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Lung: Short Report

Improved Right Ventricular Diastolic Function Assessed by Hepatic Vein Flow After Pectus Excavatum Repair

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ABSTRACT

BACKGROUND The cardiovascular benefits of surgical repair in pectus excavatum (PEx) continue to be debated, with limited data supporting repair in adult patients. Hepatic vein flow is used to identify right-sided diastolic dysfunction in cardiovascular disorders, including tricuspid stenosis, cardiac tamponade, and constrictive pericarditis. This study evaluates the effects of cardiac compression on diastolic function (as assessed by hepatic vein flow patterns and velocities) before and after repair of PEx.

METHODS A retrospective study was performed of intraoperative transesophageal echocardiograms including hepatic vein assessments of adult patients who underwent preoperative and postoperative evaluations during repair of PEx from 2018 to 2021.

RESULTS In total, 127 patients were included (median age, 29.0 [15.4] years; median Haller index, 4.2 [1.7]; 60.6% male). Statistically significant improvements were seen after pectus repair of right ventricular stroke volume and diastolic function as measured by increased postoperative velocities for hepatic vein waves ($P < .001$ for all comparisons). Preoperatively, 5.5% of patients had constrictive-like physiology with end-diastolic retrograde flow that normalized postoperatively ($P = .016$). Approximately 10% of patients changed their pattern of hepatic vein flow after surgical procedure. Patients with more proximal cardiac compression had greater improvements in hepatic vein velocities after repair.

CONCLUSIONS Surgical relief of cardiac compression resulted in an immediate improvement in hepatic vein flow and right ventricle stroke volume in patients with PEx. These results support diastolic dysfunction in a large number of patients, with improvement in function and compliance after the surgical relief of cardiac compression.

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The benefits of pectus excavatum (PEx) surgical repair on cardiac function remain debated, especially in the adult population.[1,2] Moreover, pathophysiologic mechanisms underlying cardiovascular deficits in PEx are not completely understood.[1,2] The compression of the right-sided heart chambers has been shown to cause cardiac output reduction in these patients, yet no study has been conducted to assess changes in cardiac filling patterns after surgical repair.[2,3] Efforts have been made to identify anatomic and functional variables that could predict the degree of cardiovascular impairment, but the reported results have been inconsistent.[1,4]

Hepatic vein flow velocities and patterns are established indicators of right-sided diastolic dysfunction in a

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wide spectrum of cardiovascular diseases, including tricuspid stenosis, cardiac tamponade, and constrictive pericarditis.[5,6] In some of these conditions, the correction of the underlying disease can generate a rapid improvement in hepatic vein flow, suggesting a recovery of cardiac filling.[6] Considering the external compression of the right-sided heart chambers in patients with PEx, we hypothesized that impairments in cardiac filling could be reflected in abnormalities of hepatic vein flow and the relief of the compression could generate an immediate improvement. Our study evaluates changes in hepatic vein flow patterns and velocities and the relationship with the site of maximal cardiac compression before and after a minimally invasive repair of PEx (MIRPE).

IN SHORT

- Surgical relief of cardiac compression in patients with pectus resulted in an immediate improvement in hepatic vein flow and right ventricle stroke volume.
- The more proximal location of cardiac compression was associated with higher improvements.
- These results support diastolic dysfunction in a considerable number of patients, with improvement in cardiac function and compliance after surgical correction.

PATIENTS AND METHODS

A retrospective study was performed using an electronic database at a single institution (Mayo Clinic Arizona, Phoenix). Consecutive adult patients (≥18 years old) with PEx who underwent a MIRPE between 2018 and 2021 and who underwent intraoperative transesophageal echocardiography (TEE) with both preoperative and postoperative testing were included. Intraoperative TEE is routinely performed in our hospital for PEx cases at 2 moments (before sternal elevation and after bar placement) to detect preoperative implications of cardiac compression, improvements in cardiac function after repair, and potential intraoperative complications.

