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Minimally Invasive Repair for Pectus Excavatum - Aesthetic and/or Functional?

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Rezumat

Rezolvarea chirurgicală minim invazivă a sternului înfundat - estetică și/sau funcțională?

Introducere: sternul înfundat este cea mai frecventă malformație congenitală a peretelui toracic anterior. Malformația se accentuează odată cu creşterea în vârstă şi devine maximă în adolescență, când simptomatologia clinică se acutizează şi afectarea psihică devine importantă. De-a lungul timpului s-au imaginat nenumărate tratamente, fie conservatoare, fie chirurgicale de corecție. Procedeul minim invaziv de corecție a sternului înfundat (procedeul Nuss) dezvoltat după 1986, este în prezent cel mai folosit pe plan mondial.
Material şi metodă: Analizăm 52 de pacienți cu această afecțiune, internați în Secția Clinică de Chirurgie Toracică a Spitalului Universitar de Urgență Militar Central „Carol Davila" diagnosticați, investigați şi tratați chirugical minim invaziv după procedeul Nuss. Evaluarea clinică şi paraclinică, inclusiv măsuratorile şi indicii antropometrici sunt prezentate în amănunt. Sunt prezentate şi indicațiile şi contraindicațiile procedeului Nuss, precum şi posibile complicații intraoperatorii şi postoperatorii recente şi tardive.
Rezultate şi concluzii: Sunt prezentate beneficiile clare ale procedeului Nuss, precum şi îmbunătățirea parametrilor funcționali şi estetici. Procedeul Nuss are o serie de avantaje: procedeu minim invaziv, timp operator redus, pierderi sangvine minime, precum şi o reintegrare rapidă socioprofesională.

Cuvinte cheie: stern înfundat, minim invaziv, procedeu Nuss

Abstract

Introduction: Pectus excavatum is the most frequent anterior thoracic wall congenital malformation. This malformation is increasing its effects with the aging process and has its peak during teenage, when the clinical symptoms become more acute and psychological effects are really important. Across the course of time many treatment techniques have been proposed, among which conservative or surgical correction techniques. The minimally invasive repair of pectus excavatum, "Nuss technique", developed after 1987, is the most frequently performed technique world wide.
Material and Method: This article analyzes 52 patients, admitted to the University Emergency Military Hospital "Carol Davila" - Thoracic Surgery Department, diagnosed, investigated and surgically treated according to Nuss procedure. Therapeutic and diagnostic protocols will be presented and analyzed: clinical and paraclinical evaluation, indications and contraindications of Nuss procedure, as well as possible intraoperative and post-operative complications.
Results and Conclusions: Nuss procedure's benefits will be presented, as well as improvements of functional and aesthetic parameters. Nuss procedure has a series of advantages: minimally invasive surgical procedure reduced operative time, minimal blood loss and fast socio-professional reinstatement.

Key words: pectus excavatum, funnel chest, minimally invasive, Nuss technique

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Introduction and definition of pectus excavatum

Pectus excavatum defines a congenital malformation of the anterior thoracic wall, characterized by a depression of the sternalbody and adjacent ribs, thus resulting the funnel form (*Fig. 1, 2*).

The malformation is less visible on newborns and children, but becomes more and more visible with aging, with a peak during teenage.

The rate of occurrence of this malformation is, according to some authors, 1 out of 1000 newborns. Other authors consider it even more frequent (Ravitch – 1 out of 400 newborns) (1).

This condition may appear as a single malformation or in association with other congenital cardiac malformations, asthma, Marfan syndrome, Ehlers-Danlos syndrome, Poland syndrome, etc. (2).

If the sternal funnel is on the median line, we speak of a symmetric pectus excavatum (*Fig. 1, 2*) and if the sternal funnel is on either side of the median line we speak of an asymmetric pectus excavatum (*Fig. 3, 4*). This fact must be well known from the start because it is essential for the surgical correction procedure.

