ORIGINAL ARTICLE

MODIFIED PECTUS UP AND THE PORTUGUESE CASE SERIES

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Abstract

Introduction: *Pectus excavatum (PE) is the most common congenital chest wall deformity, with an incidence of 1 in 400 births. Surgical approaches vary depending on the severity of the condition. Recently, the taulinoplasty approach - "Pectus Up®" - was described as an alternative to lift the sternum through external traction, avoiding invading the mediastinum or pleural cavity. We describe our progressively modified taulinoplasty technique and case series.*

Materials and Methods: *From 2022 to 2024, 13 consecutive patients with pectus excavatum underwent surgical correction with a modified taulinoplasty (Pectus Up®) technique. Demographics, clinical characteristics, preoperative cardiorespiratory data and surgical outcomes were evaluated. The modifications introduced to the technique include preoperative stainless steel skin reaction testing, vertical skin incision, 3D-printed surgical guide and a partial chondrotomy of the costal cartilages involved in the deformity.*

Results: *The average interference of the pectus excavatum in the quality of life was 7,2 (Likert scale of 0 to 10) and the most common symptom was fatigue on exertion (30,8%). No perioperative complications and no mortality were observed, and 84,6% of patients were discharged on second post-operative day. During a median follow-up of 20 months, there was one case of metal bar allergy requiring oral corticoid therapy, and one case of infection with suture dehiscence requiring oral antibiotic therapy, surgical debridement and negative pressure therapy. In both cases, the pectus bar was not removed. The average pain in the first year after surgery and aesthetic satisfaction were 3,7 and 8,6, respectively (scale 0 to 10).*

Conclusion: *The implemented modifications result in a more "standardized" technique, which has been providing consistent and reproducible outcomes. This technique seems to be a valid therapeutic option for well selected patients.*

INTRODUCTION

Pectus excavatum (PE) is the most common congenital chest wall deformity, with an incidence of 1 in 400 births.[1,2] Its aetiology remains unclear, but it appears to be polygenetic.[3,4] PE is sometimes associated with certain connective tissue disorders or syndromes, but most cases occur in otherwise healthy individuals without any underlying conditions. [5]

Surgical approaches vary depending on the severity of the condition and any associated symptoms. Mild cases may not require any treatment beyond monitoring, while symptomatic patients with a Haller Index (HI) greater than 3.25 and associated pulmonary or cardiac abnormalities, are candidates for surgical repair.[6]

Until the end of the past century, the Ravitch procedure was the standard surgical treatment of PE and consisted in subperichondral resection of the affected costosternal joints and internal osteosynthesis of the fractures created to correct the defect.[7]

In 1998, Nuss published a 10-year review of his minimally invasive technique for the correction of the pectus excavatum. [8] Due to its excellent outcomes and effectiveness, further improved by several modifications later introduced to the Nuss technique - leading to the generic term "Minimally Invasive Repair of Pectus Excavatum" (MIRPE) - it largely replaced open surgical procedures.[6,9,10,11] MIRPE achieves the correction of sternal collapse with the rotation of the pectus bar, according to the physical principle of levers that states that any weight can be lifted by a fulcrum and a long enough lever arm.[12]

The taulinoplasty approach, also known as "Pectus Up®", was first described in 2016 as an alternative to lift the sternum through external traction and avoid invading the mediastinum or pleural cavity.[13,12] This technique requires a plate for extrathoracic implantation and a traction system designed to support and distribute the necessary loads over the defect and counteract the reduction of the anterior chest wall.[13,12]

We present our series of consecutive cases of PE repair using the taulinoplasty approach and modifications to the technique implemented over time.

MATERIALS AND METHODS

This retrospective clinical study was conducted at a tertiary teaching hospital. From 2022 to 2024, 13 consecutive patients with pectus excavatum underwent surgical correction with a modified taulinoplasty technique. Demographics, clinical characteristics, preoperative cardiorespiratory data and surgical outcomes were retrieved from medical records and through telephone contact. Interference in quality of life, post-operative pain in the first year and aesthetic satisfaction were evaluated with Likert scales (0-10). The same analgesic protocol was used for all patients. The descriptive statistical analysis is shown as means and standard deviations for quantitative variables and medians and interquartile ranges for non-normal quantitative variables.

