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The Depression Index: an objective measure of the severity of pectus excavatum based on vertebral diameter, a morphometric correlate to patient size

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ABSTRACT

Background/Purpose: In patients with Pectus Excavatum (PEX), the proposed Depression Index (DI) is derived from the absolute measurement of sternal depression using the transverse vertebral body diameter as a surrogate for height. The previously described objective and useful Pectus Index (PI) and Correction Index (CI), utilize thoracic diameters and do not always reflect the severity of the deformity as observed by clinicians.

Methods: Data for age, weight, height and vertebral diameter of T9, 10 and 11 were collected on 60 patients, with normal skeletons, undergoing CT scanning. The DI, PI and CI were calculated from CT scans on 76 patients with PEX. Indices were also compared to subjective rankings of the deformity from visual inspection of photographs by 5 clinicians.

Results: All parameters of age, weight and height correlated with the vertebral diameter. The DI correlated with the severity of the PEX deformity as also measured by the PI and the CI. There was a better correlation of the observed deformity severity to the DI than the PI or CI.

Conclusion: There is a strong correlation between transverse vertebral size and patient height. The DI is an objective measurement of the severity of a PEX deformity that is independent of the thoracic diameters.

The clinical appearance and impression of the severity of a pectus excavatum deformity (PEX) have not always correlated with current objective indices calculated from data derived from CT scan analysis, based on personal observations and communications with other surgeons treating chest wall deformities. Both the Pectus Index (PI), described by Haller [1], and the Correction Index (CI), described by St Peter [2], utilize thoracic diameters in their calculations. These diameters (transverse and sternal–vertebral distance) of the thoracic cavity are significant factors affecting the calculated results. This study proposes a Depression Index (DI) that uses the vertebral body diameter as a correlate to an individual's size (height, weight and age), which can then be used as the denominator for an index of PEX severity that *is independent of the diameters of the thorax.*

Objectively analyzing and comparing the severity of the deformity of PEX among patients proved difficult for surgeons that treated this disorder, until 1987 when Haller introduced the PI. Prior to the use of this ratio the deformity was often simply measured as the absolute distance of the sternal depression [3]. This approach resulted in discrepancies of a meaningful depression in patients of different sizes. The PI, the ratio of the transverse diameter of the chest divided by the sternal to vertebral distance, subsequently became the gold standard measure of the deformity's severity. St. Peter introduced, in 2011, the CI that seemed to provide a better separation of patients with moderate to severe deformities from those with more normal thoracic skeletons. This index varies from 0 to 100%, indicating the percentage of the anterior–posterior diameter of the thorax that the sternum must be moved to bring it to a neutral position.

The shape of the thoracic cage, whether more circular or elliptical on axial section, can produce marked changes in both the PI and CI. Patients with similar appearing sternal depressions can have quite different values for these two indices. It was the intent of this study to develop an objective index that would correlate better with the clinically observed severity of the deformity. Three hypotheses were developed: 1) that the diameter of the vertebral body correlates to an individual's size, 2) that a ratio of the actual skeletal sternal depression divided by the vertebral diameter results in a DI that can be used to compare patients with PEX, 3) that the DI correlates more closely than the PI or CI with the observed severity of the deformity.

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1. Materials and methods

1.1. Patients

The research protocol was reviewed and approved by the Institutional Review Board of the Human Study Protection Office at Penn State Hershey Medical Center for this retrospective study. Informed consent was not required.

The first hypothesis of the study was addressed by an analysis of patients with normal skeletal anatomy that underwent CT scanning for other conditions at a single tertiary care children's hospital. The imaging data base (Centricity) was searched for all CT exams of patients between 10 and 20 years of age with "chest" in the exam description, completed between 1/1/2008 and 12/31/2010. The electronic medical record was reviewed for patient age, height and weight within 3 months of the date of the chest CT. Patients were excluded if age, height and weight were not all available. Patients were also excluded from this study phase if a spine or thoracic skeletal abnormality was noted in the imaging report. Based on personal observations T9, T10 and T11 are the vertebrae that oppose the point of maximal sternal depression in most patients with PEX and were, therefore chosen for measurement. The anterior–posterior and transverse dimensions of T9, T10, and T11 vertebral bodies were calculated using the imaging measurement palette tool available in the Picture Archiving and Communication System (PACS) from axial images reviewed in bone windows. 60 patients met all criteria. Patient age, weight, and height were individually plotted against the AP and transverse measurements of the three selected vertebrae and analyzed.

