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ORIGINAL ARTICLE

CARDIAC FUNCTION DURING MINI-INVASIVE REPAIR OF PECTUS EXCAVATUM WITH THE NUSS PROCEDURE

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ABSTRACT

The aim of the study was to analyze cardiac function during Nuss procedure under the combination of general anesthesia with different variants of the regional block.

Materials and methods: The observative prospective study included 60 adolescents (boys/girls=47/13) undergone Nuss procedure for pectus excavatum correction under the combination of general anaesthesia and regional blocks. The patients were randomized into three groups (n=20 in each) according to the perioperative regional analgesia technique: standart epidural anaesthesia (SEA), high epidural anaesthesia (HEA) and bilateral paravertebral anaesthesia (PVA). The following parameters of cardiac function were analyzed: heart rate, estimated cardiac output (esCCO), cardiac index (esCCI), stroke volume (esSV) and stroke volume index (esSVI) using non-invasive monitoring.

Results: Induction of anesthesia and regional blocks led to a significant decrease in esCCO (-9.4%) and esCCI (-9.8%), while esSV and esSVI remained almost unchanged in all groups (H=4.9; p=0.09). At this stage, the decrease in cardiac output was mainly due to decreased heart rate. At the stage of sternal elevation we found an increase in esSV, which was more pronounced in the groups of epidural blocks (+23.1% in HEA and +18.5% in SEA). After awakening from anesthesia and tracheal extubation esSV was by 11% higher than before surgery without ingergroup difference.

Conclusions: The Nuss procedure for pectus excavatum correction lead to improved cardiac function. increase in stroke volume and its index were more informative than cardiac output and cardiac index which are dependent on heart rate that is under the influence of anaesthesia technique.

KEY WORDS: pectus excavatum, Nuss procedure, cardiac function, epidural anaesthesia, paravertebral anaesthesia

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INTRODUCTION

Pectus excavatum (PE) is manifested by displacement of the sternum posteriorly and occurs with a frequency of 1: 300 to 1: 1000 newborns. The most common complaint of patients is associated with a cosmetic defect, which leads to the formation of psychological complexes, but the progression of the deformity in adult age leads to restrictive respiratory failure, symptoms of heart compression, decreased exercise tolerance and posture disorders [1]. The minimally invasive repair of PE (MIRPE) by Nuss is widely used over the last decades [2]. This technique of sterno-chondrodistraction includes the placement of curved bar retrosternally under the thoracoscopic control at the level of maximal deformity. The bar is rotated by 180° with reposition of deformity and left in place for 2-3 years. The Nuss procedure is mainly performed under the combination of general anaesthesia with regional blocks such as epidural and bilateral paravertebral blocks [3, 4].

The results of the Nuss procedure for cardiorespiratory function are contradictory in the literature [5, 6, 7]. Most of the studies were focused on long-term results of Nuss procedure [8]. Given the elimination of deformity during surgery, it is expected a rapid improvement in cardiac function intraoperatively due to the release of compression of the heart chambers [9]. But there is an effect of general anesthesia and regional blocks on hemodynamics and cardiac function during Nuss procedure. No study has evaluated cardiac function in terms of the combined effect of regional blocks and Nuss procedure itself.

THE AIM

The aim of the study was to analyze cardiac function during the correction of PE by Nuss under the combination of general anesthesia with different variants of the regional block.

MATERIALS AND METHODS

The study was performed as part of the research work of the Department of Anesthesiology and Intensive Care of Danylo Halytsky Lviv National Medical University «Clinical and pathogenetic aspects of anesthesiologic guidance of surgery and intensive care in patients with affected homeostasis (№ state registration: 0115U000049. Work code IH.21.06.0001.15.). A positive conclusion on compliance with the principles of the Declaration of Helsinki, the Council of Europe Convention on Human Rights and Biomedicine, ICH GCP and relevant laws of Ukraine was received from the Commission on Bioethics of Danylo Halytsky Lviv National Medical University (Protocol №1, January 31, 2018, chaiman Prof. AY Nakonechny).

The observational prospective study included 60 patients who underwent Nuss procedure for correction of pectus excavatum at Lviv Regional Pediatric Clinical Hospital. The informed consent to participate in the study was received prior to inclusion in the study from the patients and their parents.