Treatment options

Nowadays the most utilized surgical therapeutic options have been reduced to a number of three: minimally invasive repair for pectus excavatum (Nuss procedure), suited for symmetrical or slightly asymmetrical malformations (3,5); Ravitch procedure for asymmetrical or complex conditions (1); and plastic surgeons fill the sternal funnel with silicone implants, thus assessing only the aesthetic correction for these teenagers.

Minimally invasive repair for pectus excavatum (Nuss procedure) – MIRPE

This procedure utilizes the standard thoracoscopic setup and a special kit for pectus excavatum. It was introduced by

Figure 1. *Pectus excavatum – anterior aspect*

Figure 2. *Pectus excavatum – lateral aspect*

Figure 3. *Asymmetrical pectus excavatum - preoperative*

Figure 4. *Asymmetrical pectus excavatum - postoperative*

Dr. Donald Nuss in 1987, in collaboration with Walter Lorentz Surgical Inc. and at first it was used for children and teenagers (3). The procedure consists in placing a special, curved, stainless steel, nickel or titanium blade behind the sternum, under thoracoscopic control.

Our results

The symptomatology of these patients is due to the compression exerted by the sternal funnel over the intra-thoracic organs (especially the heart and lungs), or to their anatomic displacement. Another aspect is the aesthetics, which these patients observe especially during teenage.

Regarding respiratory and cardiovascular functions, there are contradictory studies. This is why we wanted to analyze the improvements, if there are any, of Nuss procedure over the aesthetic and ventilatory function. Several authors state that this malformation does not lead to important cardiac or respiratory impairment. Others have demonstrated that these functions benefit from the surgical intervention (4,5).

During the study we had two categories of patients with this condition: symptomatic and asymptomatic patients. Surgical intervention was advised to symptomatic patients, after a complete clinical and paraclinical evaluation. For asymptomatic patients, kept under further observation by the general practitioner, conservative postural treatment has been advised and surgical re-evaluation every six months. They will be categorized as symptomatic patients when one of the following criteria is met: deepening of the sternal excavation, increased effort intolerance, thoracic pain and dyspnoea, palpitations and paraclinical evaluation revealing cardiac or lung displacement.

The clinical evaluation includes the inspection of the thorax, the excavation analysis and the association with other thoracic wall malformations. The clinical evaluation also sets the size of the utilized blade.

For paraclinical evaluation we conducted a set of investigations, which we consider as standard for pectus excavatum: thoracic X-Ray, thoracic computerized tomography, lung ventilatory function test and cardiologic exam (with cardiac ultrasonography for left ventricle function).

We also advised psychological and psychiatric examination of the patient before the surgical intervention.

Computerized tomography is mandatory because it brings all the necessary information for the surgical intervention. Also it can specify if we are facing a symmetrical or asymmetrical malformation (*Fig. 5, 6*).

Between October 2007 and May 2012, 52 patients (48 men and 4 women) underwent this surgical procedure. The average age was of 17.9 years old (varying between 8 and 38 years old); the ideal age for this intervention is considered to be between 6 and 18 years old (3).

During the day before surgery we measured the patient's chest in order to determine the most suited blade. The measurements are made at the deepest excavation point, between the left and right medium axillary lines. The chosen blade will be 2 cm smaller than initial measurements because the template measures the external thoracic diameter, while the blade passes the internal thoracic diameter.

The surgical intervention requires general anaesthesia with selective intubation of the right lung. For perioperative pain and postoperative management we used an epidural catheter. An antibiotic was also administrated perioperatively.

The patient is placed in supine position with arms in abduction at shoulders' level (*Fig. 7*). The excavation's lowest point will be marked, as well as the highest parasternal points. The horizontal plane joining these three points will be bilateral extended to the chest wall and, between the anterior and medium axillary lines, future incisions will be marked. Then the accurate template must be chosen, followed by the blade's modelling, using the special bending device.

