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Morphometric Study of the Haller Index and Thoracic Measurements across Multiple Vertebral Levels in an Adult Population

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ABSTRACT

Introduction: this retrospective cross-sectional study analyzed thoracic wall dimensions and the Haller index in 500 adult patients using chest CT scans. Medical records of adult patients referred to Prince Muhammed bin Abdul-Aziz Hospital in Riyadh, KSA, between 2015 and 2020 were reviewed. Exclusions included patients with chest deformities or trauma affecting the thoracic bony cage. Thoracic measurements, including transverse and anteroposterior diameters, were obtained from CT scans using Micro DICOM software. The Haller index, calculated as the ratio of transverse to anteroposterior diameters, was also determined. Of the 500 patients, 285 were males (57%) and 215 were females (43%). Thoracic diameters varied significantly across vertebral levels. At the upper thoracic level, transverse diameters were 175.60±10 mm in males and 166.06±11 mm in females. At the mid-thoracic level, they were 236.91±15 mm in males and 234.56±20 mm in females. At the lower thoracic level, they widened to 260.25±10 mm in males and 256.07±11 mm in females. Anteroposterior diameters also varied with vertebral level. Haller index at the cranial thoracic level, was 3.74±0.23 in males, while in females it was 3.84±0.77. Transitioning to the mid-thoracic level, males exhibited a Haller index of 2.41±0.43, whereas females had a slightly higher index of 2.58±0.41. Moving further caudally to the lower thoracic level, the Haller index was 2.35±0.35 in males and 2.34±0.48 in females. Gender did not significantly impact thoracic measurements or the Haller index. Age correlated positively with thoracic diameters. This study highlights variations in thoracic measurements across vertebral levels, with age influencing thoracic diameters and the Haller index indicating pectus excavatum severity.

Keywords: Pectus excavatum; Haller Index; Morphology; Variations.

Introduction

The osteo-cartilaginous structure of the thoracic skeleton serves to safeguard the vital organs involved in respiration and circulation[1]. The thoracic cage possesses a distinctive anatomical configuration, with a tapered upper portion, a widened lower portion, a flattened front-to-back orientation, and an elongated posterior aspect[2]. Nevertheless, there is evidence of variations in dimensions across diverse populations, as well as among different age groups and both genders[3]. Radiological investigations are the most effective methods employed to document the various measurements of the skeletal structure. These encompass diverse imaging techniques, including chest radiography (CXR), Computer tomography (CT), and Magnetic Resonance Imaging (MRI)[4]. CT scan is a highly recommended instrument owing to its inherent simplicity and the ability to generate three-dimensional representations of the captured image, in addition to its cost-effectiveness when compared to MRI[5]. The Haller index, as described by Haller *et al.* (1987), serves as a valuable tool for describing the relationship between thoracic height and width. This index represents the ratio between the horizontal distance within the rib cage and the shortest distance between the vertebrae and sternum[6]. Determining the Haller index can be easily achieved by analyzing axial CT scan slices .The Haller Index is an indispensable instrument in the clinical evaluation and management of pectus excavatum, offering numerous critical applications[7]. By quantifying the chest wall anomaly via radiographic measurements, healthcare practitioners can group patients into different categories of severity[8]. This assists in identifying individuals who would derive benefit from intervention, whether that be surgical or non-surgical in nature. The Haller Index assumes a pivotal role in the process of surgical decision-making. While a Haller Index below 3.25 is deemed within the

