operates via nitrous oxide cooling to temperatures between –50°C and –70°C to ablate intercostal nerves at the incision level and adjacent interspaces [11, 12]. While cryoablation requires a longer operative time than TE, it reduces short-term opioid consumption, length of hospital stay, and overall hospitalization cost [10, 12-16]. Cryoablation has become a common adjunct to pectus excavatum repair and is also used in other thoracic surgeries [10, 12, 14, 15, 17, 18].

While the short-term benefits of cryoablation are well documented, long-term sensory effects remain incompletely characterized. Concerns have been raised regarding the potential for persistent

sensory disturbances, including chest wall pain, paresthesia, numbness, and allodynia [19]. Recent investigations involving cryoablation during minimally invasive repair of pectus excavatum in pediatric populations have demonstrated frequent but typically transient chest wall sensory changes, such as hypoesthesia and hypersensitivity, which tend to diminish over time [20-23]. Most patients recover normal sensation within one year, and chronic neuropathic pain is rare [20-24].

This study aims to evaluate long-term subjective sensory outcomes—specifically pain, numbness, paresthesia, and allodynia—among pediatric patients who underwent chest wall surgery with cryoablation compared to those who underwent other chest wall surgeries with TE or general anesthesia (GA) alone. A secondary objective was to determine if cryoablation is associated with differential changes in shortness of breath, cosmetic distress, or anxiety and depression after surgery compared to TE or GA. These findings may help clarify the long-term risk-benefit profile of cryoablation in children undergoing chest wall procedures.