MODIFIED TAULINOPLASTY (PECTUS UP®) TECHNIQUE

The taulinoplasty technique has been described in detail by Bardají et al.[13] To standardize procedures and achieve improved and consistent outcomes, regardless of the experience of the surgeon, we modified the standard technique (figure 1), as follows:

Planning

All candidates perform a skin reaction test with a small "test medal" made from stainless steel (AISI 316LVM), the material used to fabricate the sternal plate and pectus bar used in the procedure. The test consists of placing the "test medal" in contact with the skin of the forearm for one week and evaluate if there is any irritative reaction. If so, the patient consults an immunoallergist for further investigation before being considered for surgery.

All candidates with a negative skin reaction test or information from the immunoallergist ruling out allergy to the tested material, perform a chest CT for segmentation and 3D planning (performed by Pagaimo Medical, a company based in Portugal, using Inobitec PRO software, version 2.15.1. The segmentation and planning are offered as service included on the implant final price), in order to evaluate the following aspects:

Asymmetry Index (AI)(14)

(AI assesses the lateral asymmetry of the depression, defined by the ratio between the difference and the maximum of the sternal distances to the posterior thoracic wall)

Haller Index(14)

(HI quantifies the overall severity of the chest wall depression by expressing the ratio between the transverse diameter of the thorax and the anteroposterior distance from the sternum to the spine)

Correction Index (CI)(14)

(CI evaluates the degree of sternal displacement relative to the expected anterior chest wall contour. It is expressed as a percentage and reflects the potential for anatomical correction. CI exceeding 30% are commonly associated with clinically significant deformities, even in patients with borderline HI values)

Each index captures a distinct morphological feature of the deformity, providing complementary information. When used in combination, these indices provide a more nuanced understanding of pectus excavatum than any single parameter alone, supporting a more accurate phenotyping and individualized treatment planning.

Sternal rotation

The reference point for the fixation of the elevating system (distance from the upper border of the manubrium in the midline and in caudal direction).

The exact place where the sternal should be fixed (the place of most depression with adequate cortical bone thickness to anchor the screws) is determined through a 3D segmented model, confirming the sternum thickness and the cortical bone tissue thickness in that area, allowing the definition of the size of the fixing screws to be used.

How far may the sternum be lifted from its original position.

The adequate dimensions of the elevator plate

A report is elaborated with all this information to guide the surgical procedure. Similarly, a 3D-printed model of the anterior chest wall is sterilized and brought to the operating field to allow visualization and testing of the placement of the surgical guide, screws and pectus bar.

PREPARATION

We place the patient in a dorsal supine decubitus with the arms alongside the body under general anaesthesia.

EXPOSURE

The standard technique provides a 3–4 cm horizontal midline incision at the deepest point of the defect. We determine the site of incision according to the distance from the upper border of the manubrium, in the midline and in caudal direction, which is presented in the planning report. We modified the skin incision from horizontal to vertical, because we believe that the vertical incision allows a more anatomical closure of surgical planes, with less tension and reducing "dead space" between muscle and skin and is also more aesthetically pleasing. This modification was also described by Fernandi et al.[15], and they believe it to reduce the risk of post-operative seroma and wound dehiscence.

