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Technology of minimally invasive surgical correction funnel-shaped deformation of the chest in children

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The most common method surgical treatment of pectus excavatum (PE) is thoracoplasty according by D.Nuss at the moment. But serious complications associated with trauma to the pericardium, blood vessels, and bleeding are known. Objective. Development of a modified technology surgical correction of pectus excavatum, which involves exclusively extrapleural passage of the plate, according to the individual size and shape of the deformation of the patient's chest, in order to prevent intraoperative complications. Methods. 81 patients aged 10 to 17 years were involved in the study. A modified technology of extrapleural surgical correction of PE was performed. The plate was carried level of the VI–VII sternocostal joints through the formed through submuscular-extrapleural retrosternal tunnel from right to left under control of right-sided thoracoscopy. The plate was modeled according by individual deformation parameters chest. The analysis was carried out according to the following criteria: age, gender, type of deformity, Haller index, duration of surgery, intraoperative and early postoperative complications according by Clavien–Dindo classification. Results. The median age of patients was (13.8 ± 1.9) years, of which there were 65 (85.25 %) boys, 16 (19.75 %) girls. 48 (59.3 %) children were diagnosed with type I (symmetric) deformity, and 33 (40.7 %) with type II (asymmetric) according to the classification. The median Haller was (4.07 ± 0.62), which corresponds to 2–3 degrees. Differences in the degree of deformation in children of different sexes were not determined (p = 0.828). Impaired lung function was diagnosed in 55.55 % (n = 45), impaired heart function — 40.74 % (n = 33). The duration of the operation was on average (70.6 ± 15.4) minutes, from 50 to 110 minutes. Early postoperative complications were found in 5 (6.17 %) patients classified as grade I (mild) according to the Clavien–Dindo classification, which did not require additional medical or surgical correction. After the operation, the correction of chest deformation was on average (2.35 ± 0.22) according by Haller index, which was statistically significantly (p = 0.001) different from the initial level. Conclusions. The use of modified technology surgical correction of PE meets safety requirements and minimizes postoperative complications.

Наразі найбільш розповсюдженим методом хірургічного лікування вродженої лійкоподібної деформації грудної клітки (ВЛДГК) у дітей є торакопластика за D. Nuss. Проте відомо про серйозні ускладнення, які пов'язані з травмуванням перикарду, судин, кровотечею. Мета. Розробити модифіковану технологію хірургічної корекції ВЛДГК, яка передбачає виключно позаплевральне проведення пластини відповідно до індивідуальних розмірів і форми деформації грудної клітки з метою запобігання інтраопераційних ускладнень. Методи. У дослідження залучено 81 пацієнт віком від 10 до 17 років. Виконано модифіковану технологію позаплевральної хірургічної корекції ВЛДГК. Пластина проводилась на рівні VI–VII грудинно-реберних суглобів по сформованому наскрізному підм'язово-позаплевральному загрудинному тунелю справа наліво під контролем правобічної торакоскопії. Пластину змодельовано згідно з індивідуальними параметрами деформації. Проведено аналіз за наступними критеріями: вік, стать, тип деформації, індекс Haller, тривалість втручання, інтраопераційні та ранні післяопераційні ускладнення за Clavien-Dindo. Результати. У 48 (59,3 %) дітей діагностовано деформацію I типу (симетричну), у 33 (40,7 %) — II типу (асиметричну) згідно з класифікацією Park. Середній індекс деформації за Haller становив (4,07 ± 0,62), що відповідає II–III ступеням. Діагностовано порушення функцій: легень — в 55,55 % (n = 45), серця — 40,74 % (n = 33). Тривалість операції становила в середньому (70,6 ± 15,4) хв, від 50 до 110 хв. Ранні післяопераційні ускладнення виявлені в 5 (6,17 %) пацієнтів, які за класифікацією Clavien-Dindo віднесені до I ступеня (легкі) та не потребують додаткової медикаментозної чи хірургічної корекції. Після виконання операції корекція деформації грудної клітки становила в середньому (2,35 ± 0,22) за індексом Haller, що статистично значущо (p = 0,001) відрізнялось від початкового рівня. Висновки. Застосування модифікованої технології хірургічної корекції ВЛДГК відповідає вимогам безпечності та мінімізує післяопераційні ускладнення. Ключові слова. Лійкоподібна деформація, торакопластика, ускладнення, діти.