2.5 cm lateral incisions (horizontal, vertical or oblique) are made on the medium axillary line, at marked intercostal

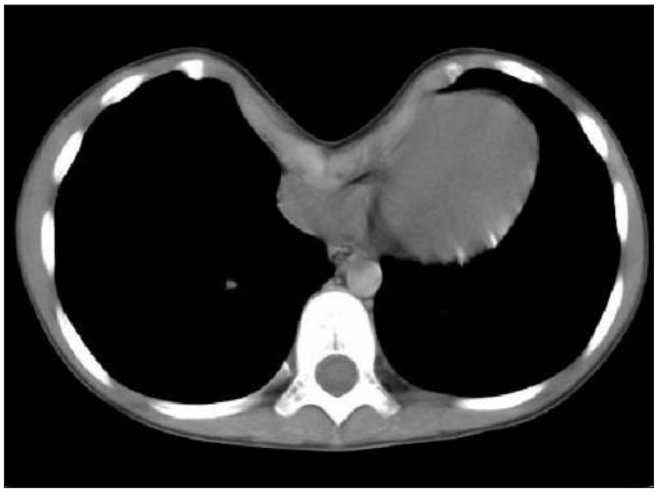

Figure 5. *Symmetrical pectus excavatum*

Figure 6. *Asymmetrical pectus excavatum*

Figure 7. *Patient's position, anaesthesia*

Figure 8. *Sterile drape, shaped blade*

Figure 9. *Introduction of 10 mm and 30º thoracoscope inside the right hemithorax*

Figure 10. *Thoracoscopic aspects of thoracic malformation - "U" shaped pectus excavatum*

space level. Lately we observed that the most adequate position for placing these incisions is half distance between the anterior and medium axillary lines due to of a more facile blade extraction and less postoperative pain.

The next step is tunnelling the tegument above the intercostal space towards the highest points of the excavation, which were already marked.

The thoracoscopic procedure uses a 5 or 10 mm, 0º or 30º thoracoscope. It is introduced through the right hemithorax, one or two intercostal spaces inferior to the lateral incision. The thoracoscopic procedure may be also used for the left hemithorax, through the already made incision or through another incision, one or two spaces inferior to the left incision. The thoracic cavity is inspected: possible injuries are highlighted, the sternal malformation, most depressed area, relationship with pericardium and right internal mammary vessels are also confirmed (*Fig. 9, 10*).

Very important information is given by the thoracoscopic inspection: the aspect of the malformation. This can be a "U" shaped malformation, when the sternal deformed surface is longer, or a "V" shaped malformation, when the deformed surface is like an acute angle. Considering this characteristic, the blade's stabilization is taken into account: the "U" shaped malformation provides better stabilization than the "V" shaped malformation, which involves its fixation with two stabilizers in multiple points. These are our personal findings; we didn't find any marks on this aspect in literature.

Retrosternal passing of the introducer, at maximum depth level, from right to left, must be made without any lesions to the internal mammary vascular package, pericardium or heart. Until the right margin, the introducer's passing can be visualized thoracoscopically; from this point on, through the mediastinum, retrosternal fat tissue and until the left incision, comes the blind time of the procedure and this is why it must be made with gentle moves to avoid any kind of incident (*Fig. 11*). Some authors visualize the blade inside all the spaces it passes (right hemithorax, mediastinum, left hemithorax). In this case the patient will have 5 incisions. We consider that