Table 1 Preoperative data of patients who underwent taulinoplasty for the correction of pectus excavatum

	N or mean (±DP)	%
Age (years)	21,3 (±5,7)	
Age ≥30	2	
Sex		
Male	6	46,2%
Female	7	53,8%
Symptoms		
Asymptomatic	6	46,2%
Fatigue on exertion	4	30,8%
Chest pain and dyspnea on exertion	2	15,4%
Depression	1	7,7%
Quality of Life interference (0-10)	7,2 (±1,5)	
Personal history		
Asthma	2	15,4%
Atopic Dermatitis	1	8,3%
Patent Arteriosus Ductus	1	8,3%
Allergic Rhinitis	2	15,4%
Pneumothorax	1	8,3%
Haller Index	3,9 (±0,5)	
LVEF (%)	57,2 (±4,4)	
Right ventricle compression (TTE)	2	15,4%
FEV1 (% of predicted)	85,5 (±16,3)	
FVC (% of predicted)	79,1 (±14,6)	
Ribs deformity		
Bilateral	3	23,1%
Unilateral	10	76,9%

Table 2 Operative data of taulinoplasty for the correction of pectus excavatum

	N	%
	1	
Pectus up technique	3	
Skin incision		100%
	1	
Vertical	0	76,9%
Horizontal	3	23,1%
Surgery duration		
	1	
< 2 hours	3	100,0%
> 2 hours	-	-
Intra-operative complications	-	-
	1	
Negative pressure drainage	2	92,3%

Table 3 Post-operative data of patients who underwent taulinoplasty for the correction of pectus excavatum

	N	%
Drainage removal		
1st day post-op	8	66,7%
2nd day post-op	3	25,0%
3rd day post-op	1	8,3%
Discharge		
2nd day post-op	11	84,6%
3rd day post-op	2	15,4%
Mortality	-	-

Table 4 Long-term outcomes of patients who underwent taulinoplasty for the correction of pectus excavatum

	N	%
Pain during the 1st year (0-10)	3,7 (±2,1)	
Aesthetic satisfaction (0-10)	8,6 (±1,4)	
Metal bar allergy (corticoids)	1	7,7%
Superficial suture dehiscence (revision + ABT)	1	7,7%
Follow-up (months)	20 (12)	

OPERATION

After dissecting the subcutaneous tissue, the pectoralis major is detached from the sternum and a retro-muscular pouch is created to accommodate the pectus bar. A 3D-printed surgical guide with the sternal plate fitted on its lower surface is placed exactly where the sternal plate should be fixed (figure 2). This guide is of the utmost importance because it places exactly the sternal plate as planned and allows the drilling of 5 holes at 90 degrees. The correct perpendicular drilling leads to correct placement of all 5 screws, avoiding slight shifts of the sternal plate and tension in different directions caused by less precise drilling and screw placement. After fixing the sternal plate, we perform a partial chondrotomy of the costal cartilages involved in the deformity to reduce the force needed to elevate the sunken sternum. According to Weber et al.,[16] in adults, the average force required to elevate the sternum to the desired level is more than 200 newton and about 50% of this tension can be eliminated by costal chondrotomy

Standard taulinoplasty provides the placement of back-up steel sutures laterally to the device in order to reinforce the anchorage to the sternum. We replaced the steel wires with

