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Original Article

Effect of minimally invasive repair of pectus excavatum on postoperative chest flatness, cardiopulmonary function, and bone metabolism indexes in children at different ages

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Abstract: Objective: To observe the effects of minimally invasive surgical repair of pectus excavatum (NUSS) on the degree of chest flatness, cardiopulmonary function, and bone metabolism indexes in children of various age groups. Methods: In this retrospective study, 62 children with pectus excavatum admitted to our hospital were divided into two groups: group A (3-12 years old) and group B (>12 years old), with 31 cases in each group. All of them were treated with NUSS. The treatment effectiveness, perioperative indexes (operation time, blood loss, ground time, and hospitalization time), degree of chest flatness, cardiopulmonary function, bone metabolism indicators, and complications were compared between the two groups. Results: There was no significant difference between patients in the two groups in terms of operation time, blood loss, ground time, and hospitalization time (all P>0.05). The overall response rate to treatment in group A (93.55%) was higher than that of group B (70.97%; P<0.05). Three months after the operation, the chest flatness as well as serum alkaline phosphatase and its bone isoform levels in both groups were decreased, while left ventricular ejection fraction, cardiac index, stroke volume, FEV1, and peak expiratory flow levels were increased compared to before the operation, and the improvement in the above indicators of group A was better than Group B (all P<0.05). There was no significant difference in the incidence of complications between the two groups (16.13% *vs.* 9.68%; P>0.05). Conclusion: NUSS surgery can achieve satisfactory results in treating children with pectus excavatum at different ages. However, in a certain age range, a younger age indicates a better effect. NUSS procedure effectively improves postoperative flat chest, cardiopulmonary function, and bone metabolism indexes.

Keywords: Minimally invasive surgery of pectus excavatum, different ages, the degree of flat chest, cardiopulmonary function, bone metabolism index, complications

Introduction

Pectus excavatum is a common chest wall deformity. It is mainly characterized by sternal depression, which accounts for about 90% of children's chest wall deformities. The disease is difficult to detect when the symptoms of compression of the pectus excavatum are mild in infancy. Some children only have inspiratory stridor and sternal aspiration depression, and there is no respiratory tract obstruction [1]. Due to the thinness of young children, pediatric patients are prone to upper respiratory tract infection. As the disease progresses, the infection can further compress the heart and lungs, and cause respiratory difficulty, chest pain, and palpitation due to declines in cardiopulmonary function [2, 3]. If the disease progresses to a serious degree, in addition to thoracic deformities, there will be special body problems such as hunchback and abdominal protrusion, which seriously affect the psychological and physical health of children [4]. Research showed that children's age is closely related to the degree of thoracic deformity depression [5]. The older the age is, the higher the degree of external thorax flatness will be with worse postoperative treatment effect. Therefore, the option of an effective surgical method is of great significance for improving the surgical effect in children of different ages, shortening recovery time, and effectively improving the postoperative degree of chest flatness.

At present, the clinical treatment of pectus excavatum is mainly based on surgical methods. The traditional methods are mainly sterno-turnover operation and sternal lift (Ravitch). The former is seldom used clinically because of tremendous trauma, more intraoperative bleeding, and higher risk of postoperative complications such as abnormal breathing, sternal infection, and necrosis [6]. Although the latter is suitable for patients of all ages and any malformation, the long surgical incision, serious complications such as abnormal breathing and thoracic stenosis still occur after the operation, and thus it has limited clinical application [7]. Minimally invasive surgical correction of pectus excavatum (NUSS) has become the most widely used method in recent years. It mainly supports the sternum through a prefabricated shaping steel plate, creating a minimally invasive operation without cutting costal cartilage and sternal osteotomy [8, 9]. However, at present, the ideal surgical age is still controversial. Given this, this study observed the effects of NUSS on postoperative flat chest, cardiopulmonary function, and bone metabolism indexes in different age groups, which can be used as a reference for both clinical selection of the operation timing and prediction of postoperative efficacy.

Materials and methods

General data

Approved by Guangdong Women and Children Hospital Medical Ethics Committee (No. 2022-01083), this retrospective study analyzed clinical data of 62 children with pectus excavatum treated in our hospital from March 2017 to February 2021. They were divided into group A (3-12 years old) and group B (>12 years old), with 31 cases in each group. The patients' family members were informed of the research contents and signed informed consent form.

