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Magnetic Resonance Imaging in the Evaluation of Pectus Excavatum

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ABSTRACT

BACKGROUND: Magnetic resonance imaging is more often used to confirm the presence of pectus excavatum and assess compression changes in the heart at this level.

AIM: To evaluate pectus excavatum preoperatively according to magnetic resonance imaging findings.

MATERIALS AND METHODS: A retrospective evaluation of chest magnetic resonance imaging data of 38 patients (male, $n = 30$; female, $n = 8$) was performed. The average age was 19.9 years (±9 years).Cardiac magnetic resonance imaging was performed on a 1.5-T General Electric Optima MR450w GEM scanner with 2D-FIESTA-C pulse sequences, as well as functional assessment of the left and right ventricles. Parameters for surgical treatment of pectus excavatum were as follows: the Haller index, correction index, and sternum rotation angle. Statistical analysis of the relationship between the Haller index, correction index, and sternum rotation angle and ejection fraction of the right ventricle was conducted. A p-value <0.05 was considered significant.

RESULTS: Moderate and severe pectus excavatum were found in 92% of the cases. No significant Pearson correlation was obtained between the Haller index and right ventricular ejection fraction (inspiratory and expiratory ejection fraction, $P = 0.777$ and 0.798, respectively). The mean right ventricular ejection fraction was 46%. A correlation was noted between the Haller index and the correction index ($P < 0.05$). The rotation angle of the sternum, which required modification of surgical intervention, was detected in 44.7% of patients.

CONCLUSION: Magnetic resonance imaging is an informative diagnostic method for pectus excavatum pectus excavatum without radiation exposure and enables detailed preoperative assessment. A correlation was noted between the Haller index and the correction index ($P < 0.05$). Magnetic resonance imaging revealed a decrease in the ejection fraction of the right ventricle.

Keywords: pectus excavatum; magnetic resonance imaging; right ventricle ejection fraction; Haller index; correction index; sternal torsion angle.

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Магнитно-резонансная томография при воронкообразной деформации грудной клетки

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АННОТАЦИЯ

Обоснование. Магнитно-резонансная томография чаще применяется для подтверждения факта наличия воронкообразной деформации грудной клетки, а также для оценки компрессионных изменений сердца на этом уровне.

Цель — прицельная предоперационная оценка воронкообразной деформации грудной клетки по данным магнитно-резонансной томографии.

Материалы и методы. Проведена ретроспективная оценка магнитно-резонансной томографии органов грудной клетки у 38 пациентов (30 мужского пола, 8 женского пола). Средний возраст — 19,9 года (±9 лет).

Магнитно-резонансная томография сердца выполнялась на аппарате General Electric Optima MR450w GEM 1,5 Тл с использованием импульсных последовательностей 2D-FIESTA-C с электрокардиографической синхронизацией с функциональной оценкой состояния левого и правого желудочков. Были получены параметры, необходимые для дальнейшего оперативного лечения пациентов по поводу воронкообразной деформации грудины — индекс Галлера, индекс коррекции, угол ротации грудины.

Проведена статистическая обработка полученных данных, поиск взаимосвязи между индексом Галлера, индексом коррекции, углом ротации грудины и фракцией выброса правого желудочка. Значение p <0,05 считали границей статистической значимости.

Результаты. В 92% случаев у пациентов выявлена умеренная и тяжёлая воронкообразная деформация грудной клетки. При поиске взаимосвязи между значениями индекса Галлера и фракцией выброса правого желудочка не было получено статистически значимой корреляции Пирсона (p=0,777 для значений фракции выброса на вдохе и p=0,798 для значений фракции выброса на выдохе). Среднее значение фракции выброса правого желудочка составило 46%.

При статистическом анализе по мере увеличения индекса Галлера (увеличение степени деформации органов грудной клетки) было отмечено увеличение индекса коррекции (p <0,05). Значения угла ротации грудины, потребовавшие модификации оперативного вмешательства (более 15°), были выявлены у 44,7% пациентов.

Заключение. Магнитно-резонансная томография — высокоинформативный метод диагностики при воронкообразной деформации грудной клетки: без лучевой нагрузки и с возможностью подробной предоперационной оценки патологических изменений.