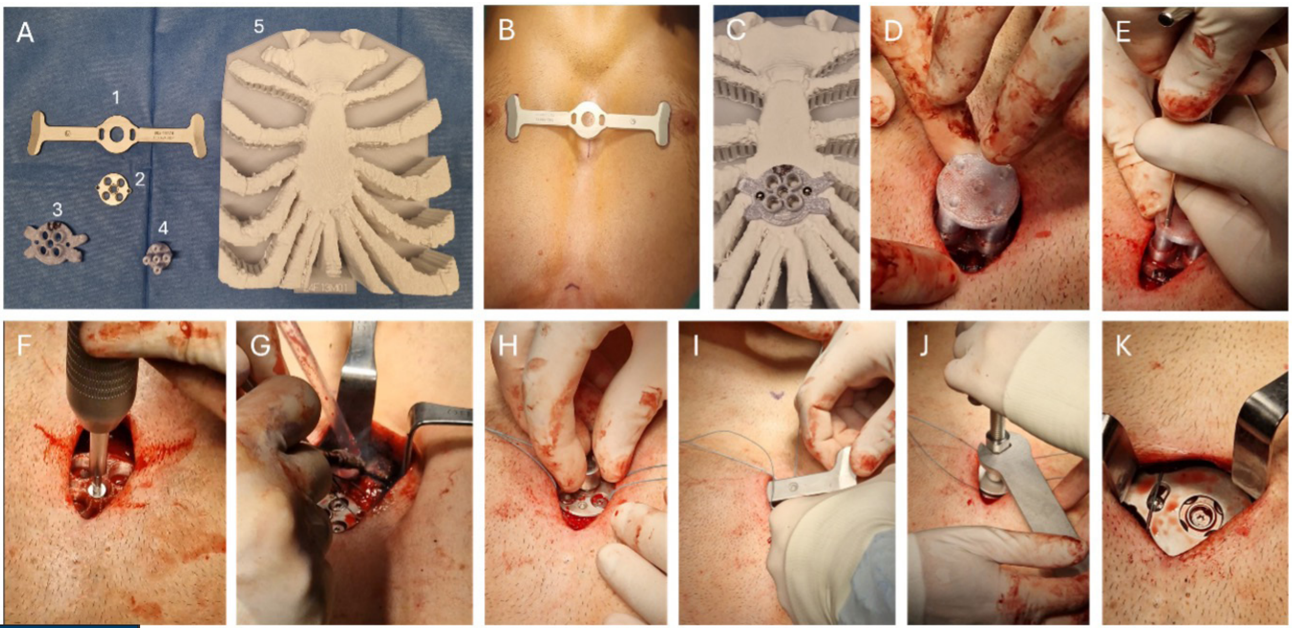

Figure 1

A – 1. Pectus bar; 2 – Sternal plate; 3 – Main component of the surgical guide; 4 – Drill component of the surgical guide; 5 – 3D-printed model of the chest wall. B – Drawing of the reference points for the procedure. C – Surgical guide placed as planned on the 3D-printed model; "UP" sign indicates the cephalic direction. D - Surgical guide with its drilling component placed as planned on the sternum of the patient. E – Perpendicular drilling. F – Placing of the screws to fix the sternal plate in the planned position. G – Partial chondrotomy of the costal cartilages involved in the deformity. H – Placement of a double screw over the central screw of the sternal plate. I – Placement of the pectus bar in the retro-pectoral pouch. J – Traction system. K – Pectus bar and sternal plate adjacent and screwed together.