The inclusion criteria in the study were as follows: age from 10 to 18 years; the presence of indications for the correction of PE by Nuss, the absence of contraindications for regional methods of analgesia. The criteria for non-inclusion in the study were: contraindications or rejection of regional methods of analgesia. Before surgery, children were randomized into three groups using a random number generator (https://www.random.org) depending on the method of perioperative analgesia.

All children underwent general anesthesia with tracheal intubation and artificial lung ventilation. Propofol was used as a hypnotic agent, fentanyl – as an analgesic, and atracurium for neuro-muscular blockage. Regional blocks used for intra- and postoperative analgesia were: in the SEA group – standard epidural anesthesia with catheterization at the level of maximum deformity (Th5-Th8), in the HEA group – high epidural anesthesia with catheterization at the level of Th2-Th3, and in the PVA group – bilateral paravertebral anesthesia with catheterization at the level of maximum deformity. G18 epidural anesthesia kits (Perifix, B.Braun, Germany) were used to catheterize both the epidural and paravertebral spaces. The epidural space was identified by "loss of resistance" test, paravertebral spaces were identified under the ultrasound control. The catheter was placed cranially to a depth of approximately 3 cm. For intraoperative analgesia, bupivacaine 0.5% was used in all three groups. After a negative test dose, a bolus of the calculated dose of anesthetic was administered.

The following parameters of cardiac function were analyzed: heart rate, Estimated Continuous Cardiac Output (esCCO), Estimated Continuous Cardiac Index (esCCI), Estimated Stroke Volume (esSV) and Estimated Stroke Volume Index (esSVI) using non-invasive arterial waveform analysis monitoring (Nihon Kohden, Tokyo, Japan). The severity of PE was assessed by Haller index (HI), which is determined by the formula: maximum transverse diameter of the chest: the narrowest anterior-posterior diameter (normal = 2.5) [10].

The three patient groups were comparable in terms of demographic, anthropometric and clinical data, as well as in the duration of the operation and the amount of blood loss (table I).

STATISTICAL ANALYSIS

Statistical analysis of the obtained data was performed using Statistica 8.0 (StatSoft Inc., USA). Normality was tested using the Kolmogorov-Smirnov, Lilliefors, Shapiro±Wilk tests. Categorical variables are presented as n (%). Normally distributed continuous variables are presented as mean±standard deviation (M±σ) and the significance of the differences between the groups were evaluated using one-way analysis of variance. Non-normally distributed continuous variables are presented as median (25% and 75% percentiles), and intergroup differences were assessed by the Kruskal-Wallis test. The Wilcoxon test was used to assess the dynamics of parameters at the stages of the study. The relationship between the parameters was determined using the Spearman correlation coefficient (r). The difference between the values and the correlation was considered statistically significant at a value of P <0.05.

RESULTS

The hemodynamic parameters were analyzed at seven stages: 1 – before anaesthesia in the operating room, 2 – after induction of anaesthesia and tracheal intubation and perfoming regional blocks, 3 – after sternum elevation, 4 – after applying capnothorax, 5 – after bar rotation, 6 – after extubation of trachea, 7 – before tansportation from

Table I. Patient characteristics in groups.

Parameter	SEA group	HEA group	PVA group	Intergroup difference significance
n	20	20	20	
Data with normal distribution, mean±standard deviation (M±σ)				
Height, cm	166±10	166±12	166±7	P=0.85
Body weight, kg	54.5±13	55±11	52.9±9	P=0.86
Body mass index	19.5±2.7	20.0±2.6	19.2±2.6	P=0.62
Data with non-normal distribution, median [25% and 75% percentile]				
Age, years	14.5 [13-16]	14 [14-16]	15 [14-15]	H=0.10; p=0.81
Gender (male/female), n (%)	14/6 (70%/30%)	17/3 (85%/15%)	16/4 (80%/20%)	H=1.35; p=0.51
Haller index	3.8 [3.5-4]	3.9 [3.6-4.6]	3.8 [3.6-4]	H=1.92; p=0.38
Physical status by ASA, class	1 [1-1.5]	1 [1-1.5]	1 [1-1]	H=1.84; p=0.40
Surgery duration, min	85 [80-90]	85 [80-90]	80 [75-90]	H=0.19; p=0.91
Blood loss, ml	70 [55-75]	60 [55-80]	70 [70-80]	H=2.78; p=0.25

