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Chest fast MRI: an Imaging alternative on pre-operative evaluation of Pectus Excavatum

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Abstract
Background: Standard imaging methods in evaluating chest wall deformities, such as Pectus Excavatum (PE) in paediatric and adolescent patients, include baseline 2-view chest radiography and chest CT scan. Only few studies to date investigated the value of fast MRIin the pre operative assessment of patient affected by PE.
Objective: To evaluate the efficacy of chest fast MRI in pre-operative management of patient affected by PE. To obtain the Haller Index (HI) and Asymmetry Index (AI) from chest fast MRI protecting patients from radiation exposure.
Materials and Methods: We analyzed the data of 42 consecutive patients with severe PE who underwent minimally invasive repair between March 2007 and March 2010. All 42 patients received chest fast MRI, but only the first 5 in view of the results, were studied also with chest ultrafast CT scan. In both examinations, data at the deepest point of the depression were collected.
Results: Severity indices of the deformity using HI and AI, collected from CT scan and fast MRI in the first 5 patients, were comparable. In the remaining 37 fast chest MRI offered good images of the chest wall deformities with no radiation exposure, detailing anatomical information such as displacement and rotation of the heart or great vessels anomalies.
Conclusion: This study suggests the use of chest MRI in pre operative workup for patients with PE to obtain severity indices (Haller Index and Asymmetry Index avoiding radiation exposure to paediatric patients.

Pectus Excavatum (PE), also known as funnel or sunken chest is the most common type of congenital chest wall abnormality [1,2]. PE occurs in an estimated 1 out of 300-400 births with a male predominance (M: F = 3:1) and represents the most common anterior chest wall deformity seen by paediatricians and general practitioners [1]. It is characterized by a depression of the body of the sternum with associated abnormalities of the costal cartilages. The appearance of the defect varies widely from mild to very severe; in a number of cases a significant asymmetry

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between the right and left hemithorax is present [3-5]. The exact mechanism involved in this abnormal bone and cartilage overgrowth is not know and to date, no genetic defect has been directly related to the development of PE [4,6].

PE is often asymptomatic during early childhood but symptoms like easy fatigability and decreased endurance usually appear when patients with PE reach adolescence and are involved in competitive sports [7].

In severe forms of PE, the heart is displaced to the left side of the chest and pulmonary expansion during inspiration is moderately affected, resulting in a "restrictive" defect on pulmonary function tests. Moreover, the condition is also described associated with Marfan's and Poland syndrome [8-10].

Surgical correction for PE has become more prevalent with the development of the mini-invasive repair (MIRPE) described by Nuss in 1989 [11].

Preoperatively, X-rays and CT scan are the radiological examinations usually performed to evaluate the degree of sternal depression. These imaging modalities provide useful information on abnormal chest anatomy using the Haller Index (HI) and Asymmetry Index (AI) [12,13]. However, especially in case of the multislice high resolution CT, they expose patients to a significant amount of ionizing radiation [14,15].

There is sparse information in the literature on the use of MRI in the assessment of patients with PE. Raichura et al. on 2001, evaluated a series of six patients affected by PE using turbo Flash MRI, obtaining indexes of chest deformity and information about diaphragmatic excursion and cardiac displacement [16].

We designed this prospective study in two parts. First we compared indices obtained by chest CT scan to those obtained by MRI in order to demonstrate that all the measurements taken on CT scan could be easily obtained from MRI. We subsequently evaluated results obtained when only MRI was performed.

The study was approved by the Institutional Review Board of the Department of Sciences for Women and Child's Health, University of Florence.

1. Materials and methods

We enrolled 42 patients with severe PE who underwent Nuss procedure in our Department of Paediatric Surgery, from March 2007 to March 2010.

The MIRPE technique consisted in positioning a previously shaped stainless steel bar into the chest, under thoracoscopic control. Afterwards, the bar was fixed bilaterally with two lateral transverse stabilizers. All the patients were operated by the same Consultant Paediatric Surgeon (AM). Informed consent was obtained from patients and/or their parents.