Inclusion and exclusion criteria

Inclusion criteria: (1) Patients whose pectus excavatum met the relevant diagnostic criteria in the Chinese Expert Consensus on the Surgical Treatment of Pectus excavatum [9]. (2) Patients who received surgical treatment for the first time and their symptoms met the surgical indications. (3) The clinical data of all patients were complete.

Exclusion criteria: (1) Patients who had other respiratory system diseases or diseases that may cause respiratory dysfunction except for pectus excavatum. (2) Patients who had coagulation dysfunction. (3) Patients who had severe hepatic or renal dysfunction; (4) Patients who participated in other studies at the same time or could not cooperate with the medical staff.

Treatment methods

All the children underwent NUSS procedure. The details were as follows. The children lay supine on the operating table with both upper limbs maintained at a 90° angle. The surgery was conducted under general anesthesia with endotracheal intubation. The lowest point of the sternum was used as the steel plate penetration position and marked, and the highest point of the sternum was used as the steel plate exit position and also marked before the operation. The bender was used to make a steel plate of appropriate length into an appropriate curvature, parallel to the lowest part of the sternum depression. Two transverse incisions of about 2-3 cm in length were made at the intersection with the axillary midline of the chest wall. The intercostal muscles were separated, and the steel plate passed through the left tunnel, intercostal space, and sternal depression in turn under the guidance of the guide and finally exited at the highest point of the edge of the right side of the depression. The steel plate should adhere to the front chest wall and not enter the chest cavity when passing through the chest. After the right tunnel was passed through, the guide's front end was connected to one end of the plastic steel plate. During the connecting process, the steel plate concavity was kept upward and it was ensured that it enter the left tunnel. When the steel plate reached the depression of the sternum, it was turned horizontally by a 180° angle, and the convex surface of the steel plate was directly pushed up the chest wall for shaping. Operators should ensure that both ends of the steel plate are closely attached to the gap between the chest walls and fixed. According to the age, a one end fixed piece or two-side fixed piece were used for fixation. After the operation, all children were given analgesia, and their families were told that children were prohibited from tumbling and bending within seven days. Bending and moving objects were prohibited within two months. According to the individual differences of the children, the steel plate was usually removed in two years, and the indwelling time of the steel plate was prolonged for those with older age or severe deformity.

Outcome measures

All the children underwent outpatient review once a month after discharge, during which patients were followed up, and the prognosis of the patients was assessed by cardiopulmonary function and degree of thoracic flattening.

<u>*Primary outcome measures*</u>

Surgical effects: The effect of the operation was evaluated two days after the operation. It was defined as markedly effective when the child's sternum was plump and smooth, with no depression, no residual sternal depression and better thoracic elasticity, when the position of the fixed plate and the steel plate were normal according to the chest X-ray examination. Effectiveness indicated that the child's sternum was slightly depressed, the fixation plate and the steel plate had no displacement, and the degree of residual sternal depression was less than 20% before the operation through chest X-ray examination. Ineffectiveness meant that the child's sternum was collapsed, the appearance of the chest was deformed, and the fixation plate and the steel plate were shifted seriously. Total effective rate = (significantly effective number of people + effective number of people)/total number of people *100%.

Cardiopulmonary function: The JQ-H cardiac function tester (Hefei Jianqiao Medical Electronics Co., Ltd., Wanxie Zhuzhun 20162210-287) was used to detect left ventricular ejection fraction (LVEF), cardiac index (CI), and stroke volume (SV) before and 3 months after the operation. CI ($L/(min \cdot m^2)$) = (heart rate (beats/min) × stroke index (mL/m^2))/1,000. The percentage of forced expiration (FEV1), vital capacity (VC), and peak flow rate (PEF) before and 7d after the operation were measured by Spirostik Complete pulmonary function meter (German Gretel Pulmonary Function Priority Company, National Instruments Injection 20152070890).

Chest flatness degree: The funnel index (FI) before and 3 months after the operation was calculated according to the Wada Shoulang method. FI = funnel depression external edge longitudinal diameter length (cm) × funnel depression external edge transverse diameter length (cm) × the length of the horizontal line of the outer edge of the funnel depression to the deepest part of the depression (cm)/sternal length (cm) × sternal transverse diameter (cm) × the shortest distance from the posterior edge of the sternal angle to the anterior edge of the extraction. FI<0.1 means mildly flat; FI is moderately flat between 0.1 and 0.2; FI is severely flat between 0.2 and 0.3; FI>0.3 is extremely severe flattening.

