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Assessment of potential confounders when imaging pectus excavatum with chest radiography alone☆

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ABSTRACT

Background: Chest radiography (CXR) has emerged as an attractive alternative imaging option for objective pre-operative assessment of pectus excavatum (PE) with comparable accuracy, reduced cost, and less radiation exposure when compared to computed tomography (CT). This study asked whether image quality, scoliosis, and asymmetry of the PE deformity would decrease the accuracy of CXR as compared to CT.
Methods: A database of PE patients receiving preoperative CXR and CT was created, and Haller-indices (HI) and correction-indices (CI) were calculated using each imaging modality. Each potential confounding variable were analyzed using Spearman correlations the Fisher r-to-z transformation test.
Results: The database was comprised of 77 patients. Image quality, scoliosis and the 'eccentric type' of asymmetry did not demonstrate any significant worsening of measurement accuracy. However, the correlation coefficients for CIs for those with and without the 'unbalanced type' of asymmetry were 0.593 and 0.890, respectively, with a Fisher r-to-z of 2.16 ($p = .031$).
Conclusions: The accuracy of CXR-derived pectus indices remains quite favorable despite the heterogeneity from radiographic quality, scoliosis and chest wall asymmetry. Nonetheless, the unbalanced type of chest wall asymmetry did emerge as a significant confounder. As such, use of CXR alone in cases of gross chest wall asymmetry should be cautioned.

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1. Background

Pectus excavatum (PE), an anatomic deformity defined as a depression of the sternum and costal cartilages, occurs in 1 out of 300 to 400 births and represents the most common congenital deformity of the chest wall [1,2]. Surgical referrals are often made for physiologic and cosmetic reasons, but such decisions are often subjective and necessitate objective pre-operative criteria to define PE severity. The original index developed for this purpose, the Haller Index (HI), was established more than 25 years ago [3]. More contemporary studies suggest that a new measurement, the correction Index (CI), more accurately assesses pectus severity in PE patients, as well as those with significant discrepancies of anterior–posterior to medial–lateral chest wall dimensions [4,5].

Initially, both HI and CI measurements were performed using computed tomography (CT) scans. However, issues of cost and radiation exposure in children have prompted researchers to explore the use of chest radiography (CXR) as an alternative imaging modality for evaluating PE severity [6,7]. In this regard, CXR (two-view for HI calculation and lateral view only for CI measurement) has been shown to be a reliable and accurate preoperative imaging modality for evaluating PE [8–12].

In an attempt to further refine the accuracy of using CXR alone in measuring the severity of PE, we derived a list of potential confounding variables that could lead to inaccurate CXR measurements. We hypothesized that CXR image quality, scoliosis, and pectus asymmetry would decrease previously studied correlations between CXR and CT in measuring HI and CI.

2. Materials and methods

2.1. Study design

This study was approved by the University of Iowa institutional review board, with a waiver of need for patient consent. A retrospective database was created consisting of all patients at our institution receiving a PE diagnosis from January 2003 to July 2012. From this original database, only patients receiving a preoperative chest CT scan with breath holding and a two-way CXR at full inspiration were included. For each patient, a staff radiologist calculated an HI and CI from the CT axial image with the greatest depression. For CXR measurements, two pediatric cardiothoracic surgeons (observers 1 and 2), blinded to the CT

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scores, independently calculated the HI and CI for all patients. These 2 measurements were then averaged together.

Patients were then divided into two groups based on each predetermined potential confounding factor (CXR image quality, scoliosis, and pectus asymmetry); one group constituting only those measurements containing the confounding factor to be examined and the other group containing only those measurements without the given confounding factor. Each confounding factor was examined independently from the others. A pediatric cardiothoracic surgeon determined CXR image quality. Images were separated in binary fashion, either appropriate quality or inappropriate quality to definitively calculate an index. Scoliosis was measured by calculating the Cobb angle for each patient as described by Morrissy et al. [13]. Patients with Cobb angles of >10 degrees were examined, as this represents the clinical diagnosis of scoliosis. Pectus asymmetry was determined according to a study by Park and colleagues in which two types of asymmetry were defined [14]. First, asymmetry was defined as >2 cm malalignment between the center of maximal pectus depression and the center of the sternum. This type of asymmetry has been coined “eccentric type” (Fig. 1A). The second type of asymmetry, the “unbalanced type”, was characterized by depression on one side of the thoracic cavity being more severe than the contralateral side. This was measured by the angle created by the vertical axis in the midline, with the left and right thoracic walls, respectively (Fig. 1B). Unbalanced asymmetry was defined as a difference in angles of >10 degrees. Asymmetry of each type separately, and then asymmetry of the entire group of patients with either type of asymmetry were assessed.