Radiological assessment and analysis of the data of the 42 patients were carried out by two different consultant radiologists: the first acquired and analysed CT images (Fig. 1) the second assessed the MRI images (Fig. 2). A third consultant radiologist analysed both CT and MRI data. The HI was calculated by the ratio of the transverse dimension of the chest (from the two inner ribs) to the A (anterior) – P (Posterior) dimension (from vertebral body to sternum). The AI was calculated, by the ratio of the sagittal length of the chest wall on the right (C1) and left side (C2) at the level of greatest deformity.HI was considered severe if higher than 3.5. AI was considered pathological if significantly different from the value of 100.

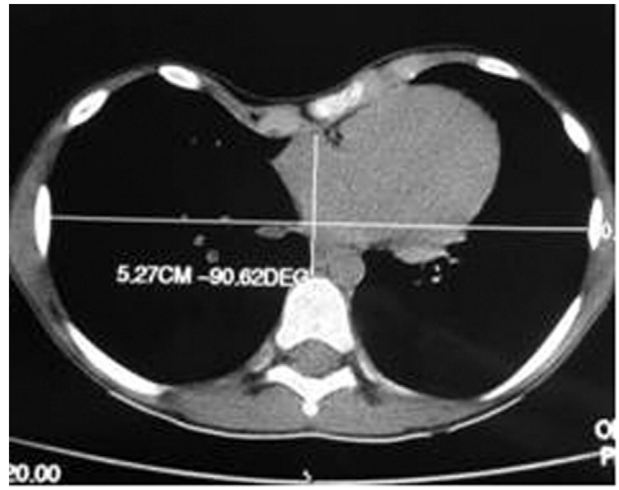

Fig. 1 HI calculated from Chest CT scan.

2. Methods

CT images were collected using Philips Brilliance 40 MSCT on the first 5 patients of the study. MRI was performed, in all patients, using a Philips Achieva 1.5 T during normal breathing with ECG synchronisation to reduce artefact from cardiac movement.

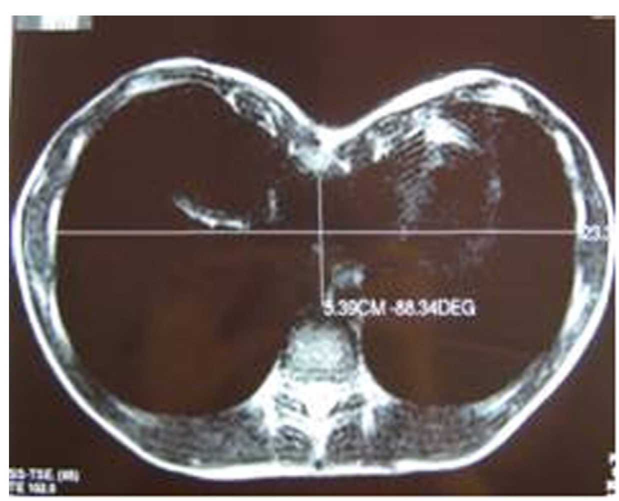

Fig. 2 HI calculated from Chest MRI.

The Radiology department created a specific MRI fast protocol of total acquisition time of 6 minutes. Slice thickness was kept constant to 7 mm. An ultra fast imaging scan turbo spin echo T_1 weighted breath hold (BH) FOV 350 × 282 mm, TR/TE of 383/40 ms, and total scan time of 69 seconds was performed for anatomical axial images with 48 echo train length, 4.5 ms echo spacing that performs a millimetric spatial resolution image. A transverse gradient echo sequence in breath hold with TR/TE of 7.5/4.5 ms with flip angle of 20° NSA (number of sampling average) of 2 was performed to enhance edges between tissue with very different magnetic susceptibility. In this case was used the SENSE factor of 1.4 in the measure direction to reduce total scan time to 49 seconds. A balanced-TFE (balanced steady state free precession) in breath hold is the last scan technique applies to our work because gives us a very good signal to noise ratio and a contrast that depends on T2/T1 ratio rather than T2. 24 slices acquired with 1 mm of gap, FOV of 375 × 299 mm, NSA of 2 and TR/flip/TE of 3.6/90°/1.82 optimized for chest tissues under investigation give a total scan time of 47 seconds with SENSE factor of 1.4 in the measure direction.