Bone metabolism index: A total of 5 mL of fasting venous blood of the two groups before and 3 months after the operation was collected in the early morning. After centrifugation at 3,000 r/min for 10 min, the serum was collected and stored in an environment at -80°C for examination. BS-850 automatic biochemical analyzer (Shenzhen Mairui Biomedical Electronics Co., Ltd., Yuexie Zhuzhun 20172401214) was used to detect alkaline phosphatase (ALP) level. The whole blood dry chemistry and immunoconcentration technology were used to detect bone alkaline phosphatase (BALP) activity.

<u>*Secondary outcome measures*</u>

(1) The perioperative indicators, including operation time, blood loss, underground activity time, and hospitalization time in the two groups were recorded.

(2) Postoperative complications such as pneumothorax, subcutaneous effusion, atelectasis, and stent displacement were recorded for patients in the two groups.

The total incidence of complications = the number of complication cases/the total number of people *100%.

Table 1. Comparison of general data n/($\bar{x}$±sd)

Group	Gender (Male/Female)	Age (years)	Severity (Moderate/Severe/Extremely severe)	Funnel chest typing (Symmetrical/Asymmetric)
Group A (n = 31)	25/6	6.4±0.8	18/12/1	29/2
Group B (n = 31)	24/7	14.7±2.1	16/13/2	27/4
χ^2/t	0.097	19.078	0.251	0.738
P	0.755	<0.001	0.698	0.390

Table 2. Comparison of perioperative related indexes between the two groups ($\bar{x}$±sd)

Group	Operation time (min)	Blood loss (mL)	Ground activity time (d)	Hospitalization time (d)
Group A (n = 31)	32.23±5.85	8.71±4.62	1.45±0.73	7.24±0.62
Group B (n = 31)	31.85±4.79	8.42±3.73	1.58±0.66	7.17±0.54
t	0.280	0.272	0.735	0.474
P	0.780	0.787	0.465	0.637

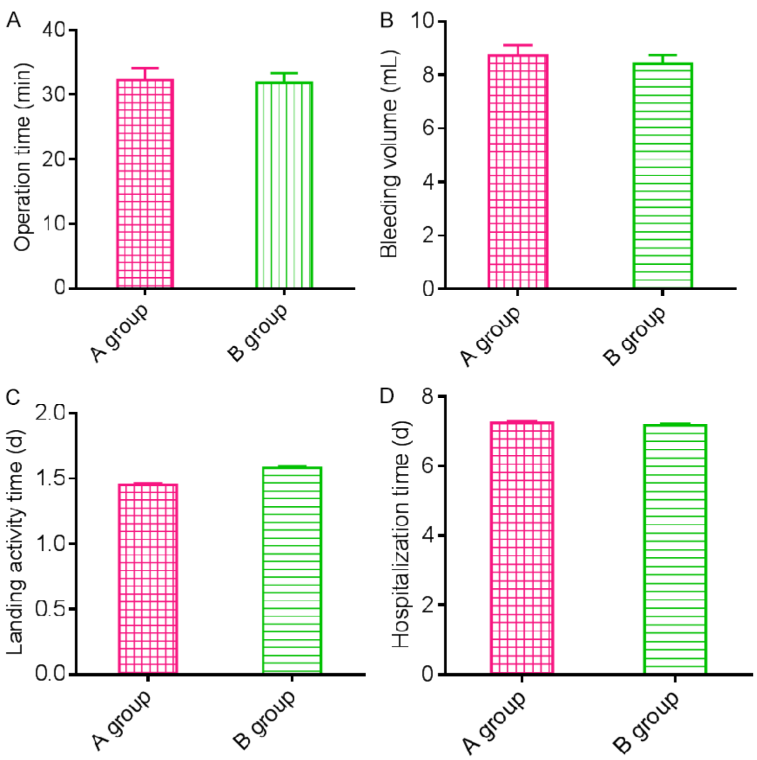

Figure 1. Comparison of perioperative related indexes between the two groups. A: Operation time (min); B: Blood loss (mL); C: Ground activity time (d); D: Hospitalization time (d).