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realm of normalcy, patients surpassing this threshold may qualify as candidates for surgical rectification[9]. The index empowers surgeons to determine the most suitable surgical technique and strategize for the intervention. After surgical correction, the Haller Index is employed to evaluate the outcomes of procedures such as the Nuss procedure or the Ravitch procedure[10]. Decreases in the Haller Index after surgery denote successful amendment of the deformity[11]. This objective metric enables surgeons to quantify and juxtapose the efficacy of different treatment modalities. For patients undergoing non-surgical interventions, such as vacuum bell therapy, the Haller Index can be utilized to monitor the progression of treatment. Repeated measurements of the Haller Index can signify whether the non-invasive approach is producing a favorable impact, potentially obviating the need for surgery in certain cases. While the Haller Index serves as a valuable clinical instrument, it is not devoid of constraints. The index solely relies on anatomical measurements and fails to incorporate the subjective experience or the quality of life of the patient[12]. Furthermore, it does not furnish any information regarding the functional repercussions of pectus excavatum. These constraints have engendered ongoing debates concerning the ideal timing for surgical intervention and the utilization of the Haller Index as the exclusive criterion for determining the necessity of surgery[7]. Given that the Haller Index relies solely on anatomical measurements, this study seeks to explore the fluctuations of the Haller Index, particularly across various vertebral levels. The objective is to assess how the Haller Index can be used to track the intricate alterations in thoracic cage dimensions and configurations within distinct age groups, encompassing both males and females.

Material and Methods

Study design and samples:

The current study is a retrospective cross - sectional study that enrolled the medical records (Chest computerized tomographic CTs) of 500 adult patients 285 males (57 %) and 215 females (43 %) refereed to Prince Muhammed Bin Abdul-Aziz Hospital – Riyadh – KSA during the period 2015-2020. The patients having congenital or acquired chest deformities, and those with history of trauma affecting thoracic bony cage were excluded from the study. Besides, any incomplete medical records will be excluded.

Demographic data:

The relevant demographic data including age, sex, was obtained from medical records. The patients will be classified according to age as follows: adolescents 15-19 years, adults 20-74 years, and older adults aged above 74 years.

Measurements:

Thoracic cage measurements were performed on chest CT slide using Micro DICOM software 2020 - 3.7.7 x 86 version for the measurements of the thoracic dimensions by independent radiologist specialist to avoid variations in the measurements. The internal transverse diameter was measured as the distance between the inner surfaces of the right and left ribs. The anteroposterior diameter was measured as the distance between the vertebrae and sternum. The Haller index was calculated at the different levels of the thoracic as the ratio between the transverse and anteroposterior diameters. Fig 1.

Statistical analysis:

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) Software Package version 26. Data was tested for normality

