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Intercostal Nerve Cryoanalgesia in Pectus Excavatum Repair – A Narrative Review

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ABSTRACT

Background. Effective postoperative pain management is a major challenge after minimally invasive pectus excavatum repair. Cryoanalgesia has developed as a potential support to conventional analgesic strategies. This narrative review summarizes current evidence for the efficacy of intercostal nerve cryoanalgesia after Nuss procedure in pediatric population with pectus excavatum.

Aim. The aim of this narrative review was to sum up current evidence comparing intercostal nerve cryoanalgesia with conventional analgesic strategies following surgical repair of pectus excavatum in pediatric population.

Material and methods. A narrative literature review was performed using PubMed and Cochrane databases. Studies evaluating intercostal nerve cryoanalgesia in pediatric patients undergoing the Nuss procedure were analyzed, with particular focus on length of hospital stay, procedure duration, pain outcomes, and opioid consumption.

Results. Cryoanalgesia was associated with a shorter hospital stay compared to conventional analgesic strategies and longer time of procedure. Pain outcomes and opioid usage varied across studies.

Conclusions. Cryoanalgesia appears to be a promising adjunct to postoperative pain management strategies for patients undergoing minimally invasive repair of pectus excavatum. Across the reviewed studies, the cryoanalgesia was associated with shorter hospital stay and longer procedural time compared to standard analgesic strategies. Pain outcomes and opioid usage varied across studies, but available evidence suggests that cryoanalgesia of intercostal

nerves may reduce postoperative opioid usage and improve postoperative pain control. Further high-quality randomized trials are necessary to evaluate the optimal cryoanalgesia protocol.
Keywords: cryoanalgesia, pectus excavatum, nuss procedure, postoperative pain, length of hospital stay

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1. Introduction

Effective postoperative pain management is one of the main challenges following minimally invasive repair of pectus excavatum. Pectus excavatum is the most common congenital chest wall deformity, affecting approximately 1 in 400 to 1100 individuals and occurring five times more frequently in males. The deformity is characterized by posterior displacement of the sternum and abnormal rib curvature [1,21]. The Nuss procedure remains the gold standard for surgical correction of pectus excavatum [2,3]. The Nuss surgery is associated with severe and prolonged postoperative pain affecting postoperative recovery and length of stay in the hospital [16,17]

Traditionally, postoperative pain treatment following the Nuss procedure was based on patient-controlled intravenous opioid analgesia, thoracic epidural anesthesia, and regional nerve blocks [1,2]. These strategies provide pain relief that is limited by well-recognized opioid-related adverse effects such as nausea, vomiting, constipation, respiratory depression, sedation, tolerance, and the risk of long-term dependence [2,3]. In response to these challenges, cryoanalgesia has emerged as an additional method for postoperative pain management in patients undergoing Nuss procedure due to pectus excavatum.

Cryoanalgesia is a method in which extreme cold is applied to peripheral sensory nerves, performing a reversible neuronal injury. The extreme cold causes Wallerian degeneration, which is a reversible breakdown of the nerve axon, inhibiting the conduction of afferent and efferent signals. Because the endoneurium, perineurium and epineurium are preserved, the axon regenerates at approximately 1 to 2 mm/day. When the axon has regenerated, the conduction and sensations return. The origins of modern cryoanalgesia date back to 1961 when Cooper et al. introduced a device using liquid nitrogen within an insulated tube, capable of reaching a temperature as low as -196 °C. Cryoanalgesia gained prominence in 1976 when Lloyd et al. published the first significant paper suggesting its advantages [15]. Since then, cryoanalgesia has been developed and adopted across multiple surgical disciplines, including thoracic surgery, orthopedics, and chronic pain management [23-26].

Several clinical studies have suggested that use of cryoanalgesia may be associated with reduced opioid consumption, lower pain scores, and shorter hospital stays, supporting its role within ERAS (ERAS – enhanced recovery after surgery) pathways for patients undergoing the Nuss procedure [2-6].

2. Research materials and methods

2.1. Data collection and analysis

A narrative review was prepared using PubMed and Cochrane databases. The search strategy was based on the PICO framework and included search terms such as cryoanalgesia, cryoablation, pectus excavatum, Nuss procedure, standard analgesia, epidural analgesia, patient-controlled analgesia, opioid analgesia, postoperative pain, opioid consumption, pediatric population. Articles within the last 5 years that compared outcomes of intercostal nerve cryoanalgesia to conventional postoperative analgesic strategies in pediatric patients undergoing Nuss procedure due to pectus excavatum were selected. Randomized controlled trials, comparative and observational cohort studies were included. Additional studies and reviews were used to provide a broader clinical context.