Получены данные о наличии корреляции между значениями индекса Галлера и индекса коррекции (p <0,05). Кроме того, по данным магнитно-резонансной томографии выявлено уменьшение фракции выброса правого желудочка.

Ключевые слова: воронкообразная деформация грудной клетки; магнитно-резонансная томография; фракция выброса правого желудочка; индекс Галлера; индекс коррекции; угол ротации грудины.

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漏斗胸畸形的磁共振成像

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摘要

论证。磁共振成像更常用于确认是否存在漏斗胸畸形，并评估该水平的心脏压迫变化。

目的是通过磁共振成像对漏斗胸畸形进行术前评估。

材料和方法。我们对 38 名患者（30 名男性，8 名女性）的胸部器官磁共振成像进行了回顾性评估。平均年龄为 19.9 岁（±9 岁）。

心脏磁共振成像是在 General Electric Optima MR450w GEM 1.5 特斯拉设备上进行的，使用的是 2D-FIESTA-C 脉冲序列，同时进行了伴有左心室和右心室功能评估的心电图同步。获得了对漏斗胸畸形患者进行进一步手术治疗所需的参数：Haller 指数、矫正指数、胸骨旋转角度。

对获得的数据进行统计处理，寻找 Haller 指数、矫正指数、胸骨旋转角度和右心室射血分数之间的相关性。P<0.05的值被认为是统计学意义的边界。

结果。在 92% 的患者中发现了中度和重度漏斗胸畸形。在寻找 Haller指数值与右心室射血分数之间的相关性时，未发现有统计学意义的 Pearson 相关性（吸气射血分数值的相关性为 P=0.777，呼气射血分数值的相关性为 P=0.798）。右心室射血分数的平均值为 46%。在统计分析中，随着 Haller 指数（胸腔器官畸形程度的增加）的增加，矫正指数也在增加（P<0.05）。44.7% 的患者的胸骨旋转角度值需要修改手术干预（超过15°）。

结论。磁共振成像是一种对漏斗胸畸形有高度参考价值的诊断方法：无需放射线照射，还能对病理变化进行详细的术前评估。

数据显示了，Haller 指数与矫正指数值之间存在相关性（P<0.05）。此外，磁共振成像数据显示了，右心室射血分数有所下降。

关键词：漏斗胸畸形；磁共振成像；右心室射血分数；Haller 指数；矫正指数；胸骨旋转角度。

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BACKGROUND

Pectus excavatum (PE) is a prevalent developmental chest wall deformity affecting 1:300–1:1,000 newborns, with clinical manifestations most commonly observed at 10–12 years of age and during puberty [1, 2].

The sternum and anterior ribs “sink” into the thorax in PE, resulting in a depression of varying depth and shape. The chest wall deformity is believed to be the result of aberrant rib cartilage development, which causes progressive displacement of the sternum due to their excessive growth. The attachment of ribs 6 and 7 to the sternum is where the most substantial alterations are observed. Pectus carinatum, a protrusion chest deformity also known as “keel chest,” is diagnosed when the sternum is displaced forward. “PE,” or “funnel chest” deformity, is diagnosed when the sternum is displaced inward [2].

In addition to cosmetic defects, PE is linked to displacement of mediastinal organs and structures and compression of lung tissue, which can impact heart and lung function and reduce physical activity [3–6].

Due to its accessibility and speed, computed tomography (CT) is widely employed to evaluate the degree of deformity and the position of the mediastinal organs in relation to the deformed chest wall [3].

Magnetic resonance imaging (MRI) is also used to verify the presence of a deformity and evaluate possible compression of the heart [3]. MRI does not involve radiation exposure and offers comparable diagnostic information regarding the sternum and ribs to CT. Nevertheless, there are only a limited number of sources that provide comprehensive information regarding the informative value of MRI in evaluating the parameters required for surgical planning [4].

Given the significance of establishing the appropriate indications for the surgical treatment of PE, the severity of this malformation is assessed using several parameters, including the Haller index, the correction index, and the sternal rotation angle.