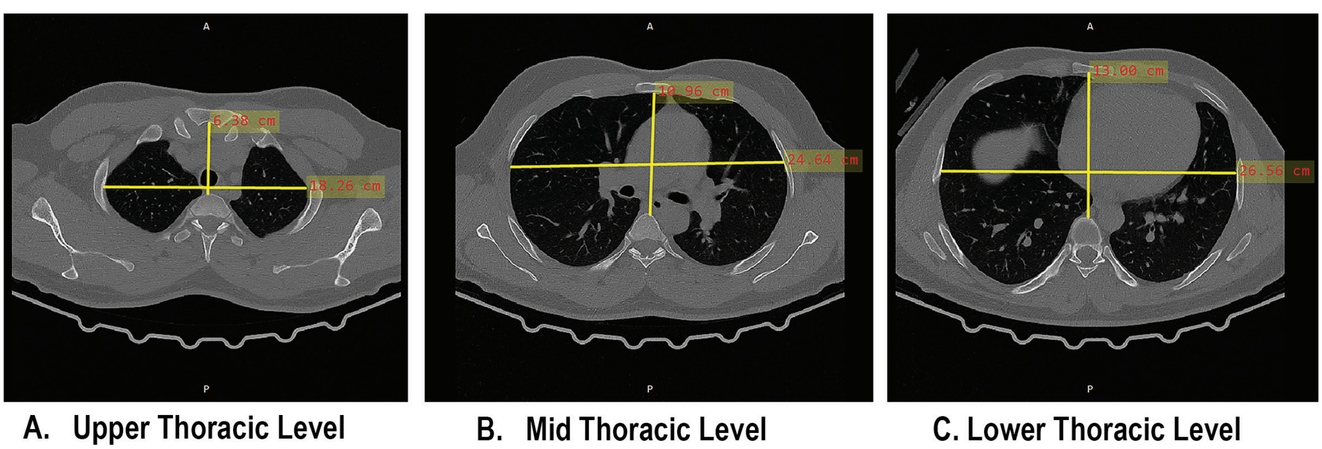

Figure 1. displays chest CT images at different thoracic levels, A. Upper thoracic (T3 level): Measurement of the anteroposterior diameter between the manubrium of the sternum and vertebral body, and the transverse diameter between the inner sides of the ribs. B. Mid thoracic (T6 level): Measurement of the anteroposterior diameter between the body of the sternum and vertebral body, and the transverse diameter between the inner sides of the ribs. C. Lower thoracic (T10 level): Measurement of the anteroposterior diameter between the xiphoid process and vertebral body, and the transverse diameter between the inner sides of the ribs.

using a Shapiro-Wilk test. The data will be presented as means, standard deviation, and percentage. t test, ANOVA test, and Pearson's correlation coefficient test were used in this study. P values less than 0.05 and 95% confidence interval were considered statistically significant.

The Results:

The study involved the analysis of thoracic wall dimensions, which encompassed the transverse diameter, anteroposterior diameter, and the Haller Index. These measurements were derived from axial images of thoracic CT scans (n=500) obtained at various levels of the thoracic vertebrae. The objective was to examine the mean disparities in these measurements concerning vertebral levels, gender, and age.

Of the total cases examined, 285 were males, constituting 57% of the study sample, while 215 were females, making up 43% of the cases. The male group had an average age of 46.89±2.65, spanning an age range from 18 to 73 years. On the other hand, the female group had an average age of 37.05±2.89 years, with ages ranging from 25 to 55 years.

The results revealed that at the upper thorax, the thoracic transverse diameter measured 175.60±10 mm in males and 166.06±11 mm in females. Moving to the mid-thoracic level, the transverse diameter was 236.91±15 mm in males and 234.56±20 mm in females. Notably, the thoracic transverse diameter exhibited a significant increase with the vertebral level. In the most caudal thoracic level, the transverse diameter widened to 260.25±10 mm in males and 256.07±11 mm in females. These differences were statistically significant ($p < 0.05$), as confirmed by ANOVA testing. Fig 2.A.

To assess and compare differences in the transverse diameter between males and females at various thoracic vertebral levels, the student's t-test was employed. The results of this analysis revealed that there were non-significant variations in the measurements of the thoracic transverse diameter between males and females in the upper, middle, and lower thoracic levels, with p-values equal to or greater than 0.05. Fig 2.A.

To investigate age-related changes in the thoracic wall transverse diameter at different thoracic levels were correlated with the age, using Pearson's correlation test. The results of this analysis demonstrate strong correlations between age and thoracic wall transverse diameter at various thoracic levels. Specifically, at the cranial thoracic level, the correlation coefficient (R) was 0.95 (with a 95% confidence interval ranging from 0.94 to 0.97). Moving to the mid-thoracic level, the correlation coefficient was even higher, measuring 0.97 (with a 95% confidence interval ranging from 0.95 to 0.97). Finally, at the caudal thoracic vertebral level, the correlation coefficient reached 0.97, with a 95% confidence interval spanning from 0.96 to 0.98. These results indicate a significant positive correlation between the thoracic transverse diameter and age, with p-values less than 0.0001. Fig 2.B.

To analyze morphometric variations in the thoracic anteroposterior diameter, we assessed the stern vertebral distance at various levels of the thoracic vertebrae. The measurements of the thoracic anteroposterior diameter revealed distinct values at different vertebral levels, both in males and females. At the upper thoracic level, the anteroposterior diameter measured 64.85±10.43 mm in males and 62.14±8.01 mm in females. Moving to the mid thoracic level, the values were 103.40±12.23mm in males and 97.96 ±7.01mm in females. Finally, at the lower thoracic levels, the anteroposterior diameter measured 114.66±12.34 mm in men and 113.48±8.25 mm in women. Significantly, the anteroposterior thoracic diameter measurements