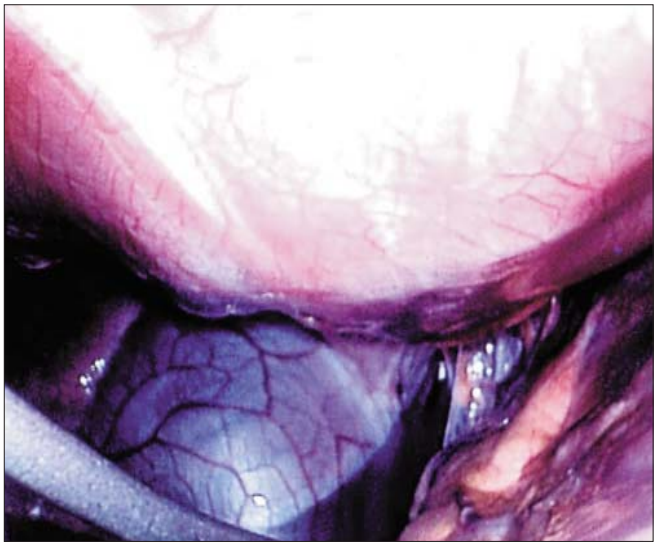

Figure 11. *Dissector's progression from right to left*

Figure 12. *Retracting the introducer and a thread attached to its tip*

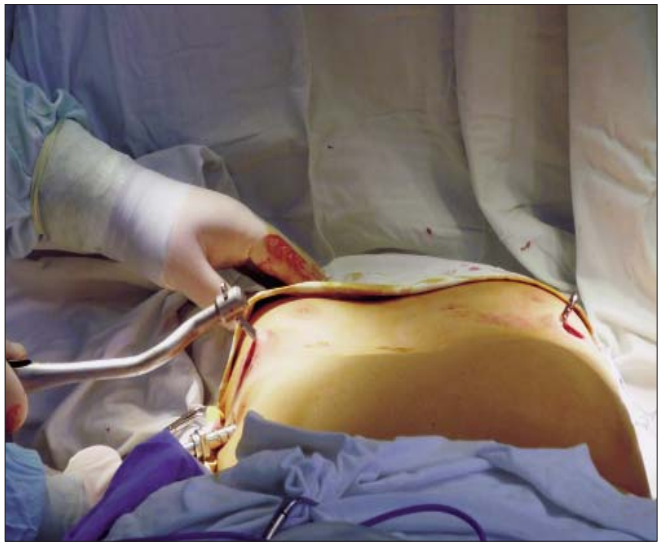

Figure 13. *Passing the blade behind the sternum with the concavity facing upwards*

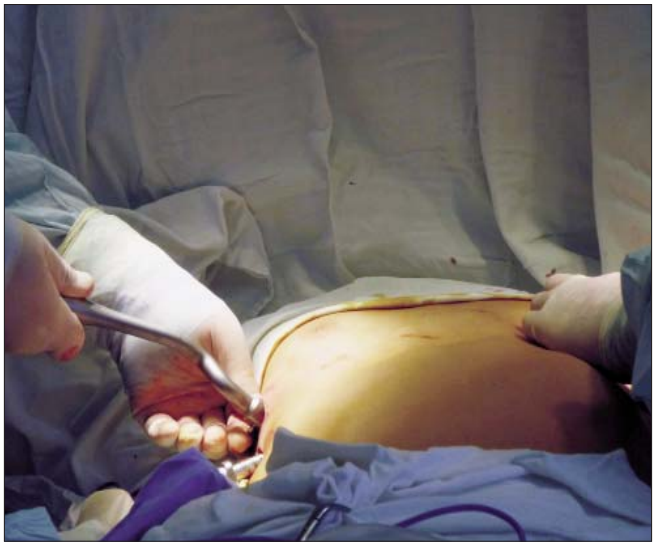

Figure 14. *Flipping the blade 180º*

minimally invasive also means a small number of skin incisions. Considering this aspect we only perform 3 incisions (2 on the right hemithorax and one on the left hemithorax). In some cases we can even drop the second right incision by introducing the 5 mm camera through the same incision as the blade.

After passing the introducer from right to left, the surgeon can proceed to modelling the sternum through manual pressure above and beneath deformation to obtain the desired shape. This manoeuvre is repeated several times to spread the connective tissue and correct the excavation. For complex deformation two introducers will be passed to correct it and two blades will be mounted.

Next is the retraction of the introducer and the thread attached to its tip (*Fig. 12*). An osteosynthesis curved blade is attached to the thread or a drainage tube and is pushed and gently pulled by the thread from right to left, with the concavity facing upwards (*Fig. 13*).

After the blade's introduction, it must be flipped at 180º with the special kit flipper; this way the blade changes its concavity from its initial position (facing upwards) to the final position, with the concavity facing towards the spinal cord, correcting this way the deformation (*Fig. 14*). If the deformation was not corrected the surgeon may proceed mounting a second blade, below or above the first blade.

Stabilizing the blade at the thoracic wall using stabilizers from the special kit is the next step; these stabilizers are attached to the blade's end and to the thoracic wall muscles. Depending on physical development, patient's age, "U" or "V" aspect of the pectus excavatum, one or two stabilizers can be used.