Keywords. Pectus excavatum, thoracoplasty, complications, children

Introduction

Today, the commonly accepted method of surgical correction of congenital pectus excavatum (CPE) in children is the D. Nuss method [1–5]. The closed operation is performed with two skin incisions, a tunnel is formed through the pleural cavity behind the sternum, through which the plate is passed, its rotation is carried out and the deformation is corrected [6].

During the period of spread of the technique, there were reports of serious complications, namely damage to the heart and vessels of the mediastinum, traumatic damage to the diaphragm and the formation of a diaphragmatic hernia, injuries to the liver, lung parenchyma [7, 8]. Despite the rare cases of their fixation, it should be taken into account that there is a threat to the patient's life [9, 10].

Surgical CPE correction according to the D. Nuss method requires thorough surgical intervention during sternum elevation. This method has proven itself not only as the most widely used, but also low-traumatic, with sufficient deformation correction and reliability of the obtained result. The safety of patients with CPE is a key condition, as it involves avoiding complications associated with damage to the anatomical structures of the mediastinum (pericardium, heart, main vessels, etc.) and the contents of the pleural cavity (lungs, bronchi) during the elements of the sternum elevation procedure. For the surgeon, the safety of CPE correction operation is determined, first of all, by experience, knowledge of possible options for conducting the conductor and installing the plate, visualization of actions with the help of thoracoscopy, which allow to prevent these complications.

Purpose: to develop a modified technology of surgical correction of CPE, which involves exclusively extrapleural passage of the plate in accordance with the individual dimensions and shape of the patient's chest deformation to prevent intraoperative complications.

Material and methods

The study included 81 patients aged 10 to 17 years who underwent surgical intervention using a modified technology based on the D. Nuss operation from January 2017 to June 2024. The research was performed in accordance with the principles of Helsinki Declaration. The study was approved at the meeting of the commission on biomedical ethics at Dnipro State Medical University (Protocol No. 1 dated 18.01.2015). Informed consent for examination and treatment was obtained from all patients' parents. This work included a retrospective analysis of observations. The following parameters were analyzed for each patient: age, sex, type of deformity, Haller index, duration of surgery, intraoperative and early postoperative complications according to the Clavien-Dindo classification [11].

Examination of the patients included clinical blood and urine tests, blood type and Rhesus factor determination, biochemical blood assay, ultrasound examination of the heart, electrocardiography, spirography, radiography (direct and lateral projections) and computed tomography of the chest.

An indication for surgical intervention was the presence of chest deformation with a Haller index ≥ 3.25, significant compression of the heart or lungs with a violation of their indicators in Haller index < 3.25.

Operation technique

Surgical intervention was performed under combined endotracheal anesthesia in combination with epidural analgesia. On the operating table, anthropometric measurements of the dimensions of the funnel-shaped deformity were carried out using a ruler, namely, the width was determined as the distance between the protruding parts of the ribs at the level of maximum depth (Fig. 1, a). The optimal length of the plate (L) was calculated individually, which was twice the width of the deformation (D), according to the formula: $L = 2D$ (Fig. 1, b). Further, during the preparation of the plate for modeling, its marking was carried out, the width of the sternum and the places of attachment to the most protruding parts of the ribs on both sides were noted (Fig. 1, c).

The depth of the funnel-shaped depression was measured using a ruler (Fig. 2, a). Then the plate was modeled using a special tool (Fig. 2, b). It was bent in such a way that the retrosternal part remained horizontal to the width of the sternum and had the form of a platform that fully corresponds to the dorsal surface of the sternum. The side parts of the plate are bent at the level of the maximum width of the deformation above the supporting ribs, this allows a tight fit to the sternum and ribs and improves stability. At the same time, the bending value of the plate for correction should be ½ more than the determined depth of the funnel-shaped deformation (Fig. 2, c). This was necessary to receive the planned correction of the chest.

Preliminary studies of the mechanical properties of the plate showed that it could withstand corrective loads, but in the lateral sections, its inconsistency with the restored form of the chest due to an increase in the anterior-posterior size was revealed.

The mathematical modeling of the newly formed shape of the chest during thoracoplasty according to D. Nuss established the relationship between the depth of deformation and the size in the frontal plane. In this way, the coefficient of restoration of the shape of the chest was calculated, which is 2 ($2\Delta = h$), where h is the depth of deformation of the chest. For this, the distance between the lateral ends of the plate, which reproduces the shape of the chest and adheres to the ribs, was reduced by ½ the depth of the funnel-shaped deformation for full adherence to the ribs in the postoperative period. Also, these actions increase the area of contact of the plate with the chest and reduce the level of tension in the "sternum-ribs-spine" system [12].