2.2. Calculations

The Haller scores were measured from digital two-way CXR by first re-sizing the images to be equal, then by identifying and measuring the distance from the maximal posterior depression of the sternum to the anterior aspect of the nearest vertebral body on lateral CXR (Fig. 2B). This value was then divided into the measured transverse diameter of the chest obtained at the same level on the anterior–posterior image (Fig. 2C). HI measured by CT was done as previously described [3,11]. CIs were calculated by measuring the distance between the posterior aspect of the corrected sternum and anterior aspect of the vertebra on both CT imaging (Fig. 3A) and lateral CXR (Fig. 3B). This number was subtracted by the distance between the posterior aspect of the sternum at the site of deepest depression and anterior vertebra. This difference was divided by the first measurement and multiplied by 100 to represent the percentage of chest depression and, therefore, potential correction (Fig. 3).

2.3. Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp). Data were assessed for normality using the Shapiro–Wilk test. Continuous data are presented as median with range, and categorical variables are presented as frequencies with percentages. Spearman correlations were calculated to estimate agreement between CT and CXR for both the group with the given confounding factor being assessed, and for the group without the confounding factor. This was done for both HI and CI measurements. Fisher's r-to-z transformation was then used to compare the Spearman correlations between the group with the confounding factor and the group without for each of the confounding factors identified: CXR image quality, scoliosis, and pectus asymmetry. Z-scores were derived from the Fisher's r-to-z transformation and 2-tailed p-values were calculated and presented with 95% confidence intervals.

3. Results

Table 1 depicts the demographics and median index calculations for the studied cohort. In total, 77 patients were identified to have both preoperative CT scans and two-way CXR.

Five patients were identified as having poor CXR image quality. For these images, the Spearman correlation coefficient between CT HI and CXR HI was 1.0 and between CT CI and CXR CI was 0.4. The Spearman correlation coefficient for the group with adequate CXR image quality was 0.838 for HI and .828 for CI. Fisher's r-to-z transformation test of difference z-score was −3.6 ($p < 0.001$) for HI and 1.15 ($p = 0.250$) for CI (Tables 2 and 3).

Eleven patients were found to have a Cobb angle >10 degrees. Spearman correlation coefficient for angles >10 between CT HI and CXR HI was 0.918, and between CT CI and CXR CI, it was 0.964. Spearman correlation coefficients for patients without scoliosis (Cobb angles <10 degrees) was 0.828 for HI and .826 for CI. Fisher's r-to-z transformation test of difference z-score was −1.05 ($p < 0.294$) for HI and −2.2 ($p = 0.029$) for CI (Tables 2 and 3).

For asymmetry, 14 patients had >2 cm difference between the center of the sternum and the center of pectus depression (eccentric asymmetry). The correlation for HIs was 0.864 for patients with a > 2 cm difference and 0.846 for those without a > 2 cm difference. The respective fisher R-to-z was −0.2 ($p = 8.412$). The correlation for CIs was 0.925 for those with >2 cm separation and 0.846 for those without. The fisher r-to-z was −1.16 ($p = 0.246$). Thirteen patients were found to have the unbalanced type of asymmetry. The correlation coefficients for HIs for those with and without a > 10 degree differences were 0.725 and 0.859, respectively, with a Fisher r-to-z of 1.09 ($p = 0.276$). The correlation coefficients for CIs for those with and without a > 10 degree difference were 0.593 and 0.890 respectively with a Fisher r-to-z of 2.16 ($p = .031$). When both types of asymmetry were considered, 21 patients had either type of asymmetry. The HI correlations for those with and without the confounding variables were 0.805 and 0.854 with a Fisher r-to-z of 0.580 ($p = 0.562$). The CI correlation coefficients were 0.73 for those with either of the confounders and 0.879 for neither confounder with a Fisher r-to-z 1.61 ($p = 0.107$) (Tables 2 and 3).

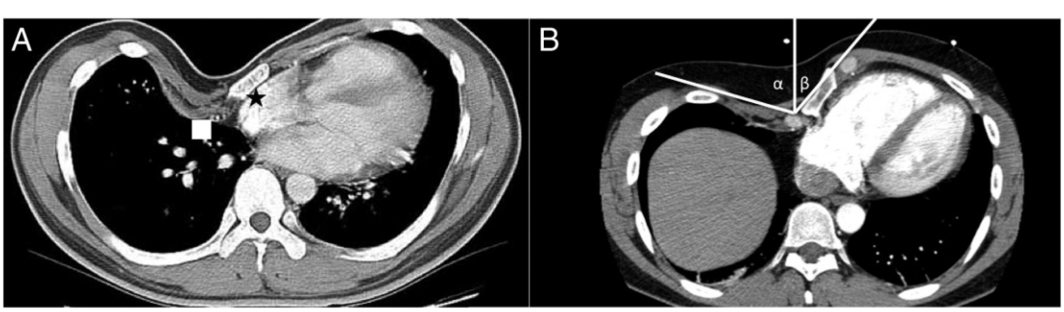

Fig. 1. Illustration of pectus asymmetry measurements. **(A)** The ‘eccentric type’ of asymmetry is demonstrated in the figure by the center of the pectus depression (white box) not being symmetrically located with the center of the sternum (black star). **(B)** The ‘unbalanced type’ of asymmetry is demonstrated where one side of the wall of the depression is more severely depressed than the other. This creates a situation where the angles created by each wall and the vertical axis are different ($\alpha \neq \beta$).

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