Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/17344
DOI URL: http://dx.doi.org/10.21474/IJAR01/17344

RESEARCH ARTICLE

THORAX AND IDIOPATHIC SCOLIOSIS

Dr. Theodoros B. Grivas MD PhD
Orthopaedic Surgeon, Former Head for the Orthopaedic and Traumatology Department of –Tzaneio‖ General Hospital of Piraeus, Piraeus, Greece.

……………………………………………………………………………………………………..

Manuscript Info

……………………..

Manuscript History
Received: 31 May 2023
Final Accepted: 30 June 2023
Published: July 2023

Key words:-
Idiopathic Scoliosis, Thorax, Rib Cage, Embryology, Growth Of Rib Cage, Lungs, Thoracic Index, Thoracic Stability, Icp Model, Growth, Segmental Thoracic Ratios, Segmental Rib-Vertebra Angles

Abstract

………………………………………………………………

This review is related to the role of thorax in scoliogenesis. The embryology, the prenatal and the postnatal growth of the rib cage of (RC) and the lungs are briefly described. The development of normal RC, the frontal and sagittal diameters of it, the values of mid-thoracic diameters, the thoracic index, the biomechanical contribution of the RC to thoracic stability, the increase in frontal and sagittal thoracic diameter during breathing are defined. The infancy, childhood, puberty (ICP) model of growth is used in both the segmental thoracic ratios (TR) and the Segmental Rib-vertebra angles (RVA) in order to assess the normal and deformed RC in Early Onset (EOS) and Late Onset Scoliosis (LOS). The neuromuscular mechanisms as possible factors causing age-related RVAs changes are discussed. Then the posterior truncal/thoracic asymmetries are reviewed related to school scoliosis screening (SSS) referrals. Next, the development of RC is analyzed in resolving and progressive infantile idiopathic scoliosis (IIS), and in adolescent idiopathic scoliosis (AIS). The menarche and laterality of thoracic scoliotic curves, congenitally fused ribs and pulmonary function in children with idiopathic scoliosis (IS) is also discussed. The pathogenesis of IS according to the Nottingham concept and RC, the thorax and pelvis complex during gait and rotational inertia, the Double Rib Contour Sign (DRCS) and Rib Index (RI), the effect of growth on the relationship of spinal and thoracic deformity are explained. The postoperative fate of IS hump deformity in relation to the RI and the aetiological implications for IS are then stated. The role of the rib-sternum complex is mentioned. John Sevastik‗s thoracospinal concept of aetiopathogenesis of AIS and his research about IS are described, namely experiments on ribs, correction of experimentally produced scoliosis, suggested surgical intervention on the ribs, experiments on nerves, vascular changes in the chest wall after unilateral resection of the intercostal nerves, and breast asymmetries in female suffering AIS. A biomechanical model using different Cobb angle and rib hump (RH) correction is mentioned. The issue of thoracic kyphosis and hypokyphosis and the impact of the lateral spinal profile (LSP), that is the sagittal plane, is discussed. Finally, IS and evolution of thoracic shape as a "scar of evolution" are pointed out.

Corresponding Author:- Dr. Theodoros B. Grivas, MD PhD
Address:- Orthopaedic Surgeon, Former Head for the Orthopaedic and Traumatology Department of –Tzaneio‖ General Hospital of Piraeus, Piraeus, Greece.

This review is dedicated to the memory of Professor Richard Geoffrey Burwell

Introduction: - The normal thorax or rib cage (RC) includes the thoracic spine, thoracic spinal cord, heart, lungs, abdominal organs, diaphragm, respiratory muscles and sternum.

The RC is made up of 12 pairs of ribs with their costal cartilages connected anteriorly to sternum, and are articulated to the 12 thoracic vertebrae (T1–T12) posteriorly. The ribs are classified as true ribs (1–7) and false ribs (8–12). The last two pairs of false ribs are also known as floating ribs (11–12). The sternum consists of the manubrium, body, and xiphoid process. In normal growth and pathology, the RC and thoracic spine are influenced by each other and are interdependent. The RC during growth remodels changing its shape from inverted funnel-shaped to a barrel-like shaped structure in maturity.
The outstanding function of the thorax is in respiration. It acts as a respiratory pump, and protects the lungs, the heart and the contained within it large vessels. In addition, the ribs are the principal agents for the support of the thoracic vertebrae by virtue of their rigidity, not only as bony braces but also because of their service as instruments/levers through which the forces exerted by the attached muscles and ligaments and the forces of intrathoracic pressures and stresses are transmitted to the vertebrae through their costovertebral articulations [1,2].

2.Embryology of RC

The mesoderm is one of the three germinal layers that appears in the third week of embryonic development. It is formed through a process called gastrulation. There are four components, which are the axial, paraxial, intermediate, and lateral plate mesoderm. The development of bone and muscle begins at the fourth gestational week, when the paraxial mesoderm differentiates into somites: the latter gives rise to sclerotomes and dermomyotomes. Sclerotomes form the vertebra and the ribs**,** whereas myotomes form the majority of the muscular system. The sternum arises from paired longitudinal concentrations of the somatic mesoderm in the sixth week of development. The somatic mesoderm is the outer layer formed after the split of the lateral plate mesoderm. The paired sternal bars fuse in the midline to form a cartilaginous sternal plate at around the10th week, and it contributes greatly to the development and stability of the thorax. The vertebral column, the ribs, and the sternum are formed by endochondral ossification, [3,4]

3.Prenatal growth of RC

The outstanding function of the thorax is in respiration. In this connection, Keith (1909), [5], distinguished four mechanisms in the enlargement of the thoracic cavity during inhalation: the thoracic lid (1^{st}rib and manubrium sterni), the upper costal series (2^{nd}- 5^{th} ribs inclusive), the lower costal series (6^{th} –10^{th} ribs inclusive) and the diaphragm.

Consequently, it is interesting to know the prenatal development of the upper and the lower costal series, according to the Keith distinction.

The two series/regions of the RC develop at different rates and under different signaling conditions, each series/region affecting the embryonal, fetal, and postnatal development of the other series/region, [6,7].

The factors that influence RC morphology differ across the embryonic period due to the simultaneous development of the organs within the RC and to other related structures such as the upper extremities, abdomen, and pelvis, [8,9].

From a functional perspective, breathing movement starts only in the late embryonic period, with an occasional hiccup at 9 weeks of gestation and breathing movement at the10^{th} week of gestation, [10, 11, 12].

Carnegie stages (CS) are a standardized system of 23 stages used to provide a unified developmental chronology of the vertebral embryo, [13].

Okumo et al 2019, [12], described the 3-D description of the morphogenesis of the human RC (including the ribs and vertebrae) during the embryonic period and they characteristically wrote:

Formation of Cranial View of each Rib pair: The morphology of all rib pairs was similar at Carnegie stage CS17, with the RC consisting of almost linear rib pairs concentrated on the dorsal side. The morphological differences between the upper and lower regions of the RC became prominent at around CS20, when the ribs appeared curved, with their ends elongating medially to form an arch in the upper region after CS20. As the ends of the ribs in the upper region became joined with the sternum, the ends of the ribs in the lower region elongated almost anterolaterally.

Formation of the Ventral View of RC: The depth of the RC was smaller than its width and height at CS17–19. The differences between the upper and lower regions of the RC became prominent after CS20, with two notable features: a downward shift in the area of largest width and the joining of ribs in the upper region. The RC cage was initially larger in the upper than in the lower region, but the area of largest width shifted caudally toward the end of the embryonic period, being located at the 5th rib pair at CS17, the 6th rib pair at CS18, the 7th rib pair at CS19, the 8th rib pair at CS20– CS22 and the 9th rib pair at CS23. Regarding these important feature, the ends of the ribs from the 1st to the 7th pair became closer in the median plane. Their eventual fusion would lead to the formation of the sternum. This process resembled the closing of a zipper from the cranial end to the caudal end between CS21and CS23. Specifically, the ends of corresponding ribs were separated by 2.02–4.14 mm for all 12 pairs of ribs between CS17 and CS19 but then decreased in the upper region and increased in the lower region during development explaining the developmental differences between the two regions.

Formation of the Lateral View of RC: At CS17, the depth of the RC was similar across the 1st– 7th rib pairs, with the largest depth at the 3rd pair. Enlargement of the RC was detected after CS20, with a prominent local maximum in the middle. The largest depth of the RC was noted for the 7th rib pair at CS20 and CS21 and for the 8th pair at CS22 and CS23. The degree of curvature of the thoracic spine was similar from CS17 through CS19. However, the spine became more kyphotic after CS20, increasing to38.1 ± 6.6 degrees by CS23.

The curvature of the thoracic spine affects the orientation of the ribs forming the RC, the angle of each rib pair in relation to the ventral-dorsal axis. The ribs in the upper region, from the 1st pair to the level with maximum width (7th rib pair), elongate to fuse together in the median plane, while the ribs in the lower region separate caudally, [12].

The heart and the liver develop and become functional during the early embryonic period and descent, that is the heart is situated just inferior to the pairs of ribs that give the highest depth of the rib cage, whereas the liver is located just inferior to the pairs of ribs that give the highest width of the rib cage in almost all specimens. In contrast, respiratory organs develop relatively later, [8,9,12]. Furthermore, the chest cavity is not filled with the lungs during the embryonic period, [14]. Therefore, the size and form of the rib cage may not be affected by the size of the lungs. These facts may be a significant reason for the narrower shape of the upper rib cage, and wider lower RC forming the funnel shape of the newborn thorax.

4. Postnatal development of RC and lung

The funnel shape of the RC of the newborn remodels during growth into a barrel- like shaped construction due to widening of the upper part of the RC and the narrowing of the lower part of it, [15, 16].

4.1 Development of the normal RC. The newborn infant's RC is circular in cross section. As the infant grows, the RC becomes more barrel shaped, with greater width in the mid-thoracic spine and there is symmetry and coupled growth between the upper and lower thoracic ribs. The mid-thoracic ribs grow linearly, and increase in volume according to the **Fibonacci** sequence – logarithmic spiral, fig.1.

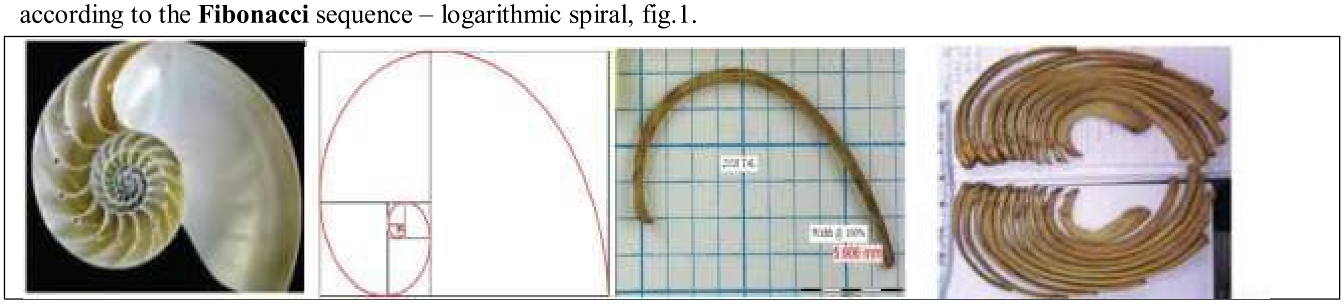


Fig.1: - The growth according to the mathematical representation of a logarithmic spiral, –sequence of Fibonacci, (Modified from [19]).

Growth of the RC cage is more linear with only small increases in annual growth rates during the pubertal growth spurt, while the most important events occur during the first few years of postnatal growth. The circular cross-section of the very young child's thorax reaches ovoid shape, adult-like, before the age of six years, [17], fig. 2.

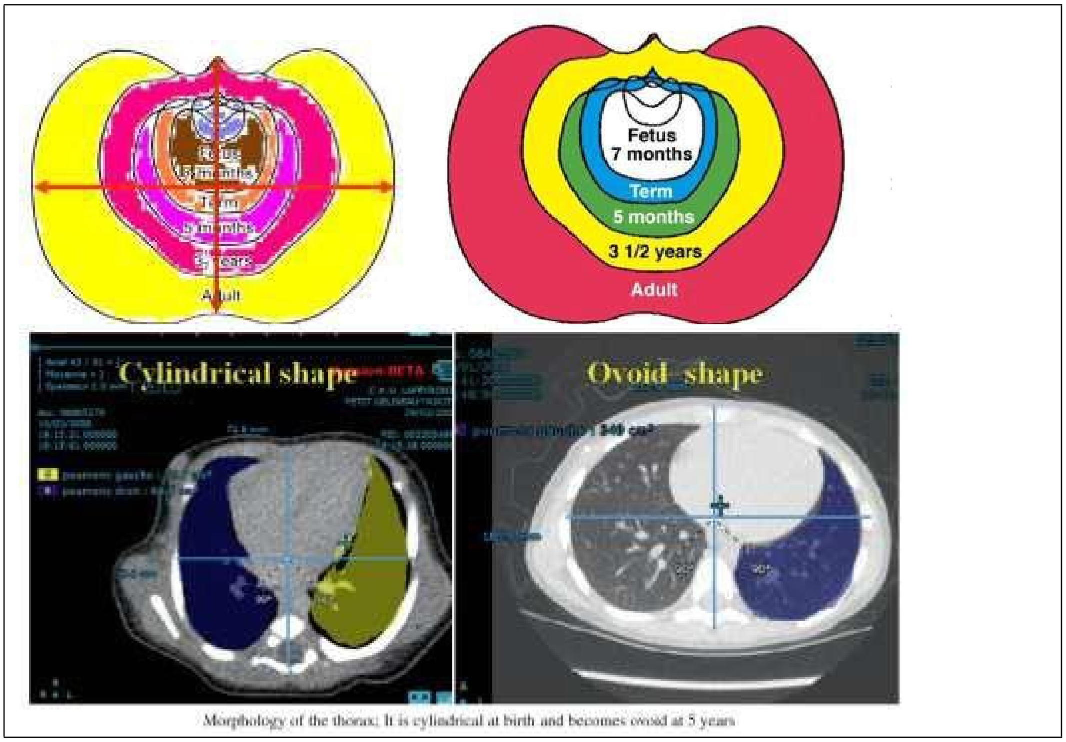


Fig. 2: - The changes in shape of the thorax during growth are shown in this figure, (Modified from [20]].