The Haller index is determined using axial scanning. This index is calculated by dividing the transverse diameter of the chest wall (the maximum distance between the inner surfaces of the ribs) by the anteroposterior diameter of the chest (the distance between the posterior aspect of the sternum and the anterior aspect of the vertebra) [7]. In PE, the anteroposterior diameter decreases because of the depression of the sternocostal complex, which causes the Haller index to increase [8]. The Haller index is classified as follows:

- Normal: <2.0
- Mild PE: 2.0–3.2
- Moderate PE: 3.2–3.5
- Severe PE: >3.5

Surgical treatment of PE is indicated when the Haller index exceeds 3.25.

The correction index is defined as the ratio of the expected increase in thoracic deformity of the corrected sternum (as reflected by the formula calculating the difference between the maximum size and the available minimum size) to the maximum anterior and posterior internal chest size, expressed as a percentage. The correction index has been used to guide the treatment of PE patients only recently [9].

The sternal rotation angle is a critical parameter in PE patients, as understanding the severity and direction of the angle is required for appropriate subsequent surgical planning [10].

STUDY AIM

To construct a targeted evaluation of PE parameters using MRI.

MATERIALS AND METHODS

Study Design

This single-center retrospective study evaluated heart and chest findings in 38 patients.

Eligibility Criteria

Inclusion criteria:

- Examination for PE
- Available heart and chest MRI scans
- Signed informed consent form

Exclusion criteria:

- Electronic pacemaker, metal elements inside body
- Claustrophobia
- Inadequate patient behavior

Description of Medical Intervention

Heart MRI was performed as part of the preoperative evaluation employing a General Electric Optima MR450w GEM 1.5 T scanner (GE Healthcare, USA) with 2D-FIESTA-C pulse sequences. A functional evaluation of the left and right ventricular myocardium was incorporated into the electrocardiographic synchronization protocol. The functional examination used standard sequences to acquire cine images of the heart (balanced gradient echo) in standard cardiac axes (long 2- and 4-chamber, short 2-chamber axes). The right ventricular ejection fraction was determined in a semiautomatic mode (with manual adjustment of the values obtained) during inspiration and expiration.

Haller index, correction index, and sternal rotation angle were also evaluated as parameters necessary for the further surgical management of patients with PE during the cardiac function assessment.

Ethical Review

The heart MRI was conducted as part of the preoperative evaluation in response to the request of clinicians. Therefore, no ethical review was performed during the retrospective evaluation of the studies conducted.

Statistical Analysis

The sample size required for the study was not precalculated. The mean values and standard deviations of the measured parameters were calculated for the statistical analysis of the data obtained. The Shapiro–Wilk test was used to determine the normality of distribution of the quantitative parameters. Pearson correlation coefficient and Spearman's rank correlation coefficient were used to evaluate the correlation between the quantitative characteristics. The P-value, along with the 95% confidence interval limits and correlation coefficients, were reported. A two-sided significance level was estimated. A *P*-value of <0.05 was considered to be statistically significant. The GraphPad Prism 9 (GraphPad Software, USA) was employed for the analysis.

RESULTS

Study Subjects

This retrospective study analyzed the heart and chest MRI data of 38 patients (30 males, 8 females). The mean age was 19.9 years (±9 years).

Haller Index

Patients were divided into three subgroups based on the Haller index (Fig. 1, Table 1). Mild PE patients did not require further surgery. The surgery was performed for patients with moderate to severe chest wall deformities.

When assessing the correlation between the Haller index and the right ventricular ejection fraction, no statistically significant Pearson correlation was observed (P = 0.777 for inspiratory ejection fraction and P = 0.798 for expiratory ejection fraction) (Fig. 2, Table 2). The mean right ventricular ejection fraction was 46%.

There was no statistically significant association between the Haller index and the sternal rotation angle (P = 0.9489).

Correction Index

The mean correction index in this study was 31.5 (±11) (Fig. 3). The correction index increased in tandem with the Haller index (the degree of chest wall deformity), as indicated by the statistical analysis $P < 0.05$ (Fig. 4). For instance, the mean correction index was 13, 24, and 35 in patients with mild, moderate, and severe PE, respectively.