Statistical analyses

SPSS 23.0 was used for statistical analysis. The counted data were expressed as a percentage and analyzed with χ^2 test. The measured data were expressed as ($\bar{x}$±sd). The independent sample t-test and paired sample t-test were used for comparison between the two groups and within the same group, respectively. P<0.05 indicated that a difference was significant.

Results

General data

Except for age, the two groups had a good balance of other general data (all P>0.05), as shown in **Table 1**.

Perioperative indexes

There were no significant differences in terms of operation time, blood loss, ground time, and hospitalization time between the two groups (all P>0.05). See **Table 2** and **Figure 1**.

Surgical outcome

The total effectiveness rate of treatment in group A (93.55%) was higher than that of group B (70.97%; P<0.05). It can be seen that the younger age indicated the better surgical effect. See **Table 3**.

Flat chest degree

The postoperative flat chest degrees of the two groups were decreased 3 months after the operation compared with that before the opera-

Table 3. Comparison of surgical effects between the two groups (n, %)

Group	Significant effect	Effective	Ineffective	Total effective rate
Group A (n = 31)	25 (80.65)	4 (12.90)	2 (6.45)	29 (93.55)
Group B (n = 31)	19 (61.29)	3 (9.68)	9 (29.03)	22 (70.97)
χ^2	-	-	-	5.415
P	-	-	-	0.020

Table 4. Comparison of preoperative and postoperative degree of chest flatness between the two groups ($\bar{x}\pm sd$)

Group	Before the operation	Three months after the operation
Group A (n = 31)	4.24±1.31	2.43±0.36***
Group B (n = 31)	4.18±1.43	3.45±0.42***
t	0.172	10.266
P	0.864	<0.001

Note: Compared to before the operation, ***P<0.001.

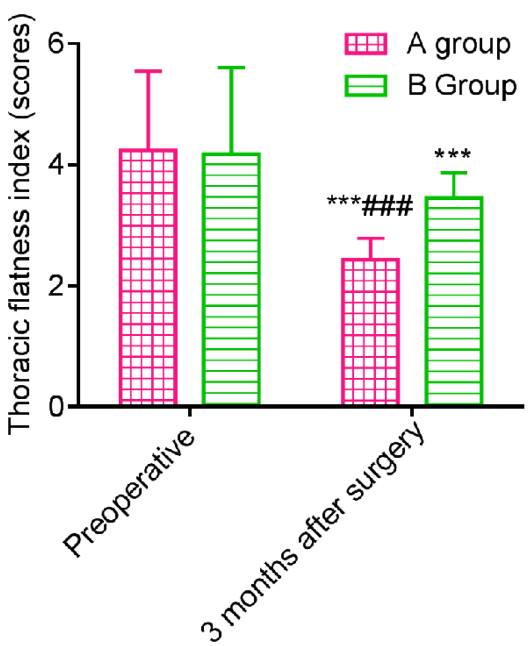

Figure 2. Comparison of preoperative and postoperative chest flatness degree between the two groups. Compared to before the operation, ***P<0.001; compared to group B, ###P<0.001.

tion, and that of group A was lower than that of group B (P<0.001). It was revealed that the younger the age was, the better the improvement of postoperative chest flatness would be. See **Table 4** and **Figures 2-4**.

Cardiopulmonary function

The levels of LVEF, CI, SV, and PEF in both groups were increased 3 months after the operation compared to those before the operation, and those in group A were higher than those in group B (all P<0.05). The younger the age was, the more significant the improvement of cardiopulmonary function. See **Table 5**.

Bone metabolism index

Compared to those before the operation, the serum ALP and BALP levels in both groups decreased three months after the operation, but those of group A were lower than those of group B (all P<0.001). It was shown that the younger the age was, the more obvious the improvement of bone metabolism indexes would be. See **Table 6**.

Complications

There was no significant difference in the total incidence of complications between the two groups (P>0.05). It can be seen that NUSS procedure was safe, and the risk of complications did not increase due to a younger age. See **Table 7**.