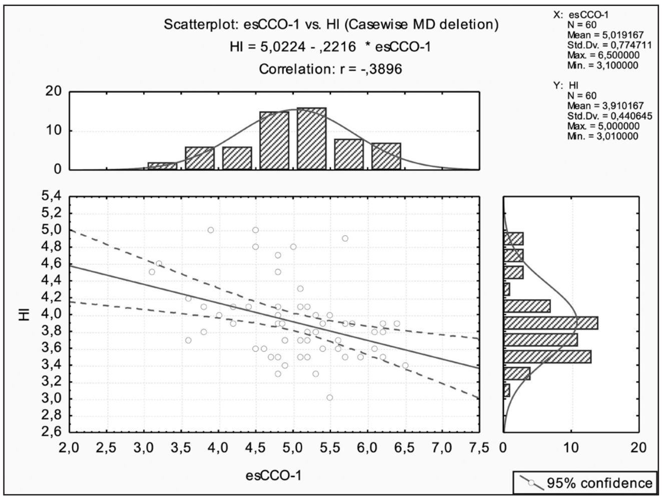

Fig. 1. The correlation between esCCO-1 and HI.

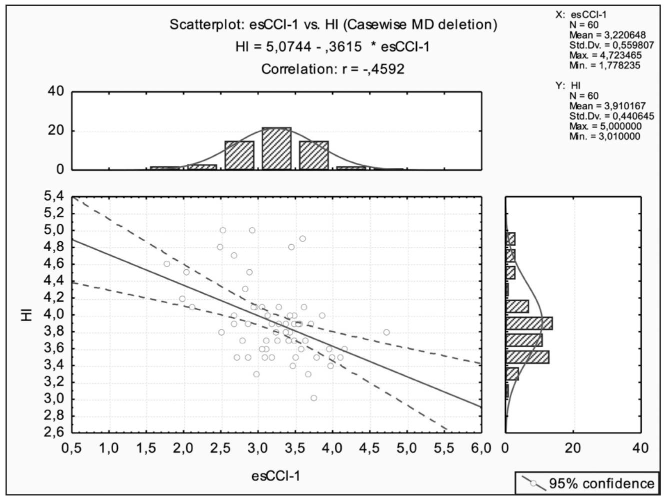

Fig. 2. The correlation between esCCI-1 and HI.

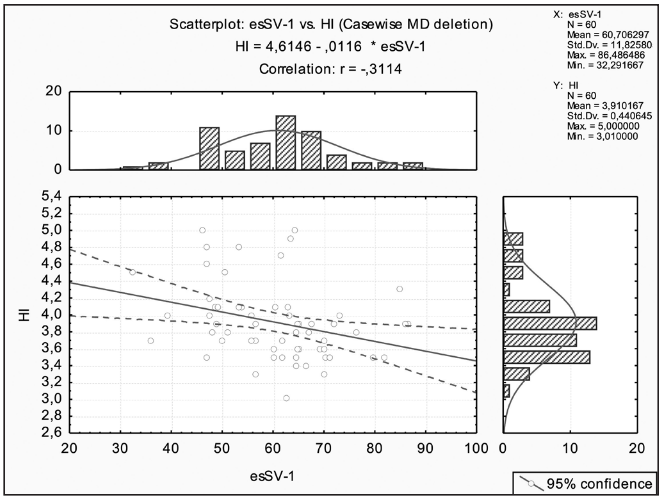

Fig. 3. The correlation between esSV-1 and HI.