2.2. AI

Artificial intelligence was used in this study for text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional language corrections of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Research results

Five studies out of the 37 identified records met the inclusion criteria and were included in analysis in this narrative review. Studies comparing intercostal nerve cryoanalgesia with conventional analgesic strategies *(EBS – epidural-based strategies, PCA – patient-controlled analgesia)* after Nuss procedure were analyzed. Length of hospital stay, procedure duration, postoperative pain outcomes, and opioid consumption outcomes were analyzed when possible. Additional studies, data and reviews were used to provide broader clinical context in discussion.

3.1 Length of stay and procedure duration

Across the reviewed articles cryoanalgesia was associated with a reduced length of hospital stay compared to standard analgesic strategies. In Bastianello et al., van Braak et al., Santana et al., and Iglesias et al. studies, hospital stay was 1–3 days shorter for patients undergoing cryoanalgesia compared to conventional strategies (Table 1). In contrast, procedure duration was generally longer in patients undergoing cryoanalgesia in analyzed studies, although metrics differed across articles (Table 2) [2,3,4].

Article (Author, year)	Comparison	Length of hospital stay (days)
Bastianello et al., 2025	Cryoanalgesia vs EBS	3.4 vs 4.4
van Braak et al., 2024	Cryoanalgesia + PCA vs EBS + PCA	3.0 vs 6.0
Santana et al., 2024	Cryoanalgesia vs Thoracic Epidural Analgesia vs PCA	2.9 vs 4.7 vs 3.7
Iglesias et al., 2025	Cryoanalgesia vs EBS	2.0 vs 4.0

Table 1. Comparison of length of hospital stay (PCA – patient-controlled analgesia, EBS – epidural-based strategies, vs - versus). Values are presented as reported in the original studies.

Article (Author, year)	Comparison	Procedure duration (minutes)
Bastianello et al., 2025	Cryoanalgesia vs no cryoanalgesia	234.0 vs 219.0 (total procedural time)
Rim et al., 2023	Cryoanalgesia vs no cryoanalgesia	159.0 vs 125.0 (operative time)
van Braak et al., 2024	Cryoanalgesia vs no cryoanalgesia	135.0 vs 119.4 (operation room time)

Table 2. Comparison of procedure duration. Values are presented as reported in the original studies. Procedure duration metrics differ between studies.

3.2. Pain outcomes

Van Braak et al. demonstrated lower pain scores NRS (NRS – Numerical Rating Scale) in cryoanalgesia group on day 1 and 2 between the groups, while directly after surgery pain scores were similar between the groups. Rim et al. revealed lower pain scores in cryoanalgesia group at 6h (5.38 vs 7.04) and 48h (3.17 vs 5.67) in VAS Scale (VAS - Visual Analog Scale). Furthermore Santana et al. reported that pain perception was lower in the cryoanalgesia group

compared to the rest of the groups, except the epidurals, which were similar. In contrast, Bastianello et al. found similar pain levels between cryoanalgesia and EBS, however initially higher pain scores (assessment upon awakening NRS 5.2 vs 2.7) were noted in the cryoanalgesia group, followed by an improvement from the second postoperative day, while patients receiving EBS had a better pain control soon after surgery [2]. Iglesias et al. reported that intercostal nerve cryoablation was associated with significantly reduced postoperative pain (10% vs 21%).

3.3. Opioid consumption

Bastianello et al. reported overall similar morphine consumption between cryoanalgesia and EBS in post-operative period. However, it was noted that remifentanil consumption during surgery and morphine consumption in the recovery period were significantly higher in the cryoanalgesia group. Santana et al. reported the lowest cumulative opioid exposure (MME [MME - morphine milligram equivalents]: 50.4 vs 117.0 vs 172.1) in the cryoanalgesia group compared to thoracic epidural analgesia and PCA strategies. Moreover van Braak et al. revealed also fewer patients requiring opioids at discharge (30.3% vs 97.0%) and at one week (6.1% vs 45.4%) postoperatively in the cryoanalgesia group. It is worth noting that also in van Braak et al. study reduced use of gabapentin in the cryoanalgesia group (18.2% vs 78.8%) was demonstrated.

4. Discussion

4.1 Discussion of the results

Across analyzed studies cryoanalgesia was associated with a shorter length of hospital stay compared to standard analgesic strategies. This result indicates a clinically important benefit in postoperative recovery and earlier readiness for discharge from the hospital (Table 1). Procedure duration was generally longer in patients undergoing cryoanalgesia what may be explained by additional surgical steps required for identification and cryoablation of the intercostal nerves (Table 2). Moreover, available evidence suggests that cryoanalgesia of intercostal nerves during Nuss procedure may reduce postoperative opioid usage and improve postoperative pain control compared to conventional analgesic strategies. However, outcomes remain different across studies. Differences in results may be caused by different overall pain treatment strategies, different methods of assessing pain intensity, technique, parameters of cryosonda, thus it is necessary to examine these parameters in a standardized way.