No statistically significant association was detected between the sternal rotation angle and the correction index (P = 0.35) as well as between the correction index and the right ventricular ejection fraction (P = 0.1).

Sternal Rotation Angle

The sternal rotation angle is a crucial factor in planning the treatment strategy (Fig. 5).

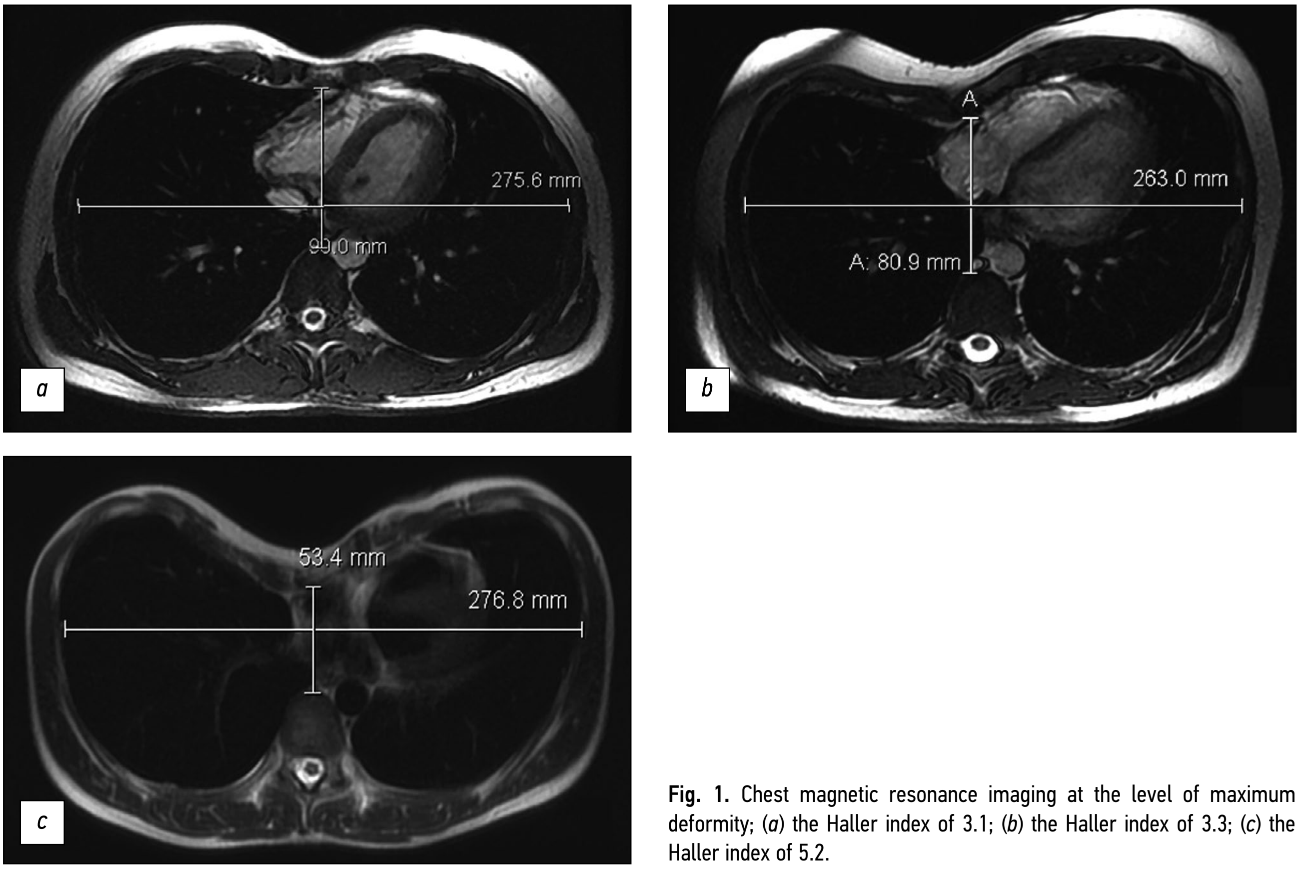

Fig. 1. Chest magnetic resonance imaging at the level of maximum deformity; (*a*) the Haller index of 3.1; (*b*) the Haller index of 3.3; (*c*) the Haller index of 5.2.

