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ORIGINAL ARTICLE

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Age-related normal ranges for the Haller index in children

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Abstract *Purpose*: The Haller index is an accepted CT method for evaluating thoracic dimensions in patients with pectus excavatum. The purpose of this study is to establish age- and gender-related norms for the Haller index in childhood. *Materials and methods*: We retrospectively reviewed 574 consecutive chest CT examinations (M = 285, F = 289) performed at our institution from August 2001 through March 2002. Seventeen patients with a history of chest-wall deformity, trauma, or syndrome were excluded, for a total sample size of 557 patients. The Haller index was calculated for each patient, using electronic calipers. The sample population was then separated by gender and placed into 2-year age groupings. Two-way analysis of variance and Tukey's multiple comparisons were performed to determine significance at $a = 0.05$. The least-square mean Haller index values for each age group and gender were calculated with 95% confidence intervals. *Results*: In both males and females, the 0- to 2-year age group showed a significantly smaller mean Haller index than older children. In addition, females had significantly greater Haller index values than males in the 0- to 6- and 12- to 18-year age groups. *Conclusion*: The Haller index, a quantitative measurement of chest-wall configuration, demonstrates significant age- and gender-related variability. This should be considered when evaluating the patient with suspected chest-wall deformity.

Keywords Haller index · Pectus excavatum

Introduction

Pectus excavatum is a developmental anomaly of the sternum associated with decreased exercise tolerance, chest pain, and poor self-image. Historically, surgical correction required extensive bilateral costal cartilage resection, with or without sternal osteotomy, via an anterior thoracotomy [1, 2, 3]. However, a minimally invasive, thoracoscopically-assisted technique has been developed by Nuss and colleagues that produces excellent clinical and cosmetic results [1, 2]. One of the criteria used by the Nuss group for surgical correction is a CT Haller index greater than 3.2, a value which they define as the cutoff between mild and moderate pectus excavatum [4].

The configuration of the chest wall changes during childhood, and normal age-dependent ranges for chest depth versus width have been established on plain radiographs. However, there are no such CT standards in the literature. The purpose of our study is to establish age-and gender-related norms for the Haller index in children.

Materials and methods

We retrospectively reviewed 574 consecutive chest CT examinations (M = 285, F = 289) performed at our institution from August 2001 through March 2002. Our patient population represents one of the most racially and culturally diverse groups in North America. Seventeen patients with a history of pectus excavatum, significant thoracic trauma, syndromes including chest-wall deformity, or chest-wall resection were excluded, for a total sample size of 557 patients (M = 275, F = 282). The examinations were performed on GE Highspeed Advantage or Lightspeed CT scanners and were obtained with or without intravenous contrast, depending on the clinical situation. Images were stored in and the retrieved from a GE PACS system (GE Medical Systems, Milwaukee, Wisc.).

The Haller index was calculated on each patient in this study utilizing the formula proposed by Haller et al. [5]: maximal internal transverse diameter of the chest divided by the minimal anteroposterior diameter at the same level (A/B, Fig. 1). All measurements were obtained using the PACS electronic calipers, which were corrected for scale. The patients were then subdivided by gender and by age groups, using consecutive 2-year intervals. At least 20 patients were present in each gender/age group (Table 1).

A two-way analysis of variance was performed to determine the presence or absence of significant differences in Haller index values among age groups and between genders. The analysis also assayed for significance of the interaction between age group and gender covariates. Tukey's multiple comparisons were then performed using Bonferonni's adjustment to determine which age groups had significantly different Haller indices at $a = 0.05$. The least-square mean Haller index values for each age group and gender, with 95% confidence intervals, are displayed in Figs. 2, 3, and 4.

Results

Haller index values were significantly different for age groups ($P = 0.012$) and gender ($P < 0.0001$). Also, multiple comparisons amongst age groups revealed that the 0- to 2-year group had a significantly smaller mean Haller index than the 8- to 10-, 10- to 12-, 12- to 14-, and 14- to 16-year age groups. The 14- to 16-year group had a significantly higher mean Haller index than the 0- to 2-, 2- to 4-, and 4- to 6-year age groups (Fig. 4). There was no significant interaction for age group and gender. Tukey's multiple comparisons revealed that females had significantly higher Haller indices than males across the 0- to 6- and 12- to 18-year age groups. Males had higher Haller indices than females in the 6- to 12-year age groups. The highest normal value for any patient was 2.7, for a 14-year-old girl, while the lowest normal value was 1.92, for a 3-month-old boy. All calculated Haller