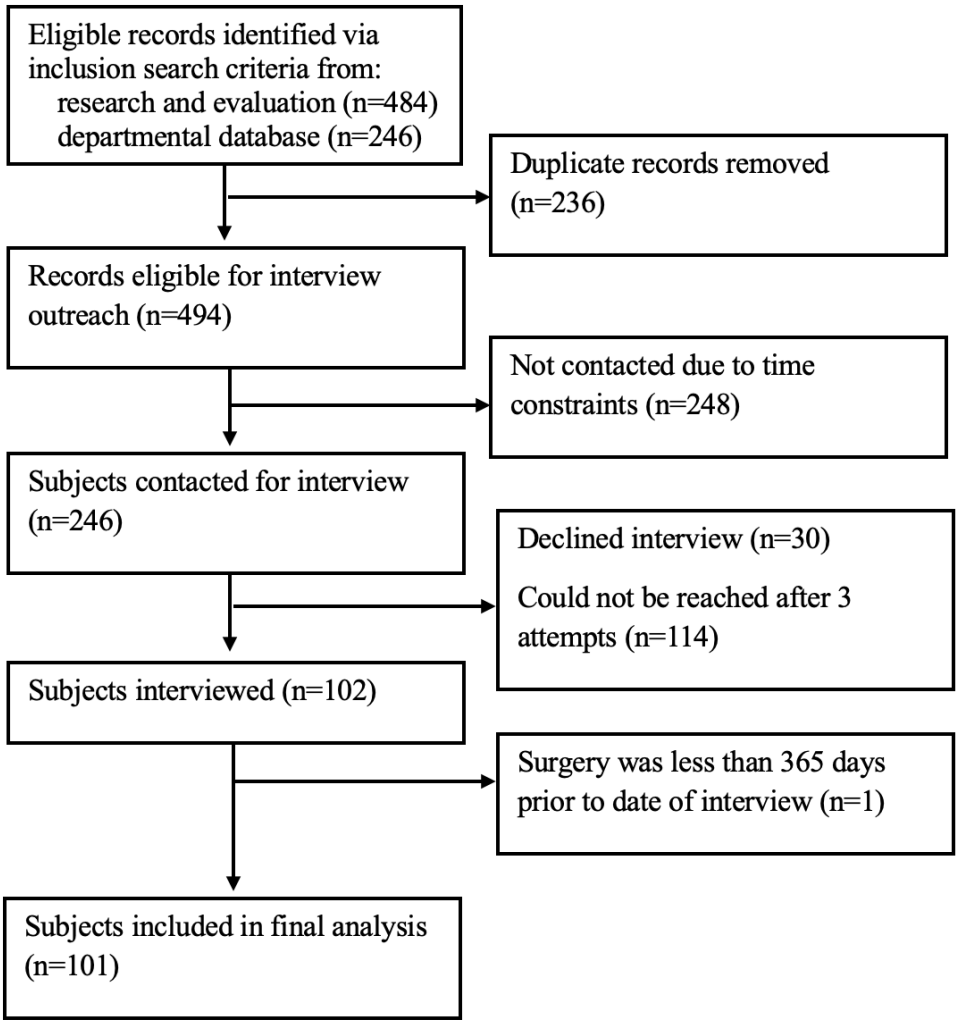
Methods

A retrospective cohort study was conducted including all patients under the age of 18 who underwent the Nuss or Ravitch procedure, thoracoscopy, thoracotomy, or chest wall tumor resection at four hospitals in a single healthcare system in Southern California between 2013 and 2023. Patients were eligible for inclusion if they had undergone a relevant surgical procedure before the age of 18. At the time of data collection, eligible individuals could be between 10 and 30 years of age. Institutional Review Board (IRB) approval was obtained through the Kaiser Permanente Southern California/Hawaii IRB (#050769).

A flow diagram outlining the participant selection process is presented in Figure 1. Electronic medical record queries for any patients meeting criteria above were conducted by both the Department of Research and Evaluation and the Department of Pediatric Surgery. Patient databases from both departments were cross-referenced to identify eligible individuals and remove duplicates. Current

Procedural Terminology (CPT) codes used in the search included 21601, 21740, 21742, 21743, and 32503. Manual chart review was performed to extract demographic data, surgical indication, and the type of perioperative pain management used, categorized as cryoablation, TE, or GA. To be included in the final analysis, at least one year must have elapsed between the date of surgery and the interview.

Figure 1: Flow diagram of participant selection for interview and inclusion in final analysis



Eligible individuals were listed by medical record number and contacted for telephone interviews in random order until approximately 100 completed interviews were obtained, which was the target sample size based on feasibility and study timeline constraints. Patients were excluded if they declined to

participate, could not be reached after three telephone contact attempts, or had undergone surgery less than one year prior to the date of contact. Recruitment was conducted via telephone using contact information listed in the electronic medical record. Verbal agreement to participate was obtained during the call from adult participants or from parents of minors, with additional agreement from minors as appropriate.

Data were collected between November 2023 and June 2024 by five interviewers using a standardized questionnaire script developed to reduce inter-interviewer variability (Appendix 1). The script was developed to explore patient experience of chest wall sensory changes based on the validated Leeds Assessment of Neuropathic Symptoms and Signs pain scale (S-LANSS) questionnaire [25]. Spanish speakers called patients whose preferred language was listed as Spanish in the electronic medical record. All recruitment materials and interview documents were available in both English and Spanish per patient preference. Spanish-speaking interviewers conducted interviews with Spanish-speaking patients.

The presence of each symptom at any time postoperatively and at the time of interview was evaluated among all patients and among those who initially reported the symptom. Exact testing for contingency tables was performed using the Fisher-Freeman-Halton test. All analyses were performed in Microsoft Excel using the Real Statistics Resource Pack (Charles Zaiontz, Purdue University, West Lafayette, Indiana) [26].

Results:

Of 494 independent records found, 246 patients were called between November 2023 and June 2024, and 102 interviews were completed, with 101 patients were included in the final analysis (Figure 1). Patients were on average 15.4 years old at the time of their operation and 23 years old at the time of interview (Table 1). Most patients were Hispanic (50%) or white (41%) and male (82%). The most

common comorbidity among those examined was depression or anxiety (25%) as revealed during patient interviews.

Table 1: Demographics and Risk Factors

		All Patients (n=101)	Cryoablation (n=49)	TE (n=35)	GA Only (n=17)
Age at time of operation, years (average)		15.4	15.7	14.8	15.8
Race/Ethnicity	Black	1 (1%)	0	0	1 (6%)
	Asian	5 (5%)	1 (2%)	3 (9%)	1 (6%)
	White	41 (41%)	23 (47%)	12 (34%)	6 (35%)
	Hispanic	50 (50%)	24 (49%)	19 (54%)	7 (41%)
	Multiracial, not disclosed	4 (3.9%)	1 (2%)	1 (3%)	2 (12%)
Male Gender (n, %)		83 (82%)	40 (81.6%)	29 (82.8%)	14 (82.3%)
Comorbidities, Risk Factors	Type 1 Diabetes Mellitus	1 (1%)	1 (2%)	0	0
	Fibromyalgia	1 (1%)	1 (2%)	0	0
	Depression or Anxiety	21 (21%)	7 (14%)	8 (23%)	6 (35%)
	Connective tissue disorder	3 (3%)	1 (2%)	1 (3%)	1 (6%)
	History of arrhythmia, valve dysfunction, or congenital heart disease	6 (6%)	2 (4%)	2 (6%)	2 (12%)
	Gastrointestinal reflux disease	3 (3%)	1 (2%)	2 (6%)	0