After the preoperative modeling of the shape of the plate, the modified technology of surgical correction of CPE was performed (Utility Model Patent of Ukraine No. 133541. Bulletin No. 7, 2019). Then the operating field was marked with a marker (Fig. 3, a). The positions of the sternocostal joints of the 6th–7th ribs, as the points of entry and exit of the plate from the retrosternal space, and the projection of dissections on both sides were marked. Dissections up to 3 cm long were made, through which submuscular tunnels are formed in the directions to the sternum on the right and left (Fig. 3, b). Access for right-sided thoracoscopy was established along the front axillary line of the chest above the skin incisions on one rib to pass the plate (Fig. 3, c).

A conductor was inserted through the submuscular tunnel formed on the right and advanced to the sternum, between the sternocostal joints of the 6th–7th ribs. Placing the plate at this level causes the least tension in the "sternum-ribs-spine" system and contributes to the stability of the location [13]. Then, under the control of thoracoscopy, the conductor was extrapleurally immersed in the retrosternal space, moved forward from right to left along the back surface of the sternum extrapleurally, to the exit between the sternocostal joints of the 6th–7th ribs on the opposite side of the chest, and was brought out through the inguinal tunnel (Fig. 4, a, b, c).

A plate was attached to the conductor, orienting its concave part to the sternum (Fig. 5, a). Traction of the plate was carried out while pulling the conductor via the created through submuscular-extrapleural tunnel in the opposite direction to the exit of the end of the plate from the opposite side. The plate was disconnected from the conductor and rotated by 180°, thereby correcting the deformation of the sternum (Fig. 5, b). At the end, the plate was fixed to the adjacent ribs with mylar threads. The lungs were actively inflated and air was removed from the chest cavity through the port. Wounds were sutured in layers (Fig. 5, c).

The technology differs from the well-known technique of D. Nuss in that the length of the plate is first determined individually (according to the formula, it is twice the width of the funnel-shaped deformation), then the plate is modeled according to the anatomical dimensions of the sternum, width and depth of the deformation, determining the supporting ribs. The plate has a horizontal platform for the width sternum and three fixed bending points on each side. Then a through-muscular-extrapleural tunnel is formed at the level of the 6th–7th sterno-costal joints through which the plate is passed extrapleurally. Control of its placement is performed with the help of right-sided thoracoscopy, the access is located along the front axillary line of the chest above the skin incisions on one rib for conducting the plate.

Results

This technique was applied during surgical correction of CPE to 81 patients, of whom 65 (85.25 %) were boys, 16 (19.75 %) were girls. The average age of the patients was (13.8 ± 1.9) years. 48 (59.3 %) children were diagnosed with type I (symmetric) deformity, and 33 (40.7 %) with type II (asymmetric) deformity according to the Park classification [14]. The average deformation index according to Haller was (4.07 ± 0.62) from 2.87 to 5.30, which corresponds to grades 2-3. However, the difference in the grade of deformation in children of different sexes was not determined ($p = 0.828$). Violations of the following functions were diagnosed: lungs in 55.55 % ($n = 45$), heart — 40.74 % ($n = 33$). The duration of the operation was on average (70.6 ± 15.4) minutes, from 50 to 110 minutes.

According to the results of postoperative observations, complications related to traumatization of the heart, mediastinal structures, or anatomical formations of the pleural cavities were not detected. Early postoperative complications were diagnosed in 5 (6.17 %) patients, according to the Clavien-Dindo classification, they were classified as grade 1 (mild) and did not require additional medical or surgical correction. Pneumothorax was recorded in 3 (3.7 %) cases, they were treated conservatively, pleural puncture was not used.

To eliminate this complication in other patients, we started using pleural drainage during the first day. Infection of the postoperative wound occurred in 1 (1.2 %) person. Within one month after the intervention, 2 (2.5%) patients were found to have atelectasis