Discussion

As a common chest deformity, pectus excavatum accounts for about 90% of children's chest wall deformities, which not only affects the appearance but also leads to chest volume reduction, non-expansion limitation, cardiac compression, and displacement due to depressed sternum and costal cartilage. This affects the cardiopulmonary function and seriously affects children's physical and mental health of [10, 11]. NUSS procedure is the primary treatment method for children's pectus excavatum. It does not cut the sternum and costal cartilage. Compared with traditional surgery, NUSS procedure has the characteristics of less bleeding, less trauma, and quicker recovery after the operation. It can effectively maintain the elasticity, expansibility, and stretch ability of the chest. It is favored by the majority of patients and clinicians [12-14].

At this stage, there is still some controversy about the ideal age for NUSS surgery in chil-

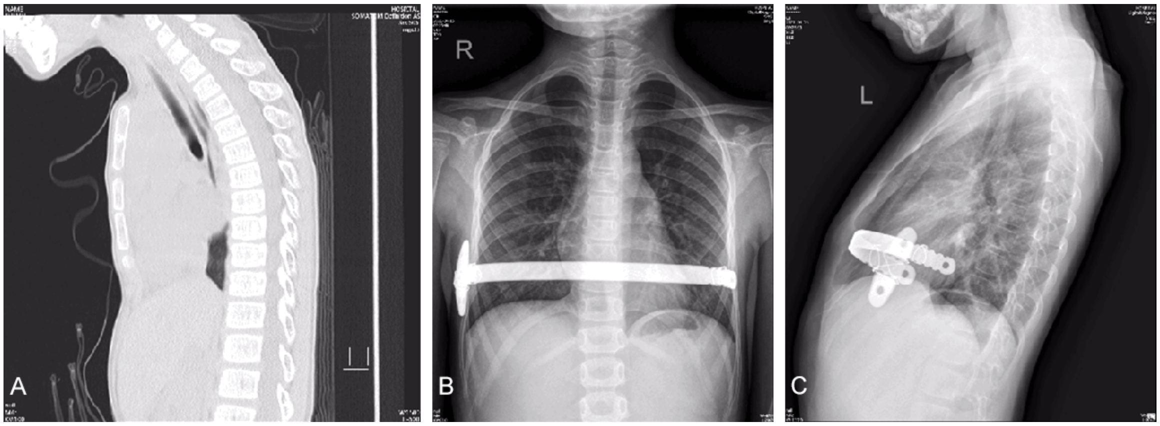

Figure 3. Contrast radiographs of a 6-year-old child before and after surgery. A: Before the operation; B: 1 month after the operation; C: 3 months after the operation.

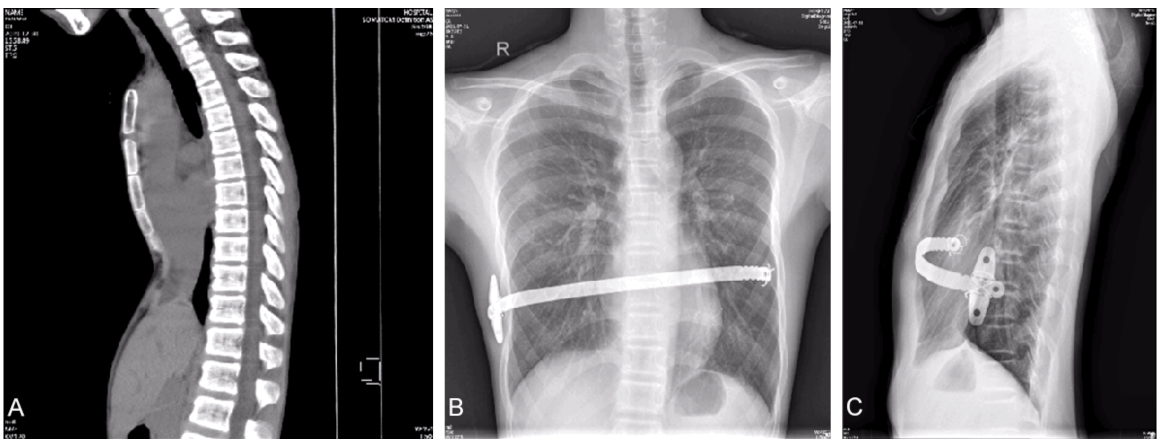

Figure 4. Contrast radiographs of a 14-year-old child before and after surgery. A: Before the operation; B: 1 month after the operation; C: 3 months after the operation.

