

## Does the sternum play a role in the aetiopathogenesis of adolescent idiopathic scoliosis? Preliminary data of a new theory

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### Abstract

**Background:** The role of the sternum, if any, in the aetiopathogenesis of adolescent idiopathic scoliosis (AIS) remains unexplored. We evaluated morphological features of the sternum for the first time in individuals with AIS.

**Methods:** Medical records of a tertiary hospital were reviewed from 2010 to 2018 to identify adolescents with thoracic or thoracolumbar AIS. We included scoliotic patients between 14 and 18 years of age on radiologic evaluation without previous treatment for the disease. A complete history and 3D computed tomography (CT) scan were also prerequisites for study inclusion. We compared the shape and position of the sternum between adolescents with AIS and age-matched individuals as control. The control group was recruited with a random selection from patients attending hospital for extraskelatal reasons during the same period. Using CT, we evaluated the part of the sternum found in the right front quadrant of the axial plane at the level of the middle of the manubrium of the sternum and apical vertebra. We also provided an evidence-based theory of the sternum involvement in AIS aetiopathogenesis.

**Results:** Twelve scoliotic patients with mean age 16.6 and mean Cobb angle 39.7 degrees were included in the study. No difference was found between groups at the level of the manubrium of the sternum ( $p=0.486$ ). At the level of the apical vertebra, there was a significant difference of the part of sternum found in the right front quadrant of the axial plane between groups (95 % vs 56 %,  $p<0.001$ ).

**Conclusions:** These are preliminary data demonstrating for the first-time morphological differences of the sternum, between AIS and age-matched non-scoliotic individuals. The sternum of adolescents with AIS was more inclined than non-scoliotic controls that could raise the hypothesis of sternum involvement in AIS pathogenesis. HIPPOKRATIA 2018, 22(4): 173-177.

**Keywords:** Adolescent idiopathic scoliosis, aetiopathogenesis, sternum, ribs, apical vertebra

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### Introduction

Adolescent Idiopathic Scoliosis (AIS) is the most common spinal deformity of puberty; though, the aetiopathogenesis of AIS remains unclear<sup>1,2</sup>. Several environmental, biomechanical, genetic, and neuromuscular reasons have been implicated; however, none has been proved to be the primary cause<sup>1,2</sup>. The disease presents a remarkable heterogeneity; the age of onset, sex prevalence, type of curvature, disease severity, and progression differs considerably among adolescents<sup>3,4</sup>.

AIS is typically defined as a vertebral rotational deformity with lateral spinal curvature and deformation of ribs<sup>3</sup>. The role of the sternum, if any, in the pathogenesis of scoliosis, remains unexplored. Any knowledge of sternal embryology, structure, and development is also limited. However, sternal deformities, as pectus excavatum, have been previously associated with scoliosis and the shorter sternum with vertebral column diseases, as

Scheuermann's disease<sup>5,6</sup>. We aimed to evaluate the morphological features of the sternum for the first time in adolescents with AIS. We compared the shape, and the position of the sternum in the transverse plane using computed tomography (CT) scans between untreated adolescents with AIS and non-scoliotic adolescents as a control.

### Materials and Methods

The null hypothesis included that there are morphological differences of the sternum between AIS and non-scoliotic controls. This retrospective radiographic cross-sectional study took place in a tertiary hospital unit between 2016 and 2018 after obtaining Institutional Scientific Research Board approval. It was conducted according to the World Medical Association Declaration of Helsinki of 1964 as revised in 1975 and 2000. All patients were informed about their participation in the study and gave informed consent.

Electronic medical records were reviewed from January 2010 to February 2018. The International Classification Codes (ICD)-10 codes, M41.1 Adolescent idiopathic scoliosis, and M41.2 Other idiopathic scoliosis, were used to identify individuals with thoracic or thoracolumbar idiopathic scoliosis upon patient's discharge.