Operative indications and parameters can be found in Table 2. Operations were carried out by 11 primary surgeons at 5 different centers in a single healthcare system in southern California. Although procedures were performed by multiple surgeons across centers, cryoablation technique within this healthcare system followed a standardized institutional approach.

Table 2: Operative Factors

		Cryoablation (n=49) n, %	TE (n=35) n, %	GA Only (n=17) n, %
Follow-up time, years (average, range)		3.8 (1.03–7.04)	9.0 (5.83–11.01)	7.0 (1.6–11.11)
Primary Indication	Pectus excavatum	43 (88%)	34 (97%)	1 (6%)
	Pectus carinatum	5 (10%)	1 (3%)	0
	Tumor Resection	1 (2%)	0	2 (12%)
	Pneumothorax	0	0	13 (76%)
	Chylothorax	0	0	1 (6%)
Primary Operation	Nuss	42 (86%)	34 (97%)	1 (6%)
	Ravitch	6 (12%)	1 (3%)	0
	Chest wall tumor resection	1 (2%)	0	0
	Lung resection, +/- pleurodesis	0	0	8 (47%)
	Pleurodesis	0	0	7 (41%)
	Decortication	0	0	1 (6%)
Placement of hardware at the time of procedure		48 (98%)	35 (100%)	1 (6%)
Still with hardware at time of interview		13 (27%)	0	0
		median time, minutes (range)		
Procedure Start to Close		136 (32–497)	108 (68–200)	79 (52–176)

Forty-nine patients were treated with cryoablation. Most (48/49) of these patients and all 35 patients who received TE were treated for a pectus deformity (Table 2). The most common surgical indication was pectus excavatum for both cryoablation (88%) and TE patients (97%). The Nuss procedure was the most common primary surgery in both groups (86% of cryoablation patients, 97% of TE patients). The Ravitch procedure was the next most common, accounting for 12% of cryoablation cases and 3% of TE cases.

For patients who only received GA, all but one had a thoracoscopy or thoracotomy for non-pectus related reasons, most commonly pneumothorax (76%). One patient was treated with the Nuss procedure for pectus excavatum. On chart review of the operative and anesthesia records, there was no explanation as to why this patient did not receive TE or cryoablation.

The average follow-up time from date of surgery to interview for cryoablation patients was 3.8 (1.03-7.04) years, with longer follow-up time for TE (9.0 (5.83-11.01) years) and thoracic surgery patients who received GA only (7.0 (1.6-11.11) years) (Table 2). Most patients receiving cryoablation (98%) or TE (100%) had hardware such as a bar, plate, or screws placed in the chest at the time of their procedure, and most had the hardware removed by the date of interview. Patients undergoing the Nuss procedure had the bar removed after two years per standard protocol.

Primary Outcomes

First, the proportion of patients reporting symptoms at any time after surgery was examined. The most common symptom among all groups was pain, followed by loss of sensation. However, no significant differences were observed between anesthesia groups for prevalence of any symptom (Table 3).