After the blade's stabilization, the evacuation of the pneumothorax from the left or right hemithorax can be made by positioning the patient in Trendelenburg position, ventilating the lungs with positive pressure, or drainage tubes can be left in the left and/or right pleural cavity for 24-48 hours (if there is also a left pneumothorax).

Postoperative radiography is mandatory for visualizing the blade's final position and, eventually, the pneumothorax. After surgery the patient is transferred to an ICU for 24 hours.

Early postoperative complications

Frequently during the first few days after surgery we met a small right residual pleural effusion, serous or hemorrhagic, due to lack of a drainage tube in the right pleural cavity or an incomplete pneumothorax evacuation and pleural effusion at the surgery's ending. Serous or hemorrhagic pericarditis is another early complication due to the lesions made by the blade to the pericardial vessels. We only encountered right pneumothorax as an early complication and only for the first patients, when its evacuation was performed without combining it with aspirated drainage afterwards.

Late postoperative complications

The most frequent late complication is bar displacement, which appears at the moment the patient starts mobilizing and does not respect the prescribed indications step by step. In situations like this, patients have to come to the hospital as soon as possible for repositioning of the blade. Late haemothorax and late pericarditis are caused by lying lesions of the correction blade and they can endanger the patient's life (respiratory insufficiency).Metal allergies, skin lesions or skin infections caused by the correction blade have been described as well (3). Also described as a late complication is overcorrection; meaning excess modelling of the blade, which can transform pectus excavatum in pectus carenatum. Illness recurrence is another late complication, which can appear in case of bulky individuals, with solid bone structure or doubtable blade quality (reused blade). This complication (illness recurrence), appears most frequently when the blade is extracted in a time period of less than 2 years from surgery.

The most frequent late complication we met was blade mobilization (3 patients). For one of them we repositioned the same blade, correcting the deformation; another patient did not have a complete correction with only one blade and a second blade was introduced for complete correction of the deformity; the third patient suffering this complication did not come for blade replacement.

We had 2 cases where keloid scars appeared, with partial skin erosion, which were surgically resolved, with local anaesthesia.

Postoperative evolution

Blade extraction is performed 2-4 years after surgery. Blade extraction earlier than 2 years after implantation was done for three patients, mainly because of intense pain, which did not yield to usual painkillers; one patient with one blade, 38 years old, where the blade's ends entered among the vasculo-nervous package in the intercostal space; another patient with two blades who had a skin suppuration at one of the stabilizers, followed by its exteriorization and a third patient who had his blade removed because of intense pain. Post extraction aspect was satisfactory for all patients. For 12 patients the blades were extracted at over 2 years from implantation, results being very good.

The mean hospitalization time was of 4.8 days.

For 50 patients only one blade was used, using blade numbers from 8 to 16, without extremes (numbers 7 and 17). For 2 patients a second blade was necessary for an adequate correction.

Mean operating time was of 58 minutes. When we began developing the technique, surgical interventions lasted longer (up to 2 or 3 hours). After several cases, operating time was substantially reduced, reaching 40 minutes.

Aesthetic results were analysed objectively and quantified using two-step Nuss questionnaire (2SNQ). Patients and their relatives answered the 12 questions of the questionnaire before the surgical intervention, 5-6 months after surgery (the moment of the first post-operative examination), as well as when they came for blade extraction (*Table 1*). Maximum score is 48 points, while the theoretical minimum is of 12 points. Scores between 41 and 48 points characterize extremely satisfied patients, scores between 31 and 40 points characterize satisfied patients and scores between 21-30 points characterize unsatisfied patients, while scores below 20 points characterize patients extremely unsatisfied. We encountered scores between 31 and 38 points preoperatively and scores between 39 and 48 points at 6 months postoperatively.

Considering the small number of patients who came for blade extraction over the advised period of time (the study started in 2007 and the advised period of time for extraction is between 2 – 4 years) we have not included aesthetic results for the blade's removal, but only for preoperative examination and first postoperative consult (*Fig. 15, 16*).