A transverse balanced TFE image was acquired three times: the first sequence was obtained in inspiration with breath hold, the second sequence was obtained in expiration with breath hold and the third sequence was obtained in free breathing.

The Haller and Asymmetry indexes were calculated only in the axial images obtained in all three sequences. Moreover we obtained the sagittal and coronal images in free breathing.

Sagittal images were evaluated in order to visualize the height of the smaller sternal-vertebral distance and both sagittal and coronal images were evaluated in order to identify vertebral column associated problems.

All the patients were co-operative and the radiologist instructed them how to hyperventilate before imaging, by taking two or three deep breaths to increase the duration of breath holding, and then to either inspire or expire fully before breath holding during image acquisition. During the exam the subjects were regularly encouraged with emphasison maximum inspiratory and expiratory effort during breath holding. The radiologist could observe the patients during the entire scanning using a video link. During the exam the radiologist could change the color of the lights in the MRI room to better communicate to the patient the different phases of breathing and help them relax.

3. Results

Clinical data of the 42 consecutive patients with diagnosed severe PE were collected.. Median age: 16 year, (range: 12-24 years); male to female ratio M:F = 39:3; median of HI: 6 (range: 3.7-12.6 and st. dev.: 2.061). The data obtained from the first 5 patients showed a strong correlation between MRI and CT (Table 1), thus supporting our initial plan to stop using CT imaging and to asses the rest of the patients with MRI only protecting them from ionizing exposure.Furthermore, a high degree of similarity between the HI and AI indices calculated from the 2 imaging modalities was confirmed and more importantly, CT scan did not provide any additional information for operative planning.

The Pectus indices (HI and AI) were derived from chest wall measurements using axial images for both CT and MRIscansat the lowest limit of the PE defect.

The values of HI reported from the two different radiological methods were strongly comparable. The mean of HI calculated from CT scan and fast MRI resulted identical. The Pearson's correlation coefficient for HI index was 0.995 and was statistically significant at the 0.01 level of statistical significance (P = .000).

The mean of AI indices acquired from CT scan and MRI was respectively105.4 and 106.5. The Pearson's correlation coefficient for AI indices was 0.994. This also evidenced a significant correlation between the two group of data. (P = .001).

The calculated indices for each of 5 patients in the two imaging modality are shown in Table 1.

4. Discussion

Pectus Excavatum is a common thoracic wall defect resulting in a diminished anterior-posterior dimension. Patients often suffer from subjective symptoms and the appearance of the chest can be very disturbing for young teenagers. Problems with self esteem and body image perception are frequently reported in teenaged patients. Psychologic disturbances are common in adolescence. In our study, the vas majority of patients were symptomatic (38 out of 42, equivalent to 90.47%) and the most common complaints were chest tightness, tachycardia, dyspnea even under moderate exertion and precordial pain in some cases. It has been suggested that such complaints could be partly psychogenic in origin. Nevertheless, recent publications highlighted that pectus excavatum is not only a cosmetic deformity [17,18] but potentially a physical disability,as many adult patients who did not undergo repair during childhood subsequently present worsening of cardiopulmonary symptoms.

In 1987Haller et al. [12], presented the use of a single CT scan to determine the Pectus index (Haller Index) to evaluate the measure of chest deformation in patients with PE. This

Table 1

Patient	Chest CT scan		Chest fast MRI	
Number	HI	*AI*	HI	*AI*
1	5.2	*93.7*	5.1	*94.4*
2	4.8	*93.9*	5	*95.7*
3	4	*106.2*	4	*106.7*
4	8	*125*	8.1	*128.5*
5	5.7	*108.3*	5.5	*107.3*
mean	5.54	105.4	5.54	106.5

severity index was calculated by measuring the inner width of the chest (at the lowest level of the PE) and dividing it by the distance between the posterior surface of the sternum and the anterior surface of the spine (at the lowest part of the defect).