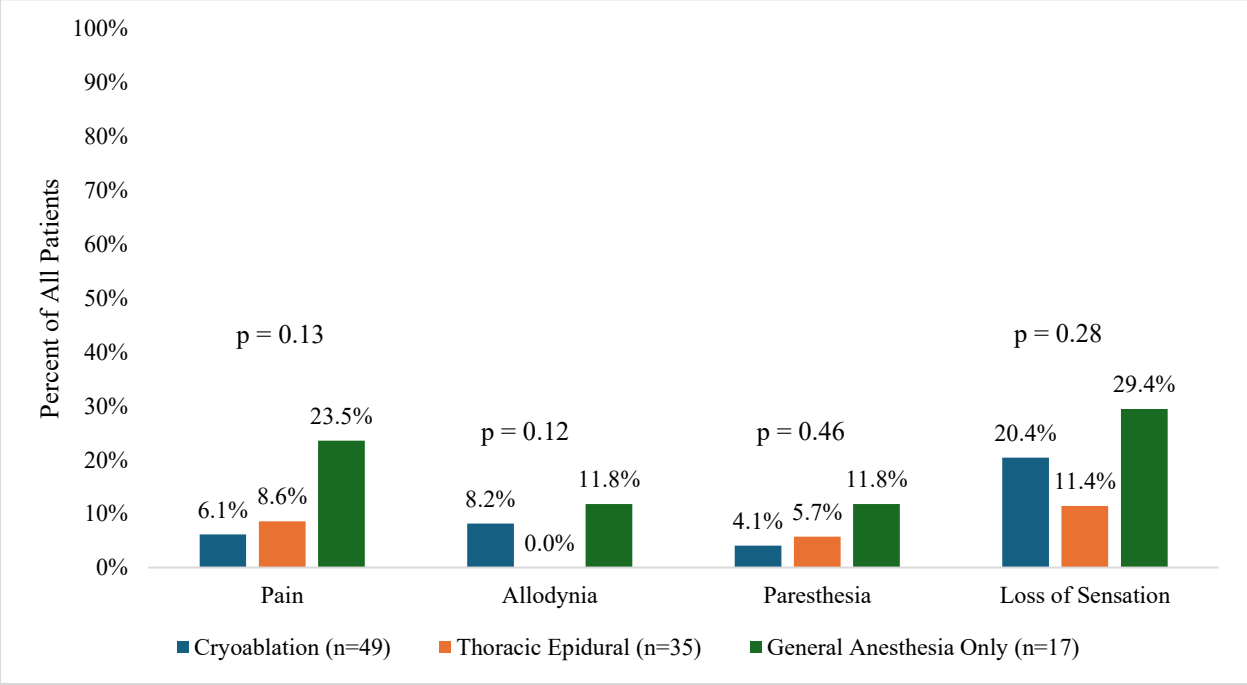
Table 3: Comparison of Postoperative Sensory Symptoms Among Anesthetic Groups

Symptom	Cryoablation (n=49)	TE (n=35)	GA (n=17)	p-value
Patients Reporting Symptoms at Any Time				
Pain	30/49 (61%)	22/35 (63%)	10/17 (59%)	0.96
Allodynia	15/49 (31%)	7/35 (20%)	4/17 (24%)	0.51
Paresthesia	12/49 (24%)	13/35 (37%)	7/17 (41%)	0.27
Loss of sensation	29/49 (59%)	15/35 (43%)	7/17 (41%)	0.24
Patients Reporting Symptoms at Time of Interview				
Pain	3/49 (6%)	3/35 (9%)	4/17 (24%)	0.13
Allodynia	4/49 (8%)	0/35 (0%)	2/17 (12%)	0.12
Paresthesia	2/49 (4%)	2/35 (6%)	2/17 (12%)	0.46
Loss of sensation	10/49 (20%)	4/35 (11%)	5/17 (29%)	0.28
Persistent Symptoms Among Patients Ever Reporting Symptoms				
Pain	3/30 (10%)	3/22 (14%)	4/10 (40%)	0.08
Allodynia	4/15 (27%)	0/7 (0%)	2/4 (50%)	0.13
Paresthesia	2/12 (17%)	2/13 (15%)	2/7 (29%)	0.72

Loss of sensation	10/29 (34%)	4/15 (27%)	5/7 (71%)	0.13

Next, the presence of chest wall symptoms at the time of interview was evaluated amongst all patients, and no significant differences were observed between groups (Table 3, Figure 2). There were no significant differences in the proportion of all patients reporting symptoms at the time of interview between groups. The most common symptom at time of interview was loss of sensation, experienced by 10/49 (20.4%) of cryoablation patients, 4/35 (11.4%) TE patients, and 5/17 (29.4%) GA patients (p=0.28).