Briefly, the ribs largely determine the RC shape and its development: the rib height at 1st year of age is half of adult rib height, the width of the ribs at the age of one year is almost that of the ribs of adults, middle ribs grow 2.6 times faster than end ribs, 0.4cm/year, the symmetrical development of the ribs determines the barrel-shaped RC, and during development of the ribs the increasing radius of the curve follows the rule of the golden spiral.

The segmental thoracic ratios, (TR), are not direct measurements of rib growth, but an indirect indication of it and the provided longitudinally obtained data from thoracic radiographs estimate lung growth, too, [25]. Unlike the centile charts form head size and foot length, the charts for lung width and length were The centile charts for lung width and length were unexpected in that the girls never exceeded the boys. By using a stereoradiographic 3-dimensional reconstruction using x-rays, direct measurements of rib growth are achievable, [21,22]. More details on normal rib growth and lung are reported, [17, 19, 23,24, 25].

Several factors influence the morphology of the RC after birth, including anatomical constraints such as the association with the sternum, functional anatomy such as the kinetics of respiration and integration with the adjacent anatomical regions i.e. pelvis, [12, 26,27,28,29,30]. In this context, the physiological remodeling of postnatal RC during growth in relation to the of pelvis and gait in humans will be discussed below.

Kinetics: 1. branch of science that deals with the effects of forces upon the motions of material bodies or with changes in a physical or chemical system: the rate of change in such a system. 2. the mechanism by which a physical or chemical change is affected.

Kinematics: a branch of dynamics that deals with aspects of motion apart from considerations of mass and force.

4.2 Frontal and sagittal diameters of the RC; values of mid-thoracic diameters and the Thoracic Index, (TI).

In a Greek population sample of 810 boys and girls, aged 2-12 years old, the values and the line graphs by age of the numerator (a1), the denominator (a2) and their quotient (a3) for the TI, (frontal diameter divided by the sagittal diameter), are listed for boys and (β1,2,3) for girls, see fig 3, 4 and 5. The found average values of the TI show that there is a clear tendency to increase by age. That is, the numerator increases or the denominator remains smaller compared to the numerator. Namely, the RC is more cylindrical at younger ages and progressively widens in the frontal plane. Until the age of 5 years for the boys and 6 for girls, TI increases more quickly the depth of the RC in relation with its width while in older children the relationship reverses and the RC becomes oval shaped, as it is seen in adults, [31].

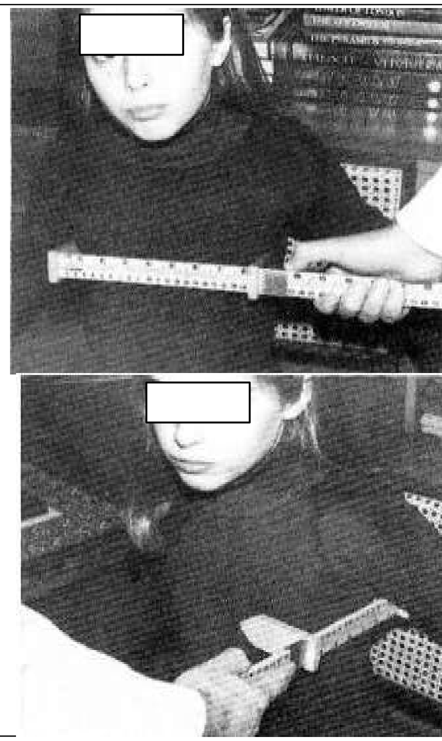
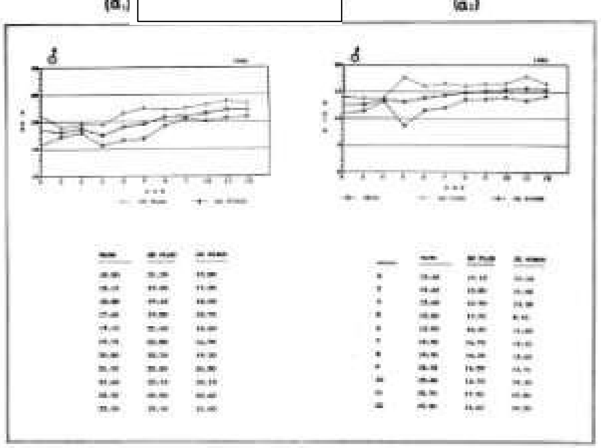


Fig. 3: - The way the frontal and anteroposterior diameter in the middle of RC is measured in a child, using a special anthropometric tool, [from Grivas 1984].

(α1) (α2)

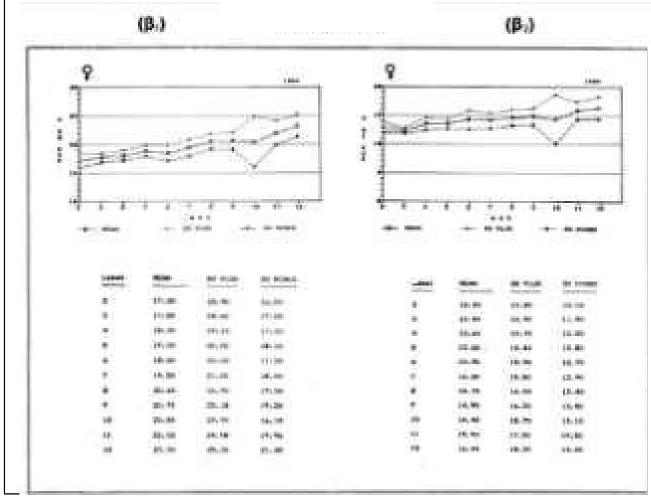


: 4

(α3)

♂	MEAN	SD PLUS	SD MINUS
(2)	1,468	1,503	1,423
(3)	1,436	1,376	1,508
(4)	1,382	1,410	1,353
(5)	1,333	1,101	1,804
(6)	1,374	1,333	1,431
(7)	1,368	1,347	1,396
(8)	1,395	1,376	1,419
(9)	1,386	1,356	1,495
(10)	1,402	1,383	1,425
(11)	1,420	1,335	1,525
(12)	1,441	1,409	1,478

Fig 4: - Frontal (α1) and sagittal (α2) measured diameter values in the middle of RC in cm ± SD for boys by age (2-12 years old), and their thoracic index, (TI), (α3), expressed as the quotient of α1 by α2, see α3, [from Grivas 1984].



(β3)

♀	MEAN	SD PLUS	SD MINUS
(2)	1,333	1,333	1,333
(3)	1,435	1,441	1,428
(4)	1,338	1,299	1,384
(5)	1,400	1,388	1,414
(6)	1,300	1,257	1,354
(7)	1,373	1,354	1,395
(8)	1,401	1,368	1,440
(9)	1,389	1,360	1,422
(10)	1,423	1,331	1,594
(11)	1,384	1,376	1,395
(12)	1,420	1,377	1,486

Fig 5: - Frontal (β1) and sagittal (β2) measured diameter values in the middle of RC in cm ± SD for girls by age (2-12 years old), and their thoracic index, (TI), (β3), expressed as the quotient of β1 by β2, see β3, [from Grivas 1984].

This developmental normal remodeling of the RC during this age period may be genetically programed to facilitate the multiplication of alveoli of the lung which happens until the age of 5-6 years in the growing child, [32,33], see fig 6.

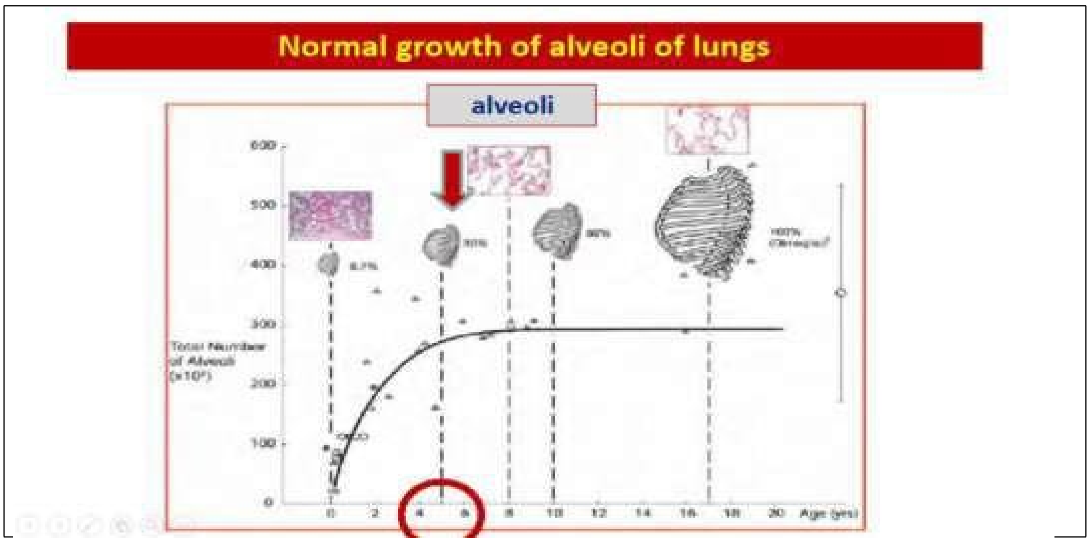


Fig 6: - Graph summarizing multiple small series of morphometric studies of autopsied lungs, [34, 35, 36, 37, 38] with relative percent adult thoracic size by age, (modified from [39]).

Meredith and Knott 1937, Sinclair 1969, [40,41], mention and Burwell et al 1980, 1983, [42, 43], agree that after the age of 5 years the RC widens. In order to understand the changes in RC width related to age and sex, the lung growth must also be considered.

4.3 Lung growth. Thurlbeck, 1975, reviewed the development of the lung after birth, [36]. Hieronymi1961, [44], stated that the shape of the lung changes as it grows, and that the growth in height is greater than the growth in width. Simon et al.1972, [25], found that, lung width and length in boys increase from 5 to 19 in a fairly linear mode, in thoracic radiographs, while in girls, lung width increases less than length. Keith 1923, [45], noted that the roots of the lungs are attached to the pericardium which is fixed to the diaphragm, and the diaphragmatic movements are therefore essential for the proper aeration to the upper RC, due to the evolution of the upright posture, [45].

The plot of TRs, by age groups, depicts the proportional changes of RC viscera, especially of the lungs, and the relative narrowing of the girls' lower RC between childhood and puberty which is consistent with the proportionate change in the girl's lung later, fig.8, [25].

4.4 Biomechanical Contribution of the RC to thoracic stability. The RC increases the stiffness of the thoracic spine in all loading directions, [46]. During flexion/extension, the sternum and anterior RC most contribute to stability. During lateral bending, the posterior RC most contributes to stability. Coupling between lateral bending and axial rotation is mild in the thoracic spine and unaffected by ribs. The stability offered by the RC differs among anatomical regions with true ribs, floating ribs, or false ribs. As far as the rotation of the thoracic spine is concerned, the large variance in the anteroposterior location of the axis of rotation (AOR) is probably due to the absence of a well-defined pivot point structure during flexion and extension. That is, with the RC and other anterior tissues sharing the load applied distally, the pivot point is shifted to a new position that is more ambiguous than the disc space, [47].

4.5 Increase in frontal & sagittal thoracic diameter during breathing. During respiration the RC expansion movements in inhalation are like (a) a pump handle in the upper ribs and like a bucket handle in the lower ribs, fig. 7

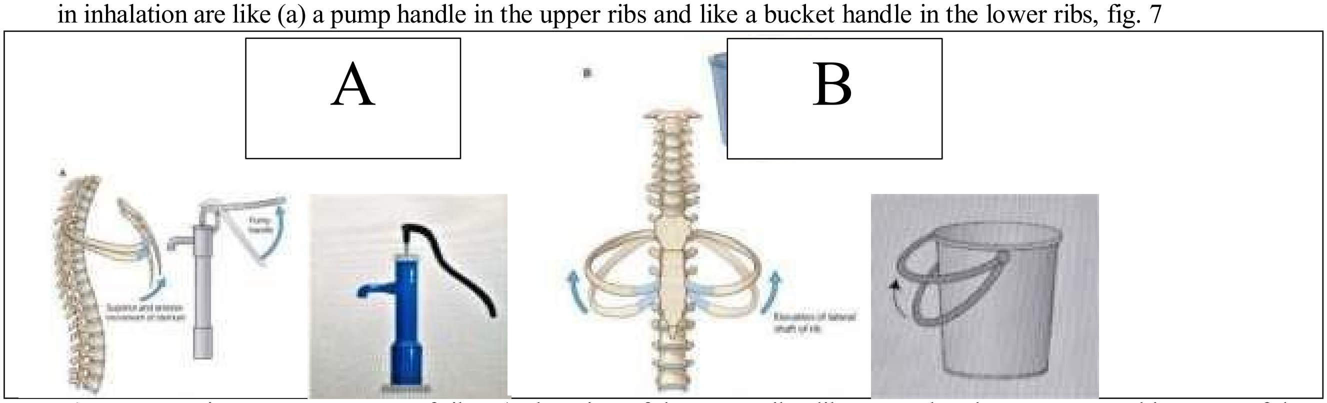


Fig. 7: - Respiratory movements of ribs: a) elevation of the upper ribs, like pump hand movement and increase of the anteroposterior diameter of thoracic cavity, b) elevation of the lower ribs like bucket handle movement and increase of the lateral diameter of thoracic cavity, (modified by [48]).