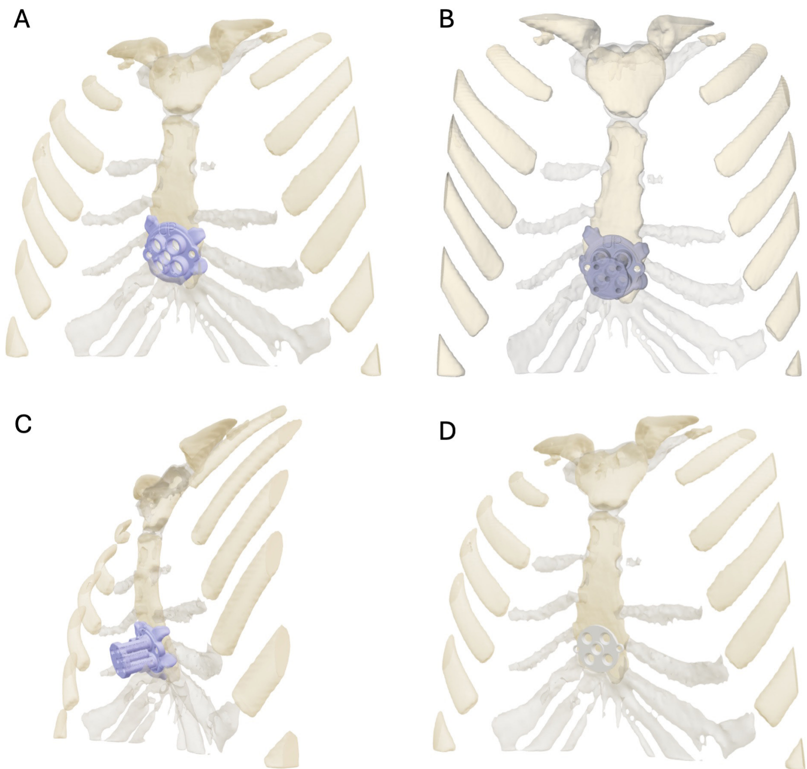

Figure 2

3D digital model showing: A – The main component of the surgical guide showing a perfect fit on the sternum with the side "claws" placed in the intercostal spaces - "UP" sign indicates the cephalic direction; B, C – The drill component placed on the main component of the surgical guide; "UP" sign indicates the cephalic direction; D – The sternal plate positioned as planned, after removing the surgical guide.

synthetic nonabsorbable braided sutures (Ethibond Excel®, Ethicon). These sutures allow us to subjectively evaluate the flexibility of the chest wall before elevating the sternum with the traction system.

The surgery proceeds as initially described: one double screw is placed over the central screw of the sternal plate; the pectus plate is housed on the retro-pectoral pouch and the traction system is mounted and coupled with the double screw; by tightening the traction system, the defect is progressively reduced until the sternal plate becomes adjacent to the pectus bar; two screws are applied in order hold the sternal plate and pectus bar together; the traction system is removed.

COMPLETION

Negative pressure drainage (hemovac) is placed in the pouch and the wound is closed with absorbable sutures and the skin with a skin closure system (Zip, Striker®).

RESULTS

The mean age of the patients was 21,3 years (range 17-36 years), with only two patients over 30 years old, and the majority were females (53,8%). Regarding symptoms attributable to the pectus excavatum, 46,2% of patients were asymptomatic, and the most common symptom was fatigue on exertion (30,8%). The average Haller Index was 3,9 and right ventricle compression was only detected by transthoracic echocardiography in 2 patients (15,4%). Moreover, the mean forced expiratory volume in the first second (FEV1) and forced vital capacity (FVC) were 85,5% and 79,1% of predicted, respectively. Three patients (23,1%) presented bilateral ribs deformity with a relatively symmetric deformity, and 10 patients (76,9%) presented unilateral rib deformity. The interference of the pectus excavatum in the quality of life (QoL) was evaluated with a Likert scale (0 to 10; 0 – no interference, 10 – total interference) and the average reported interference was 7,2 (table 1).

Intraoperatively, the skin incision was mostly performed vertically (76,9%). All procedures were performed in under 2 hours. All patients, except one (easy dissection of a small pouch with minor bleeding), had negative pressure drainage placed in the retro-pectoral pouch. No intraoperative complications were observed (table 2). The drain removal occurred mostly on the first post-operative day (66,7%) and 84,6% of patients were discharged on second post-operative day. There was no mortality associated with the procedure (table 3).

Similarly to interference in QoL, pain in the first year after surgery and aesthetic satisfaction were assessed with Likert scales (0 to 10) and averages of 3,7 and 8,6, respectively, were reported (table 4).

In terms of long-term complications, we report:

One case of a female patient with personal history of atopic skin that did the "medal test" as usual and no skin reaction was observed. One month after surgery, the patient presented a skin rash, redness and itching localized in the surgical wound and skin over the sternal plate. She consulted an immunoallergist and was medicated with oral prednisolone 20 mg once daily for 1 week with a tapering schedule, with complete symptomatic resolution. Recurrence occurred a few days after oral corticoid cessation, but symptoms were well managed with topical betamethasone and oral prednisolone as needed.

One case of a male patient that presented dehiscence of the lower end of the wound 2 months after surgery. Surgical debridement, abscess drainage, and fistulectomy of the surgical wound at the midline were performed, with placement of negative pressure therapy for two weeks. The patient underwent 14 days of oral trimethoprim-sulfamethoxazole (160 mg + 800 mg), twice daily, targeting a Staphylococcus capitis, according to the antibiotic susceptibility test.

In both cases, the treatment was effective, and signs and symptoms resolved without removing the pectus bar.