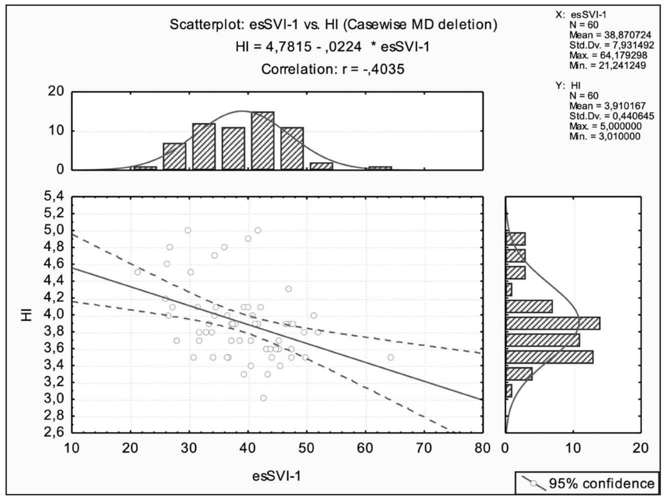

Fig. 4. The correlation between esSVI-1 and HI.

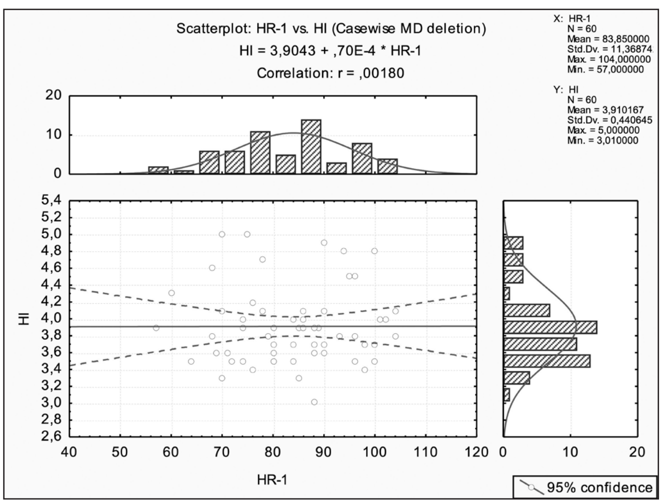

Fig. 5. The correlation between HR-1 and HI.

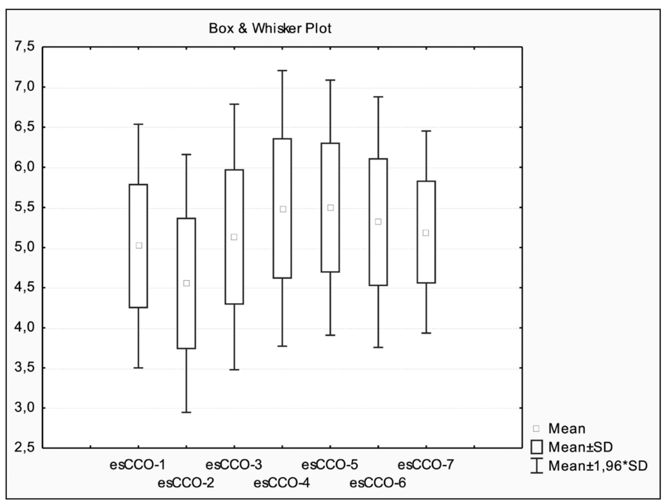

Fig. 6. The dynamics of esCCO, L/min.

operating room. The initial hemodynamic parameters at the stage 1 did not differ between three groups (p>0.05).

The esCCO-1 at the initial stage before anaesthesia and surgery had moderate negative correlation with the severity of PE by Haller index: r = – 0.39, p= 0.002 (fig. 1).

The esCCI-1 had stronger negative correlation with HI than esCCO-1: r = – 0.46, p < 0.0001 (fig. 2).

The esSV-1 at the initial stage before anaesthesia and surgery had moderate negative correlation with the severety of PE by Haller index: r = – 0.31, p= 0.015 (fig. 3).

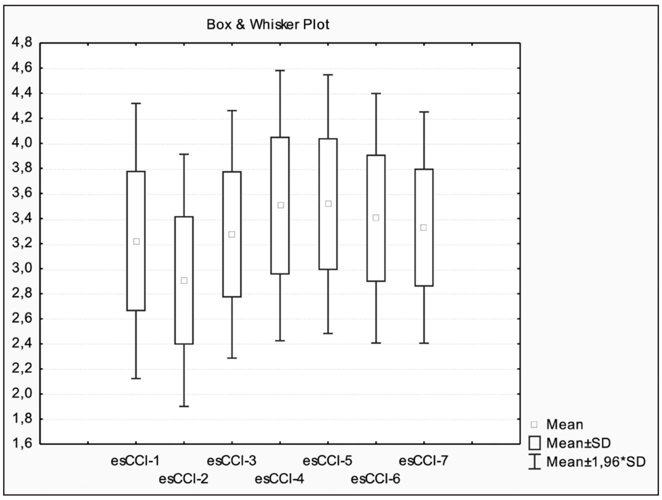

Fig. 7. The dynamics of esCCI, L/min/m^2.

