Effects of Pectus Excavatum Repair on Right and Left Ventricular Strain

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Background. The cardiopulmonary benefits of pectus excavatum repair have been debated. Echocardiographic speckle-tracking strain and strain rate have been used to evaluate and detect subclinical myocardial dysfunction in patients receiving cardiotoxic chemotherapy, and patients with valvular heart disease. This technology was applied to evaluate the effects of pectus excavatum surgery on left ventricular (LV) and right ventricular (RV) function.

Methods. Speckle tracing strain evaluation was performed on intraoperative transesophageal echocardiographic images acquired immediately before and after Nuss repair in adult patients (aged 18 years or more) from 2011 to 2014. Standard severity and compression indices were measured on chest imaging performed before pectus excavatum repair.

Results. In total, 165 patients with transesophageal echocardiographic images during repair were reviewed (71.5% male; mean age 33.0 years; range, 18 to 71; Haller index 5.7; range, 2.3 to 24.3). Significant improvement after repair was seen in global RV longitudinal strain (−13.5% ± 4.1% to −16.7% ± 4.4%, $p < 0.0001$) and strain rate (−1.3 ± 0.4 s^{-1} to −1.4 ± 0.4 s^{-1}, $p = 0.0102$); LV global circumferential strain (−18.7% ± 5.7% to −23.5% ± 5.8%, $p < 0.0001$) and strain rate (−1.5 ± 0.5 s^{-1} to −1.9 ± 0.8 s^{-1}, $p = 0.0003$); and LV radial strain (24.1% ± 13.5% to 31.1% ± 16.4%, $p = 0.0050$). There was a strong correlation between preoperative right atrial compression on transesophageal echocardiogram and improvement in RV global longitudinal strain rate immediately after pectus repair.

Conclusions. Mechanical compression and impaired RV and LV strain is improved by Nuss surgical repair of pectus deformity.

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Pectus excavatum (PE) is a common malformation of the chest wall with posterior depression of the sternum and adjacent costal cartilages. That may cause physiologic symptoms and cardiopulmonary impairment with limitation of diastolic filling through mechanical compression of right-side heart chambers [1]. Beyond cosmetic considerations [2, 3], several reports have shown an improvement in pulmonary function [4–9] and exercise capacity [2, 3, 10–12] in PE patients after surgical repair. Transthoracic echocardiography studies have also demonstrated improvement in cardiac anatomy and function in patients with PE after surgical correction [2, 6, 10, 13–15]. We previously reported on improvement in left ventricular (LV) ejection fraction, increased right-side heart chamber size, and a 38% improvement in right ventricular (RV) cardiac output by intraoperative transesophageal echocardiography (TEE) [16] before and immediately after PE repair [17]. These improvements may be greater in older adult patients with a mean increase of more than 65% in cardiac output seen in patients over the age of 30 years [18].

No imaging study has evaluated the affects of mechanical compression on the right-sided cardiac chambers from PE and the benefits of cardiac decompression by PE surgery. Speckle tracking strain is a robust method that directly evaluates myocardial contractile function. It is not subject to the need for parallel alignment of the ultrasound beam with the area of interest or the tethering effects of surrounding segments as occurs with Doppler echocardiographic methods. In this retrospective observational study, we evaluated the effect of PE repair on RV and LV contractile function by two-dimensional speckle tracking strain in patients who underwent intraoperative TEE immediately before and after PE surgical repair.

Patients and Methods

A retrospective review was performed of all patients undergoing surgical correction of PE by a single surgeon and site using the techniques of modified Nuss [19] or

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Abbreviations and Acronyms

CT	= computed tomography
LV	= left ventricular
MRI	= magnetic resonance imaging
PE	= pectus excavatum
RA	= right atrium
RV	= right ventricular
RVGLSR	= right ventricular global longitudinal strain rate
TEE	= transesophageal echocardiography

hybrid (combined Nuss procedure with partial open cartilage excision/osteotomy, plating, and support bar placement) [20, 21] during the period of May 2011 to July 2014. The indications for surgical repair were based on thoracic anteroposterior compression indices: a Haller index from computed tomography (CT) or magnetic resonance imaging (MRI) imaging (inspiratory imaging and expiratory imaging when available) of 3.25 or greater [22], or correction index 20% or greater [23], or significant or progressing cardiopulmonary symptoms [24]. The study was approved by the Institutional Review Board.