#### *Inclusion/exclusion criteria*

Patients suffering from thoracic or thoracolumbar AIS and aged between 14 and 18 years of age on radiologic evaluation were included in the study. A complete history, primary scoliotic curve greater than 20 degrees and three-dimensional (3D) thoracolumbar CT scan were also prerequisites for study inclusion. Exclusion criteria comprised any previous conservative or surgical treatment for the disease, such as brace treatment or vertebral fusion that was considered a change in the natural course of the disease. Lack of history or CT scan in their record, primary scoliotic curve less than 20 degrees and cervical, lumbar or secondary forms of scoliosis were also exclusion criteria. The control group was recruited with a random selection from patients attending hospital for extraskel-etal reasons during the same period. By definition, they were non-scoliotic adolescents, aged between 14 and 18 years, free from any pathology of the vertebral column. These adolescents also had to provide a complete history and to have performed a 3D CT scan for other reasons. The random selection of electronic software (IBM SPSS, IBM Corp., Armonk, NY, USA) conducted the random selection of controls, stratified for age and sex.

The measurements of the sternum were carried out using RadiAnt DICOM Viewer software (Medixant, Poznan, Poland)<sup>7,8</sup>. Our primary aim was to evaluate the whole shape and position of the sternum in two positions with a theoretically maximum and minimum involvement. We chose the transverse plane at the level of the middle of the manubrium of the sternum and the apical vertebra. The highest degree of vertebral deformity in scoliosis is found at the level of the apical vertebra, which is usually connected through the ribs with the middle of the body of the sternum<sup>9</sup>. This level was chosen as the level of maximum deformity. As we move away from this level, the possible deformity is lessened. We chose the middle of manubrium as the second level of measurement as this is far away from the apical vertebra with theoretical less deformity, and it is easily identified.

In both levels, we divided the transverse plane into four equal quadrants; we then estimated the proportion of the sternum found to the frontal quadrants. We compared our findings with measurements in the middle of the manubrium and the middle of the body of the sternum from non-scoliotic individuals matched for age and sex. Finally, we formed an evidence-based theory of sternal involvement in AIS aetiopathogenesis.

#### *Statistical analysis*

No previous studies and Minimal Clinical Important Difference concerning the position of the sternum in the

transverse plane had previously been published. We were based on previous limited data concerning the normal racial and sexual morphological variability of the sternum<sup>10,11</sup> to make a hypothesis of 10 % normal variation between individuals. Our statistical analysis (Lehr's formula) showed that with sufficient power of 0.8 and the  $\alpha$  value of 0.05, in order to see a difference between groups of 40 %, at least nine patients had to be enrolled in each group.

The normality of the data distribution was tested according to the Shapiro-Wilk test. Statistical tests were two-tailed. The alpha level was set at 0.05. Standard statistical methods were used for descriptive statistics. Continuous variables not-normally distributed were compared using Mann-Whitney U-test. Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA).