The statistical analysis of mean postoperative score (33.5) and postoperative score (44.1) showed a significant growth ($p < 0.001$) for both patients and their relatives.

81% of the patients stated they are extremely satisfied 6 months postoperatively, while only 5% stated that they are unsatisfied by the aesthetic results (patients with asymmetric malformation, with known less than satisfactory results - *Fig. 17*).

Regarding patients' relatives, 83% of them stated that they are extremely satisfied; while only 2% were unsatisfied by the aesthetic results (*Fig. 18*).

Over the last two years we wanted to also analyze the ventilatory improvements. Patients underwent lung function tests preoperatively, as well as 5-6 months postoperatively. The results showed an improvement of lung function tests, with a mean increase of FEV1 with 16.92% ($p < 0.001$), of FVC with 15% ($p < 0.05$) and FEF 25-75% with 26% ($p = 0.01$) (*Table 2*).

Table 1. *Nuss Questionnaire modified for Adults and the median values per question obtained (6)*

Question	Score	Mean pre-op.	Mean post-op.
Looks in general	Very happy: 4, Mostly happy: 3, Mostly unhappy: 2, Very unhappy: 1	2	4
How chest looks without shirt	Very happy: 4, Mostly happy: 3, Mostly unhappy: 2, Very unhappy: 1	1	3
Spending rest of life as chest looks now	Very happy: 4, Mostly happy: 3, Mostly unhappy: 2, Very unhappy: 1	1	4
Other people make fun of you because of your chest looks?	Very often: 1, Often: 2, Sometimes: 3, Never: 4	3	4
Avoid doing things	Very often: 1, Often: 2, Sometimes: 3, Never: 4	2	3
Hides chest	Very often: 1, Often: 2, Sometimes: 3, Never: 4	1.5	4
Bothered because of the way chest looks?	Very often: 1, Often: 2, Sometimes: 3, Never: 4	2	3.5
Feels shy/self-conscious because of chest looks?	Very often: 1, Often: 2, Sometimes: 3, Never: 4	2	4
Feels bad about her/himself	Very often: 1, Often: 2, Sometimes: 3, Never: 4	3	4
Has trouble exercising	Very often: 1, Often: 2, Sometimes: 3, Never: 4	3	3
Chest causes shortness of breath	Very often: 1, Often: 2, Sometimes: 3, Never: 4	2	4
Chest is the cause to be tired	Very often: 1, Often: 2, Sometimes: 3, Never: 4	3	4