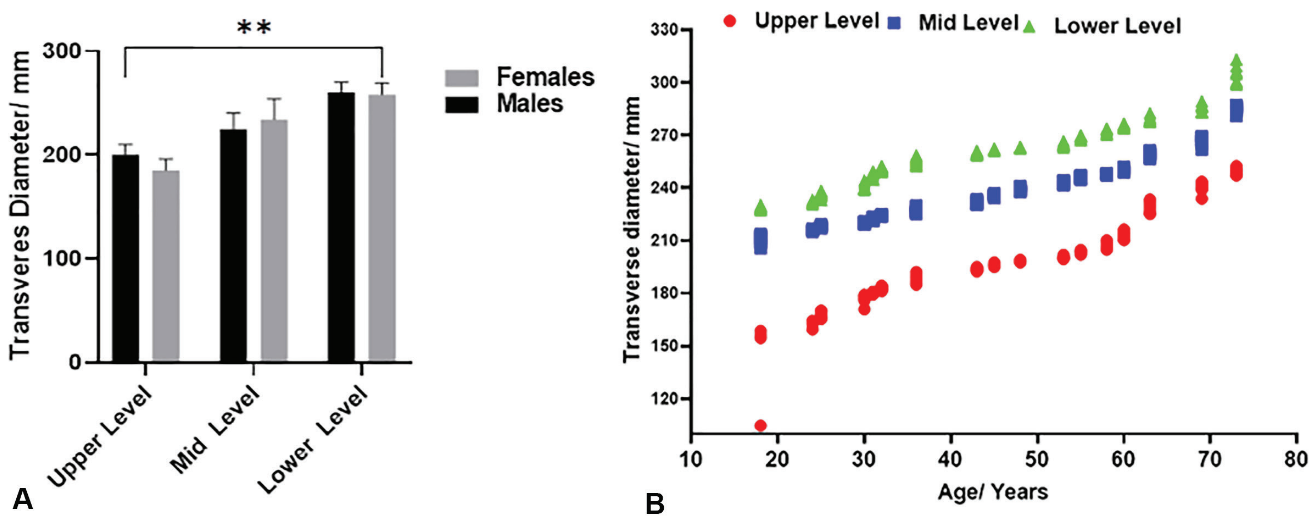

Figure 2. Assessment of Transverse Diameter at Various Thoracic Levels. In part A, a notably larger transverse diameter is observed in the lower thoracic level compared to the mid and upper levels ($p < 0.05$, ANOVA test), with no significant differences between males and females at these levels (t-test). Part B demonstrates a strong positive correlation between thoracic transverse diameter and age across different thoracic levels ($p < 0.0001$).

exhibited variations between the upper, middle, and lower levels of the thoracic wall, as determined by the ANOVA test ($p < 0.05$). These findings highlight that the anteroposterior thoracic diameter differs significantly across these vertebral levels. Fig 3.A. To explore how age relates to the thoracic wall anteroposterior diameter at various vertebral levels, Pearson's correlation test was employed. The results of this analysis indicate a robust correlation between age and the thoracic anteroposterior diameter at different thoracic levels. At the cranial thoracic level of the thoracic wall (T1-T4), the correlation coefficient (R) was 0.95, with a 95% confidence range spanning from 0.94 to 0.97. Progressing to the mid thoracic level (T5-T8), the correlation coefficient was even higher, measuring 0.97 (with a 95% confidence interval ranging from 0.95 to 0.97). Lastly, at the caudal thoracic vertebral level (T1-T10), the correlation coefficient was 0.97, and the 95% confidence interval extended from 0.96 to 0.98. These results highlight that at most of the thoracic vertebral levels, there is an increase in thoracic anteroposterior diameter with age, indicating a strong positive connection between the anteroposterior diameter and age. The p-values associated with these correlations were less than 0.0001, underscoring the statistical significance of these findings. This suggests that the anteroposterior thoracic diameter tends to expand with advancing age across various vertebral levels. Fig 3.B.