Study Population

In total, 272 consecutive adult patients underwent a Nuss or hybrid Nuss PE repair during this period. Inclusion criteria for the study included repair of significant PE deformity (Haller index greater than 3.25 or evidence for cardiac compression). One hundred seven patients were excluded for the following reasons: (1) refusal to sign consent for study participation; (2) inadequate or technically poor TEE images available for retrospective review; and (3) prior open Ravitch procedure with extensive chest wall calcification and fusion or malunion with chronic pain. The final study population consisted of 165 patients with intraoperative TEE imaging performed immediately before and after PE repair. Information on blood pressure and heart rate was collected from anesthesia records as best estimated at the time TEE before and after surgery measurements were made. That was based on anesthesia recorded time of TEE probe insertion and end of surgery. A mean of three recorded times at both of these intervals was calculated. Computed tomography or MRI was available for review in 161 patients. A control group of 17 patients was studied to assess for changes on TEE that might be due to intraoperative variables including chest manipulation, general anesthesia, or changes in blood pressure or heart rate. This control group included patients with previous PE repair and placement of stainless steel pectus support bars who underwent planned staged pectus support bar removal with intraoperative TEE imaging before and after bar removal. No patients were receiving inotropes or vasoconstrictors during anesthesia.

Echocardiography

The TEE was performed using a multiplane X7-1 MHz transducer, coupled with a Philips I-E33 ultrasound machine (Philips Healthcare, Bothell, WA). The TEEs were performed by board-certified echocardiologists using the standard TEE image acquisition protocol from which select views, as shown in Table 1, were chosen for study-related data measurements. The frame rate of stored images was greater than 50 frames per second as per echocardiography laboratory practice at our institution for all echocardiography studies.

Echocardiography Image Analysis, RV and LV Strain Measurement

All intraoperative before and postoperative TEE images were evaluated. Digital Imaging and Communications in Medicine (DICOM) images stored at the time of TEE study were retrieved onto a ProSolv image viewer. Dedicated nonforeshortened preoperative and postoperative RV views in the mid esophageal plane view at 0 degrees were selected for measurement of RV strain and strain rate. Mid short-axis views of the LV in the deep gastric view before and after surgery were selected for measurement of LV circumferential strain. Selected DICOM images were uploaded from the ProSolv (Fujifilm Medical Systems, Stamford, CT) server onto a workstation with a commercial strain measurement software technology tool (Syngo US Workplace 3.5 with Velocity Vector Imaging [VVI]; Siemens Corporation, Malvern, PA).

The RV and LV strain and strain rate measurement was performed by a single observer (C.J.C.). Automatic tracing was based on placing of points of interest along the RV endocardial border (generally, 6 to 8 points in total) in end systole, starting from the lateral tricuspid annulus, covering the RV apex, and ending at the medial tricuspid annulus. Based on the points of interest, the software produces an automatic trace of the RV endocardium and epicardium, which can be edited by the user. The global strain was calculated from the average of the individual strain curves. When two or more segments were unavailable; the measurement was considered as suboptimal and was excluded. For LV strain measurement, LV endocardium was traced by placing points of interest (6 to 8 points in total) in the short-axis view at mid papillary muscle level (excluding the papillary muscles in the trace). This was followed by an automated trace of the entire epicardium and endocardium

Table 1. Transesophageal Echocardiography Imaging Protocol: Echocardiographic Evaluation of Cardiac Size and Function, and Imaging Angles

Cardiac Evaluation	Imaging
Right ventricle	ME, 0–10 degrees, four-chamber, RV focused
Right atrium	ME, 0–10 degrees, four-chamber, RA focused
Tricuspid annulus	ME, 0–10 degrees, RV focused
LV mid papillary short axis	Transgastric, 0–20 degrees

LV = left ventricle; ME = mid esophageal; RA = right atrium; RV = right ventricle.

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