The second hypothesis was addressed with a determination of the DI in patients with PEX. Patients were selected for the study if they were analyzed for a PEX deformity with a CT scan and it was available in digital format within the PACS from 2/12/2003 through 12/16/2010. The CT scan protocol for PEX includes performing the study after end exhalation and not after full inhalation. A total of 76 patients met these criteria. The DI was computed by identifying the point of maximal depression of the sternum on the CT scan and then drawing a line across the most anterior ribs (Fig. 1). This eliminates the variable of the thickness of the soft tissue. A measurement was then taken from the mid sternum perpendicular to this line. This skeletal sternal depression was then divided by the transverse diameter of the vertebral body at that level (T9, 10 or 11). The use of the transverse diameter was based on the results of phase one in this study. The DI was then compared to the PI and CI, calculated at the same level, and correlation coefficients were calculated.

The third hypothesis of the study was addressed with the use of photographs (anterior and oblique) of patients with PEX to determine whether the DI, CI or PI better correlated with the observed severity of the deformity. If the results obtained in analyzing the second hypothesis were to indicate a statistically significant correlation of the DI with both the PI and CI for the entire group of patients, it would be expected that the clinical correlation of the appearance of patients would not be different for any of the indices when a random cohort is utilized. In addition, it is already accepted by physicians treating patients with chest wall deformities that the clinical impression, based on appearance, fails to correlate with the objective calculated severity values (PI and CI) in only a portion of patients with PEX (personal observations and communications). Therefore, it is proposed that if the DI does correlate better with the observed severity of the deformity it would only apply to a subset of patients where there is a discrepancy among the calculated indices. Anterior and oblique photographs of twelve patients were reviewed by five other Pediatric Surgeons at the institution with extensive experience in the treatment of PEX. They were asked to rank the patients according to their impression of the severity of the chest wall deformity. Patients chosen for this phase of the study were a random cohort with a wide range of severity of the PEX deformity. A subset of these patients was established where there was a discrepancy of their ranking based on each objective index. The physician rankings were then analyzed for statistical correlation of the DI, CI and PI ranking to this observed severity of the deformity.

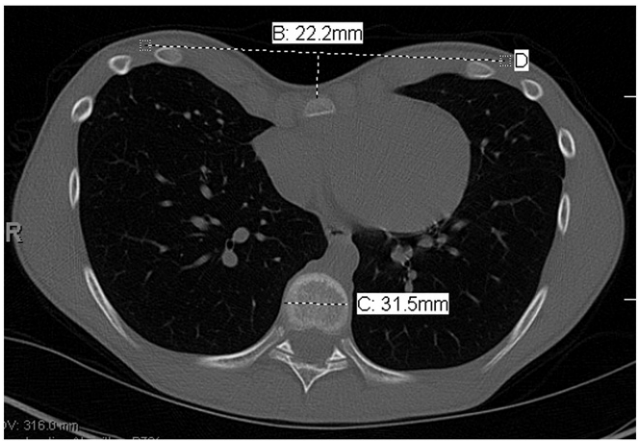

Fig. 1. Case example: Depression Index (DI) = 22.2/31.5 = 0.70.

1.2. Statistical analysis

Pearson correlation coefficients relating patient characteristics (age, weight, and height) to the transverse diameter of the 9th, 10th and 11th vertebrae were computed and significance was tested using a *t* test. This approach was also used to estimate the correlation (and significance) of the relationship between the DI and the PI, and the DI and the CI. In order to compare the similarity of the ranking of deformities, we estimated the "Euclidean distance" between gestalt (the physical pattern perceived through observation by experienced surgeons) and each of the three indices (a statistical method of analyzing rankings). Rank order disparity can be measured by the Euclidean distance, which was determined as the number of "ranking units", by subtracting the ranking number of one category (Physician, DI, PI, and CI) from that of another. The "distance" between two adjacently ranked patients is 1 unit, thereby, making the maximum distance for 12 patients a total of 11 units. Linear regression was used to model distance as a function of ranking and estimate expected distance and statistical significance of the relationship between distance and ranking. Spearman rank correlation coefficients were estimated to test the relationship between the rankings of deformities by surgeon, with significance determined using a *t* test. All statistical analyses were performed using Stata software (version 12, College Station, TX).

2. Results

The analysis of vertebral diameter to age, weight and height suggested a strong statistical correlation with all of these parameters to each of the three vertebrae measured and to both the transverse and A–P diameters. Of the morphometric parameters the best correlation was to height ($r = 0.66$, $p < 0.0001$). There was a slight improvement in correlation with the transverse diameter as compared to the A–P diameter, therefore, the transverse diameter was chosen to calculate the DI.

The range of the DI in patients evaluated for PEX was 0.15 to 1.8 with a mean of 0.74. When the DI was compared to the PI there was a strong significant correlation ($r = 0.59$, $p < 0.0001$) with a modest standard error of the mean (Fig. 2A, B). There was a stronger correlation between the DI and CI ($r = 0.83$, $p < 0.0001$). This indicates that all three indices increase with increasing severity of the deformity. However, the standard error was modest, as expected, as the three indices measure different parameters of the chest wall deformity.

The analysis of the ranking of photographs of patients with PEX by physicians experienced in evaluating and treating this disorder was