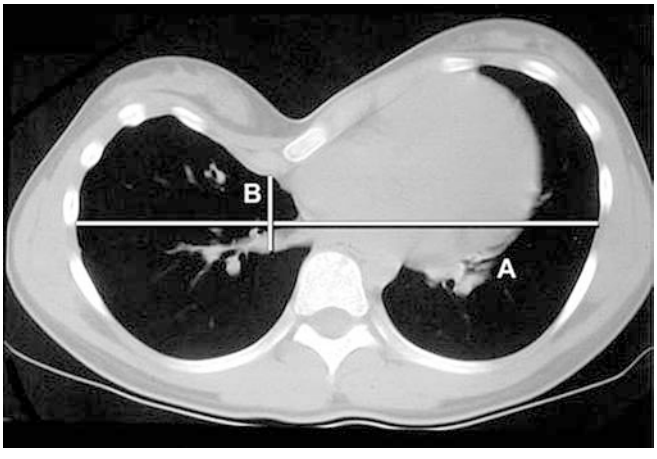

Fig. 1 Axial noncontrast CT image (bone window) of lower chest of an 11-year-old girl with asymmetrical pectus excavatum. Haller index (A/B) = 6.94

Table 1 Sample size in each age-group category

Age group	Sample size
0–2 years	88
2–4 years	52
4–6 years	55
6–8 years	60
8–10 years	43
10–12 years	67
12–14 years	63
14–16 years	70
16–18 years	59

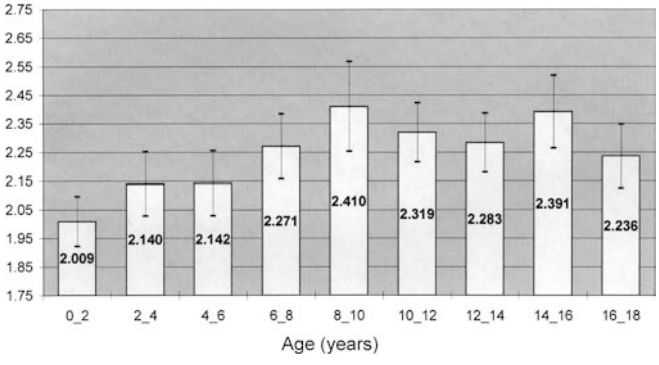

Fig. 2 Least-square mean Haller ratio for males with 95% confidence intervals

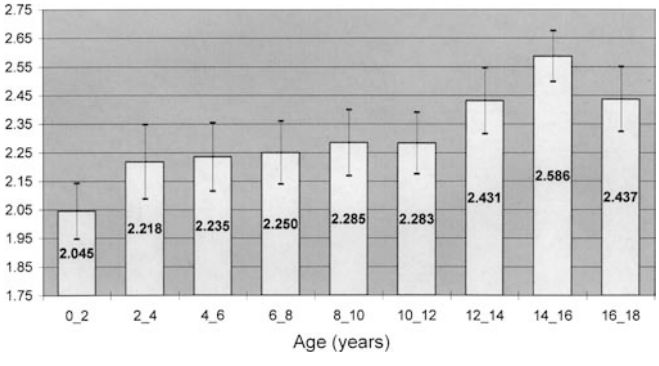

Fig. 3 Least-square mean Haller ratio for females with 95% confidence intervals

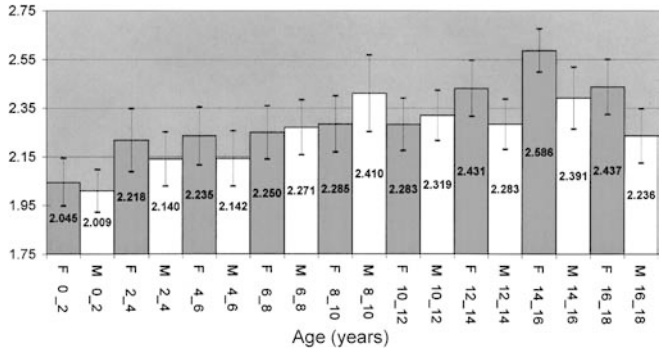

Fig. 4 Least-square mean Haller ratio with 95% confidence intervals

indices were significantly lower than the 3.2 value used as the cutoff for surgical correction of pectus excavatum by the Nuss group.