dren with pectus excavatum. Most studies believed that the optimal age for surgery was 2-5 years old, while other studies supported 6-12 years old [15-17]. Due to the slow recovery of surgery for pectus excavatum, it is difficult to determine whether there is a stable response in the short term. Therefore, we conducted a follow-up for 3 months after the surgery to evaluate the outcome 3 months after the operation. This study showed that the total effective rate, LVEF, CI, SV, FEV1, and PEF levels of group A were higher than those of group B, and there were no significant differences in perioperative indexes and complications. Zhu et al found that the excellent and good rates of NUSS surgery for children aged 4-7, 8-12, and over 12 years old with pectus excavatum were 96.77%, 90.32%, and 80.64%, respectively [18]. The younger the age is, the higher the excellent and good rate of surgery will be, which is consistent with the results of this study.

It is suggested that NUSS operation achieves satisfactory results in treating pediatric pectus excavatum of different ages. But the younger the age, the better the effect, and the higher the safety. The reason may be related to the early treatment of pectus excavatum by NUSS operation, which can effectively improve the appearance of chest wall deformities, alleviate children's inferiority feeling, and can remove the effect on cardiopulmonary function as early as possible to avoid cumulative cardiopulmonary function damage in adults [19].

It has been clinically found that with the increase of the age of children with pectus excavatum, their thoracic deformities get worse,

Table 5. Comparison of cardiopulmonary function between the two groups before and after the operation ($\bar{x}$±sd)

Group	Group A (n = 31)	Group B (n = 31)	t	P
LVEF (%)				
Before the operation	40.28±5.34	40.67±5.16	0.292	0.771
Three months after the operation	67.31±5.18*	58.36±4.74*	7.097	<0.001
CI (L/min·m^2)				
Before the operation	2.15±0.32	2.13±0.23	0.283	0.778
Three months after the operation	4.17±0.13*	3.20±0.16*	26.197	<0.001
SV (mL)				
Before the operation	35.24±2.35	35.48±2.63	0.379	0.706
Three months after the operation	62.43±3.44*	49.78±2.62*	16.288	<0.001
FEV1%pred				
Before the operation	65.42±4.31	66.23±4.65	0.711	0.480
Three months after the operation	84.36±3.24*	75.33±4.21*	9.464	<0.001
VC (L)				
Before the operation	0.78±0.14	0.75±0.15	0.814	0.419
Three months after the operation	1.68±0.70*	1.35±0.42*	2.521	0.028
PEF (L)				
Before the operation	2.74±0.37	2.65±0.32	0.427	0.671
Three months after the operation	3.68±0.62*	3.05±0.67*	3.301	0.002

Note: LVEF: left ventricular ejection fraction; CI: cardiac index; SV: stroke volume; FEV1: forced expiratory volume in one second; VC: vital capacity; PEF: peak flow rate. Compared to before the operation, *P<0.05.

Table 6. Comparison of ALP and BALP indexes between the two groups before and after the operation ($\bar{x}$±sd, U/L)

Group	ALP		BALP	
	Before the operation	Three months after the operation	Before the operation	Three months after the operation
Group A (n = 31)	494.26±82.43	322.36±30.72***	265.31±30.74	158.44±20.72***
Group B (n = 31)	491.18±80.37	405.29±30.83***	264.77±32.45	190.37±16.62***
t	0.149	6.022	0.067	10.076
P	0.882	<0.001	0.947	<0.001

Note: Compared to before the operation, ***P<0.01.

Table 7. Comparison of complications between the two groups (n, %)

Group	Pneumothorax	Subcutaneous effusion	Atelectasis	Stents shifting	Total incidence rate
Group A (n = 31)	2 (6.45)	1 (3.23)	1 (3.23)	1 (3.23)	5 (16.13)
Group B (n = 31)	1 (3.23)	0 (0.00)	1 (3.23)	1 (3.23)	3 (9.68)
χ^2					0.574
P					0.707