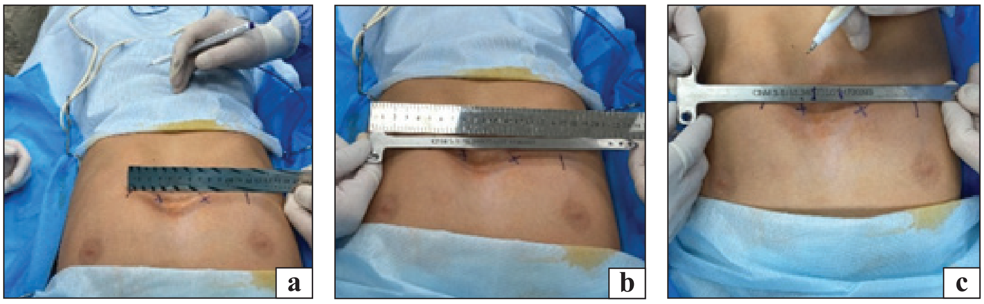

Fig. 1. Measurements of the dimensions of the deformation of the chest and preparation of the plate for modeling: a — the width of the pectus excavatum; b — optimal plate length; c — marking of the plate

Fig. 2. Preparation and modeling of the plate: a — determination of the depth of the pectus excavatum; b — plate modeling using a special tool; c — determination of the bending value of the plate

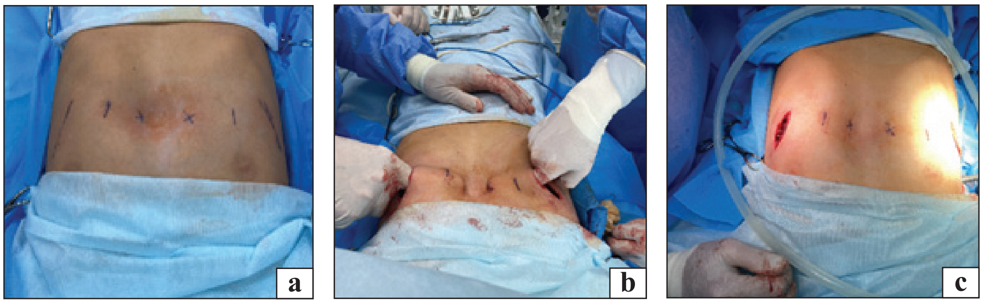

Fig. 3. Initial stages of thoracoplasty: a — marking of the operative field; b — formation of submuscular tunnels on both sides; c — right-sided thoracoscopy

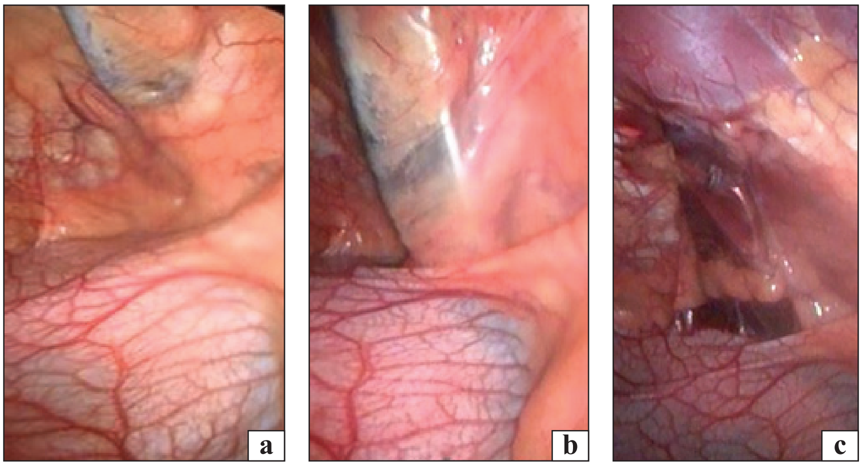

Fig. 4. Extrapleural stages of thoracoplasty under the control of thoracoscopy: a — immersion of the conductor into the retrosternal space; b — formation of extrapleural tunnel; c — carrying out the corrective plate

Fig. 5. Final stages of deformation correction: a — the conductor is attached to the plate; b — plate rotation by 180°; c — deformation correction

S10 of the left lung, and in another case, emphysematosis of the lower segment of the left lung with a size of 8–27 mm without clinical signs. Neither required additional medical or surgical treatment.

After the operation, the correction of chest deformation was on average (2.35 ± 0.22) according to the Haller index, which was statistically significantly ($p = 0.001$) different from the initial level.

At the time of writing the article, 47 (58.02 %) patients completed treatment. The correction period was on average (2.6 ± 1.0) years, from 1.7 to 5.0 years.

Discussion

The original technique of thoracoplasty according to D. Nuss, which included the elevation of the sternum due to the retrosternal correction plate, without resection of the costal cartilages, was proposed in 1998.

Given the "blind" insertion of the plate, there was a high risk of damage to the mediastinal organs, primarily the heart and pericardium, which prompted modifications aimed at increasing the safety of surgical intervention.