Table 1. Patient distribution based on the Haller index

	Pectus excavatum		
	Mild	Moderate	Severe
Number of patients	3	6	29
The mean Haller index	2.8	3.3	5.1
The standard deviation for the Haller index	0.4	0.1	1.8

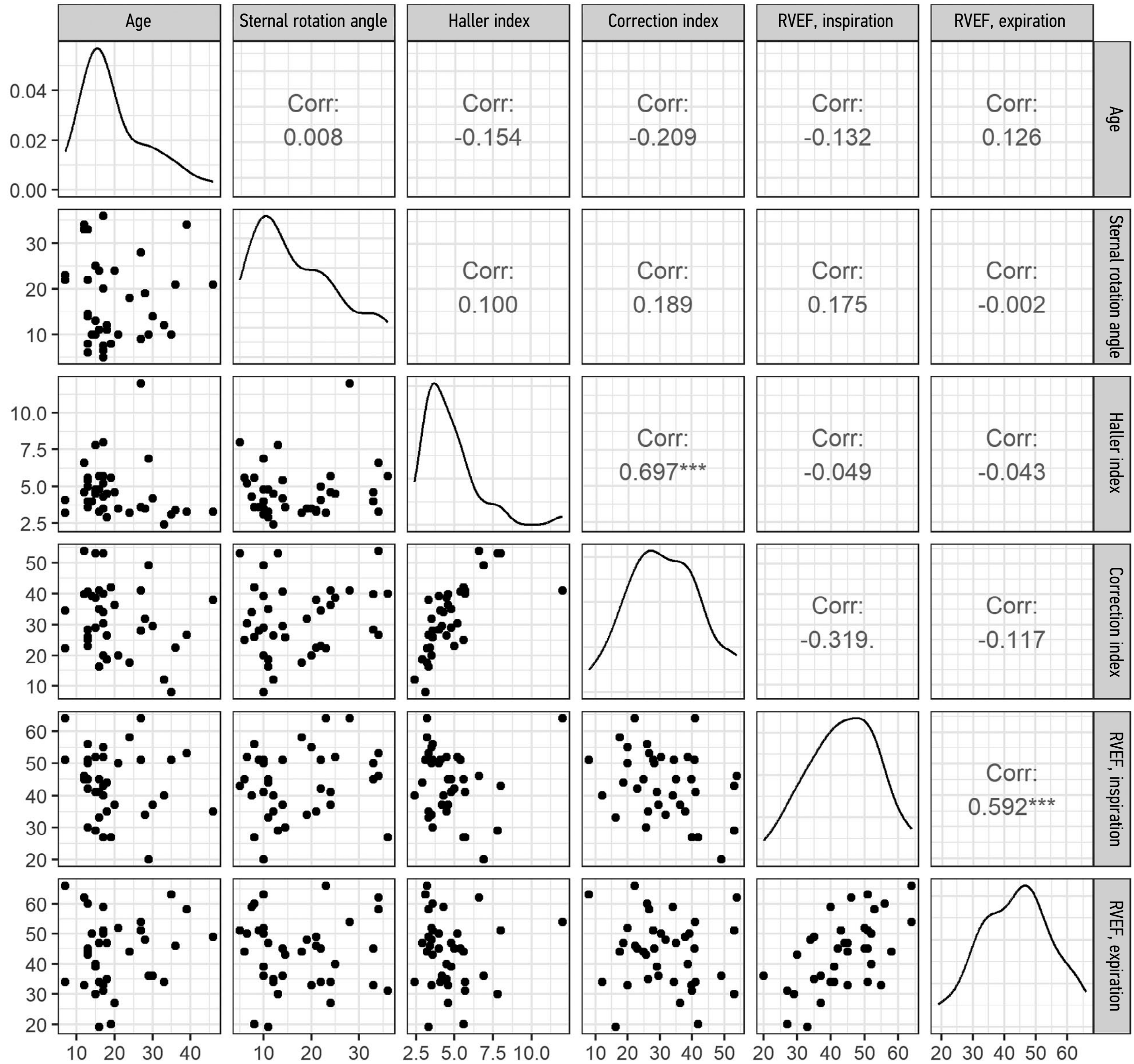

Fig. 2. Correlation data for the study parameters. RVEF, right ventricular ejection fraction.