Preoperative and postoperative comparisons of the pattern and velocities of systolic and diastolic hepatic vein waves were performed. Prespecified subgroup analyses were stratified according to the site of maximal cardiac compression by the following classification: no evident compression, proximal compression, and distal compression (Figure 1). The institutional review board approved the retrospective review of patients' medical charts and studies as well as the waiver of informed consent.

All surgeries were performed by a single surgeon (D.E.J.) using MIRPE as previously described.[7] The intraoperative TEE was performed by expert cardiologists with a certification for special competency in

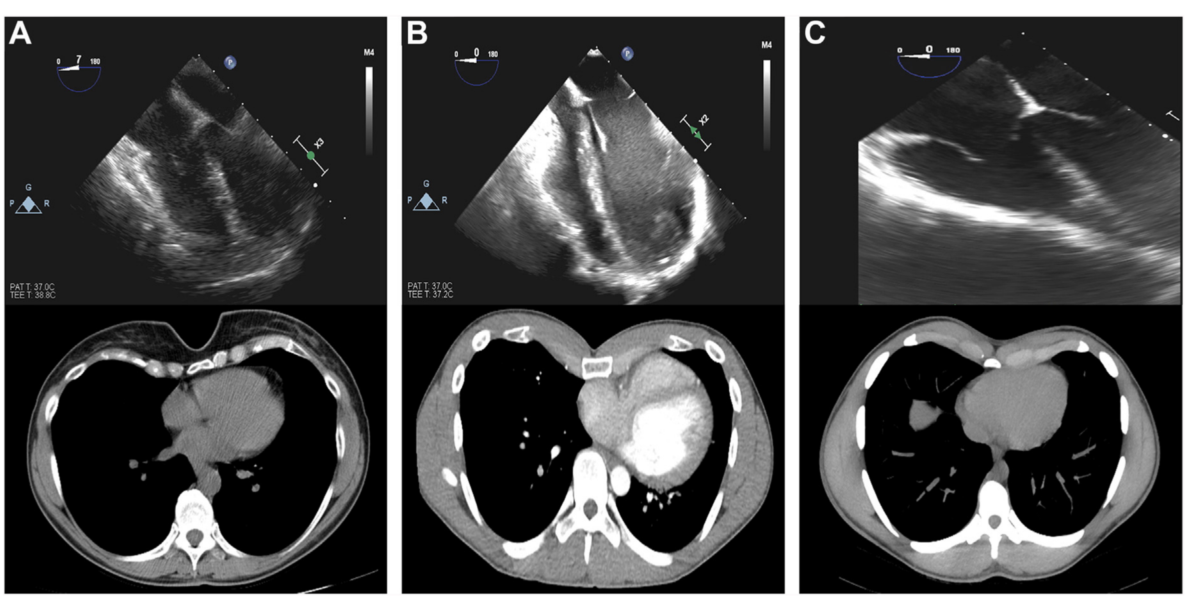

FIGURE 1 Classification of the patients according to the site of maximal cardiac compression. (A) Transesophageal echocardiography (TEE) and computed tomography (CT) showing no significant compression of right-sided heart chambers. (B) TEE and chest CT with contrast enhancement showing that the site of maximal compression is located at the level of the tricuspid annulus (proximal compression). (C) TEE and CT demonstrating compression of the right ventricle free wall and apex by left costochondral junction (distal compression).

TABLE 1 Baseline Characteristics of Included Population (N = 127)

Age, y	29.0 (15.4)
Sex, n (%)	
Male	77 (60.6)
Female	50 (39.4)
Anatomic CT parameters	
Haller index, inspiration	4.2 (1.7)
Haller index, expiration	4.7 (1.8)
Correction index, inspiration, %	35.0 ± 14.2
Correction index, expiration, %	39.3 ± 18.2
Symptoms, n (%)	
Dyspnea	122 (96.1)
Exercise intolerance	119 (93.7)
Chest pain	102 (80.3)
Palpitations	99 (77.9)
Lightheadedness/dizziness	80 (62.9)
Syncope/presyncope	23 (18.1)
Postural symptoms	84 (66.1)
Progression of symptoms	122 (96.1)
Preoperative transthoracic echocardiography measurements	
LVEF, %	60.9 ± 4.0
LVEDD, mm	45.8 ± 4.5
LVESD, mm	29.9 ± 3.7
IVS thickness, mm	8.5 ± 1.4
LVPW thickness, mm	8.2 ± 1.5
LAVI, mL/m^2	22.7 ± 5.8
TAPSE, mm	21.4 ± 3.7
Mitral E wave, m/s	0.8 ± 0.2
Mitral A wave, m/s	0.4 ± 0.1
Mitral E/A ratio	2.0 ± 0.7
Medial E/e′ ratio	6.7 ± 2.2
Lateral E/e′ ratio	5.6 ± 1.9
Estimated PASP, mm Hg	24.7 ± 4.7