COMMENT

Several studies have reported a low complication rate with MIRPE, with a trend towards further reductions over time.[6,10,11] The rates of infection, pneumothorax requiring drainage, and hemothorax are <2%.(11)(12) The most common major complication of MIRPE was bar displacement, ranging from 3.5%[10] to 19%, [17] however, recently, pectus bar stabilization systems have been described with excellent results, such as the claw fixator, the hinge plate, and bridge plates.[18, 19, 20, 21] Nevertheless, it should be noted that major adverse outcomes such as cardiac perforation, major vessel injury, and lung, liver, or diaphragmatic injury are underreported with an overall incidence ranging from 2% to 20%.[22] However, the technique of dissection of the retrosternal tunnel from left to right, with regular instruments, and the use of the Crane manoeuvre, as described by Tedde et al.[23], virtually eliminates risk of injury during this crucial time of surgery. Still, the main advantage demonstrated with the taulinoplasty approach is avoiding invasion of the mediastinum and the pleural cavity in order to reduce the main potential complications of MIRPE and the risk of injury to vital organs,[24,25] which may be mitigated by certain manoeuvres (as previously described). Garcia et al,[12] compared the outcomes of taulinoplasty and MIRPE and reported no differences between MIRPE and taulinoplasty procedures regarding major (cardiac tamponade, cardiac perforation, major bleeding, death) or minor (infections, pneumothorax, dehiscence, seroma, and pulmonary edema) surgical complications. Furthermore, patients treated with taulinoplasty required less surgical time, shorter ICU and hospital LOS, fewer days of peridural, intravenous, and oral analgesia, than those who underwent MIRPE, indicating clear advantages regarding resource utilization and patient safety.[12,26] We report a mean pain assessment in the first year after modified taulinoplasty of 3,7 on a Likert scale (0-10), suggesting, once again, that it is a well-tolerated procedure. Furthermore, considering that most surgical procedures reduce their complication rates and improve outcomes as experience increases,[11] the duration of surgery for modified taulinoplasty and LOS is expected to further improve in the future. Another relevant aspect is that the learning curve of taulinoplasty is considered to be shorter than with other PE surgical repair techniques. [13] In our study, we did not compare outcomes of taulinoplasty to those of other techniques, but we also consider the learning curve for the modified taulinoplasty to be short, especially after the modifications we introduced, and the length of surgery to rapidly decrease as one gain experience.

Moreover, the cost of the procedure should be evaluated carefully and considering not only the initial cost of the materials (modified taulinoplasty vs. MIRPE), but also the cost of UCI and hospital LOS, analgesia (eventually cryoanalgesia), among others. Thus, despite the higher initial cost of the materials for modified taulinoplasty, it could result in a cheaper overall procedure.

As previously stated, the modifications we gradually implemented to the technique, resulted from our experience.

The implanted material - stainless steel AISI 316LVM – behaves as effectively inert in most biomedical applications, but it is not absolutely inert, therefore the risk of allergy shall not be ignored. Thus, we implemented the skin reaction test, which, if positive, is followed by the consultation of an immunoallergist for further investigation. The efficacy of this "screening test" for allergy to the stainless steel remains to be proven, because, in our series, the only case we report of allergy / hypersensitivity to the implant had a negative skin reaction test. However, this issue was resolved without removing the implant. At the moment, we still consider that the medal test has its place, and further data should clarify its usefulness. The experience gained over time led us to recognize the importance of using the 3D-printed model of the chest wall in the surgical field to help us correctly identify the intercostal spaces and to quickly adjust the surgical guide to its correct position. The development of the 3D-printed surgical guide with the drilling component was an important step forward for this technique because it had a huge impact on the correct placement of the sternal plate, which is one of the most important steps of the surgery, as it determines the elevation and rotation of the sternum. Moreover, the partial chondrotomy of the costal cartilages involved in the deformity reduces the force needed to elevate the sunken sternum and, in our opinion, results in a better aesthetic result. Thus, we believe that the compound effect of all these small modifications allows us to use this technique to correct more complex chest wall deformities.