Table 2. Correlation between variables (the Haller index, sternal rotation angle) and the right ventricle ejection fraction on inspiration and expiration

Variable	Correction index	Right ventricular ejection fraction	
		Inspiration	Expiration
Sternal rotation angle	R=0.19 *P* = 0.255	R=0.18 *P* = 0.306	R=0 *P* = 0.99
Haller index	R=0.7 *P* < 0.001	R=–0.05 *P* = 0.777	R=–0.04 *P* = 0.798

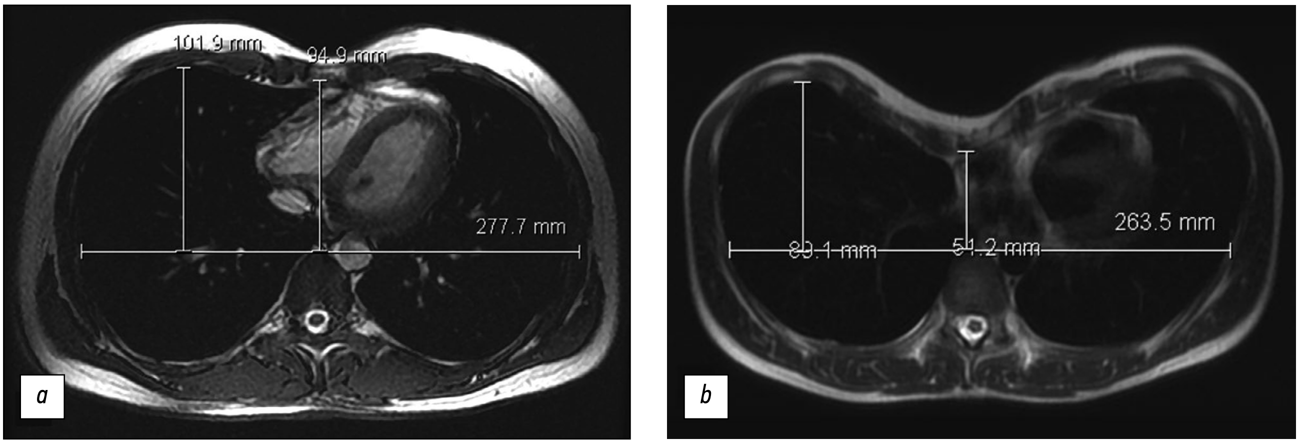

Fig. 3. Chest magnetic resonance imaging at the level of maximum deformity; (*a*) the correction index of 7%; (*b*) the correction index of 32%.

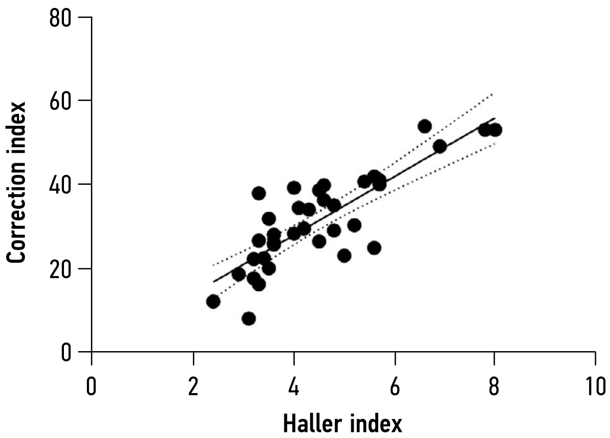

Fig. 4. Correlation data for the Haller index and the correction index ($P < 0.05$).