Different opinions have been reported in the literature regarding the imaging assessment of patients with PE. Some authors favor a multi cross-sectional imaging protocol due to the inability of the Haller Index to evaluate the asymmetry and superior-inferior range of involvement and highlighted the need for more systematic measurement to eliminate variability in interpreting images by radiologists [19]. Other authors suggest using conventional radiography (transverse and anterior-posterior measurement of the chest) for assessment of severity index.

Kilda et al. [20] recommend conventional radiography to evaluate chest wall deformity by calculating the main radiological indexes such as HI and vertebral index (obtained from vertebral body length and sterno vertebral distance).

Mueller et al. [21] in their series of twelve patients operated for PE, compared HI calculated from chest standard radiograph and CT scan. The mean Haller Index on chest CT scan was 3.97 and the mean index measured on chest X-ray was 4.08. Data analysis showed a Pearson correlation coefficient of 0.98, confirming a high degree of similarity between the Haller index calculated from the two different imaging modalities.

Khannaet al. [22] performed a retrospective analysis of radiological data from 32 children with PE (median age 14.5 years). Two radiologists independently calculated CT Haller index and radiographic Haller index and foundstatistically significant correlations between the two series. [Spearman correlation coefficient (95% confidence interval) for observer 1 = 0.71 (0.48-0.85, $P < .01$) and for observer 2 = 0.77 (0.52-0.88, $P < .01$)].

Other authors [23], in order to reduce radiation exposure of children with PE during full chest CT scan, proposed a very low dose CT protocol with limited slices (5-7 slices) centered on the area of most severe deformity. This markedly reduces the radiation dose by 80%.

As the majority of PE patients presents during childhood, they are at greater risk of radiation-induced cancer. Indeed, CT scans have been associated with radiation exposure that is 2 or 3 orders of magnitude greater than that in plain radiography [24]. In addiction children are more radiosensitive than adults, therefore an early exposure to radiation even in a single full CT scan has been associated with development of malignancy later in life. The estimated risk of developing a fatal cancer after a CT scan is between 1 in 550 and 1000 [25,26]. Radiation exposure in young patients has also been associated with growth retardation and reduced fertilitylater in life.

Therefore, in children with PE expected to undergo surgical correction, our policy is to avoid unnecessary radiation early in life. At the same time it is important to obtain information on abnormal thoracic anatomy, displacement or rotation of the heart, great vessels anomalies and asymmetric volume between right and left hemithorax. As previously mentioned, the extent of deformity is generally assessed by CT scan, with multi-slices high resolution techniques, which exposes patients to significant levels of ionizing radiation. Raichura et al. [16] first describedthe use of fast MRI to evaluate static and respiratory related dynamic chest wall characteristics, the extent of cardiac displacement and the diaphragmatic excursion in six PE patients compared with six healthy controls.

Pectus HI could be easily calculated from chest wall measurements using axial images.

In our study, in all 42 patients, the HI was easily acquired from fast MRI images (axial slices) at the deeper point of the chest abnormality. Fast MRI with very short acquisition times produced images that were free from artefacts produced by cardiac or respiratory movements.

In order to avoid ionizing radiation exposure and to obtain anatomical details for pre-operative imaging assessment of PE, we propose the use of chest fast MRI as radiological modality of choice.

5. Conclusion

In conclusion MRI proved to be a technique of great value in the evaluation of patients with PE allowing us not only to acquire the same information obtained by CT but also to reach a more complete information on the defect.The absence of ionizing radiation, excellent soft tissue contrast and multiplanar abilities are the major advantages of MRI.

In our investigation we were able to show that the Haller index and Asymmetry index calculated from measurement obtained by MRI was not significantly different from that acquired by CT scan. Both measurements accurately show the severity of chest abnormality. CT scan did not provide additional information for surgical planning.

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