Categorical variables are presented as number (percentage). Continuous variables are presented as median (interquartile range) or mean ± SD. CT, computed tomography; IVS, interventricular septum; LAVI, left atrial volume index; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; LVPW, left ventricular posterior wall; PASP, pulmonary artery systolic pressure; TAPSE, tricuspid annular plane systolic excursion.

TABLE 2 Comparison Between Preoperative and Postoperative TEE Findings

Variable	Preoperative	Postoperative	*P* (95% CI)
HVS peak velocity, cm/s	15.6 ± 5.4	20.8 ± 8.5	<.001 (3.8-6.6)
HVS VTI, cm	3.4 ± 1.5	4.9 ± 2.3	<.001 (1.1-1.8)
HVD peak velocity, cm/s	15.7 ± 5.2	18.8 ± 5.5	<.001 (2.2-4.1)
HVD VTI, cm	3.6 ± 1.8	4.2 ± 1.6	<.001 (0.4-0.9)
Presence of end-diastolic retrograde flow, n (%)	7 (5.5)	0 (0.0)	.016
Type of hepatic vein flow pattern, n (%)			.118
Systolic predominance	67 (52.7)	78 (61.4)	
Diastolic predominance	60 (47.3)	49 (38.6)	
RVOT VTI, cm (n = 77)	14.7 ± 3.2	17.3 ± 3.3	<.001 (1.9-3.5)
Right ventricle SV, cm^3 (n = 77)	43.8 ± 13.6	56.4 ± 16.1	<.001 (10.1-16.3)

Categorical variables are presented as number (percentage). Continuous variables are presented as mean ± SD. HVD, hepatic vein diastolic forward flow; HVS, hepatic vein systolic forward flow; RVOT, right ventricular outflow tract; SV, stroke volume; TEE, transesophageal echocardiography; VTI, velocity-time integral.

echocardiography. Further details of patients' selection and methods can be found in the Supplemental Methods.

RESULTS

In total, 127 patients (median age, 29.0 [15.4] years; median Haller index, 4.2 [1.7]; 60.6% male; 96% symptomatic) were included. For pectus repair, 3 bars were used in 84 cases (66%) and 2 bars in the remainder of cases. The rest of the baseline characteristics of the included population are shown in Table 1. A description of the normal characteristics of the hepatic vein flow is provided in the Supplemental Figure.

Comparing preoperative and postoperative hepatic vein flow showed a significant increase in the postoperative velocities for systolic and diastolic forward waves (Table 2; Figure 2A). Moreover, 8.7% of patients changed the hepatic vein flow pattern to normal (systolic predominance) in the postoperative evaluations, and 5.5% of cases presenting preoperatively with constrictive-like physiology and having end-diastolic retrograde flow showed an overturn of this abnormal wave (P = .016 for the comparison; Table 2; Figure 2B). No significant associations were found between the improvement in hepatic vein flow and the severity of PEx deformity (Haller index, correction index), as shown in Supplemental Table 1. In an additional analysis of the cardiovascular improvement of TEE measurements after repair, a statistically significant increase in right ventricular stroke volume was seen (Table 2).

Regarding the analysis considering the site of maximal compression, there was a significant difference between the groups in the improvement in hepatic vein systolic forward velocities (P = .001; Supplemental Table 2). Post hoc testing revealed patients with proximal compression having higher improvements than patients with no evident compression (P = .006) and patients with distal compression (P = .005; Supplemental Table 3).