Discussion

Pectus excavatum is the most common congenital deformity of the chest wall, affecting approximately 1/1,000 persons. This condition shows a 4:1 male-to-female preponderance and may be familial in up to 27% of cases. While usually an isolated condition, pectus excavatum is associated with Marfan syndrome, Noonan syndrome, scoliosis, Ehler-Danlos syndrome, and prune-belly syndrome, among others. Pectus excavatum most commonly presents during early childhood and may become progressive during periods of rapid growth, such as puberty [1, 2, 3].

Pectus excavatum may be focal or generalized [1, 2]. Exercise intolerance and, rarely, chest pain are associated with moderate-to-severe pectus excavatum. Perhaps more importantly, however, this deformity may cause profound psychological difficulties owing to an altered body image, especially during adolescence and early adulthood. Diagnostic investigations used to assess the clinical severity of the condition include: (1) echocardiography to detect mitral valve prolapse, arrhythmias, and cardiac axis deviation and (2) pulmonary function tests to assess respiratory reserve. Patients with mild pectus excavatum may be treated initially nonoperatively with an exercise and posture improvement regimen, while patients with moderate-to-severe deformity are candidates for surgical correction [1, 2].

The earliest surgical procedure for correction of pectus excavatum included resection of costal cartilages along with sternal osteotomy and external sternal traction. In 1950, Ravitch introduced internal support of the chest wall to this procedure; this technique remained the standard for pectus excavatum correction until the advent of the Nuss procedure. The Ravitch technique is an open surgical procedure, with attendant short-term postoperative morbidity, that occasionally results in clinically significant restriction of chest-wall excursion in the longer term, due to thoracic chondrodystrophy. With the Ravitch technique, recurrence of pectus excavatum is fairly common (5–36%) [1, 2, 3].

In 1987, Nuss developed a minimally invasive technique for the correction of pectus excavatum that requires no sternal osteotomy or resection of costal cartilages. This procedure consists of the intrathoracic, extrapleural passage of a curved stainless steel bar beneath the sternum, from side to side, using thoracoscopic guidance. In most patients, this bar is affixed to the chest wall via a vertical stabilizer and cerclage wire. While most patients require only one bar, two are occasionally necessary in taller patients. The bar is left in place for at least 1 year, preferably 2, and is then removed [1, 2]. The Nuss procedure is markedly less invasive than other techniques, and in experienced hands, carries reduced short- and long-term morbidity. The Nuss procedure can be performed successfully in patients with prior, failed Ravitch surgeries.

In addition to echocardiography and pulmonary function tests, the Nuss group advocates CT of the chest for patients with pectus excavatum. In addition to establishing the Haller index, chest CT affords assessment of the degree of cardiac shift or compression, the presence or absence of atelectasis or associated tracheobronchial compression, and the presence or absence of other thoracic or upper abdominal abnormalities. In 1987, Haller and colleagues developed a reproducible, easily obtained pectus index, utilizing standard CT examinations of the chest. The Haller index is defined as the maximal internal transverse diameter of the chest, measured from internal rib margin to internal rib margin, divided by the minimal anteroposterior depth of the chest at the same level, measured from the internal aspect of the depressed sternum or costal cartilage to the anterior cortex of the subjacent vertebral body or its horizontal tangent [5] (A/B, Fig. 1). In patients with a symmetrically depressed sternum, the Haller index may be measured from the internal surface of the depressed sternum to the anterior cortex of the subjacent vertebral body. However, some patients may have asymmetrical pectus deformities, and in these patients it is necessary to measure from the deepest costal cartilaginous depression to a line tangential to the anterior cortex of the subjacent vertebra. In the Nuss experience, normal patients demonstrate a Haller index from 2.0 to 3.0, while patients requiring surgical correction of pectus excavatum usually have a Haller index greater than 3.2 [1, 2, 4].

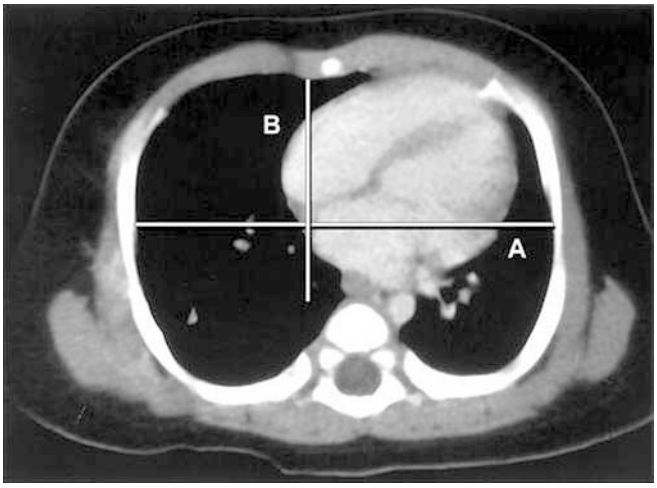

Fig. 5 Axial contrast CT image (soft-tissue window) of lower chest of a 2-month-old girl, with Haller index (A/B) = 1.86