4.6 The infancy, Childhood, puberty (ICP) model of growth. A useful way to study the normal RC remodeling due to growth after birth until the skeletal maturation, is to group the children into three age and sex groups, according to the classification of Karlberg (1989): infancy (I) = 0-2.999 years; childhood (C) = 3-10.999 years, and puberty (P) =11-17.999 years, [49]. The components of this model depict the different hormonal phases of the growth. Consequently, the above model is an improved instrument for detecting and understanding growth failure, [49]. This ICP model has already been applied to AIS, [50].

4.7 Assessment of normal and deformed RC in Early Onset Scoliosis (EOS) and Late Onset Scoliosis (LOS)- (segmental Rib Vertebra Angles (RVA), segmental RVAD differences, (RVAD), segmental Thoracic Ratios, (TR)).There are several proposed radiographical, CT and MRI methods and parameters to assess the normal thorax, and its deformity, see Harris et al 2014 Table 1.However, a convenient way to study the normal thoracic remodeling due to growth, is to use the segmental thoracic ratios (TR) and the segmental rib vertebra angles (RVA) from T1 to T12 level, on chest radiographs, to assess the shape of the thorax in the frontal plane, in growing infants, children and adolescents. This study of segmental TRs and segmental RVAs considers frontal plane radiographs. Currently more frequently three-dimensional analysis is used as a procedure to study the morphology of scoliotic curvatures, [21, 52, 53, 54, 55], as any study based exclusively on coronal plane has its limitations.

Dansereau el al. 1987, [55], proposed a 3-D rib cage assessment, which certainly offers interesting possibilities but requires special equipment. Nevertheless, from the practical point of view the studies based on anterior-posterior (a-p) radiographs may have a valuable contribution. The most important and frequently used radiological parameters are designed and measured on a-p radiographs (Cobb, Mehta, Perdriolle angles). Lateral radiographs are not systematically made to children with scoliosis. In the majority of hospitals, the material accessible for retrospective studies contains almost exclusively frontal plane radiographs. Moreover, the plain chest radiographs of children and adolescents, being easily available at medical archives, can effectively serve this study, without the need for any other special radiographs and exposure to additional radiation. One additional benefit of these methods is its implementation not only in prospective but also in retrospective studies, using the existing initially obtained chest or spinal radiographs of IS patients, provided that the radiography is performed in a standard way.

4.8 Thoracic ratios (TR). [15]. The method of TRs is a means of expressing RC shape and relative size to the distance from T1 to T12, in frontal plane, and segmentally in hemithoraces. On each anteroposterior chest radiograph, the outline of the lateral border of the thorax is drawn, fig. 8. Next, the mid-point of the distal end-plate at each vertebral body from T1 - T12 is marked. Then at each segment, the distance from the middle of the end-plate to each outline of the right and left thoracic cage is measured. These distances are standardized by dividing by the measured T1 - T12 distance, fig 8. They are termed segmental left and right TRs. Ratios are also calculated segmentally for the total width of the RC.

Table 1 Radiographic and CT-based thorax deformity parameters

Deformity feature	Parameter	Definition	Landmark equivalent
Anterior chest angulation	Angle of sternum rel. to apical vertebrae [27]	Angle formed between horizontal line bisecting sternum and vertebral bisectional line	Line 1: Sternum bisectional plane line 2: Apical VB bisectional plane
	Anterior chest wall angle [27]	Angle between frontal plane and oblique plane through the concave and convex anterior costal projects and the frontal plane	
	Sternal tilt [24]	Angle formed between frontal plane and horizontal line bisecting sternum	Line 1: sternum bisectional plane Line 2: X-axis
Area enclosed by rib cage	Frontosagittal index [25]	Ratio of Sternovertebral distance over transverse diameter as a percentage	$AJ_y/TE_x \times 100$ %
	Haller index [25]	Ratio of transverse diameter over sternovertebral distance	TE_x/AJ_y
	Kyphosis-Lordosis index [20]	Ratio of sagittal diameter over transverse diameter	AL_y/TE_x
	Pectus index [23]	Ratio of transverse diameter over sternovertebral distance	TE_x/AJ_y
	Transverse diameter [20]	Maximum distance along frontal plane projected through most lateral interior aspects of the costal at apical level	TE_x
Coronal asymmetry	[a]Apical rib vertebral angle difference [28]	A perpendicular line is drawn to the middle of either the upper or lower border o the apical vertebrae. Another line is drawn from the mid-point of the head of the rib to the mid-point of the neck of the rib, just medial to the region where the neck widens into the shaft of the rib. The rib line is extended medially to intersect the vertebral line to make the rib vertebrae angle	K'L'$_x$ and I'J'$_x$
	[a]Space Available for Lung [11]	Referencing an AP radiograph, the height of the hemithorax is defined as the distance from the middle of the most cephalad rib down to the center of the hemidiaphragm. A ratio, expressed as a percentage, is derived by dividing the height of the concave hemithorax by the height of the convex hemithorax, defining the space available for the lung	A'B'$_x$ and C'D'$_x$
Hemithorax depth asymmetry	Asymmetry index [25]	Ratio of maximum left and right AP hemithorax diameters at apical level subtracted from 1	$1-(QU_y/HC_y)$
	Chest asymmetry [24]	Absolute difference between maximum AP distances of right and left hemithorax	$\lvert QU_y - HC_y \rvert$
	Chest flatness index [25]	Ratio of twice the maximum transverse diameter and the sum of both maximum AP hemithorax diameters at apical level	$2 \times TE_x/(QU_y - HC_y)$
Hemithorax width asymmetry	[a]Apical vertebral body-rib ratio [26]	The ratio of linear measurements (larger over smaller distance) from the lateral borders of the apical thoracic vertebrae to the chest wall on an AP radiograph	E'F'$_x$ and G'H'$_x$
	Posterior hemithoracic symmetry ratio [11]	Distance between interior surface and anterior tip of the costal at the costovertebral articulation along oblique plane through tips. Ratio calculated by dividing smallest distance from largest	PO_x and DI_x
	Sternum-rib ratio [27]	Convex/Concave ratio of linear measurements from midpoint of the sternum to exterior of rib cage along frontal plane at apical level	BS_x and BF_x
Posterior rib asymmetry	Angle of trunk rotation [22]	Angle formed between frontal plane and tangential line drawn to the posterior rib hump deformity	
	Posterior rib rotation [30]	Angle between frontal plane and oblique plane traveling through posterior apexes of costals at apical level	
	[b]Rib hump [26]	Linear distance between the left and right posterior rib prominences at the apex of the rib deformity on a lateral radiograph	Not shown in figure
	Rib hump index [20]	Ratio H–D/W, where H is distance from frontal plane through the posterior central point of the vertebral foramen to the apex of the inner costal hump. D is the same measurement on the concave hemithorax. W is the distance between the sagittal planes traveling through both the apex of the convex costal and posterior central point of the vertebral foramen at the apical level	$H = LQ_y$ (convex) $D = LH_y$ (concave) $W = LQ_x$ (convex)
	Rib hump index [31]	Ratio $(H_1 - H_2)/W \times 100$ %, where H_1 is distance from frontal plane through the posterior central point of the vertebral foramen to the apex of the inner costal hump. H_2 is the same measurement on the concave hemithorax. W is the distance between interior extremes along frontal plane bisecting posterior most point of foramen at the apical level	$H_1 = LQ_y$ (convex) $H_2 = LH_y$ (concave) $W = RG_x$
Sagittal depth	Sagittal diameter [20]	Distance between posterior midpoint of sternum and anterior point of foramen along AP Plane	AL_y
	Sternovertebral distance [25]	Distance between posterior midpoint of sternum and anterior point of apical vertebrae along AP Plane	AJ_y
Sternum deviation	Midline deviation [20]	Angle between AP plane and line through posterior aspect of foramen and anterior midpoint of sternum	Line 1: Y-axis line 2: NA
	Thoracic rotation [11]	Angle between plane bisecting sternum and anterior aspect of vertebral body and plane bisecting vertebrae	Line 1: Apical vert. bisectional line Line 2: BM
	Vertebral translation [6]	Distance between AP planes though center of foramen and bisecting sternum	BM_x

[a] Measurements from AP radiograph
[b] Measurements from lateral radiograph

Eur Spine J (2014) 23:2594–2602

Table 1: - Methods and parameters to assess the normal thorax, and its deformity, (from [51]).

(left plus right measured lengths). Children with 4° or less spinal curves, were included studying the TRs because such curves may influence the results minimal. Length of the ribs in patients with IS were reported by Kasai et al 2002, [56].

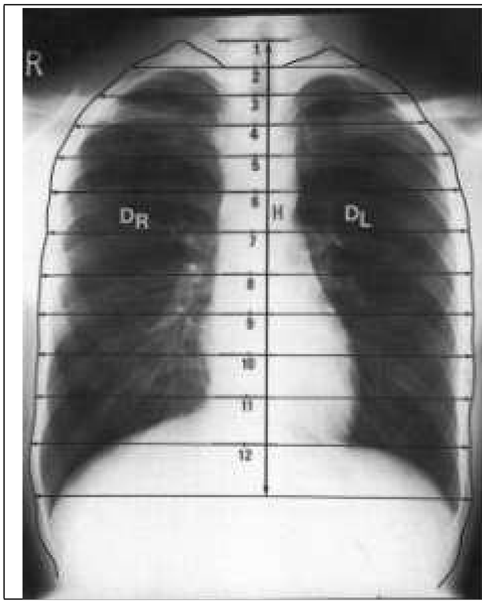


Fig.8: - Method of calculating segmental TRs on RC radiographs. DR and DL are distances from the middle of an end- plate to the outlines of the RC, H= the distance from Tl-12, [from Grivas et al 15].

In a study of the anteroposterior thoracic radiographs in 412 children with minimal disorders or diseases involving trauma, infections, foreign bodies, heart murmurs and mild asthma and none with a scoliosis of 5 degrees or more, the findings are as follows, fig. 9.

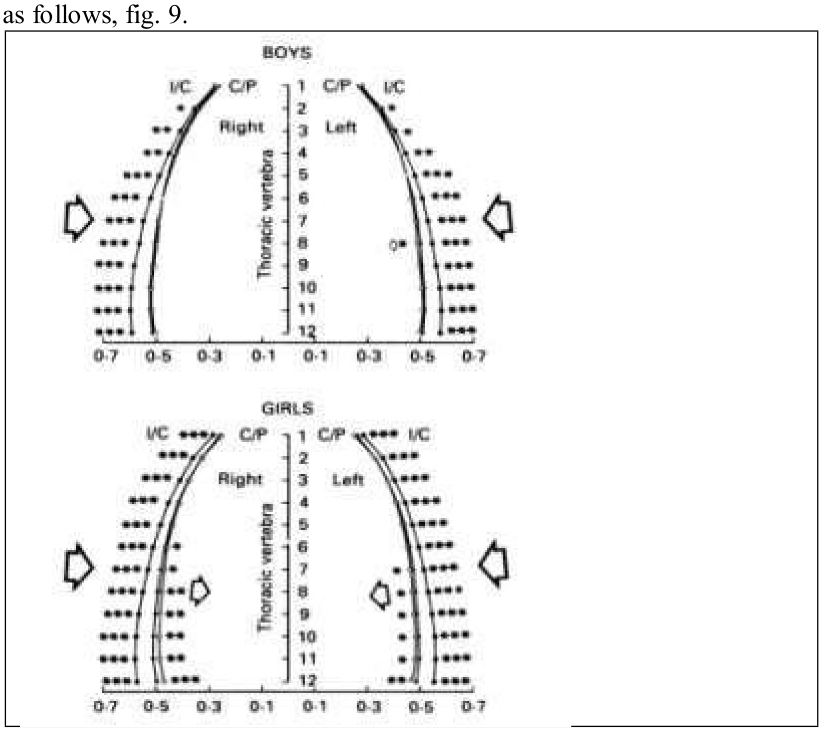


Fig. 9: - TR for normal boys and girls plotted by age group (infancy, childhood and puberty; see text). I/C, infancy / childhood; C/P, childhood/puberty. Infancy = , childhood = , puberty = ▼ o

* 0·0 1 <P < 0·0 5; ** 0·001 <P < 0·01; *** P < 0·001, [from Grivas et al 15].

4.8.a TR changes by age. In both boys and girls between infancy and childhood (I- C), per part of the RC in boys. In girls than boys at T1-4, there is a greater percentage diminution of TRs while at T5 and below the percentage diminution is similar. Between childhood and puberty (C-P), in contrast to the boys, the girls show a further relative narrowing of the lower RC belowT5(T7- 12), but little or no change in the upper part of the RC(T1-6).

4.8.b TRs and sex differences. In infancy, between boys and girls there are no significant differences in TRs. In childhood, there are no sex differences for TRs at T1-5 in the left hemithorax and at T1-9 in the right hemithorax. The sex differences for left TRs are at T6 toT10. Hence, the TRs are lower in girls than in boys and particularly for the left hemithorax; i.e. the lower, particularly left, RC of girls is narrower than that of boys. In puberty, the girls' TRs are significantly lower than those of the boys at left T1-10, right T1-12. According to these findings the girls' RC from 11 years of age is narrower relative to spinal length than that of the boys at most levels.

After birth, remodeling during the development of the normal RC, especially in its lower region relative to RC length, occurs with its broadening in the upper region in frontal plane relative to its AP dimension, fig 10; [58, 43, 31].