An angle of ⩾150° was considered significant for surgery and was reported in 44.7% of the total number of patients (Table 3). This position of the sternum required a unique oblique positioning of the sternal plate. The plate was positioned "toward" the acute sternal angle in preparation for subsequent rotation. Consequently, the sternal plate was transferred from the upper intercostal space on the right to the lower intercostal space on the left by traversing the apex of the deformity with sternal rotation when the acute angle expanded to the right (Fig. 6*a*). This occurred in 86% of all sternal rotation cases. In the case of the acute angle expanded to the left (14% of all cases), the sternal plate was accessed from the lower intercostal space on the right, through the apex of the deformity to the higher intercostal space on the left (Fig. 6*b*).

DISCUSSION

Conventionally, CT has been widely employed for diagnosing PE and evaluating diverse parameters due to its accessibility [11]. Radiation exposure is a clear limitation of chest CT; consequently, scanning protocols have been altered in recent years to mitigate this concern [12].

MRI is less frequently used to diagnose PE and is more time-consuming. However, it has the advantage of not exposing the patient to radiation and enables evaluation of compressive changes in the heart.

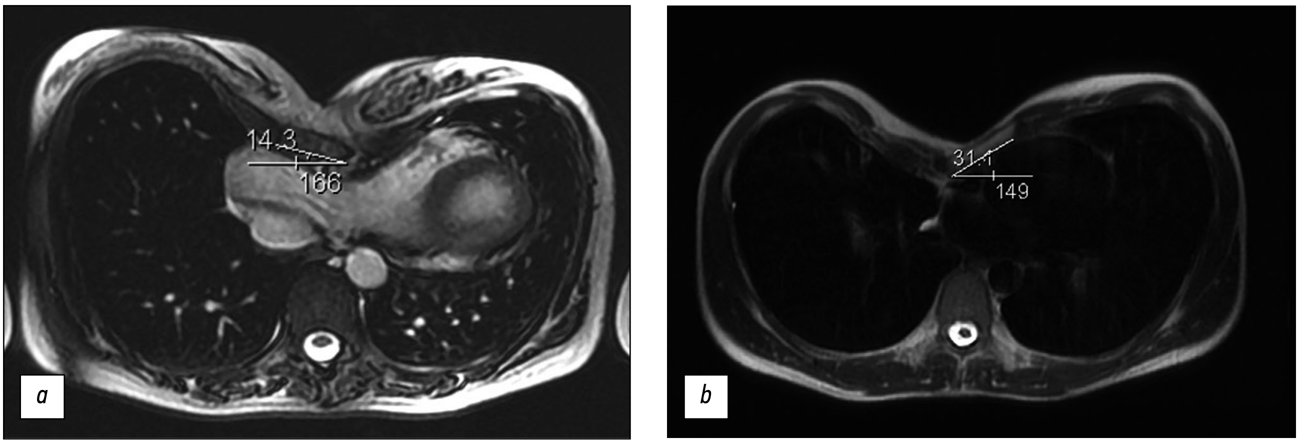

Fig. 5. Chest magnetic resonance imaging at the level of maximum deformity; (*a*) the sternal angle rotation of 14.3°; (*b*) the sternal angle rotation of 31.1°.

Table 3. Patient distribution based on the sternal rotation angle

Sternal rotation angle <15°	
Number of patients	21
The mean angle	10°
Sternal rotation angle >15°	
Number of patients	17
The mean angle	26°

Several different indices are described in the literature to evaluate PE. The Haller index is one of the most used indices to identify patients requiring surgical treatment of the deformity. The threshold value for surgery is 3.25. However, some studies have recently demonstrated potential problems associated with the exclusive use of the Haller index for surgical planning. For example, the Haller index does not correlate with age, other parameters of surgical treatment, or potential postoperative complications [13]. Furthermore, a separate study of the Haller index revealed that 48% of the Haller index numerical values for PE patients and controls overlapped [9].

Such data indicates the need to standardize data and devise additional preoperative and postoperative indices [9, 13, 14]. The correction index is one of these parameters; surgery is indicated when it is >28%, provided it correlates with the Haller index [15]. The correction index can also be utilized to compare postoperative outcomes.

In our study, the Haller index, the correction index, and the sternal rotation angle are consistent with the clinical status of the patients and the previous studies on the preoperative evaluation of chest wall deformities using CT and MRI [16, 17].