The first modification, which consisted in the use of thoracoscopy for evaluation of the pleural cavity, visualization of the mediastinum, tunnel formation and control of the plate, was recommended by D. Nuss in 2002 [15]. Another monocenter study on the use of thoracoscopic control, which lasted from 2005 to 2015, in 95 patients, proved that the frequency of serious complications decreased from 16.1 to 3.16 % [16]. We agree with the authors regarding right-sided thoracoscopy that its performance is sufficient for safe passage of the conductor, formation of the extrapleural channel behind the sternum, installation of the plate and its rotation with elimination of deformation. In our opinion, artificial pneumothorax with the help of inflation of the lungs, the use of low parameters of their ventilation during standard intubation of patients with one endotracheal tube allow to sufficiently visualize the operative access to the retrothoracic space, the location of the heart, mediastinum, lungs and diaphragm. But in the literature there are cases of heart damage during right-sided thoracoscopy in the case of severe asymmetric deformations and after open operations on the chest for heart malformations. 1 (0.2 %) heart perforation and 8 (1.3 %) pericarditis were detected during surgical correction of CPE in 639 patients [17]

K. Pawak et al. performed the procedure according to D. Nuss with left-sided thoracoscopy in 1,006 patients with CPE. In their opinion, most of the heart is located in the left pleural cavity, so correct intraoperative assessment is crucial for correct insertion of the conductor, which subsequently prevents mediastinal injury. Left-sided thoracoscopy has an advantage over right-sided thoracoscopy but does not reduce the risk of cardiac injury [18]. Bilateral thoracoscopy according to P. Lo et al. gives a possibility to monitor the passage of the plate at all stages from both sides and helps determine its location [19]. However, other authors (S. O. Senica) report on heart perforation in a 12-year-old girl with severe asymmetric CPE using bilateral thoracoscopy. This proves that the latter has no advantages over one-sided, due to the possibility of heart damage. The literature describes 16 cases of heart injury during surgery according to D. Nuss [20].

Thoracoscopic extrapleural modification proposed by K. Schaarschmidt includes bilateral thoracoscopy, exclusively extrapleural placement of the plate and its fixation with at least 10 pericostal sutures [21]. We agree with the author that this arrangement of the plate has advantages, because there is no direct contact of the plate with the visceral pleura, lungs and pericardium, which can contribute to the development of secondary pneumothorax or effusion in the pleural cavity and pericardium. The result of using this modification is the absence of secondary pneumothoraxes, seroma, effusion in the pleural cavity and a reduction in the number of pericarditis cases to 0.65 % compared to the original method (2.43 %). In our study, we did not observe these complications from the side of the lungs and pericardium. We believe that the location of the plate in the extrapleural tunnel is better, it is more physiological and safer, which makes it possible to prevent life-threatening complications.

The appropriate place for the introduction of the thoracoscopic camera and its location at an angle of 30° or 45° is another component of the safety of surgical correction of CPE. D. Nuss et al. [15] and N. Mennie et al. [16] recommended placing the trocar in the midaxillary line, that is, behind the standard approach, but, in our opinion, under such conditions, visualization is insufficient, the heart, lungs, and diaphragm are obstructed, especially in the case of significant asymmetric deformations. We introduce the trocar in the anterior axillary line above the skin incision, which allows us to avoid damage to the anatomical structures of the mediastinum, to obtain enough free operating space and to have a good visualization of the guide and the plate for their passage.

Surgical complications in CPE are determined according to the Clavien-Dindo classification. K. Pawak et al. indicated early postoperative complications in 35.6 % of cases, which belonged to grades 1 and 2, life-threatening complications were observed in 2 patients who required repeated interventions [18]. J. Han et al. early postoperative complications of the first degree were diagnosed in 17.4 % [22]. Complications observed in our center are classified as grade 1 (6.17 %), which indicates the sufficient safety of using the modified technology of surgical correction of CPE.

Conclusions

The results showed that all patients had no life-threatening complications, and early postoperative complications in 6.17% of cases had no clinical significance because they did not require surgical correction.

Thus, the obtained results of the monocenter clinical approbation of the proposed modified surgical correction technology make it possible to recommend it as meeting the safety requirements for implementation due to the high efficiency and reliability of the obtained result during the surgical treatment of congenital pectus excavatum in children.

Conflict of interest. The authors declare no conflict ofinterest.

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TECHNOLOGY OF MINIMALLY INVASIVE SURGICAL CORRECTION FUNNEL-SHAPED DEFORMATION OF THE CHEST IN CHILDREN

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