and the thorax becomes more flat, and the improvement of the degree of thoracic flattening is not obvious, which affects the effectiveness of operation [20]. It can be seen that the early improvement in chest flatness in children with pectus excavatum is of great significance for improving the effectiveness of operation and promoting physical recovery. This study showed that compared to those before the operation, the degree of chest flatness was decreased in both groups three months after the operation. That of group A was lower than that of group B, which was basically consistent with the relevant research results [21]. It was suggested that the earlier the NUSS surgery is performed, the more obvious the improvement in the degree of thoracic flatness in children with pectus excavatum. The reason may be that an earlier operation time stops the progressive aggravating factors of thoracic flatness, and then the degree of thoracic flatness can be improved [22, 23]. A study has shown that the abnormal growth of the anterior chest wall in children with pectus excavatum is related to a disorder of bone metabolism, especially ALP and BALP metabolic disorders [24]. ALP and BALP are important indicators of bone metabolism. Among them, BALP is an extracellular osteoblast enzyme, mainly derived from the vigorously growing bones. It can hydrolyze phosphate esters during osteogenesis and change in the early stage of pectus excavatum [25]. As a zinc-containing protein, ALP is widely distributed in human bones and plays an important role in osteogenesis. In this study, compared to those before the operation, the serum ALP and BALP levels in both groups decreased three months after the operation, but those in group A were lower than those of group B. This suggests that an earlier NUSS operation led to a more obvious the improvement in bone metabolism indexes in children with pectus excavatum.

However, due to the small number of samples collected and short observation time in this study, the long-term efficacy and prognosis of NUSS operation in children with pectus excavatum were not evaluated, and the mechanism of the effect of NUSS operation on the bone metabolism indexes of children with pectus excavatum has not been studied. In the future, the number of samples can be increased in clinical practice and the observation time can be extended for in-depth discussion.

To sum up, NUSS procedure achieves satisfactory results for treating children with pectus excavatum at different ages. However, within a certain age range, the younger the age is, the better the effect will be. Besides, NUSS procedure effectively improves the postoperative chest flatness, cardiopulmonary function, and bone metabolism indexes.

Disclosure of conflict of interest

None.

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References

[1] Matsuura R, Tazuke Y, Ueno T, Yamanaka H, Takama Y, Saka R and Okuyama H. Can plain chest X-ray replace computed tomography for the follow-up of children who have undergone the NUSS procedure? Surg Today 2020; 50: 1249-1254.

[2] Stearns JD, Twaibu J, Kwaku D, Pizziconi V, Abbas J, Gotimukul A and Jaroszewski DE. Efficacy of standard chest compressions in patients with NUSS bars. J Thorac Dis 2020; 12: 4299-4306.

[3] Häcker FM. Nonsurgical treatment of chest wall deformities: contradiction or complement? Eur J Pediatr Surg 2018; 28: 369-372.

[4] Lo P, Tzeng IS, Hsieh MS, Yang MC, Wei BC and Cheng YL. The NUSS procedure for pectus excavatum: an effective and safe approach using bilateral thoracoscopy and a selective approach to use multiple bars in 296 adolescent and adult patients. PLoS One 2020; 15: e0233547.

[5] Mao YZ, Tang ST and Li S. Comparison of the NUSS versus ravitch procedure for pectus excavatum repair: an updated meta-analysis. J Pediatr Surg 2017; 52: S0022346817303469.

[6] Ben XS, Deng C, Tian D, Tang JM, Xie L, Ye X, Zhou ZH, Zhou HY, Zhang DK, Shi RQ, Qiao B and Chen G. Multiple-bar NUSS operation: an individualized treatment scheme for patients with significantly asymmetric pectus excavatum. J Thorac Dis 2020; 12: 949-955.

[7] Shi HC, Sun C, Liang YS and Shi WP. Thoracoscope-assisted orthopedic plate implantation for sternal lift in the treatment of adolescent pectus excavatum: a report of 7 cases. Chin J Gen Pract 2008; 7: 851-852

[8] Bodenstein L and Notrica DM. Use of a capture-guidance surgical instrument to minimize muscle stripping during nuss repair of pectus excavatum. J Laparoendosc Adv Surg Tech A 2019; 29: 865-868.

[9] Cardiothoracic surgery Group of Pediatric surgery Branch of Chinese Medical Association; Thoracic surgery Branch of Guangdong Medical Association. Consensus of Chinese experts on surgical treatment of pectus excavatum. Chin J Pediat surg 2020; 31: 7-12.