4.2 Recent systematic review evidence

Recent systematic reviews and meta-analyses provide broader context for interpreting the findings of this narrative review. Santos et al. demonstrated shorter hospital stays, reduced postoperative opioid consumption in cryoanalgesia group combined with nerve blocks when compared to cryoanalgesia group alone, without significant differences in surgery duration [11]. Van Polen et al. reported that cryoanalgesia with an adjunct analgesic intervention e.g. intercostal nerve block or PCA after minimally invasive repair of pectus excavatum was associated with shorter hospitalization when compared to locoregional blocks with an adjunct analgesic intervention or thoracic epidural analgesia [12]. Eldredge et al. revealed that use of intercostal nerve cryoablation during MIRPE (MIRPE – minimally invasive repair of pectus excavatum) significantly reduces hospital length of stay and opioid consumption, with minimal morbidity and rare neurological complications[22]. In conclusion finding in this narrative review are consistent with systematic reviews in case of length of hospital stay.

4.3 Broader evidence and future directions

The literature highlights several additional aspects of cryoanalgesia that may be relevant for future research that were not directly analyzed in the present narrative review. Some authors suggest that cryoanalgesia of the branches of the intercostal nerves, in addition to the main intercostal nerve, may provide a broader analgesic effect [7]. Furthermore, performing cryoanalgesia earlier, prior to the Nuss procedure, has been proposed as a potential strategy to improve postoperative pain outcomes [10,14]. The potential use of digital monitoring has also been underlined, as it may enable real-time recording of patient-reported outcomes and provide more detailed pain trajectories compared with conventional measurements [8]. Authors suggest that future research could also focus on following aspects and on developing standardized protocols for the use of cryoanalgesia. Furthermore, quality of life was evaluated in the COPPER trial by Bastianello et al. reported no significant improvement in overall quality of life and similar medium- and long-term outcomes between cryoanalgesia and epidural groups, however patients treated with cryoanalgesia appeared to return earlier to social activities [2]. Last but not least surgeons should also be aware of potential complications related to intraoperative cryoanalgesia during surgical treatment of pectus excavatum. Reported complications include chest wall numbness, neuralgia, bar migration, dermatitis, lung injury, and galactorrhea [18]. However, the reported incidence of these complications varies across studies. Arshad et al. reported no increase in short-term complications among patients who underwent cryoanalgesia compared with those who did not receive this intervention [20].

Similarly, Morikawa et al. observed no procedure-related complications in either the cryoanalgesia or control groups [19]. Overall, the incidence of both early and late complications associated with cryoanalgesia remains insufficient. Review of cryoanalgesia related complications were not directly analysed in this study, nevertheless high-quality randomized evidence remains limited. Further studies with long-term follow-up and broader populations are needed for better assessment of the safety profile. The ICE trial (Janssen et al.) is an ongoing randomized clinical trial designed to evaluate intercostal nerve cryoanalgesia using standardized outcome measures [9]. The results of this and future studies may provide important insights into the role of cryoanalgesia in postoperative pain management.

4.4 Limitations

The main limitation of this study is that it is not a systematic review and does not follow a predefined protocol for study identification, selection, and quality assessment, introducing potential selection bias. Included studies were heterogenous in design, patient populations, surgical techniques, metrics and analgesic protocols. Outcome measures differed substantially, particularly for pain assessment and opioid consumption, precluding formal meta-analysis. Finally, some studies were observational or single-center, and technical variations (nerve targets, freezing duration, timing) in cryoanalgesia were not systematically evaluated.

5. Conclusions

Cryoanalgesia appears to be a promising adjunct to postoperative pain management strategies for patients undergoing minimally invasive repair of pectus excavatum. Across the reviewed studies, the technique is associated with shorter hospital stay and longer procedural time compared to standard analgesic strategies. Pain outcomes and opioid usage varied across studies, but available evidence suggests that cryoanalgesia of intercostal nerves may reduce postoperative opioid usage and improve postoperative pain control. Further high-quality randomized trials are necessary to evaluate the optimal cryoanalgesia protocol.

Disclosure

Supplementary Materials: Not applicable

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Chat GPT (OpenAI) to improve grammar and language corrections. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility fort he substantive content of the publication.

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