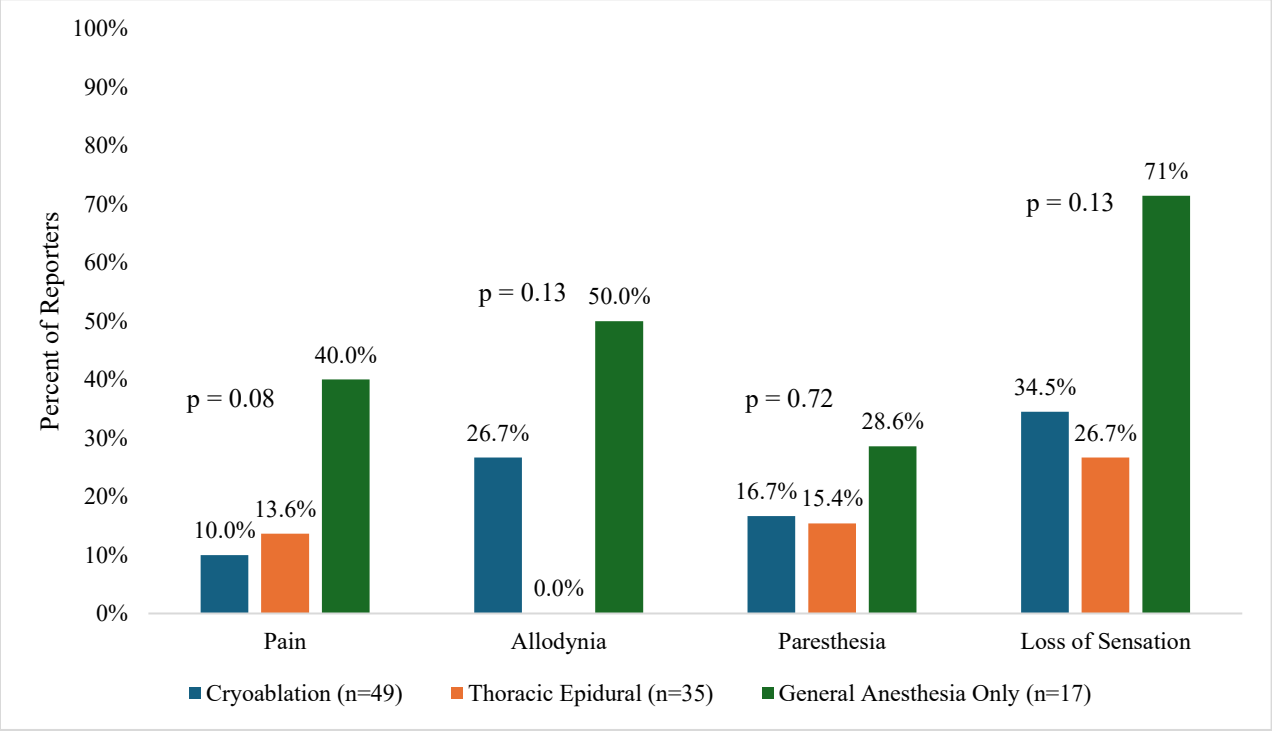
Figure 2: Percent of all patients with symptoms at time of interview



Next, persistence of symptoms at time of interview was evaluated among only those who had ever experienced a given symptom (Figure 3). For example, presence of allodynia at time of interview was evaluated amongst those patients who stated they had allodynia at any time after surgery, and so on. No significant differences were observed between groups. Pain trended toward significance (p = 0.084)

because the GA group had a higher proportion of persistent pain symptoms at interview (4/10) compared with cryoablation (3/30) and TE (3/22).

Figure 3: Persistence of symptoms at time of interview among patients who ever reported symptoms