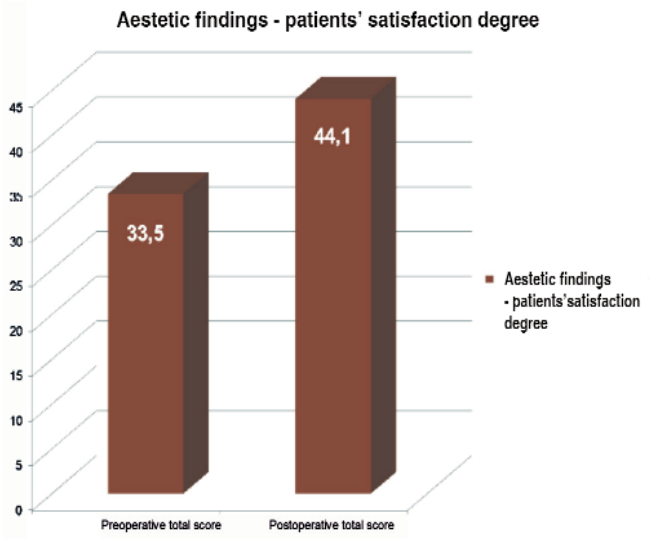

Figure 15. *Medium Nuss scoring - patients*

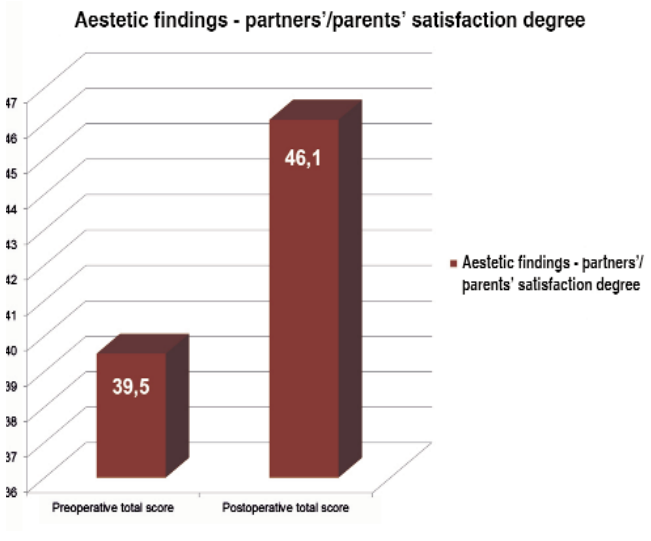

Figure 16. *Medium Nuss scoring - relatives*

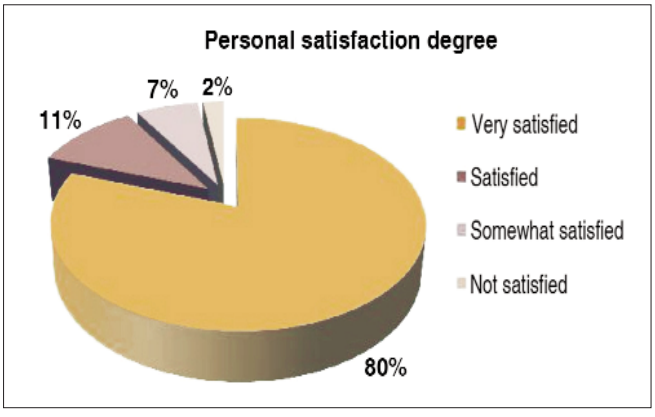

Figure 17. *Satisfaction degree - patients*

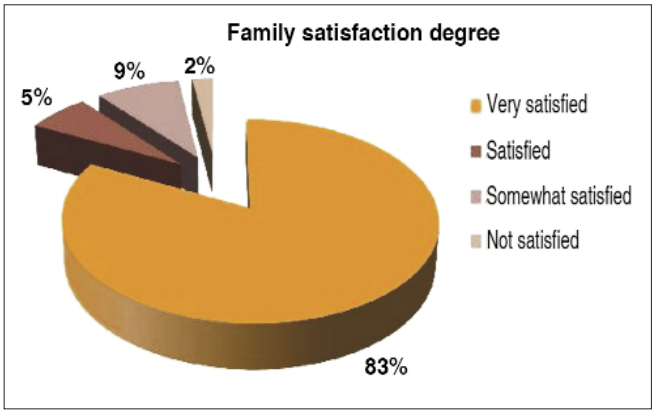

Figure 18. *Satisfaction degree - relatives*

Table 2. *Functional lung tests*

No.	FEV1 preop.	FEV1 postop.	% improvement FEV1	FVC preop.	FVC postop.	% improvement FVC	FEF 25-75% preop. (% of normal)	FEF 25-75% postop. (% of normal)	% improvement FEF 25-75%
1.	4,5	5,2	**13,46**	5,6	6,38	**12,23**	60	80	**25,00**
2.	4,1	4,9	**16,33**	4,2	5,04	**16,67**	60	83	**27,71**
3.	4,0	5,0	**20,00**	4,4	5,15	**14,56**	55	78	**29,49**
4.	3,7	4,3	**13,95**	4	4,88	**18,03**	65	90	**27,78**
5.	3,2	3,8	**15,79**	3,15	3,95	**20,25**	60	85	**29,41**
6.	3,0	3,5	**14,29**	3,17	3,85	**17,66**	71	100	**29,00**
7.	3,5	4,2	**16,67**	3,85	4,65	**17,20**	60	81	**25,93**
8.	4,2	5,0	**16,00**	5,31	6,21	**14,49**	55	75	**26,67**
9.	3,5	4,0	**12,50**	3,65	4,44	**17,79**	68	99	**31,31**
10.	3,8	4,6	**17,39**	4,02	4,80	**16,25**	76	102	**25,49**
11.	3,8	4,4	**13,64**	3,96	4,67	**15,20**	66	86	**23,26**
12.	3,5	4,2	**16,67**	4,01	4,60	**12,83**	70	87	**19,54**
13.	3,1	4,0	**22,50**	3,74	4,33	**13,63**	65	93	**30,11**
14.	4,2	5,1	**17,65**	4,6	5,25	**12,38**	63	91	**30,77**
15.	4,0	4,7	**14,89**	4,4	5,05	**12,87**	73	100	**27,00**
16.	3,8	4,7	**19,15**	4,12	5,01	**17,76**	68	90	**24,44**
17.	3,8	4,9	**22,45**	4,58	5,36	**14,55**	62	80	**22,50**
18.	3,5	4,4	**20,45**	4,03	4,70	**14,26**	60	78	**23,08**
19.	3,7	4,5	**17,78**	4,05	4,72	**14,19**	60	82	**26,83**