#### **Results**

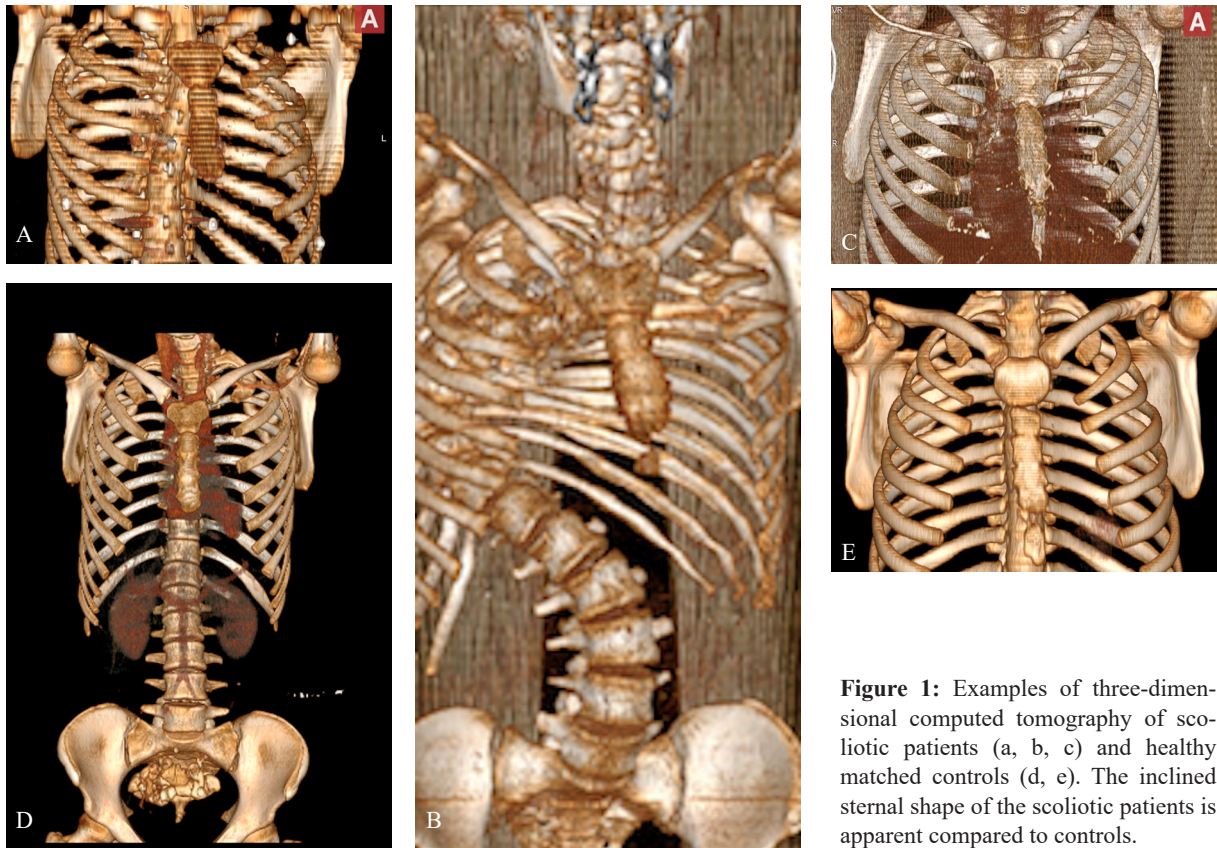
During this eight-year search period, a total of 132 adolescents with thoracic or thoracolumbar AIS were identified in the hospital medical records. Fifty-one patients were excluded upon confirmation of earlier reported treatment with Boston brace. The Cobb angle of the scoliotic curve was less than 20 degrees in twenty patients. Six patients were older than 18 years. Forty-three patients were excluded due to lack of history or CT scan in their record.

Ultimately, twelve patients (ten females, two males) were included. The mean age of the patients was 16.6 years. None of them followed conservative treatment in the past. The mean Cobb angle was 39.7 degrees. Eight of them had CT scan as a preoperative screening for surgical treatment and four for non-skeletal reasons. The control group was matched for age and sex (ten females, two males, mean age 16.6 years). All of them had their scan for pulmonary reasons.