[10] Yang G, Deng X, Yang Y and Wang JH. The NUSS procedure for pectus excavatum during atrial septal defect closure through a minimal

right oblique infra-axillary thoracotomy: a case report. Medicine 2019; 98: e13874.
[11] Zhang Q, Zeng Q, Zhang N, Chen CH, Yu J, Sun JH and Peng Y. A comparative study of thoracic indexes between 17-year-old children with pectus excavatum and healthy children. Chin J Thorac Cardiovasc Surg 2019; 35: 641-644.
[12] Bryskin RB, Robie DK, Mansfield FM, Freid EB and Sukumvanich S. Introduction of a novel ultrasound-guided extrathoracic sub-paraspinal block for control of perioperative pain in NUSS procedure patients. J Pediatr Surg 2017; 52: 484-491.
[13] Lin KH, Huang YJ, Hsu HH, Lee SC, Huang HK, Chen YY, Chang H, Chen JE and Huang TW. The role of three-dimensional printing in the NUSS procedure: three-dimensional printed model-assisted NUSS procedure. Ann Thorac Surg 2018; 105: 413.
[14] Huang YJ, Lin KH, Chen YY, Wu TH, Huang HK, Chang H, Lee SC, Chen JE and Huang TW. Feasibility and clinical effectiveness of three-dimensional printed model-assisted NUSS procedure. Ann Thorac Surg 2018; 1077: 1089-1096.
[15] Graves CE, Moyer J, Zobel MJ, Mora R, Smith D, O'Day M and Padilla BE. Intraoperative intercostal nerve cryoablation during the NUSS procedure reduces length of stay and opioid requirement: a randomized clinical trial. J Pediatr Surg 2019; 54: 2250-2256.
[16] Li M. Research progress on the optimal age of NUSS operation for pectus excavatum in children. Int J Pediat 2019; 46: 887-890.
[17] Toci GR, Davis TA, Bigelow BF and Yang SC. Analyzing outcomes of nuss and ravitch repair for primary and recurrent pectus excavatum in adults. Ann Thorac Surg 2020; 110: 272-275.
[18] Löhnhardt M, Hättich A, Andresen A, Stangenberg M, Mir TS, Reinshagen K and Dreimann M. Rescue NUSS procedure for inferior vena cava compression syndrome following posterior scoliosis surgery in Marfan syndrome. Eur Spine J 2019; 28: 31-36.
[19] Zhu JL. Analysis of clinical effect of nuss on pectus excavatum in different age groups. Chin Foreign Med 2019; 38: 31-32, 38.
[20] Pawlak K, Siorowski G, Gabryel P, Smolinski S and Dyszkiewicz W. Analyzing effectiveness of routine pleural drainage after NUSS procedure: a randomized study. Ann Thorac Surg 2017; 104: 1852-1857.
[21] Zuidema WP, Oosterhuis JWA, van der Heide SM, Zijp GW, van Baren R, van der Steeg AFW and van Heurn ELWE. Early cost-utility estimation of the surgical correction of pectus excavatum with the NUSS bar. Eur J Cardiothorac Surg 2019; 55: 699-703.
[22] Meng LF and Wang MS. Thoracoscopy assisted minimally surgery (NUSS procedure) for pectus excavatum vs. novel modified NUSS procedure - a single-center retrospective study. Heart Surg Forum 2018; 21: E404-E408.
[23] Jaroszewski DE, Gustin PJ, Haecker FM, Pilegaard 3, Park HJ, Tang ST, Li S, Yang L, Uemura S, Campos GRMD, Obermeyer R, Frantz 8FW, Torre M, McMahon L, Hebra A, Chu CC, Phillips JD, Notrica DM, Messineo A, Kelly R and Yüksel M. Pectus excavatum repair after sternotomy: the chest wall international group experience with substernal NUSS bars. Eur J Cardiothorac Surg 2017; 52: 710-717.
[24] Yeh SW, Yang MC, Chang YW, Hsu YT, Tzeng IS and Cheng YL. Improved dynamics of thoracic cage and exercise capacity after NUSS repair for pectus excavatum. Thorac Cardiovasc Surg 2020; 68: 85-91.
[25] Qi SW. Comparison of minimally invasive NUSS operation and modified ravitch operation in the treatment of pectus excavatum in children. Chin Minkang Med 2020; 32: 37.