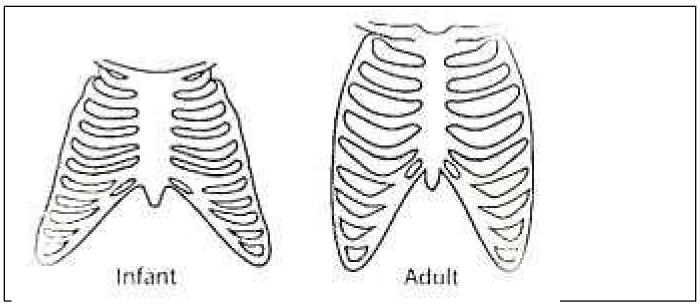


Fig 10: - The shape of the RC in infants and in adults, [modified from 57].

The hypothesis was made that the relative narrowing of the lower chest with increasing age reduces the rotational inertia of the thorax in human bipedal gait. This will be discussed furthermore below in association with the segmental rib-vertebra angles (RVAs) as well.

4.9 Segmental Rib-vertebra angles (RVA), [16]. The study of the segmental (T1-12) RVAs and rib-vertebra angle differences (RVADs), were reported by Grivas et al 1992, [49]. as a new method. The ICP model of growth was used for analysis of these data.

The RVA technique which was used previously, [59], fig. 11, was modified because the head of the rib in infants is not as clearly evident as it is in older children, and the upper ribs curve upwards and laterally from the spine. Consequently, to measure the RVAs, fig.11, a line is drawn along the distal end-plate of each vertebra. At the middle of each end-plate a vertical line is drawn and two points are defined on the rib, one where the rib meets the vertebra, and the second at a point midway between the edge of the vertebra and the outer margin of the RC. These two points are joined and extrapolated to meet the vertical line. The angle formed between the rib line and the vertical vertebral line is measured as the RVA from T1 to T12, for both left and right hemithoraces.

The findings, [16], fig. 12, show the following changes of RVAs by age and sex: 1) RVAs decrease fromT1- 12, especially so between T8 and T12. 2) Between infancy and childhood (IC), RVAs of the upper ribs increase, more so in boys than girls. 3) Between childhood and puberty/adolescence (CP) there is a further elevation of ribs, involving more ribs in boys than girls (boysT1-10, girlsT1-8). 4) Between infancy and childhood (IC), the lower ribs droop more in girls than boys (boysT9/10-12, girlsT7/8-12). There is no change in the RVAs of the lower ribs between childhood and puberty (CP) in either boys or girls. 5) We hypothesized that RVAs are influenced by the CNS mediated trunk muscle activity. 6) RVADs pattern reflects the common age, sex, and laterality patterns of IS, [16], fig.

13. Extremes of such asymmetries may be an aetiological factor for both IIS and AIS. Segmental analysis of RVAs in AlS RC, fig 12, reveals crossed RVA asymmetry with aetiological implications, [60, 16].

The above finding of our cross-sectional studies, reveal how and when the RC remodels by age and gender during growth. We suggested that the triangular-shaped RC of the neonates remodels into a barrel shaped one during growth, in evolutionary terms, asamechanismconsistentwithanadaptationoftheRCtohumanbipedalgait, [61]. The above led to a novel multifactorial theory for the pathogenesis of IS, [62].

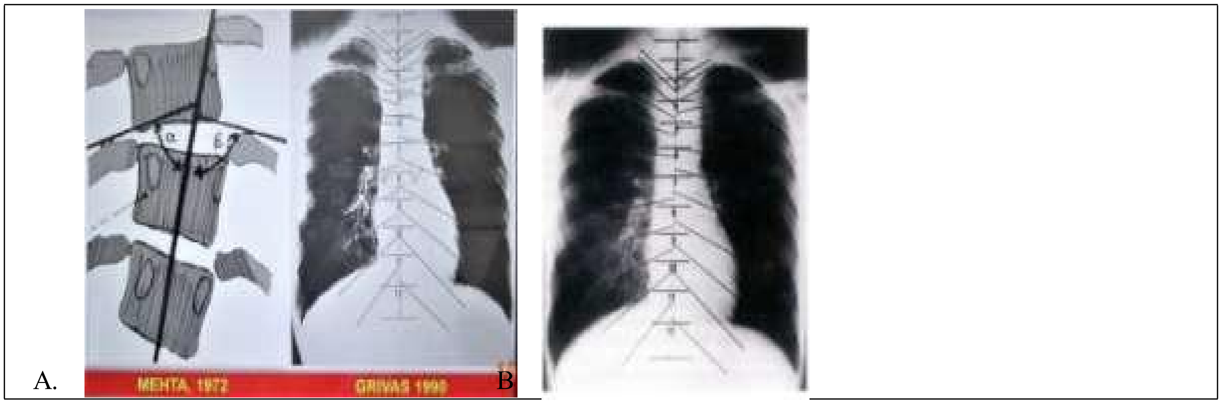


Fig.11: - Chest radiograph showing the methods of measurement of RVAs, A [59], B [modified from Grivas et al 2002, [64]).

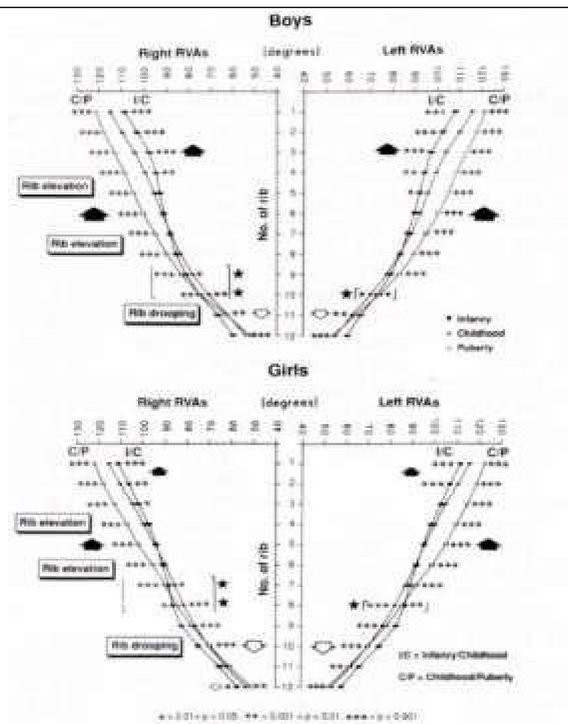


Fig. 12: - Segmental rib-vertebra angles (RVA's in degrees), in boys and girls, for each of the infancy (I), childhood (C), and puberty (P) groups by rib level. (see text), B [modified from Grivas et al 1992, [16]).

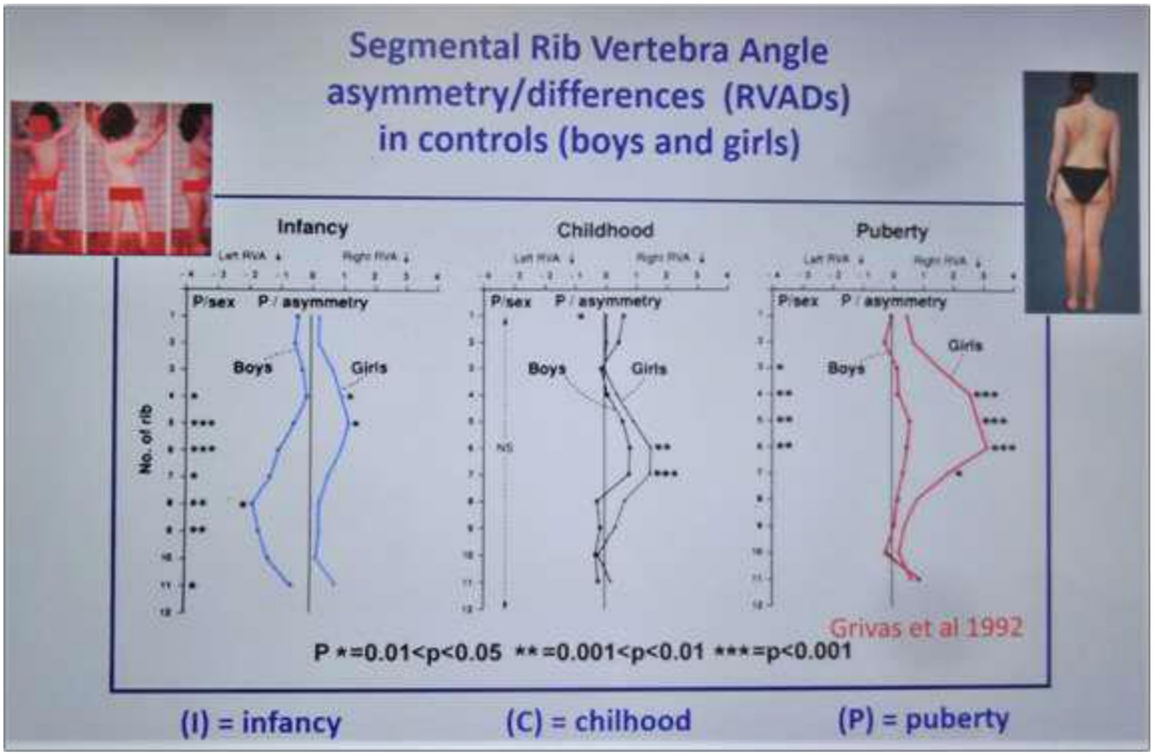


Fig.13: - Segmental RVADs asymmetries in the boys and girls for each of the infancy (I), childhood (C), and puberty (P) groups, [modified from Grivas et al 1992, [16]).

The narrowing of the RC relative to its length during growth is associated with elevating upper RVAs (above90°) and drooping lower RVAs (below90°). The latter may contribute to the relative RC narrowing in its lower part between infancy and childhood (I-C), in both boys and girls, [16]. In the period between childhood and puberty (C-P),no further relative narrowing of the RC occurs for boys. In contrast, the girls' lower chest (T6- T12) narrows further relative to its spinal length; with no further RVA drooping between childhood and puberty to explain this RC narrowing. Therefore, it is hypothesized that only in girls' rib growth in the lower half of the RC is impaired relative to spinal growth, [15,16, 50, 63, 64, 24]. This suggestion may pertain to the Nottingham concept of aetiology for AIS, [62, 63]. This concept of pathogenesis of IS is presented below in this review.

4.10 Factors that may cause changes in RVAs by age--Neuromuscular Mechanisms. In growing children, muscles attached to the ribs dictate the RVAs position. Some back muscles function in an up-and-down direction, [65], and with regard to this, a segmental study of iliocostalis proposes that the flat muscles of the trunk, as serratus anterior and abdominal muscles, play a significant role in rotatory control of the spine, [66]. Wemyss-Holden et al. (1991) [60, 67], proposed that the muscles acting to rotate the trunk during gait create a composite spiral and coined it “Composite Muscle Trunk Rotator (CMTR)”. Elevator scapulae and rhomboids, serratus anterior, external oblique, and contralateral internal oblique comprises CMTR on each side. Asymmetric action of one or more of these muscles creates a spinal curve, fig 14, and the site and type of this curve is related to the muscle involved. They also suggested that malfunction of this spiral may be responsible for IS scoliogeny; and in particular that the drop of the upper concave ribs may result from greater asymmetrical action of trunk rotator muscles on the concavity than of the convexity of the IS curve. It was proposed the hypothesis that RVAs express muscle balance, [60, 67].

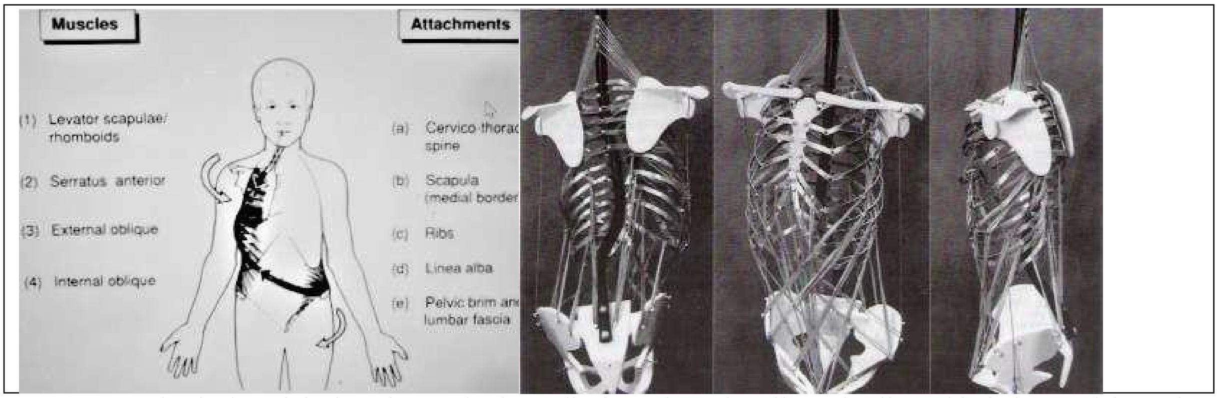


Fig.14: - Mechanical model of trunk muscles in scoliosis to show the effect of unilateral imbalance of the entire composite muscle trunk rotator (CMTR, on the left). This imbalance produces a right thoracic scoliosis (modified from Wemyss-Holden et al.1991, (Modified from Burwell et al 1992, [62]).

In line with the above findings, Yuseng Liu et al 2019, [68], studied the biomechanical properties of the thoracic paravertebral muscles on concave and convex side in AIS patients with Lenke 1-3 curves. It was found that the concave paravertebral muscle tone and stiffness were greater than those on convex side and their asymmetric biomechanical characteristics were closely related to the severity of scoliosis, [68].

Grivas et al 2015,2016, [69,70], studying Idiopathic and normal lateral lumbar curves, (LLC), commented on the existence of 12th rib length asymmetry related to these curves. They propose a pathomechanic role for quadrates lumborum, (QL) based on the new finding of bilateral length asymmetry of 12th rib related with IS and small non- scoliosis LLC, [70], see fig. 15.