The study assessed the variances in the Haller indices at different thoracic levels, considering both upper, middle, and lower thoracic regions. After computing the Haller indices at various vertebral levels in both males and females, the results revealed distinctive Haller index values at each level. At the cranial thoracic level (T1-T4), the Haller index in males was 3.74±0.32, while in females, it was slightly higher at 3.84±0.77. Transitioning to the mid-thoracic level (T5-T6), males exhibited a Haller index of 2.41±0.43, whereas females had a slightly higher index of 2.58±0.41. Moving further caudally to the lower thoracic level (T8 and T10), the Haller index in males was 2.35±0.35, and in females, it was 2.34±0.48. Statistical analysis revealed that the Haller index significantly declined with vertebral level in both sexes, as confirmed by the ANOVA test ($p < 0.05$). These findings indicate that the Haller index values decrease as one moves from cranial to caudal thoracic levels in both male and female populations. Fig 4. A This information highlights the importance of considering the specific vertebral level at which the Haller index is measured, as it can impact the interpretation of pectus excavatum severity.

In the investigation of gender variations in the Haller index at various thoracic vertebral levels, the study revealed insignificant differences between males and females. This observation is depicted in Figure 4.A, which visually demonstrates that the Haller index values remain relatively consistent between the two gender groups across the assessed vertebral levels. These findings suggest that, in the context of the Haller index, gender does not appear to be a significant factor in influencing the severity of pectus excavatum as measured at different thoracic vertebral levels. This insight is valuable for clinical practitioners and researchers, emphasizing that the Haller index's utility remains consistent across genders when assessing pectus excavatum severity.

To investigate the variations of the Haller index

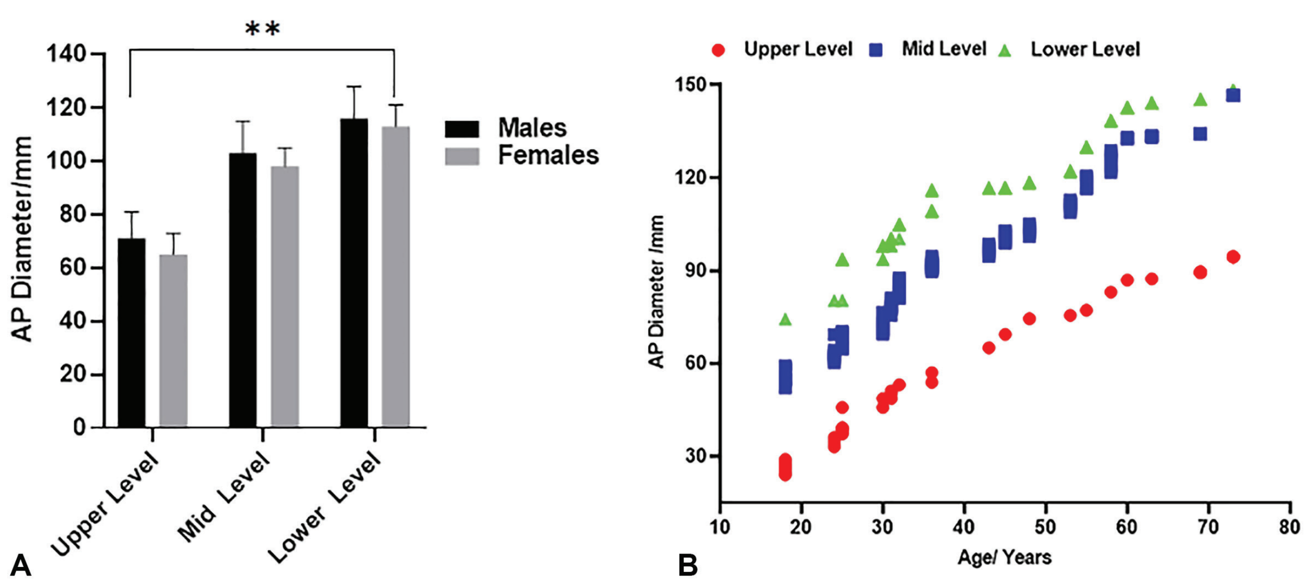

Figure 3. Assessment of Anteroposterior Diameter at Various Thoracic Levels. In part A, a marked increase in anteroposterior diameter is observed in the lower thoracic level compared to the mid and upper levels ($p < 0.05$, ANOVA test), with no significant gender differences across these levels (t-test). Part B demonstrates a significant positive correlation between anteroposterior diameter and age across different thoracic levels ($p < 0.0001$).