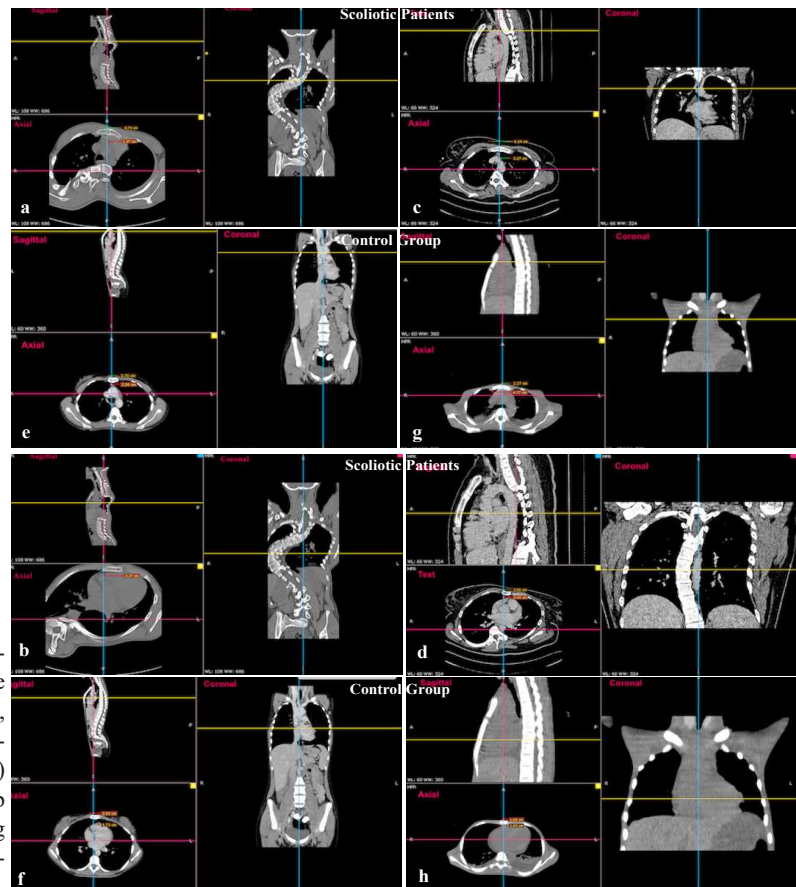
The manubrium of the sternum was more centrally positioned in the axial plane compared to the body of the sternum in both groups. The scoliotic group, however, had a more inclined position of the body and xiphoid process than the control group (Figure 1 a-e). At the level of the manubrium of the sternum 60 % ( $\pm 10$  %) of the width of the sternum was found at the right front quadrant for individuals with AIS compared to 54.5 % ( $\pm 14$  %) for the control group (Mann Whitney Test,  $p=0.486$ ). At the level of the apical vertebra, 95 % ( $\pm 10$  %) of the width of the sternum was on the field of the right front quadrant for the scoliotic group, compared to 56 % ( $\pm 7$  %) for the matched control group ( $p<0.001$ ) (Figure 2 a-h)

#### **Discussion**

Our study evaluated for the first-time morphological features of the sternum in AIS. Except for the vertebral column, the sternum may also have a scoliotic course. The body and xiphoid process of the sternum in scoliotic patients had more oblique course than the manubrium in the frontal plane. These findings are not clear evidence,



**Figure 1:** Examples of three-dimensional computed tomography of scoliotic patients (a, b, c) and healthy matched controls (d, e). The inclined sternal shape of the scoliotic patients is apparent compared to controls.



**Figure 2:** Examples of the position of sternum in the axial plane at the level of the middle of the manubrium for scoliotic (2a, 2c), and control groups (2e, 2g) and the level of apical vertebra for scoliotic (2b, 2d) and middle of the body for control group (2f, 2h). Please note that the corresponding coronal and sagittal planes are also provided.



but they are preliminary data that could raise the hypothesis of the involvement of the sternum in the aetiopathogenesis of scoliosis.

This study has certain limitations. Data presented in the study showed morphological differences of the sternum between scoliotic and healthy individuals; they are merely an observation of possible association. Besides, the deformity of the sternum could be secondary to scoliosis. However, we believe that the obliquity of the sternum in the frontal plane found in this study support a theoretical involvement of the sternum in AIS pathogenesis that is further explained by the following theory.

The human sternum consists of three parts, from above downwards: the manubrium, body, and xiphoid process. The body is the part of the sternum that is connected to the most commonly involved ribs and vertebrae in AIS. During childhood, the body consists of four segments, called sternebrae which later fuse to form one piece.

We assume that the symmetrical sternum development is responsible for the rotational stability of the thorax that balances the transmission of equal forces from the ribs to the vertebrae and controls the simultaneous balanced growth of the two hemithoraces. Asymmetry of the sternal development either an “unbalanced” growth of the bilateral ossification centers or uneven process of fusion between parts of sternebrae could transfer different forces in the vertical and sagittal level from the ribs to the vertebrae and provoke the onset of scoliosis. Several known embryonic, developmental, mechanical, and epidemiological parameters are in support of this theory.

#### *Embryonic*

The sternum has a different embryonic origin than ribs and vertebrae<sup>12</sup> and probably a different role in the development of the thorax. Sternum develops from mesoderm while the ribs and vertebrae from somites<sup>12</sup>. The sternum also has a bilateral embryonic origin<sup>12</sup>. In the seventh week of gestation, bilateral mesodermal mesenchymal bands coalesce in the middle creating the sternum. These sternal bands may be responsible for controlling the relative hemithorax.