COMMENT

The effects of cardiac compression by the depression of the anterior chest wall in PEx remain debated.[2] The difficulty in obtaining adequate transthoracic acoustic echocardiographic windows (because of the leftward dislocation of the heart) contributes to creating a scenario in which conventional TTE has failed to properly assess the full cardiac consequences of this condition.[1,2] This paper brings this evidence to light. In our cohort of 127 patients, 96% of patients were experiencing cardiovascular symptoms. Despite this, overall preoperative TTE results reported normal cardiac function in considering conventional echocardiographic parameters (Table 1). In contrast,

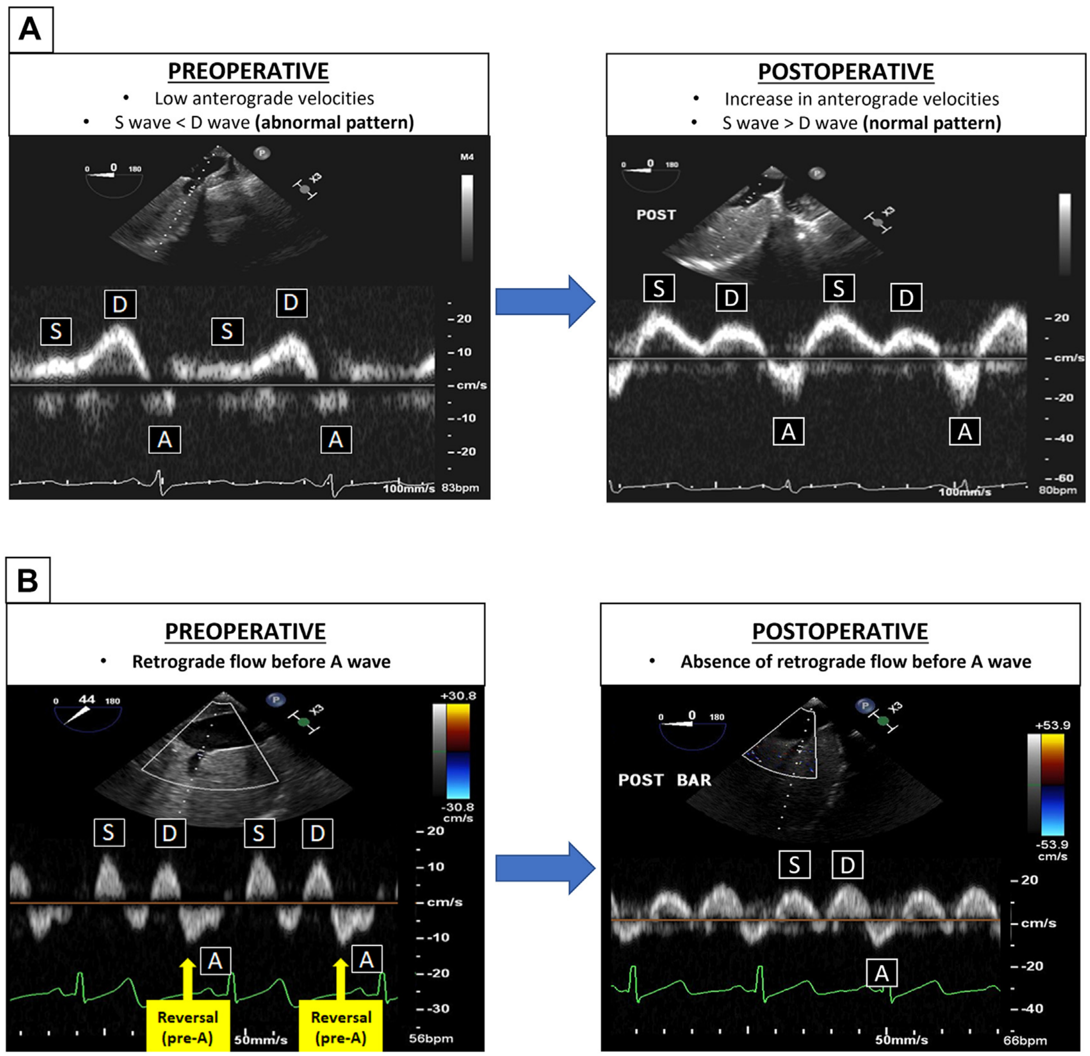

FIGURE 2 Abnormalities in hepatic vein flow in patients with pectus. (A) A 23-year-old woman with pectus excavatum. Hepatic vein flow analysis at preoperative transesophageal echocardiography showed diastolic predominance (D wave > S wave), with low anterograde systolic velocities. This abnormal pattern in hepatic vein flow has been described in patients with obstruction to the right ventricle inflow tract, such as cases of tricuspid stenosis. Postoperatively, hepatic vein flow changed to a normal pattern (S wave > D wave) with increased systolic forward velocities. (B) A 44-year-old woman with pectus excavatum. Preoperative evaluation of the hepatic vein flow revealed the presence of an end-diastolic retrograde wave before atrial contraction (pre-A wave, arrow) in a manner similar to that seen in constrictive pericarditis. After repair, the end-diastolic retrograde wave was no longer present.

in analyzing TEE imaging, 47% of cases had abnormal hepatic vein flow patterns before surgical repair (Table 2).

This innovative study provides an overall assessment of hepatic vein flow characteristics in a PEx adult population before and after MIRPE. In the postoperative tests, velocities of both hepatic vein forward waves increased and end-diastolic reversal waves disappeared, supporting an improvement in cardiac filling and compliance after the surgical relief of cardiac compression.

Hepatic vein flow analysis is used in numerous cardiac diseases, including constrictive pericarditis, tricuspid valve disease, and cardiac tamponade, as 1 of the indicators of right-sided heart chamber diastolic dysfunction.[5,6] The presence of external compression to the right-sided heart chambers in PEx may simulate these pathologic processes and mimic constrictive physiology, with previous publications already reporting functional similarities between PEx, constrictive pericarditis, and cardiac tamponade.