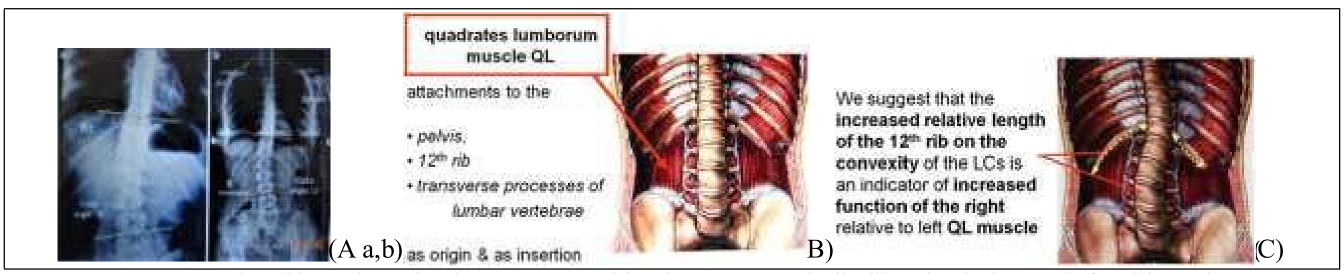


Fig 15 A) a, 15° Cobb angle Rt lumbar IS curve with a longer Rt 12th rib, likewise in b, a 22°of Cobb angle Rt lumbar IS with a Rt 12th rib longer **B)** QL attachments, **C)** the suggested hypothesis for Rt lumbar IS curves, [From Grivas et al 2016, [70]).

To the 12th ribs, numerous small muscles are attached, including the diaphragm, QL, fig. 15b, internal and external intercostals, serratus posterior inferior, short and long rib elevators, external oblique abdominal, internal oblique abdominal, transversus abdominis, iliocostalis and longissimus thoracis. The largest of these muscles is QL which has attachments as origins and as insertions the pelvis, 12th ribs and transverse processes of lumbar vertebrae, and very probably exert the greatest forces on the 12th ribs. Two theories were proposed: a) a relatively increased activity of the right QL muscle causes the LLCs, and b) QL counteracts the lumbar curvature as part of the body's attempt to compensate for the curvature, [70]. Grivas et al 2016, proposed that one mechanism responsible for the relatively increased length of the right 12th ribs is mechanotransduction, {71], according to Wolff's and Pauwels laws, fig. 15C, [72,73, 74, 75].

5. Posterior truncal asymmetries (TA) and school scoliosis screening (SSS)

Knowledge of the normal variability of the posterior truncal morphology in healthy children and adolescents is essential since the presence of asymmetry is an indicator for referral to specialists and further orthopaedic evaluation. Grivas et al 2006, 2008a, b, documented this variability, analyzing the data of their SSS program. The scoliometer was used to assess back TA, in mid thoracic, thoracolumbar and lumbar region. Juveniles were more symmetric than adolescents and girls more symmetric than boys. Juvenile back TA pattern seems to be the same, with the higher incidence of JIS, in boys. Moreover, severe TA, which could be linked with a IS curve, was found more frequently to the left side. Adolescence girls were more frequently asymmetric than boys. Right TA was more frequent than left, [76, 77,78].

Grivas et al 2006 presented a study assessing the probable correlation of TA, measured with a scoliometer, to lateralization of the brain as expressed by handedness in a school aged children, [79]. A strong, ($p < 0.038$), correlation of TA and handedness was found both in boys and girls, at mid-thoracic region having 2-7 degrees of TA. Thus, this significant correlation to the dominant brain hemisphere in terms of handedness, exists in children who are entitled at risk of developing IS, and implicate a potential scoliogenetic role of cerebral cortex function in the formation of the RC external morphology, [79].

6. The RC in IS

The shape of RC was assessed segmentally, using the TR method, both in radiographs of 24 pre-operative children suffering progressive IIS, and in the chest radiographs of 233 heathy children. The RC in progressive IIS is considerably narrower at T1-T5 compared to normal peers.

The funnel-shaped upper RC of IIS is similar to the one of the normal human foetus, of the rabbit and of the RC in Jeune's disease, fig 16, suggesting different postnatal growth patterns of upper and lower ribs in humans.

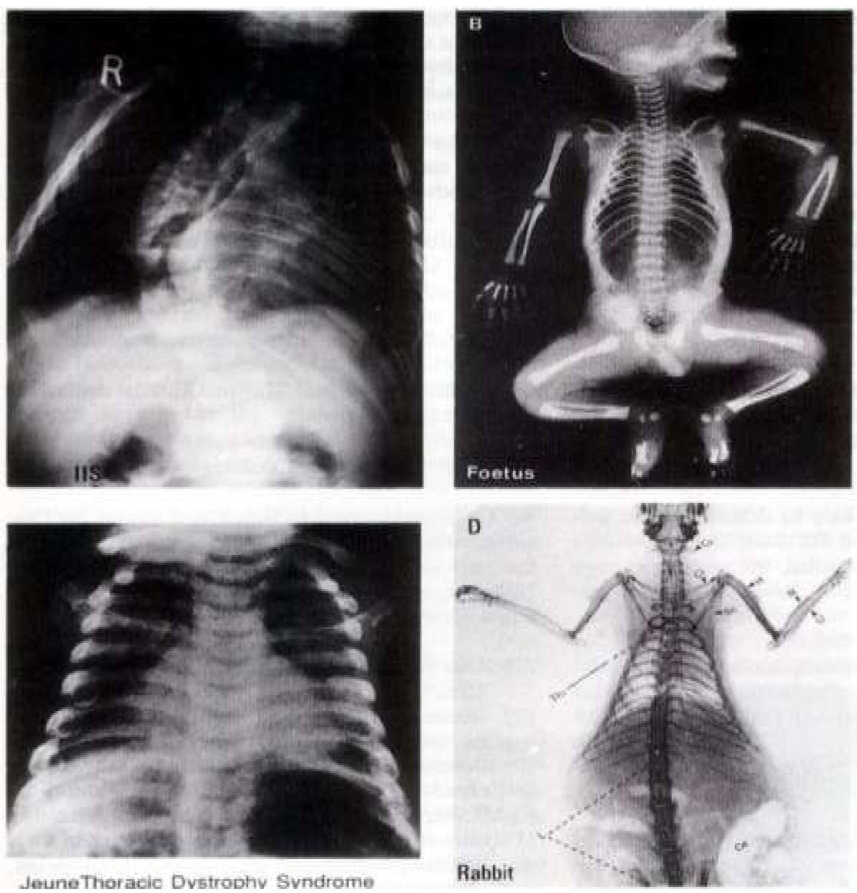


Fig. 16: - The funnel-shaped upper RC of IIS is similar to the one of the normal human foetus, the thorax in Jeune's disease, and the rabbit, (from Grivas et al 1992, [80]).

The pre-operative vertebral rotation at T4-T5 is significantly related to the apical one at follow-up. It was suggested that the prognostic value of specific rotation above the apex of the thoracic curve (Perdriolle and Vidal, 1985) reflects reduced rib control of spinal rotation due to the growth defect of the upper RC, [80,81, 82, 83].

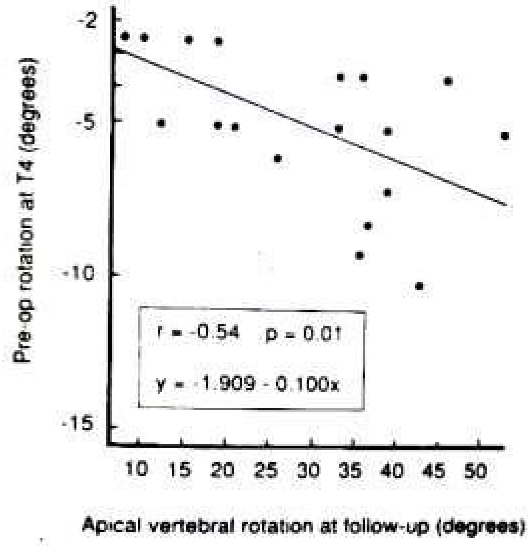


Fig. 18: - The vertebral rotation at T4-T5 is significantly related to the apical one at follow-up, (from Grivas et al 1992, [80]).

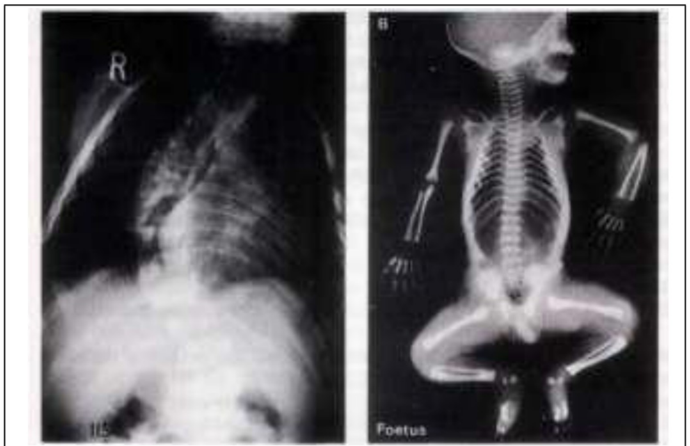
The funnel shape of the RC at birth in order to become barrel-shaped during aging towards adolescence and adulthood must undergo the following changes: a) an increase to the development of the ribs in the upper part of the RC in relation to the thoracic spine and/or a satisfactory elevation of the upper ribs (increase of their RVA) and drooping of the lower ribs of the RC. To achieve this, the muscles of the shoulder girdle must be developed normally and be robust. Also, the ribs of the lower part of the RC must "droop" with a reduction of their RVAs as a result; the muscles that attach at these ribs must contract robustly caudally, and they must not be weak and/or underdeveloped. In IIS, the chest shows the characteristic of a funnel-shaped RC of the newborn child, in other words, the shape of the fetal shaped chest remains in infants.

6.1 RC development in resolving IIS, [85, 90,91].

Jones et al 1992, [85], reported the RC deformity regression in resolving in IIS by age. The segmental findings relating to thoracic shape in 19 children (15 boys, 4 girls) with resolving IIS from the peak of the spinal curvature to its resolution up to 14 years of age were documented. Ribcage shape was evaluated by measuring thoracic ratios segmentally from a longitudinal series of spinal radiographs for each child. The TR were calculated for each vertebral level using the method of Grivas et al. (1991), [15], correcting for the loss of height due to the scoliosis by the method of Hodgett et al (1986), [84]. The findings show that the RC in resolving IIS is considerably narrower than that of controls at all vertebra levels, at both peak and resolution of the curve. However, the RC in the resolving scoliotics shows the same physiological narrowing of the lower RC by growth as the controls do. In the light of the Nottingharn theory of aetiology for IS, it is suggested that the onset of resolving IIS involves a selection process from the general population of infants and young children who have both: 1) a developmental anomaly of the RC (narrowing); and 2) a central nervous system (CNS) asymmetry. According to this concept, resolution of IIS curves results from two mechanisms: 1. CNS function establishes symmetry with increasing age; 2. The narrowing of an already narrow RC allows a reduction in the rotational inertia produced by the pelvis in gait; this rebalances the pelvic rotation-inducing and the spinal rotation-defending systems in the trunk, [85, 90, 91].

6.2 RC development in progressive IIS {86, 92,93].

In progressive IIS the shape of the upper part of the RC is funnel-shaped and looks like the one of a normal human foetus, fig. 18.



A B

Fig.18: - The funnel-shaped upper chest of progressive IIS, (A), compared with a normal human foetus, (B), (from Grivas et al 2006, [86]).

A B

Fig 19: - A. Chest radiograph of a normal girl aged 18 months, showing the difference in the shape of the thorax compared to a scoliotic RC of a IIS boy aged 19 months, B, (from Grivas et al 2006, [86]).

Grivas et al 2006, assessing the TRs in a sample of IIS patients compared to matched controls, showed that IIS RC is considerably narrower than controls at every spinal levels, fig. 20, [86].

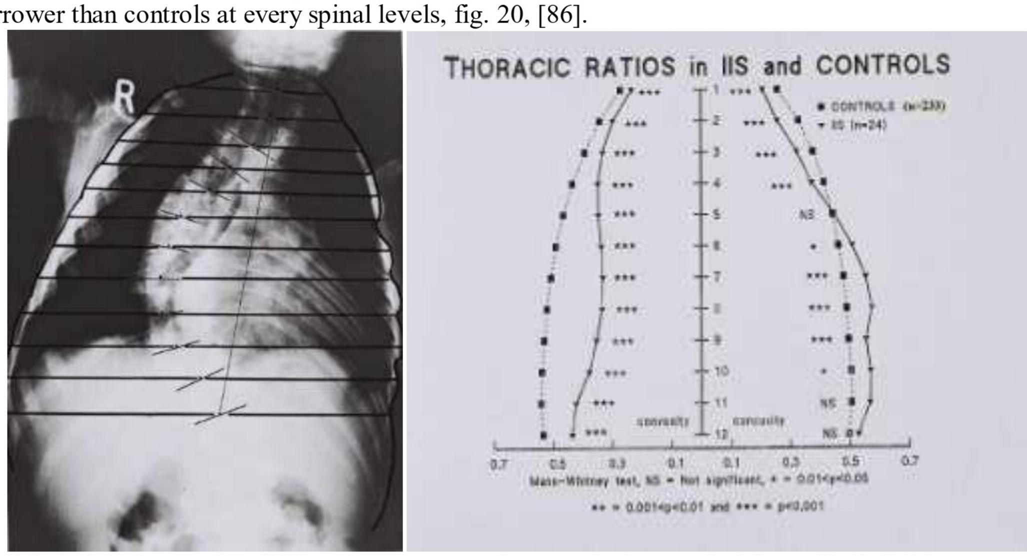


Fig 20: - The TRs of a sample of IIS patients compared to matched controls. The scoliotic RC is considerably narrower than controls at every spinal levels, [(from Grivas et al 2006, [86]).