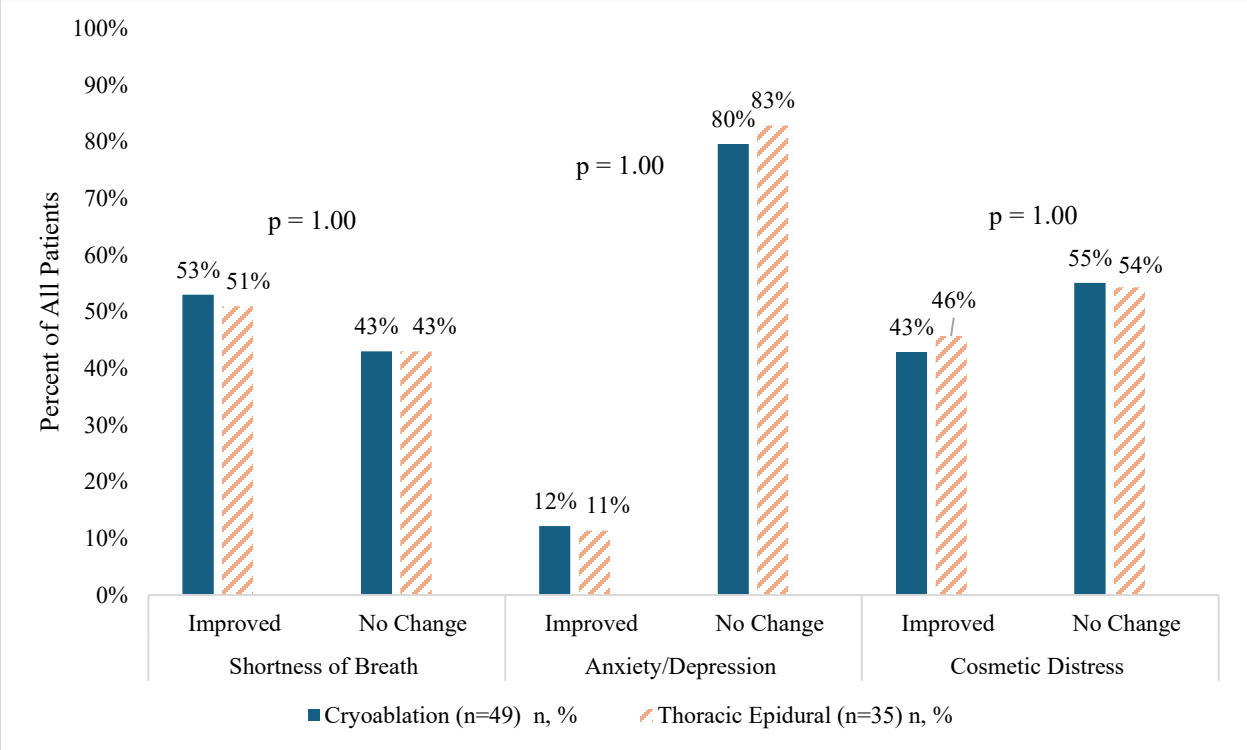


Finally, a sub-analysis was conducted of the 32 cryoablation patients with at least three years of follow-up time (mean 4.8 years, 3.0-7.0 years). At the time of interview, only 1 patient (2.0%) continued to report pain, 3 (6.1%) had persistent allodynia, 6 (12.2%) continued to note loss of sensation, and none endorsed ongoing paresthesia.

Secondary Outcomes

Secondary outcomes of interest included the prevalence of shortness of breath, anxiety and depression, and cosmetic distress before and after the procedure (Figure 4). There was no significant difference in the change in subjective shortness of breath, anxiety and depression, or cosmetic distress reported between cryoablation and TE patients. Most patients (53% cryoablation, 51% TE) reported improved shortness of breath. However, presence of anxiety and depression did not change for the majority of patients (78% Cryoablation, 83% TE). Likewise, presence of cosmetic distress improved (43% Cryoablation, 46% TE) or did not change (55% cryoablation, 54% TE) for most patients.

Figure 4: Change in Shortness of Breath, Anxiety/Depression, and Cosmetic Distress Before and After Surgery



Discussion

This study evaluated subjective long-term chest wall sensory outcomes in pediatric patients undergoing the Nuss, Ravitch, or other chest wall procedures with cryoablation for pain control compared to TE or GA alone. Due to increased use of cryoablation over time at the study institution, the follow-up

time for TE patients was substantially longer than for cryoablation patients. Despite this, the prevalence of subjective chest wall sensory changes did not significantly differ overall or at the time of interview between anesthesia groups. Similarly, there was no difference in symptom persistence among patients who initially reported symptoms. Patients who underwent unrelated thoracic procedures (e.g., pleurodesis) under GA only without cryoablation or epidural reported similar subjective symptoms, suggesting that chest wall sensory changes may be a common sequela of chest wall surgery regardless of analgesic strategy.

A recent study by Eldredge et al (2026) examined chest wall sensory changes after pectus repair in 130 patients with use of cryoablation vs 36 without cryoablation before and after bar removal [23]. Regardless of use of cryoablation, numbness near the pectus bar was present in about half of patients prior to bar removal (58% cryo, 50% non-cryo, p=0.451). However, most patients (85% cryo, 95% non-cryo, p=0.460) had normal sensation after bar removal. These findings similarly suggest that cryoablation does not result in a greater prevalence of long-term chest wall sensory changes compared to other analgesic strategies. Further, patients who underwent thoracic procedures under GA alone without cryoablation, epidural analgesia, or chest wall hardware placement reported similar rates of chest wall sensory changes, supporting the idea that chest wall surgery itself may contribute to long-term sensory changes regardless of analgesic method.