The mean right ventricular ejection fraction in patients with PE was decreased to 46% in our study. Such findings align with research data reporting the diminished right ventricular ejection fraction in patients with chest wall deformities [18–20]. However, statistical analysis did not reveal a correlation between the numerical values of the Haller index and ejection fraction. This may be attributed to the uneven distribution of patients based on the severity of their deformity and requires further study.

Study Limitations

Our study is limited by its retrospective nature, a relatively small patient sample size, an imbalanced distribution of patients by progression of changes, and the absence of a comparison with chest CT as the gold standard.

CONCLUSION

Our study revealed that MRI is a highly informative diagnostic tool for PE that does not expose patients to radiation and provides a comprehensive preoperative assessment of abnormalities.

The Haller index and the correction index were found to be correlated ($P < 0.05$).

Our study demonstrated the decreased right ventricular ejection fractions in PE patients. Nevertheless, no correlation was detected between this parameter and the Haller index, and this may be attributed to the study limitations.

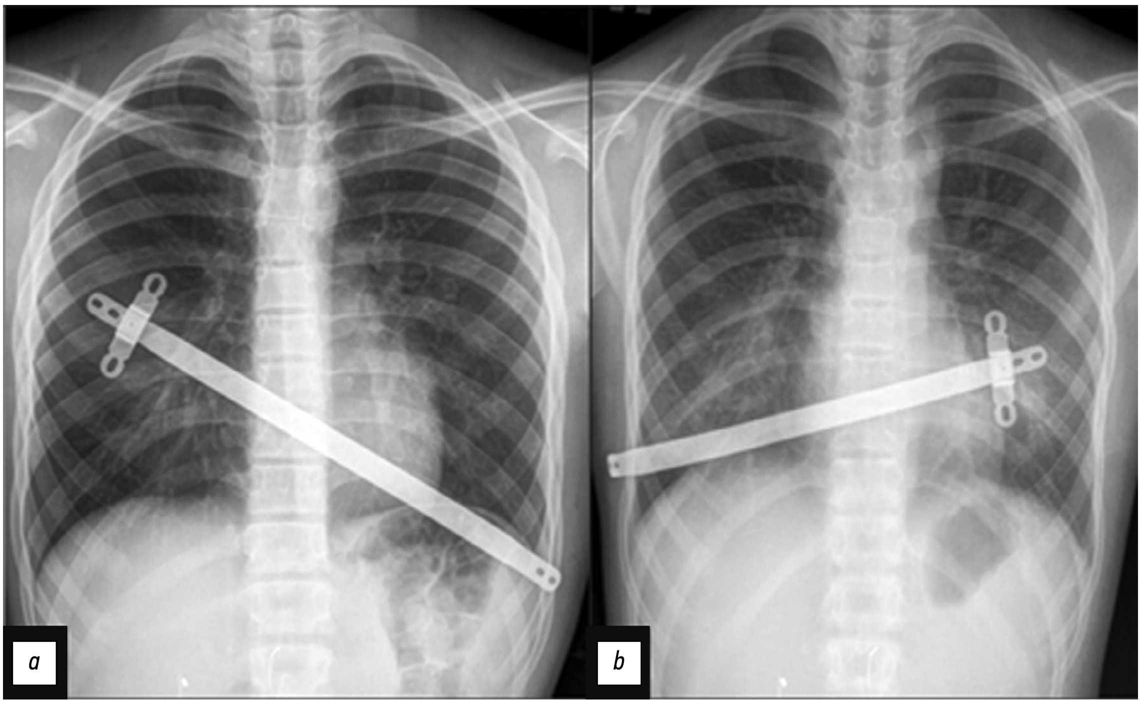

Fig. 6. Frontal chest X-ray following pectus excavatum treatment. Plates positioned if the angle opens: (*a*) right; (*b*) left.

ADDITIONAL INFORMATION

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. M.V. Vishnyakova — study concept and design, text editing; G.S. Muzafarova — writing text, collecting and processing materials; A.S. Abramenko — collection and processing of materials; V.A. Kuzmichev, V.V Gatsutsyn — research concept, text editing.

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