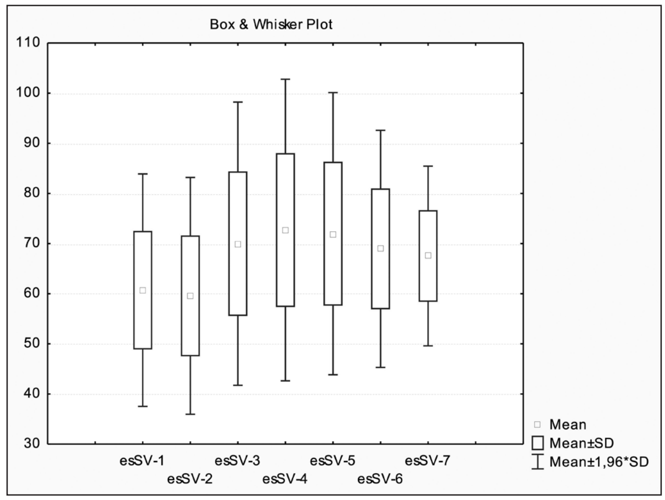

Fig. 8. The dynamics of esSV, ml.

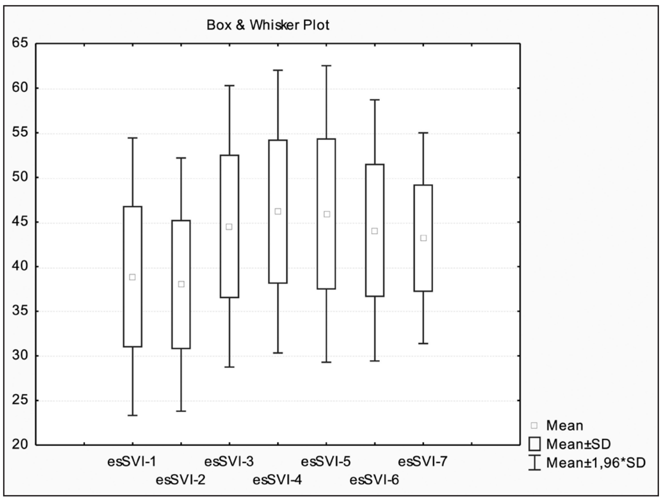

Fig. 9. The dynamics of esSVI, ml/m^2.

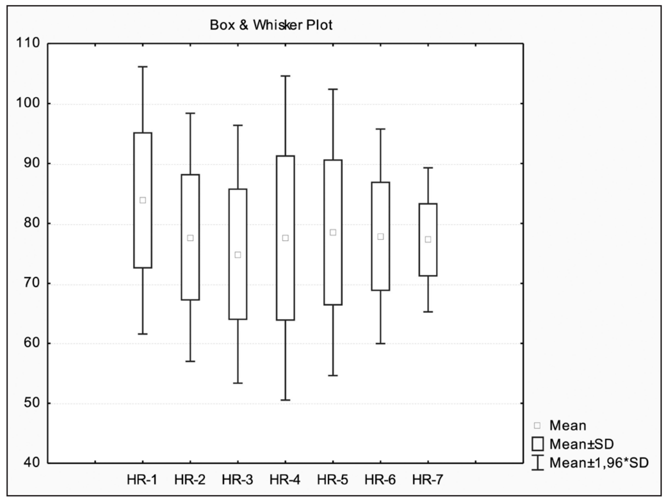

Fig. 10. The dynamics of HR, beats/min.

The esSVI-1 had stronger negative correlation with HI than esSV-1: r = – 0.40, p = 0.001 (fig. 4).

There was no correlation between HR-1 and the severety of deformity by HI: r = 0.0018, p = 0.99 (fig. 5).

The dynamics of esCCO (fig. 6).