Neuropathic pain, Allodynia, and Paresthesia

Previous studies have generally found low rates of persistent neuropathic symptoms after cryoablation. Zobel et al. used the S-LANSS survey to evaluate neuropathic symptoms in 43 patients undergoing the Nuss procedure with cryoablation and found that none of the patients having surgery at a younger age (<21 years) and 38.5% of older patients experienced neuropathic pain at any time, with 23.1% of older patients still symptomatic at one year [24]. Similarly, DiFiore et al. reported hypersensitivity in 20.7% of patients, typically resolving within one year [22]. In this study, rates of

allodynia and paresthesia were similar regardless of analgesia type, with no statistically significant differences between groups. Only 3/49 (6.1%) of cryoablation patients with more than three years of follow-up reported ongoing allodynia, suggesting that neuropathic sensory symptoms continue to diminish over time.

Numbness

Eldredge et al. reported persistent numbness in 46.8% of cryoablation patients undergoing pectus surgery after three years [21]. Zobel et al. found that 100% of younger patients and 84.6% of older patients experienced numbness at any time, with persistent numbness at one year in 3.3% of younger and 23.1% of older patients [24]. In this study, 59% of cryoablation patients experienced numbness at any time, while 20% reported ongoing loss of sensation at the time of interview after a mean follow-up of 3.8 years (1.03-7.04 years**).** Among patients with more than three years of follow-up (n=32**,** mean 4.8 (3.0-7.0) years), only 12.2% reported persistent subjective loss of sensation, suggesting that these symptoms continue to diminish over time.

This study extends prior research in several meaningful ways. The data show that TE and GA patients experience chest wall sensory changes at similar rates compared to cryoablation patients, even if the patients had a completely different type of chest wall surgery. This study also includes 32 cryoablation patients with more than three years (mean 4.8 years) of follow-up; in this group, sensory symptoms continue to resolve over time. In addition, the study shows that even patients undergoing non-pectus chest wall procedures with general anesthesia had similar rates of subjective chest wall sensory changes to those undergoing pectus repair with cryoablation or TE.

Secondary Outcomes

Finally, changes in shortness of breath, anxiety and depression, and cosmetic distress between cryoablation and TE patients were evaluated. All but one of these patients underwent corrective surgery for a chest wall deformity. The reported changes were very similar between patients who received

cryoablation and those who received TE. This suggests that the method of pain control used does not impact the change in these symptoms for patients which likely have more to do with the surgery itself and less with the type of pain control used.

Limitations

This study has several limitations. First, it was retrospective in nature and relied on patient recall, introducing the potential for recall bias, particularly given that some patients were interviewed up to 8–9 years after surgery. There was also substantial variation in follow-up duration between groups, which may confound comparisons of symptom persistence at the time of interview. Patients with longer follow-up may be less likely to report ongoing symptoms due to natural resolution over time. Symptom data were obtained via phone interviews rather than clinical evaluation, which may have affected accuracy. Second, the sample size was modest, particularly for subgroup analyses by symptom type and anesthesia group, which may have increased the likelihood of type II error when examining symptom characteristics across groups. Third, patients receiving GA differed in their operative indications, which may have introduced unmeasured confounding. Fourth, while efforts were made to standardize data collection, inter-interviewer variability may have influenced patient responses. Patients were not asked about the specific area of the chest involved with each symptom, which may be different for patients treated with different analgesia types. Finally, while most postoperative patients experience some pain in the immediate postoperative period, this study's questionnaire did not distinguish this from long-term outcomes; all such patients described onset of pain as less than a year from surgery. However, prevalence of subjective postoperative pain was not statistically significantly different across groups.

Conclusion

In conclusion, this study supports the finding of other studies in the literature that subjective chest wall sensory changes are common following chest wall surgery. However, persistence of symptoms over time is not significantly impacted by the type of analgesia used for pain control. Even patients who are

treated with GA for other surgical indications report these symptoms with similar prevalence at any time and at time of interview. All symptoms tend to resolve over time and are not associated with long-term functional impairment. Cryoablation remains a safe and effective pain control strategy, offering advantages in short-term recovery without long-term sensory disadvantage.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used Chat GPT (OpenAI, San Francisco, CA) in order to clarify phrasing. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixATelephoneSurvey.docx
- AppendixBInformationalSheetEnglishCryoablation.docx