LIMITATIONS

Absolute contraindications for this procedure are rare, the main one being allergy to the implant material. On the other hand, one may consider several relative contraindications, such as very low sternal density or insufficient thickness for secure fixation, highly ossified thoracic cage, extreme depth of deformity ("grand canyon") may require double implant or combined procedures, severe asymmetry, isolated costal flare or deformity limited to the xiphoid region.

Some of these situations can be addressed by combining Pectus Up with other procedures such as chondrotomies, partial sternotomy, cartilage resection, or dual-implant placement. Potential for improvement lies in further developing the procedure to include the treatment of such deformities, as well as cases where other techniques have failed.[13]

Until this day we have never removed any pectus bar. Bardaji et al.[13] reported the removal of several pectus bars, following the same indications of the MIRPE bar removals, and no difficulties during surgery were described. However, long-term follow-up and recurrence of PE was not reported, which leaves room for concern.

CONCLUSION

The modifications we made to the technique were gradual and each one was the answer to a specific technical challenge. In our opinion, the implemented modifications result in a more reproducible technique, which has been providing consistent outcomes. This technique is not suitable to all patients but, for selected patients, it seems to be a valid therapeutic option within the surgical arsenal.

The preliminary results of this study are encouraging but the series is still small, and more data is required to truly evaluate the efficacy of the procedure, particularly in cases where it may be necessary to remove the pectus bar.

REFERENCES

1. Obermeyer RJ, Cohen NS, Jaroszewski DE. The physiologic impact of pectus excavatum repair. Semin Pediatr Surg. 2018 Jun 1;27(3):127–32.
2. Obermeyer RJ, Goretsky MJ. Chest Wall Deformities in Pediatric Surgery. Surgical Clinics of North America. 2012 Jun;92(3):669–84.
3. Kotzot D, Schwabegger AH. Etiology of chest wall deformities-a genetic review for the treating physician. Vol. 44, Journal of Pediatric Surgery. 2009. p. 2004–11.
4. Fokin AA, Steuerwald NM, Ahrens WA, Allen KE. Anatomical, Histologic, and Genetic Characteristics of Congenital Chest Wall Deformities. Semin Thorac Cardiovasc Surg. 2009 Mar;21(1):44–57.
5. Frediani S, Corbi L, Pardi V, Aloi I Pietro, Bertocchini A, Accinni A, et al. Case Report: Double Pectus Up in severe pectus excavatum, the new frontier of modified taulinoplasty. Front Pediatr. 2024;12.
6. Croitoru DP, Kelly RE, Goretsky MJ, Lawson ML, Swoveland B, Nuss D. Experience and modification update for the minimally invasive Nuss technique for pectus excavatum repair in 303 patients. J Pediatr Surg. 2002;37(3):437–45.
7. Ravitch MM. THE OPERATIVE TREATMENT OF PECTUS EXCAVATUM*. Ann Surg. 1949 Apr;129:429–44.
8. Nuss D, Kelly Jr RE, Croitoru DP, Katz ME. A 10-Year Review of a Minimally Invasive Technique for the Correction of Pectus Excavatum. J Pediatr Surg. 1998;33:545–52.
9. Nuss D, Croitoru D, Kelly Jr. R, Goretsky M, Nuss K, Gustin