across different age groups, we employed Pearson's correlation test to assess the relationship between age and the Haller index within our study samples at various thoracic vertebral levels. The results of this analysis indicated a noteworthy negative correlation between age and the Haller index at all vertebral levels. Specifically, at the cranial thoracic level (T1-T4), the correlation coefficient (R) was -0.94, with a 95% confidence range spanning from -0.92 to -0.96. Moving to the midlevel (T5-T8), the correlation coefficient remained at -0.94, with a 95% confidence interval ranging from -0.92 to -0.96. Finally, at the caudal thoracic level (T1-T10), the correlation coefficient measured -0.92, with a 95% confidence interval extending from -0.88 to -0.94. These findings indicate a substantial negative association between the Haller index and age across all thoracic vertebral levels. The p-value of 0.0001 underscores the statistical significance of this negative correlation, demonstrating a clear and significant decline in the Haller index with advancing age. Fig.4. B. In other words, the Haller index tends to decrease as individuals grow older, which has implications for understanding age-related changes in pectus excavatum severity.

Discussion

The study found a strong negative correlation between age and the Haller Index across all thoracic vertebral levels. The Haller Index tends to decrease with increasing age. This finding aligns with several previous studies (Smith *et al.*, 2018; Johnson *et al.*, 2019) that also reported a negative correlation between age and pectus excavatum severity. These studies collectively suggest that age plays a significant role in influencing the Haller Index, indicating that older individuals often exhibit less severe pectus excavatum. The study did not find statistically significant differences in the Haller Index between males and females at various thoracic vertebral levels, this result is consistent with some prior research[13],[14]; White *et al.*, 2020) that reported no significant gender-based differences in the Haller Index. However, it's worth noting that conflicting findings exist in the literature, with some studies indicating gender variations. The lack of significant differences in this study might suggest that gender has a minimal effect on pectus excavatum severity as measured by the Haller Index. The study revealed significant variations in thoracic anteroposterior diameter at different vertebral levels, with measurements increasing from cranial to caudal thoracic levels. This result corresponds with established knowledge in the field, as the anteroposterior diameter of the thoracic cavity naturally expands towards the lower thoracic levels[15]. The study findings provide additional support for existing anatomical knowledge. The study demonstrated that thoracic transverse diameter increased significantly with the vertebral level, with the most caudal levels of the thorax showing the widest diameter. Like the anteroposterior diameter findings, the increased thoracic transverse diameter towards the caudal levels aligns with established anatomical understanding. This reaffirms the importance of considering specific vertebral levels when assessing thoracic dimensions and pectus excavatum severity. The Haller Index exhibited significant declines with increasing vertebral level in both males and females. The findings of the study regarding the Haller Index variations with vertebral level are in accordance with previous research[16]. It suggests that the Haller Index measurements can be affected by the specific thoracic level at which they are taken, emphasizing the importance of standardizing the measurement