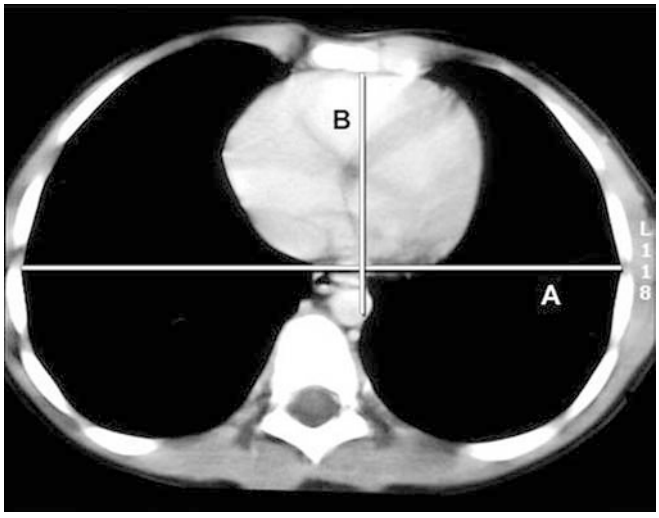

Fig. 7 Axial contrast CT image of lower chest (soft-tissue window) of a 12-year-old boy, with Haller index (A/B) = 2.4

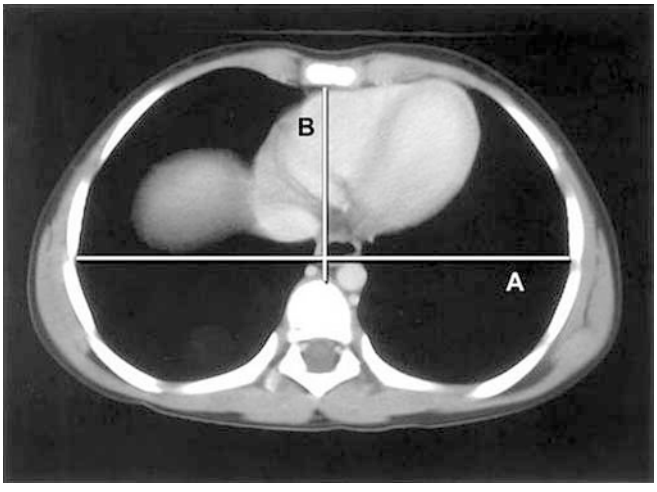

Fig. 6 Axial contrast CT image of lower chest (soft-tissue window) of an 8-year-old boy, with Haller index (A/B) = 2.56

In 2001, Ohno and colleagues described age-related changes in chest wall configuration in 210 normal children, using anteroposterior and lateral chest radiographs [6]. These investigators calculated a frontosagittal index (FSI), defined as the minimal internal anteroposterior diameter of the chest, from sternum to the subjacent vertebral body, divided by the maximal internal transverse diameter, multiplied by 100 (B/A ×100). This is the inverse of the Haller index. Ohno et al. found a significant difference in the FSI in children younger than 3 years when compared to older children. Our study also demonstrates this finding, in addition to sex-related differences, obtained from chest CT examinations that are often prerequisite to corrective surgery in the United States and Canada.

Our study demonstrates that the Haller index is significantly lower for males and females under 2 years of age when compared with older children. Females between the ages of 0–6 and 12–18 years tend to have higher Haller index values than males of the same ages, indicative of a slightly flatter, normal chest configuration for these girls. Conversely, boys between the ages of 6 and 12 years have slightly higher Haller indices than age-matched girls. While the diagnosis of pectus excavatum remains a clinical one, especially in patients with mild chest wall deformities, our data suggest that the upper limit of normal for the Haller index in children, regardless of age or sex, is approximately 2.7. None of the normal children in our study had Haller index values approaching the cutoff value of 3.2 used by the Nuss group as one factor in the selection of patients for minimally invasive surgical correction of pectus excavatum (Figs. 5, 6, 7).

In conclusion, there are significant age-related and sex-related ranges in the chest-wall configuration of children, as measured by the Haller index. These differences should be considered when evaluating children with pectus excavatum, whether previously diagnosed or undetected.

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