[8,9] These preceding findings are supported by the presence of end-diastolic reversal waves in 5.5% of our patients and the overturn of these abnormal waves in the postoperative evaluations (Figure 2B). This investigation, however, takes a step forward by including a larger cohort and by evaluating the preoperative abnormalities and the postoperative changes, thus highlighting the functional benefits of the surgical repair.

In addition, the presence of proximal cardiac compression in PEx may mimic the consequences of an obstruction to the right ventricle inflow tract, simulating the effects of a tricuspid stenosis.[10] Our analysis showed greater increases in hepatic vein velocities in cases with proximal compression, therefore suggesting that the obstruction to the right ventricle inflow tract can play a substantial role in cardiac impairment in PEx (Figure 2A).

Cardiovascular benefits after surgical correction of PEx have been previously reported by our group.[1,9] The increase in postoperative right ventricular stroke volume seen in this study supports our previous findings and could be associated, among other factors, with the improvement in the right-sided heart filling as demonstrated by this study.

The association between cardiovascular involvement, anatomic features, and severity of PEx has previously been investigated with controversial results.[1,3] In our study, there was an overall enhancement in hepatic vein flow in the included population, but the more proximal location of cardiac compression was associated with higher improvements.

Total recovery of diastolic function may occur over time. Despite the immediate postoperative improvement seen in our study, 38% of cases persisted with abnormal flow patterns at postoperative evaluation. Therefore, the search for additional improvements in right-sided heart filling patterns during long-term follow-up could be a future field of study.

The Supplemental Material can be viewed in the online version of this article [https://doi.org/10.1016/j.atssr.2023.02.009] on http://www.annalsthoracicsurgery.org.

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DISCLOSURES

Dawn E. Jaroszewski reports a relationship with Zimmer Biomet Holdings Inc that includes: consulting or advisory and equity or stocks. Dawn E. Jaroszewski has patent PectusBlu NexGen with royalties paid to B151018. Dawn E. Jaroszewski is a consultant and has IP/royalty rights under Mayo Clinic Ventures with Zimmer Biomet, Inc. The other authors have no conflict of interest to declare.

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