At the initial stage 1 the average esCCO-1 among all patients was 5.02 [4.65 – 5.55] L/min. with insignificant intergroup difference (Kruskal-Wallis test: H (2, N= 60) = 0.22; p = 0.89). At the stage 2 under general anaesthesia with regional blocks (epidural or paravertebral) esCCO-2 decreased by 9.4% to 4.55 [4.00 – 5.05] L/min. (p< 0.00001). The most decreased was esCCO-2 in group SEA – by 20% comparing to initial stage 1, whereas in other groups the rate of decrease was much smaller: in group HEA – by 5.9%, and in group PVA – by 5.4% (Kruskal-Wallis test: H (2, N= 60) = 9.22; p =0.0099). After the sternal elevation esCCO-3 increased in all groups up to the initial rate (Kruskal-Wallis test: H (2, N= 60) = 0.78; p = 0.68). At the stage 4 after the applying capnothorax esCCO-4 demonstrated futher increase up to 5.49 [5.23 – 5.90] L/min. (+9.4% vs esCCO-1; p< 0.00001) in all groups (Kruskal-Wallis test: H (2, N= 60) = 2.12; p = 0.35). After the rotation of bar placed substernally under the thoracoscopic guidance there was no change in average esCCO-5 comparing to previous stage and intergroup differences were insignificant (Kruskal-Wallis test: H (2, N= 60) = 1.95; p = 0.38). At the stage 6 after the surgery finished and the tracheal extubation esCCO-6 decreased up to 5.32 [4.80 – 5.60] L/min. with insignificant intergroup difference (Kruskal-Wallis test: H (2, N= 60) = 2.13; p = 0.35). Just before the transportation from operating room in fully conscious patients the avarage esCCO-7 was 5.19 [4.85 – 5.55] L/min. with no difference between groups (Kruskal-Wallis test: H (2, N= 60) = 0.77; p = 0.68). At this final stage esCCO-7 was by 3.4% higher than at the initial stage 1 (p=0.04).

The dynamics of esCCI (fig. 7).

The dynamics of esCCI was similar to the dynamics of esCCO at all stages. The average initial rate of esCCI-1 among all patients was 3.22 [2.87 – 3.56] L/min/m^2 without significant intergroup difference (Kruskal-Wallis test: H (2, N= 60) =1.68; p = 0.43). The average decrease rate esCCI-2 after performing general anaesthesia and regional blocks was by 9.8% comparing to initial stage 1 (p< 0.00001). The most decreased esCCI-2 was in the SEA group (-20%), comparing to HEA group (-6.4%) and PVA group (-7.2%) (Kruskal-Wallis test: H (2, N= 60) =9.14; p =0.01). After the sternal elevation esCCI-3 increased almost to initial level (p=0.05 vs esCCI-1) in all groups (Kruskal-Wallis test: H (2, N= 60) = 1.01; p = 0.60). On the basis of capnothorax esCCI-4 increased by 8.7% compared to initial level at the stage 1. At the most traumatic moment of surgery when rotating the bar esCCI-5 was kept at the same level as previous. At the end of surgery esCCI-6 was decreasing and at the time of transportation to the ward esCCI-7 was by 3.4% higher than initial esCCI-1 before surgery and anaesthesia (p=0.03). At all stages except stage 2 the intergroup difference was insignificant (p>0.05).

The dynamics of esSV (fig. 8).