It is hypothesized that there is a developmental delay of upper ribs leading to the funnel – shaped RC in progressive IIS, [89]. The funnel-shaped upper RC may be considered an early expression of RC asymmetry and it seems to derange the symmetric forces that the ribs act on the spine and may contribute to the development of the spinal deformity. Namely, the upper rib system is insufficient to act as spinal rotation-defending system in the trunk against the pelvic rotation-inducing system during gait, particularly in this very sensitive developmental period when bipedal gait in infants is established. This hypothesis may be relevant to the Nottingham concept of IS aetiology.

Curves in IIS are usually left thoracic. Boys are more affected than girls. At childhood, pre-menarche girls, present usually left thoracic curves like these that usually IIS scoliotics suffer, while post-menarche girls usually present with right thoracic curves like these in AIS, [86, 94]. We hypothesize that the mechanism of the development of these left curves in girls at their early age period may be similar to the one that develops IIS. Specifically, the upper RC ribs may do not grow and elevate symmetrically in both sides but for some reason this only happens unilaterally (i.e. there is no increase of RVA in one side) and unlike to the healthy thorax in childhood ,which undergoes normal remodeling, in these girls the upper rib system is insufficient to act as spinal rotation-defending system in the trunk to the pelvic rotation-inducing system during gait, causing deformity. This hypothesis may also be relevant to the Nottingham concept of IS aetiology.

*6.3. RC development in AIS***.** Grivas et al 2002, [64], compared the RVAs of 47 children with thoracic (T), thoracolumbar (TL), and lumbar (L) curves 10 °- 20° of Cobb angle suffering LOS with mean age 12 .4 years to the RVAs of 60 nonscoliotic children of a similar age group previously studied, (Grivas et al 1992). Comparing the RVAs between the scoliotic and nonscoliotic children, it was shown that the LOS children RC had lower RVAs ($p<0.01$) at almost all thoracic levels. It was reported that RVAs is an expression of the opposing muscle forces, that act on each rib, and that RVA asymmetries are aetiological for IS by weakening the spinal rotation-defending system, [62]. This study showed that scoliotic children with mild curves have underdeveloped RC compared to normals, fig 21. The differences are more apparent in the scoliotic children with thoracic curves. We suggested that the differences of the RVAs between right and left side in this group are an expression of asymmetric muscle forces acting on the RC. We concluded that asymmetric muscle forces participate in the pathogenesis of IS on the RC, which deforms before the spine.

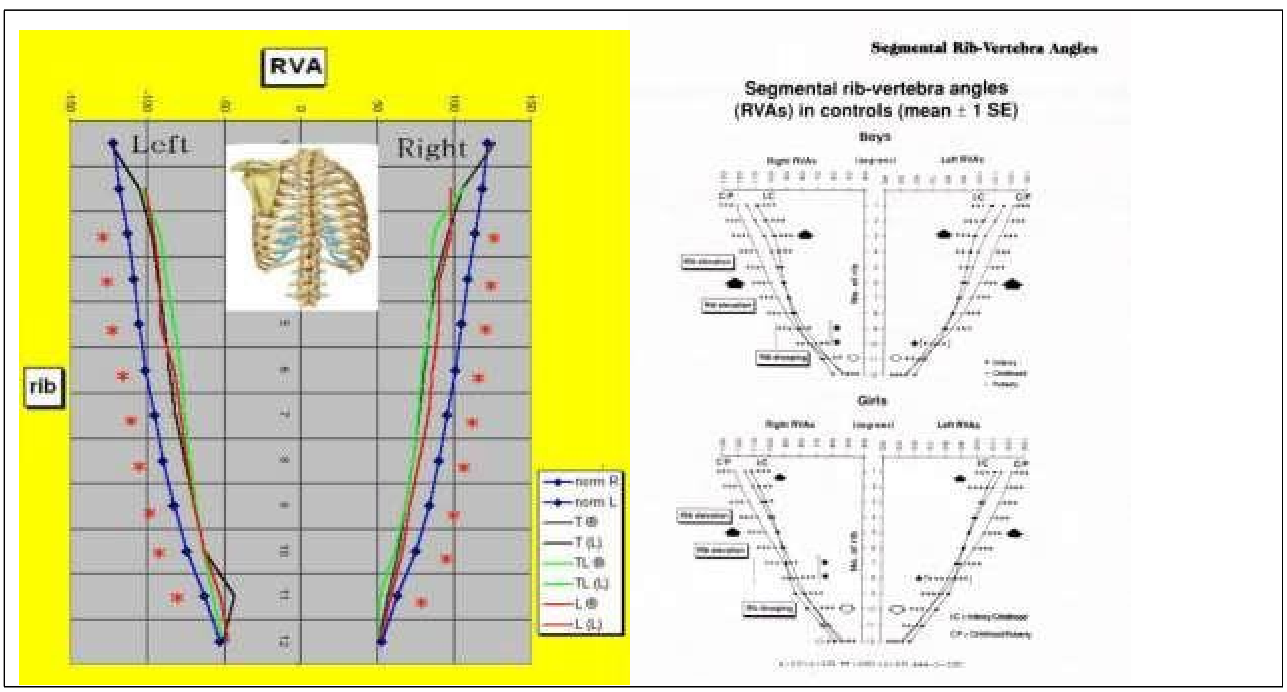


Fig.21: - Children with mild and moderate IS have underdeveloped RC compared to nonscoliotic counterparts, (blue line represents the RVAs for the nonscoliotics, and the rest lines, are those of T, TL, and L curves' RVAs, * = statistical significant different), (modified from Grivas et al 1992 and 2002, [16, 64]).

6.4 Menarche and laterality of thoracic curves, [87].
Grivas et al 2002, in a SSS program referred sample, gender and age documented, [87], found that girls before menarche had considerably more left curves, (10 degrees or more) and after menarche more right curves. A hypothetical mechanism for the development of these curves was discussed above, but also this finding may support the view that left curves result from a physiological mechanism that controls left/right laterality, [95, 96].

6.5 Scoliotics and congenitally fused ribs. Scoliotics suffering congenitally fused ribs in one hemithorax may develop scoliosis through the same mechanism, in line with the above described hypothesis for IIS. Congenital rib fusions of one upper hemithorax (hemi–funneling), fig. 22, show that they can be associated with narrowing of the hemithorax on the affected side and with an IS curve below the level of rib fusions which is convex to the side of the rib defect. These outcomes may be relevant to a Nottingham concept of aetiology for IS, and they are also in line with the observation of Bisgard 1934, [97], that the apex of the curve in thoracogenic scoliosis, moves downward with each successive stage of multistage thoracoplasties, [50, 62, 80, 89, 97, 98].

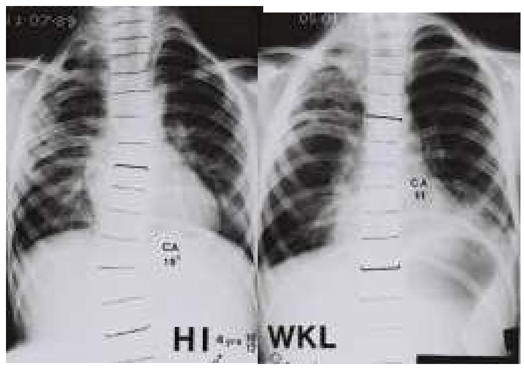


Fig. 22:- Congenital rib abnormalities and scoliosis. [(from Grivas et al 2006, [86]).

6.6 Pulmonary function in children with IS
Tsiligiannis and Grivas 2012, [99], in a review on pulmonary function in IS children stated that IS affects respiratory function during periods of rapid somatic growth. Scoliosis results in a restrictive lung disease with a multifactorial decrease in lung volumes, displaces the intrathoracic organs, hinders the movement of ribs and disturbs the mechanics of the respiratory muscles. Scoliosis decreases the RC wall as well as the lung compliance and results in increased work of breathing at rest, during exercise and sleep. Pulmonary hypertension and respiratory failure may develop in severe disease. Mayer and Redding 2009note that the lung volumes change due to EOS, [100]. FVC and RV reflect total lung capacity (TLC). The Forced Vital Capacity (FVC) reflects intrathoracic volume, RC wall mobility and respiratory muscle function and in 53 EOS children it was found the 62 ±4% of normals. The residual volume (RV), reflects the gas reservoir left after complete exhalation, and it was found 79±12% of normals, as well. Redding 2013, [101], stated that especially in severe cases of IS, the low lung volumes lead to hypoxemia, poor sleep and cor-pulmonale. The decreased RC wall distensibility and excursion result to increased effort and poor growth. The decreased respiratory muscle force and movement lead to decreased exercise tolerance. All these deficiencies and weaknesses may lead to respiratory failure. It is common knowledge that restrictive lung disease (RLD) is associated with IS as well as with syndromic and congenital scoliosis, [102].

7. Pathogenesis of IS: The Nottingham concept and RC

No generally accepted scientific theory for the aetiology of IS exists up to now, [103], therefore, current treatment is symptomatic and not aetiological. In Nottingham UK, a new concept of scoliogenesis was presented based on Studies of the hips, pelvis, spine, RC and trunk muscles in scoliotic (pre-and post-operative), control patients, and cadavers. Evidence was presented that IS results in part from a developmental abnormality in the CNS, involving functional asymmetry of one or more inherited and actively acquired (by movement repetition) spinal cord central pattern generators (CPGs) which control gait, [104].

The ensuing neuromuscular asymmetry results to a cyclical failure of mechanisms of rotation control in the trunk. These mechanisms involve rotation defending (mainly musculo-costal, but also musculo- spinal, discal and ligamentous) and inducing (pelvi-spinal) mechanisms acting mainly in gait, see 'Dinner Plate'- 'Flagpole' concept. In essence, when the human RC is developmentally unable to control these muscular forces in the spine which are transmitted to it from forces generated elsewhere in the skeleton during physical activity and particularly gait, a cyclical failure of trunk rotation equipoise occurs which is termed IS. Pelvi-thoracic size disparity may contribute to this mechanical impairment of rotation; the latter occurs in relation with a lateral spinal curvature and a short- segment lordosis to increase the initial deformity of IS. The ensuing asymmetrical loading on the immature human spine in the erect position alters spinal growth; this abnormal growth together with normal linear spinal growth, potentiate the continuing mechanical failure resulting from the opposing rotation-defending and rotation- inducing mechanisms to produce progressive IS. Resolution of asymmetry in CPGs, [104], explains the resolution of Infantile and Juvenile IS before irreversible changes occur in the spine and RC. The Nottingham concept views IS in the broader view point of function in the trunk, development and human evolution, relative to bipedalism. In the last three million years of human evolution, the rounding of the RC and pelvis may have been caused by the CNS and trunk muscles adapting to their new role of oscillating the trunk to give man his unique bipedal gait; the rounding of the female pelvis may have contributed to the rapid evolution brain size in humans. The predisposition of adolescent girls to progressive IS is likely to result from several factors involving the pelvis, spine, ribcage, trunk muscles, CNS, growth and joint laxity, [105, 106].

An important unanswered question raises as to which of the above mentioned factors play a protagonistic deleterious role and which is the harmful resultant effect on the rest of the above involved factors.

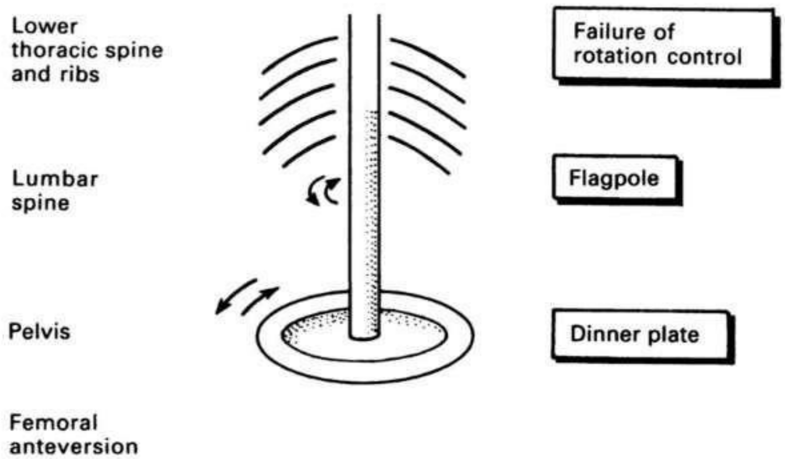


Fig. 23: - The AIS scoliogeny concept, ('Dinner Plate'-'Flagpole' concept), (from Burwell et al.1981, [105]).

The elevation of the upper ribs during postnatal growth may change respiratory volume. Additionally, may provide more stability of the upper thoracic spine, more control of the spine in the frontal plane during lateral flexion, and of spinal counter-rotations against to the rotations of the thoracolumbar spine and pelvis during gait with a cross-over at T7, [105, 107].

8. Thorax and pelvis during gait - the rotational inertia

The study of postnatal remodeling of RC using the TR and RVAs shown that the funnel-shaped upper newborn RC gradually changes to a barrel-shaped one, [15, 16, 89].

The drooping of the lower ribs seems to provide an evolutionary explanation for the development of the barrel-shaped RC, a mechanism to save energy by narrowing the lower chest and consequently to reduce the rotational inertia transmitted to the thorax from the rotating thoracolumbar spine and pelvis in gait, [50].

This drooping of the lower ribs is greater in girls, due to their larger mature pelvis diameter in the frontal plane, fig. 24, and the larger mass of their larger pelves, the teleology of which is that his sexual dimorphism is an evolutionary mechanism to serve an easier and safer birth giving, due to the human infant's evolved increased head size.

This relative narrowing of the RC during growth triggered the postulation of the concept involving pelvic and thoracic rotational inertia in gait. The decrease of TRs of the lower RC by age in boys and girls may be a way to reduce the rotational inertia created in the RC from the rotating thoracolumbar spine and pelvis in gait. Such a mechanism would consume energy. It will be recalled that inertia (I) equals Σmr2, (where Σ= sum, m = mass and r = radius), fig 24. Hence, a relative diminution of lower RC width would produce a much greater reduction of rotational inertia, as inertia is a function of the square of the distance. The RC narrowing, in evolutionary terms, is consistent with an adaptation of the RC to bipedal gait of humans, [50].