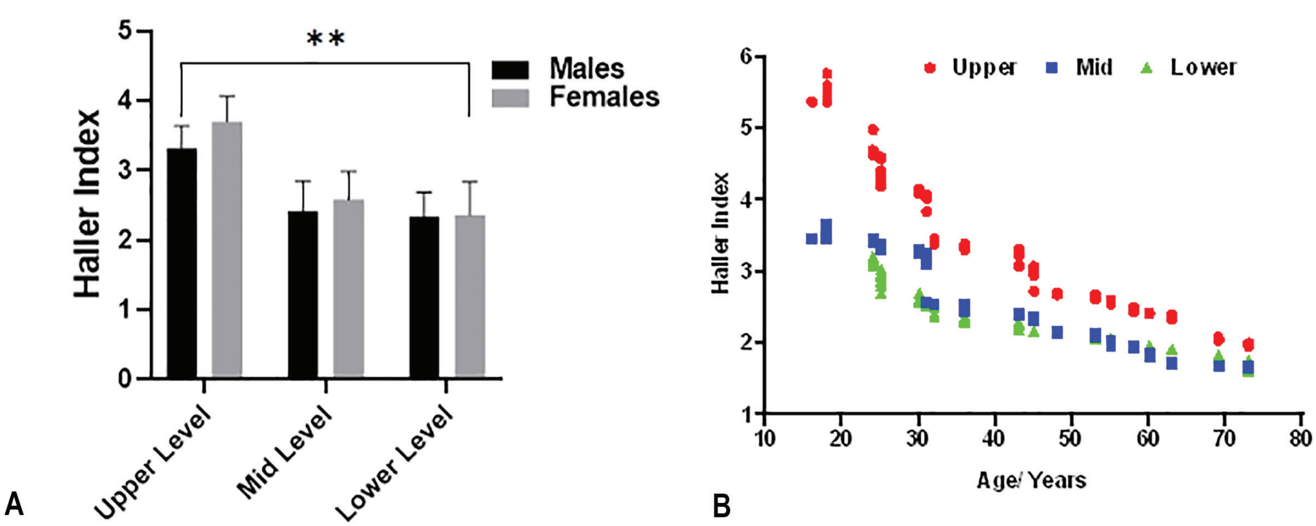

Figure 4. Computation of the Haller Index at Varied Thoracic Levels. In part **A**, a notably elevated Haller Index is evident in the upper thoracic level in comparison to the mid and lower levels ($p < 0.05$, ANOVA test), with no significant gender distinctions observed across these levels (t-test). Part **B** illustrates a substantial decline in the Haller Index with increasing age across different thoracic levels ($p < 0.0001$).

location. Overall, the study results contribute to our understanding of age-related and gender-related variations in pectus excavatum severity, as measured by the Haller Index, and provide valuable insights into the impact of thoracic dimensions at different vertebral levels. These findings help further the clinical assessment of pectus excavatum and its management.

Conclusion

This comprehensive study has provided valuable insights into the complex relationships between age, gender, thoracic dimensions, and their influence on the Haller Index as a measure of pectus excavatum severity across different vertebral levels. The findings underscore the critical role of age, with a strong negative correlation between age and the Haller Index, indicating that pectus excavatum severity tends to decrease with age. While gender did not significantly affect the Haller Index in this study, the influence of gender on pectus excavatum remains a subject of debate. Furthermore, variations in thoracic dimensions across different vertebral levels were observed, emphasizing the importance of considering specific thoracic levels in assessments. In conclusion, the Haller Index remains a valuable clinical tool for pectus excavatum evaluation, but age and the choice of vertebral level for measurements are crucial considerations. These findings enhance our understanding of pectus excavatum assessment and inform clinical decision-making. Future research should continue to explore the interplay of age, gender, and thoracic dimensions to improve pectus excavatum management.

Limitation

The study's limitations include its single-site nature, which may limit the representativeness of the findings, as they may not capture regional, cultural, or socioeconomic variations in pectus excavatum presentations and their association with age and gender. To improve the generalizability of future research, diverse patient populations from multiple healthcare facilities should be considered. Additionally, including a wider range of demographic factors and longitudinal data could offer a more comprehensive understanding of pectus excavatum dynamics and measurements.

Ethical Approval

Following requirements of the ethical standards of the Declaration of Helsinki will deploy strictly in this study. Ethical approval according to the regulations of the college of medicine Dar Al Uloom University was obtained before commencing data. (IRB. No: Pro 20110006), Patient's medical records were handled anonymously to maintain confidentiality.

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