Discussion

Starting from publication of Donald Nuss' article in 1987 (3) regarding minimally invasive repair of pectus excavatum many discussions have arisen. Many North American surgeons adopted the technique, reporting series of hundreds, even thousands of cases with excellent results (10). This technique extended in South America and Asia, where series with important numbers of minimally invasive procedures for pectus excavatum were also reported (11,13). In Europe the technique was adopted at a later time, but now there are a number of centers with excellent results. For example, in Turkey an important number of surgeons use this procedure, with excellent results and a very impressive number of cases (12).

From its beginning the technique has suffered improvements regarding the anaesthetic procedure, materials used for bars' manufacturing process (14,15) and also regarding its indication for "V"-shaped malformations (3).

Regarding the technique itself, a number of improvements have been added to the original Donald Nuss procedure. While initially the technique addressed only symmetrical pectus excavatum, afterwards the procedure has been extended, even by us, to the slightly asymmetric pectus excavatum. Good results regarding this improvement to the technique have also been reported by Hyung Joo Park (13). Improvements have been developed also for the pectus excavatum kit, many medical companies creating their own kit and gear for minimally invasive repair for pectus excavatum. The blade stabilizing system has also been improved: unilateral stabilization, absorbable stabilizers, etc.

After 52 Nuss procedures performed we can state that this method has its benefits: minimally invasive surgery, reduced operating time, minimal blood loss, fast social and professional reinstatement, as well as improved lung ventilatory function with excellent aesthetic long term results (*Fig. 19, 20*).

As it can be seen, pectus excavatum does not have only aesthetic repercussions, it also has physiological involvement. As a consequence of these factors we consider that the surgical intervention is essential regarding the aesthetic improvement, as well as the ventilatory lung function improve-

Figure 19. *Asymmetrical pectus excavatum - preoperative*

Figure 20. *Asymmetrical pectus excavatum - postoperative*

ment. The general practitioner has a very important role regarding the diagnosis and guidance of symptomatic patients towards the surgeon, because these are the patients who will most benefit from the surgical intervention.

Also of great importance is the patient's age at the time of the procedure and the time passed between the diagnosis and the surgical intervention. The faster the surgery, the better the aesthetic and functional results are.

For the next years we want to follow patients with cardiac function disorders regarding pectus excavatum. For this we are gathering data and we will be publishing them as soon as we will have a complete picture.

In conclusion, minimally invasive repair for pectus excavatum – Nuss procedure – is an efficient method, with excellent aesthetic and functional results, with fast social and professional reintegration.

In our study, after analyzing all the patients, we observed that patients' and their relatives' satisfaction degree is excellent in over 80% of cases - this completely justifies the surgical approach for this condition.

In Romania this method has became more and more known to thoracic surgeons and, although our centre has the biggest experience in using this procedure with over 52 cases, more and more centres all over the country have started utilizing this procedure (Bucharest, Timișoara, Oradea, etc.). Surely, if the osteosynthesis system would be financially covered by the assurances, a greater number of patients would address this procedure. We hope that in the near future this procedure could be performed in an acceptable manner for patients, as well as for the doctors.

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