One other hypothetical reason for the change of funnel shaped to the barrel-shaped thorax during growth could be based on an evolutionary theory claiming that this took place in response to a warmer climate and a meat-based diet, which favored a taller, thinner body, [108, 109].

The size of the female pelvis and human head size at birth. Contemporary growth data show that the human head grows most rapidly in the first two years of postnatal life. It seems likely then that the natural selection to an increase in human head size, in order to contain an evolutionarily larger human brain over the last three million years, was made possible by the natural selection of females with a larger pelvis to provide for a larger fetal head at birth. This larger pelvis of females is likely to have affected the RC development of females differently from that of males due to the need, in gait, to reduce rotational inertia transmitted to the thorax from the larger female pelvis [110, 40, 42]; this explains the sexual dimorphism in the RC, figs. 24. Some credence for this interpretation is provided by comparative anatomical studies of the pelvis, [111].

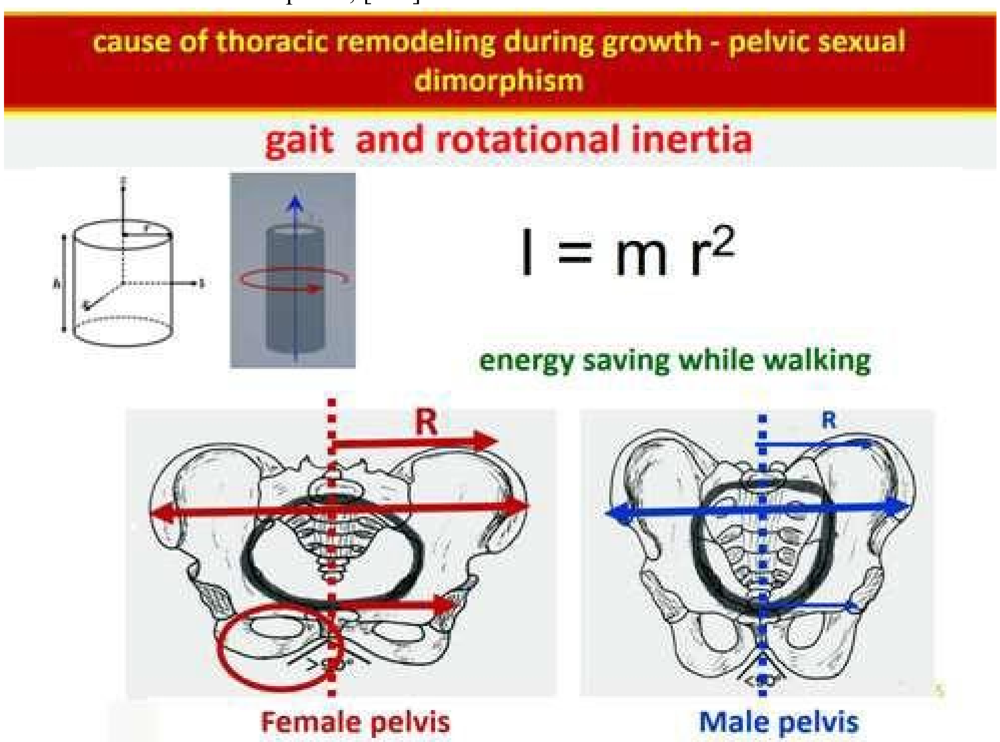


Fig. 24: - The sexual dimorphism of human pelvis. The females have larger mature pelvis diameter in the frontal plane.

9. The Double Rib Contour Sign (DRCS) and Rib Index (RI)

The assessment of the IS deformity in the coronal and sagittal plane depends on radiographic measurements of the Cobb angles, Cobb 1948, [112]. Nash and Moe 1965, [113], used the pedicle shadow to assess the vertebral rotation. Bunnel 1984, [114], introduced and used a scoliometer to measure clinically the hump deformity. Perdriolle and Vidal, 1987, 1985, [81, 115], used the pedicle shadow and measured the rotation angle through a line drawn through the convex pedicle. Grivas et al 2002, [116], introduced the rib index (RI) method extracted from the double rib contour sign (DRCS) as radiographic method to evaluate RH deformity, (RHD), in IS patients, attempting to create a safe reproducible way to assess the RHD based on lateral radiographs.

IS results in a deformity of the RC, which is a primary concern for the patient and the family, which causes a significant cosmetic problem, affecting negatively the patient’s self-image and self-esteem. The RHD is also a constant concern for the orthopedic surgeon and a major cause of spinal revision surgery in AIS patients, [117, 118].

In the lateral spinal radiographs of all asymmetric children with a RHD, it is found that there is a double rib contour (DRC), an interesting radiologic sign. Grivas et al 2002, [116], coined this "double rib contour sign, (DRCS)", fig 25, [119, 120,121].

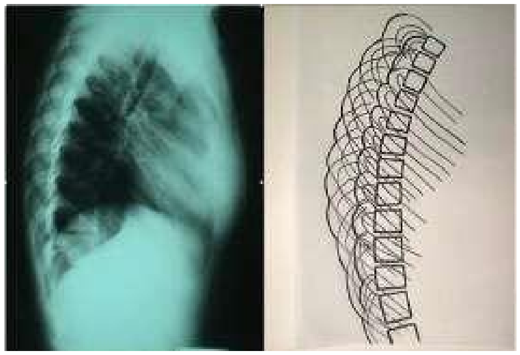


Fig 25: - The DRCS in lateral radiographs, (from Grivas et al 2002, [116]).

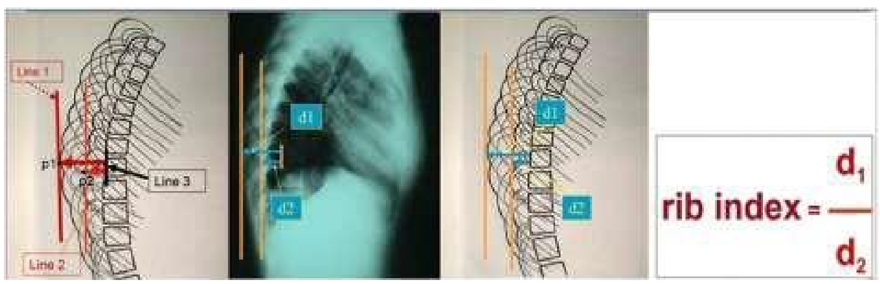


Fig 26: - The DRCS of the RC in a spinal radiograph and the RI, (from Grivas 2014, [121]).

In a scoliosis school screening (SSS) program, the screened children were those attending the first grade of the primary school aged 5 to 6 years to the last grade of high school aged 17 to18 years. Therefore, the collected data covered this wide range of ages. The children were screened with a scoliometer and the asymmetric ones presenting with an angle of trunk rotation (ATR) reading more than 5 degrees were referred to the scoliosis clinic of the hospital, for more evaluation. These referred children, at the initial period of our SSS program, were assessed radiographically. The RC and the spine were assessed in coronal and sagittal plane. The Cobb angle and these segmental left and right RVAs of the RC were also measured. In the lateral spinal radiographs in all asymmetric children the DRCS was present, fig 25.

The assessment of the severity of the deformity of the RC is based on both clinical and radiographic measures, [118]. Multiple methods have been proposed to radiographically assess the rotational deformity of the ribs with the Nash and Moe, [113], and Perdriolle and Vidal methods [81, 82, 83, 115], remaining the most commonly used. However, these methods do not assess the degree of RHD affecting the RC. The DRCS was reported as being an excellent method of assessing RHD because of its simplicity and the ability to be calculated on the lateral IS radiographs with no need for special imaging or additional exposure to radiation, [118]. In line with this, Haber et al 2020, [122], stated that as many patients and visits were lacking scoliometer measurements, the rib index can be used as a surrogate to scoliometric measurement. It must be noted that the RI is a measurement on the standing radiographs. The scoliometer reads asymmetry in the bending, (during Adams test), and not in the erect position, (in standing radiographs). Maragkoudakis et al 2019, [123], found that in all three anatomical regions of the spine (thoracic, thoracolumbar and lumbar), in both males and females, the change from a forward bending position, (Adam test), to a standing erect position shows a reduction of the mean trunk asymmetry, probably due to the vertebral rotation changes during the change of the two positions. Consequently, if these subjects had their TA assessed using a scoliometer in Adams test, their TA would be greater that this measured using the RI method at the erect taken radiographs. Therefore, as shown above, the RI is a reasonably strong surrogate for scoliometric assessment of asymmetry.

10. The effect of growth on the relationship of spinal and thoracic deformity

It is commonly accepted that growth is an important factor for the worsening of a scoliotic curve. However, the question is if growth affects the thoracic deformity simultaneously with the spinal deformity and if there is a relationship of spinal and thoracic deformity during growth. The answer to this question could be addressed studying the initiating deformity and not the severe and progressed IS and this could also provide an answer whether the spinal or the thoracic deformity presides this condition, [124].

Several studies on the correlation between the surface deformity (existence of the hump) and the Cobb angle were conducted but without considering growth as an important factor that may influence this correlation. Grivas et al, [124], reported that in some younger referred children from the SSS program there was a discrepancy between the thoracic scoliometer readings and the morphology of their spine. Namely there was a RHD but no spinal curve and consequently no Cobb angle reading in spinal radiographs, discrepancy which fades away in older children, [124]. Therefore, it was hypothesized that in scoliotics the correlation between the RC deformity and this of the spine is weak in younger children and vice versa. Eighty-three girls on the basis of their hump reading on the scoliometer referred, with a mean age of 13.4 years old (range7–18), and were studied. The spinal deformity was assessed by measuring the thoracic Cobb angle from the postero- anterior spinal radiographs. The RC deformity was quantified by measuring the rib index (RI) at the apex of the thoracic curve to the lateral spinal radiographs. The RI is defined as the ratio between the distance of the posterior margin of the vertebral body and the most extended point of the most projecting rib contour, divided by the distance between the posterior margin of the same vertebral body and the most protruding point of the least projecting rib contour. Statistical analysis included linear regression models with and without the effect of the variable age. The sample was divided in two subgroups according to the mean age of participants, namely the younger (7–13 years old) and the older (14–18yearsold). A univariate linear regression analysis was performed for each age group in order to assess the effect of age on Cobb
Angle and RC correlation. Twenty-five percent of patients with an angle of trunk inclination, (ATI), more than or equal 7 degrees had a spinal curve under 10 degrees or had a straight spine. Linear regression between the dependent variable "Thoracic Cobb angle" with the independent variable" rib-index" without the effect of the variable "age" is not statistical significant. After sample split, the linear relationship is statistically significant at the age group14–18 years old ($p<0.03$). It could be stated that growth has a significant effect in the correlation between the thoracic and the spinal deformity in girls with IS, fig 27. Pizones et al 2016, [125], confirm the correlation of thoracic deformity in ages more than 14 years and in severe IS. Therefore, the age should be taken into consideration when trying to assess the spinal deformity from surface measurements. These findings, [124,126], implicate the protagonistic role of the thorax, as it shows that the RC deformity precedes the spinal deformity in the pathogenesis of IS.

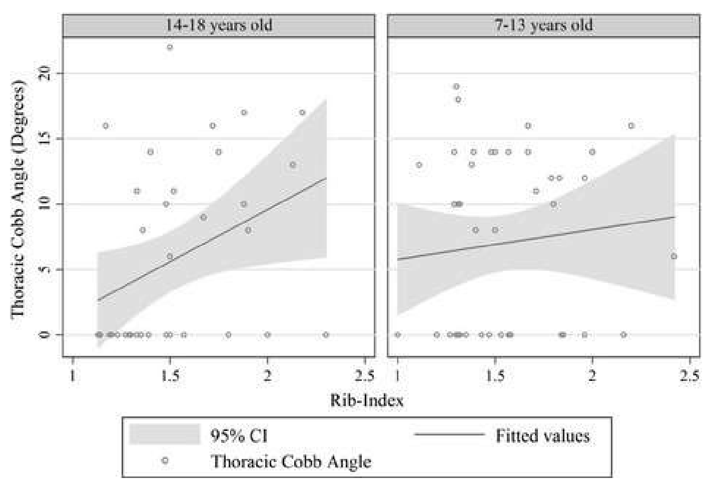


Fig 27: - Linear relationship between thoracic Cobb angle and RI is only found at the age group of 14–18 years.

11. Postoperative fate of IS hump deformity

The RH expresses the thoracic deformity in IS mainly in the transverse plane. It is of great significance to see the reports on the correction of the RH after surgical treatment of IS by posterior spinal fusion (PSF), which addresses the spinal deformity only and does not involve the RC. This study will provide valuable information on the relationship between the RC and the vertebral column.

Among the articles cited the article "The Double Rib Contour Sign (DRCS) in lateral spinal radiographs, aetiologic implications for scoliosis", [116], selected those that used the RI to assess and present the results of the operation of spine and the RHD. Additionally, we reviewed similar articles using a different method than the RI for evaluate the RHD fate postoperatively. Nineteen relevant articles were found published from 1976 to 2022. In these reports, the correction of the thoracic deformity in terms of RH fate, indicate that the hump not only is insufficiently corrected compared to the spinal correction, but it also reasserts during the follow up, especially more intensively in the skeletally immature operated scoliotics, see Table 1, and fig. 28 and 29.