#### *Biomechanical*

The sternum and ribs assist with the axial and rotational stability of the spine<sup>13,14</sup>. The load from the rib is transferred via the costotransverse articulation to the lamina and the vertebral body through the facet joint<sup>13</sup>. Healthy individuals usually have rib length symmetry<sup>15,16</sup>. Animal model studies revealed induction of scoliosis after rib resection or elongation<sup>17,18</sup>. Human studies also demonstrated rib length discrepancy between scoliotic patients and controls<sup>15,16,19</sup>. Scoliotic patients had a significantly longer length of ribs on the concave side at the level of the apical vertebra compared to non-scoliotic vertebral levels<sup>15</sup>. During adolescence<sup>20,21</sup>, asymmetrical development of the sternum could transfer an excessive load from the ribs to the vertebrae, causing secondary rib

transformation and vertebral rotational deformity.

#### *Developmental*

The sternal ossification centers are present at birth, but only the manubrium and the first mesosternebrae are utterly ossified. Multiple ossification centers symmetrically or asymmetrically positioned on both sides of the midline of the sternebrae, fuse later in a craniocaudal direction to form the body of the sternum<sup>10</sup>. The number and topography of ossification centers and fusion of mesosternebrae vary considerably among individuals<sup>12</sup>. Non-scoliotic adolescents demonstrated variability of the shape of the sternum and at least three different combinations of the number of ossification centers per sternebra<sup>10-12</sup>, or malaligned bifid centers that were associated with rib articulation asymmetry or rib migration<sup>12</sup>. At the age of 1-5 years, all sternebrae are separated. The fusion between 3<sup>rd</sup>-4<sup>th</sup> sternebrae ranges from 6-10 years to 15-17 years at the latest. The scoliotic patients may demonstrate further asymmetry in the number, location, and time of ossification of sternal centers; this could explain the variability of magnitude and the type of the scoliotic curve. We speculate that asymmetric ossification of sternal centers of the same sternebra, presence of additional centers or unsynchronised fusion of the two hemi-sternebrae could transfer unequal forces in the sagittal level from the ribs to the vertebrae and produce rib length transformation and vertebral rotational deformity.

#### *Epidemiological*

Variations of sternal development could also explain the epidemiology of AIS.

1. Typically, the fusion of third and fourth mesosternebrae starts around 6-10 years of age and is completed roughly around the 15<sup>th</sup> year of age, which is the timeline that the AIS is most commonly to occur<sup>16</sup>. The first and second sternebrae fuse even later at about 16<sup>th</sup> year of age in boys and the 18<sup>th</sup> year in girls. Mesosternum and manubrium collision does not take place earlier than the age of 21 years in males or females.

2. The higher incidence of AIS in girls could be related to sex differences in sternal development. Non-scoliotic girls demonstrated significantly larger sagittal dimensions and fewer sternebrae than boys<sup>10</sup>. Additionally, the time of fusion between the three sternum parts differs between girls and boys<sup>10,11</sup>. Racial differences in the time of sternebrae fusion could also explain the ethnic differences in the AIS incidence<sup>11</sup>.

#### *Sternum and other thoracic deformities*

Sternal deformities have been epidemiologically related with scoliosis or other vertebral deformities. Patients with pectus excavatum showed an increased incidence of scoliosis too<sup>5</sup>. Fotiadis et al. supported that the shorter sternum, following accelerated fusion, increases the compressing forces to the anterior portion of the vertebral body leading to kyphosis and Scheuermann's disease<sup>6</sup>.

## Conclusion

Our study is the first demonstrating morphological differences of the sternum between AIS and healthy individuals. We do not have enough information to ascertain that discrepancies in the development of sternum are the primary cause of AIS. However, we must consider that the sternal development remains poorly understood, and knowledge of the ribs and vertebral growth is remarkably limited. We suggest that in future investigators should also focus on the sternal development in scoliotic patients. The dimensions, shape, and course of the sternum, the ossification centers, and pattern types, the number of sternebrae, age-specific sternebrae fusion, manubriosternal, and sternoxiphoidal fusion must be evaluated in adolescents suffering from AIS.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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