T. Review and Discussion of the Complications of Minimally Invasive Pectus Excavatum Repair. Eur J Pediatr Surg. 2002;12:230–4.
10. Hosie S, Sitkiewicz T, Petersen C, Göbel P, Schaarschmidt K, Till H, et al. Minimally Invasive Repair of Pectus Excavatum ± The Nuss Procedure. A European Multicentre Experience. Vol. 12, Eur J Pediatr Surg. 2002.
11. Park HJ, Jeong JY, Jo WM, Shin JS, Lee IS, Kim KT, et al. Minimally invasive repair of pectus excavatum: A novel morphology-tailored, patient-specific approach. Journal of Thoracic and Cardiovascular Surgery. 2010 Feb;139(2):379–86.
12. Garciá BN, Garciá NÁ, Aquino-Esperanza J, Miró CE, Pérez-Gaspar M, Gómez JJ, et al. Efficacy and Safety of Taulinoplasty Compared with the Minimally Invasive Repair of Pectus Excavatum Approach to Correct Pectus Excavatum. Journal of Laparoendoscopic and Advanced Surgical Techniques. 2021 Dec 1;31(12):1402–7
13. Bardají C, Cassou L. Taulinoplasty: The traction technique-a new extrathoracic repair for pectus excavatum. Ann Cardiothorac Surg. 2016 Sep 1;5(5):519–22.
14. Sujka JA, St. Peter SD. Quantification of pectus excavatum: Anatomic indices. Semin Pediatr Surg. 2018 Jun 1;27(3):122–6.
15. Frediani S, Beati F, Pardi V, Aloi I Pietro, Bertocchini A, Accinni A, et al. Case Report: Modified Taulinoplasty: a new technique for minimally invasive repair of pectus excavatum. Front Surg. 2023;10.
16. Weber PG, Huemmer HP, Reingruber B. Forces to be overcome in correction of pectus excavatum. Journal of Thoracic and Cardiovascular Surgery. 2006 Dec;132(6):1369–73.
17. Hebra A, Swoveland B, Egbert M, Tagge EP, Georgeson K, Biemann Othersen H, et al. Outcome Analysis of Minimally Invasive Repair of Pectus Excavatum: Review of 251 Cases. J Pediatr Surg. 2000;35(2):252–8.
18. Park HJ, Rim G, Yoon SK. Recent Advancements in Pectus Surgery: Crane Lifting, Multiple-Bar Approach, Bridge Stabilization, and Sandwich Technique. J Pediatr Surg. 2024 Apr 1;59(4):640–7.
19. Kim H, Rim G, Park HJ. Technical Advances in Pectus Bar Stabilization in Chest Wall Deformity Surgery: 10-Year Trends and an Appraisal with 1,500 Patients. J Chest Surg. 2023;56(4):229–37.
20. de Carvalho RLC, Tedde ML, de Campos JRM, Hamilton NN, Guilherme GF, Sousa VM, et al. Quality of life outcomes after minimally invasive repair of pectus excavatum utilizing a new set of metallic bars and stabilizers. J Pediatr Surg. 2021 Mar 1;56(3):545–9.
21. Diaz YL, Ramos TM, Tedde ML, Gomes da Silva DA. The The Sandwich Technique For Minimally Invasive Repair Of Pectus Carinatum. Port J Card Thorac Vasc Surg. 2024 May 13;31(1):53–5.
22. Hebra A, Kelly RE, Ferro MM, Yüksel M, Campos JRM, Nuss D. Life-threatening complications and mortality of minimally invasive pectus surgery. J Pediatr Surg. 2018 Apr 1;53(4):728–32.
23. Tedde ML, Togoro SY, Eisinger RS, Okumura EM, Fernandes A, Pêgo-Fernandes PM, et al. Back to the future: A case series of minimally invasive repair of pectus excavatum with regular instruments. Jornal Brasileiro de Pneumologia. 2019;45(1).
24. Kelly RE, Mellins RB, Shamberger RC, Mitchell KK, Lawson ML, Oldham KT, et al. Multicenter study of pectus excavatum, final report: Complications, static/exercise pulmonary function, and anatomic outcomes. J Am Coll Surg. 2013 Dec;217(6):1080–9.
25. Schaarschmidt K, Lempe M, Schlesinger F, Jaeschke U, Park W, Polleichtner S. Lessons learned from lethal cardiac injury by nuss repair of pectus excavatum in a 16-year-old. Annals of Thoracic Surgery. 2013;95(5):1793–5.
26. Papic JC, Finnell SME, Howenstein AM, Breckler F, Leys CM. Postoperative opioid analgesic use after Nuss versus Ravitch pectus excavatum repair. J Pediatr Surg. 2014;49(6):919–23.