The average initial rate of esSV-1 was 60.7 [50.7 – 67.5] ml with insignificant intergroup difference (Kruskal-Wallis test: H (2, N= 60) = 0.17; p = 0.92). After performing general anaesthesia with tracheal intubation and regional blocks esSV-2 decreased among all patients by only 2% comparing to initial level (p=0.59). esSV-2 decreased by 7.9% in SEA group, increased by 4.6% in HEA group and decreased only by 2.5% in PVA group. But intergroup difference at the stage 2 was statistically insignificant (Kruskal-Wallis test: H (2, N= 60) = 4.9; p =0.09). After the sternal elevation esSV-3 increased up to 70.0 [59.2 – 81.0] ml, so it was by 15.3% higher than initial level before anaesthesia (p=0.000001). The most increase esSV-3 comparing to stage 1 was seen in in HEA group by 23.1% and in SEA group by 18.5%, and in PVA group only by 4.4% (Kruskal-Wallis test: H (2, N= 60) = 6.9; p = 0.03). After the applying capnothorax esSV-4 further increased and was by 20% higher than esSV-1 among all patients (p=0.000001). This tendency was seen mainly in groups SEA (+25%) and HEA (+30%) and it was only +4.7% in PVA group (Kruskal-Wallis test: H (2, N= 60) = 11.8; p = 0.003). The bar rotation did not change esSV-5 comparing to stage 4. After surgery finished and patients extubated there was some decrease in esSV-5 and esSV-6. But at the discharge from operating room the average esSV-7 was 67.5 [62,2 – 72,5] ml which is higher by 11% than initial level esSV-1 (p=0.000017). The changes in esSV at stages 5-7 took place mainly in groups SEA and HEA and were neglected in PVA group (Kruskal-Wallis test: H (2, N= 60) = 12.6, p = 0.0018 for SV-5; H = 9.08, p = 0.01 for esSV-6; and H = 5.63, p = 0.06 for esSV-7).

The dynamics of esSVI (fig. 9).

The average initial esSVI-1 was 39.9 [33.5 – 44.4] among all patients and did not differ significantly between groups (Kruskal-Wallis test: H (2, N= 60) = 0.76; p = 0.68). The dynamics of esSVI was similar to the dynamics of esSV at all stages. The most increased esSVI was at the stage 4, so esSVI-4 was higher by 18.3% than esSVI-1 (p=0.00003). At the end of surgery before discharge from operating room esSVI-7 was higher by 11% than esSVI-1 (p=0.000016). The changes in esSVI during surgery were more pronounced in HEA and SEA groups and insignificant in PVA group. At the final stages esSV-6 and esSV-7 did not differ significantly between groups.

The dynamics of HR (fig. 10).

At the initial stage average HR among all patients was 83.8 [75.5 – 91.5] and did not differ significantly between groups (Kruskal-Wallis test: H (2, N= 60) = 0.2; p = 0.90). Performing general anaesthesia and regional blocks resulted to decrease in HR-2 by 7% (p=0.00003). This tendency was seen in groups SEA and HEA, but not in PVA group. The further decrease in HR took place after sternal elevation in groups SEA and HEA, then HR was stable during surgery in these groups. But in PVA group HR was higher than initial HR-1 especially after applying capnothorax and bar rotation. After surgery finished HR was comparable in all groups and lower than HR-1 before anaesthesia and surgery.

DISCUSSION

The published literature data on cardiac function in patients with PE and its changes as a result of Nuss procedure are controversial in many aspects. Most of the authors focused attention on the right heart function as more susceptible to compression due to sternal deformation. Many variants of methods for assessment of cardiac function are used: echocardiography, transesophageal echocardiography, echocardiographic speckle-tracking strain, cardiac magnetic resonance tissue tracking, radionuclides, radiographic planimetry, and cardiac output by the Fick method. Each of these techniques has its limitations in patients with PE [8,9].

We used a non-invasive method to assess hemodynamics and cardiac function during Nuss procedure for PE correction. The informativeness of this technique has been criticized [11], but it is quite useful for assessing the dynamics of cardiac function in the same patient. MIRPE does not require invasive hemodynamic monitoring, the risk of which may outweigh the benefits of such surgery. Echocardiography in patients with PE can meet some difficulties in probe placement due to thoracic wall abnormalities. Surgical procedures during correction of PE can lead to dicplacement of esophageal probe.

At the initial state before surgery and anesthesia, the indicators of cardiac function had an inverse correlation of moderate strength with the severity of PE by HI. This indicates the effect of sternal deformity on cardiac function. Literature data on correlation between HI and cardiac function are controversial [12]. In our study the strength of the correlation with HI was higher for the indices of cardiac function calculated on the body surface area (esCCI and esSVI), than for the corresponding indicators (esCCO, esSV). Patients with PE usually have a reduced BMI (in our study, BMI = 19.6 ± 2.62), so indicators that are calculated on the body surface area may be more informative than their direct counterparts.

Many authors studied cardiac function after PE correction in long-term follow-up from months to years [5]. Only e few studies were published on immediate cardiac effects of such surgery. Chao et al studied cardiac function immediately after modified Nuss procedure in 168 patients of age from 18 to 71 years [13]. In this study the authors showed a significant increase in cardiac output and stroke volume of right ventricle immediately after Nuss procedure.

Huang et al. [14] studied 10 patients aged 4 to 54 years undergone Nuss procedure perioperatively. They found an improved ejection fraction and stroke volume of left ventricle, but these changes were statistically insignificant probably due to small patient number.

Krueger et al. studied cardiac function in 17 patients in age from 17 to 54 years perioperatively after open correction of PE [15]. The authors demonstrated a significant increase in left ventricular ejection fraction and right ventricular end-diastolic diameter.

O'Keefe J. et al. demonstrated the insignificantly improved cardiac output and stroke volume, but not cardiac index in long-term follow-up in 39 months after PE correction in 67 adolescents of mean age 14-years [16].

Sigalet et al. [17,18] showed an significant increase in cardiac output and stroke volume, but increase in cardiac index was insignificant.

Cardiac function during Nuss procedure is influenced by many intraoperative factors: anaesthetic agents, sympathetic blockage due to regional anaesthesia, sternal elevation which relieves cardiac compression and capnothorax leading to increased intrathoracic pressure. We studied cardiac function at several stages of anaesthesia and surgical procedure. Induction of anesthesia and regional blocks led to a significant decrease in esCCO and esCCI, while esSV and esSVI remained almost unchanged. At this stage, the decrease in cardiac output was mainly due to a decrease in heart rate, which may be due to the sympatholytic effect of the components of anesthesia. The SEA led to a significant reduction in cardiac output due to both stroke volume and decreased heart rate. HEA had almost no effect on stroke volume and moderately decreased heart rate, so the reduction in cardiac output in this group was less pronounced. It is possible that HEA causes less severe sympathetic blockade of internal organs, but more pronounced bradycardia than SEA. PVA had virtually no effect on heart rate.

The stage of sternal elevation can be considered as the moment of elimination of heart compression. At this stage, we found an increase in esSV, which was more pronounced in the groups of epidural blocks. This may be due to a combination of effects from the elimination of cardiac compression and a decrease in peripheral vascular resistance due to epidural anesthesia. The applying of capnothorax led to a further increase in esSV, especially in the epidural groups. The bar rotation had almost no effect on cardiac function. After awakening from anesthesia and tracheal extubation, there was some reduction in cardiac function, but it remained better than before surgery, regardless of the type of regional block.

Our results for increased cardiac output and stroke volume during Nuss procedure are consistent with the findings of other authors. The study group from Mayo Clinic Arizona, (Phoenix, Arizona, USA) reported improvement in left ventricular ejection fraction, increased right-side heart chamber size, and a 38% improvement in right ventricular cardiac output by intraoperative transesophageal echocardiography immediately after PE repair [13]. Recently they demonstrated that mechanical compression and impaired RV and LV strain is improved by Nuss surgical repair of pectus deformity using echocardiographic speckle-tracking strain [6].

Jeong et al. demonstrated morphologic cardiac changes after Nuss procedure suggesting that the heart tends to return to a normal position and shape, and that these changes may contribute to improvement in cardiac function [7].

Other studies did not confirm an improvement in left ventricle function after the PE correction [14, 19].

Maagaard M. and Heiberg J. reviewed the literature on cardiac function benefits from PE correction for 1972-2016 years and concluded that the positive physiological impact of the surgery is emphasized and the potential gain in cardiac function should be integrated in the clinical assessment of patients with PE [5].

Our study had limitations relating to the non-invasive technique of monitoring that we discussed above. Another limitation of our study is the lack of a control group of healthy people. But it is difficult to imagine the reproduction of the studied factors (stages of surgery, components of anesthesia) in healthy people.

CONCLUSIONS

The Nuss procedure for pectus excavatum correction lead to improved cardiac function. The changes in cardiac function were seen at the stage of sternal elevation and futher improved after applying capnothorax and bar rotation. The increase in stroke volume and its index were more informative than cardiac output and cardiac index which are dependent on heart rate that is under the influence of anaesthesia technique.

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