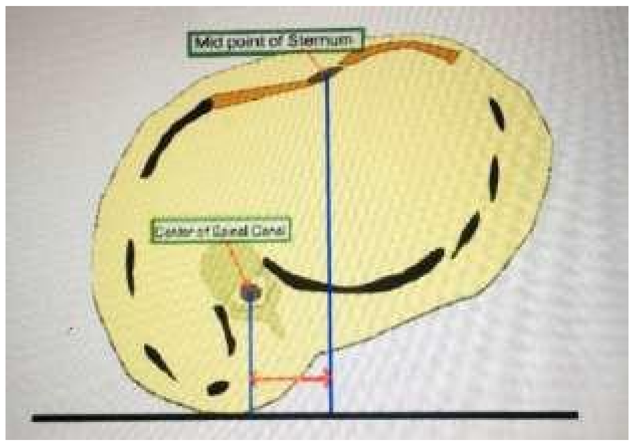


Fig. 28: - Measurement of the vertebra translation (VT) in axial section of the CT scan. Measured in millimeters as the horizontal distance between the line dropped from the center of the spinal canal and the center of the sternal width, [modified from Easwar et al 2011 [140]).

Fig 29: - Similarity of the RI method depicted in the two middle photographs with this in right photo (B)-Rib hump index (RH) measured in a CD, which means the maximal differences in the RH divided by the distance from the dorsal central aspect of the vertebral foramen to the peak of the inner rib cage wall. (RH = D1–D2/H), (from Grivas et al 2014, and modified from [121, 140, 141]).

Surgery is straightening the central axis, that is the spine. However, the degree of the RHD improvement approximately matches to the improvement of the post-operative degree of spinal derotation. The only way to correct significantly or completely the RHD is the costoplasty, which usually, for many reasons, is not done. The main cause of the formation of the RHD is the asymmetric development of the ribs and much less than the vertebral rotation. The operation does not a) limit the asymmetric growth of the ribs in IS and b) does not interrupt the mechanism that leads to their asymmetrical development. The results in all the reviewed articles, in table 1, imply the view that the protagonistic role on scoliogenesis of the thorax, which probably lead to the deformity, [148].

A	B	C	D	E
Thulbourne and Gillespie 1976, [127]	Harrington instrumenation + posterior fusion	3 AIS	The improvement in rib depression but litle change in rib hump	hump deformity not relates to Cobb angle, hump deformity not relates to RVAs
Gains et al, 1981, [128]	Harrington instrumenation + posterior fusion	21 AIS	the compression system makes a major contribution to the correction of total rib deformity in over two-thirds of the patients, and the correction of the rib valley is much more significant than correction of the rib hump. Postoperative spine roentgenograms --> the extent of the rib correction does not correlate with spine derotation as measured by the system of Nash and Moe	
Hefti and McMaster 1983, [129]	Harrington instrumenation before the age of 11 yrs	24 IIS & JIS	recurrense of the rib hump at FU	
Weatherley et al 1987, [130]	Harrington instrumenation + posterior fusion	47 AIS	progression of rib hump after 4 yrs FU in 64% of cases	Lateral carve coration no effect on vertebral rotation
Dubousset et al, 1989	Harrington distraction rod, Harrington-Luque, Luque double "L" rod, Harringcon distraction and compression	40 IS patients	increased rib inclination at FU	
Delorme et al 2000, [131]	multi rod, hook and screw system, Cotrel-Dubousset instrumentation	39 AIS	The rib hump at the apex and at the adjacent lower level were improved 36% and 38%	The frontal spinal curve correction averaged 53% in the frontal plane
Pratt et al 2001, [132]	Posterior Universal Spine System instrumentation	27 AIS	Maximum ATI from 17° to 13° (only 22% correction) - Rib-hump reassertion occurred between 8 weeks and 1 year	Cobb angle corrected from 58° to 34° (41%), AVR from 26° to 20° (23%), AVT from 4.5 to 2.4 cm (47%)
Easwar et al 2011, [140]	Pre-operative	75 AIS	Rib hump index nor related to Cobb angle, vertebra rotation, vertebra translateion, Risser sign	
Hong J-Y et al 2011, [141]	Posterior pedicle screw fixation only, derotation maneuver after fixation of the screws	50 AIS	RHI from 0.22+/- 0.22 to 0.10+/- 0.14	Cobb from 58,46±18,07 degrees to 18,52± 15,14, VR from 16.41 ± 9.92 to 14.88 ± 10.00
Hwang et al 2013, [133]	Pedicle screw instrumentation ([80 % pedicle screws used for possible points of fixation)	99 AIS	The thoracic rib prominence improved from 14.5 ± 5.7° to 6.9 ± 3.9° while the lumbar prominence decreased from 8.1 ± 5.6° to 2.8 ± 2.7°	51.7 ± 14.2° with a mean correction of 66 and 64 % at 2 and 5 years (p = 0.16).
Mattila et al 2013, [134]	Pedicle screw edicle screw construct, 24 had pedicle screw instrumentation with apical monoaxial screws without derotation (N-DVR) and 48 with en bloc DVR	72 AIS	TRH averaged 12.3° ± 3.6° versus 14.2° ± 5.0° (P = 0.075) post-op and 7.2° ± 3.8° versus 8.3° ± 3.7° at 2-year follow-up in the N-DVR and in the DVR both groups, respectively (P = 0.30).	56° ± 9° and 57° ± 11° and was corrected to 16° ± 6° in both groups at 2 yrs FU
Lykissas et al 2015, [118]	Posterior spinal fusion without costoplasty, instrumented with pedicle screws or hybrid constructs	36 AIS	RI for group I was 1.61, post-op was 1.39, the correction of RI was 13.7%	pre-op Cobb 49.7° ,post-op 10° 2yrs FU
Sultanis et al 2015, [135]	AIS 16 full with screw instrumentation, 9 hybrid construct	25 AIS	In group A RI mean pre-op RI=1.93 and post-op =1.37, in group B mean pre-op RI=2.06 while post-op=1.51, between group A and B the post-operative RI correction mean values were found to be no statistically significant, p=0.803	Provided that the full screw construct is powerful, the post-operative derotation and RHD correction was expected to be better than when a hybrid construct is applied. It is implied that the RHD results more likely from the asymmetric rib growth rather than from vertebral rotation, as it has been widely believed.
Pizones et al 2016, [146]	Pre-operative	113 AIS	pre-op RI was 2.5 ± 1.3, 3 ± 1.5, 2.5 ± 1 by Lenke type curves 1,2, and 3 respectively	mean age 14.9 ± 1.9 years, mean MTCobb 59.6° ± 11.9. so clinical RH progression could be an alert parameter preceding curve magnitude progression in recent diagnosed IS patients".
Haber et al 2020, [136]	stapling with Nitinol Staples	16 AIS	no statistically significant difference in preoperative, first postoperative and final follow-up RI	the RI was used as a surrogate to scoliometric measurement
Hamzaoglu et al 2021, [137]	selective thoracic fusion	43 AIS	Mean pre-op RI= 2.18 (1.13–5.3) and FU RI=1.61 (1.14–2.84)	
Igoumenou et al 2016, 2021, [138, 139]	(a) 23 full pedicle screw system, (b) 18 hybrid construct, (c)15 Harrington rod system	56 AIS	Mean RI correction was (a)=30.6%, (b)=28.2% and ©=28%	Provided that the full screw construct is powerful, the RHD correction was expected to be better than b and c groups, which is notthe case.
Tsirikos and McMillan 2022, [142]	80 hybrid pedicle–hook–screw (HS), 80 all pedicle screw (AS)	160 AIS	All-Screw Pre-op RI =2.09 (1.4–3.7) and post-op 1.6 (1.1–2.4), correction index **23,4 (0–50) (%)** –Hybrid Hook–Screw 2.1 (1.5–3.2), 1.46 (1.1–2) and **30.5 (0–48) (%)**	Both techniques achieved ≥ **75% scoliosis correction.**
Lertudomphonwanit et al 2022, [143],	Low density, LD, high density HD constructs	99 AIS	RI correction was for LD 18.4±9.1%-and for HD 16.5±8.1% only	

(the relative excel file will also be sent to replace this picture)

Table 1. A) the author/s of the reviewed articles and related figures, B) the instrumentation used, or the preoperative findings acting as alert parameters preceding curve magnitude progression in diagnosed IS patients, C) Number of patients, D) pre-operative and postoperative RI outcomes of RH correction, E) Cobb angle outcomes.

12. RI and aetiological implications

Changes in TA with age in normal subjects leading to AIS were interpreted as the result of growth resulting in RC deformity, which precedes the spinal deformity, [124]. The role of the RC asymmetry was also recognized as responsible for the development of IS, and as an evidence that the deformity of the RC goes before the spinal deformity, in mild scoliosis, [124]. Additionally, Grivas et al 2022, confirmed that there is the lack of correlation of surface topography findings, (hump), that is the TA, to the Cobb angle in mild and moderate IS, [149].

TA without central axis deformity, that is spinal deformity, was described in bibliography, [150, 151]. Pruijs et al stated that –surface topography can be used in SSS, but does not allow a sharp distinction between normal and pathologic cases, although they didn’t complete any study on their examined sample by age, [150,151].

Nissinen et al 1989, [152], stated that –hump size was found to be the most powerful predictor of scoliosis. Large humps were more prevalent among those children that subsequently developed IS. The predictive significance of baseline TA was independent of all the other determinants entered in the multifactorial logistic model, (sitting height, kyphosis, lordosis, arm length inequality, pelvic tilt).

The relative risk (odds ratio) for an increase of 1 mm of hump size was 1.72 in boys and 1.55 in girls. Thus boys with humps of 6 mm had approximately a fivefold risk of developing IS as compared with boys having a symmetric trunk (hump = 0 mm) at the age of 10.8 years. Additionally, Nissinen et al 1993, [153], stated that the asymmetric children with a hump deformity, but without radiographical diagnosed scoliosis, will develop IS with an odds ratio 1.72 in boys and 1.55in girls, during a three years follow up in 896 children who were free from scoliosis at entry, having several anthropometric measurements for their prediction of IS.

In a longitudinal analysis of a case series, all children in whom progressive IS developed also had visible asymmetry at the age of 10 years, [154].

Willner 1984, also reported, using the moiré topography method, [156,157], that on the moiré photographs with the children standing in the erect position, 12% of the girls and 9% of the boys with clinically observed asymmetries in the forward bending position had very small shadow asymmetries (deviation of < 1 contour line). Also, in former Malmo studies, these small asymmetries of the trunk were not related to a lateral deviation of the spine, seen roentgenographically, exceeding 9°.

In our SSS program, approximately 30% of our SSS program referred asymmetric girls with an ATR ≥ 7°aged less than 13 years, assessed either with a straight spine or a curve less than 10°Cobb angle. In this age group the correlation between clinical deformity in terms of TA and radiographic measurement in terms of Cobb angle, is not statistically significant, while in aged 14–18 years girls it is, [124]. This finding was confirmed in one of our more recent studies, {149]. The correlation of surface topography deformity – hump - to radiographical shown deformity - Cobb angle - was quite poor, Pearson corr. Coeff. 0.077, −0.211, p: 0.768. Therefore, it was shown that the changes in the spine in IS are secondary, because these children have a preceding thoracic deformity without a spinal deformity, fig. 30, [149].

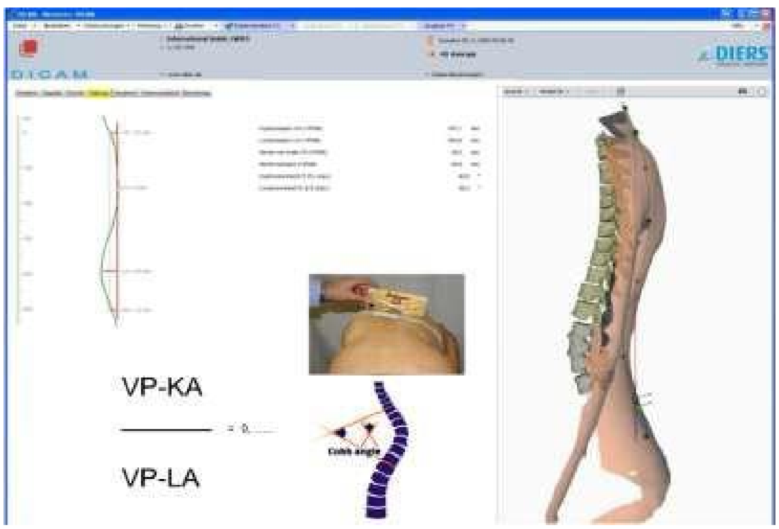


Fig 30:- In mild and moderate scoliosis, the RHD of the RC, assessed by the scoliometer and the sagittal spinal profile are not correlated to Cobb angle,(from Grivas et al 2021. [149].

At this point, we highlight our view, that is, "at initiating and mild IS, the patho -biomechanics are probably dissimilar from the biomechanics when the curve is severe". Furthermore, we consider that at initiating and mild IS, genetics, epigenetics, and biology have the dominant/protagonistic aetiological role; however, we should not overlook the non-protagonistic role of patho-biomechanics at this stage, which later become dominant for progressive IS, [157].

Based on our above findings, our evidence-based policy recommendation on SSS implementation currently is: all younger asymmetric SSS referrals, who are assessed having a TA without a radiographically confirmed spinal curve are at risk of developing IS, and they need to be followed and not discharged from the scoliosis clinics.

13. The role of sternum: The rib-sternum complex

Kenanidis et al 2018, [158], in their study reported preliminary data demonstrating morphological differences of the sternum, between AIS and normal peers. They concluded that the sternum of AIS was more inclined than In normal peers and they hypothesized that the sternum is involvement in scoliogenesis, [158].

14. John Sevastik research about IS thoracic deformity

Professor John Sevastikoglou, (John Sevastik), was one of the world famous researchers and a real milestone on the study of the RC related to aetiology of AIS. He postulated that ―asymmetric growth of the ribs may be the primary cause of the thoracospinal deformity. Additionally, asymmetric growth and increased vascularization of the often larger breast may stimulate, asymmetric left right, longitudinal growth at the underlying costosternal cartilage upsetting the balance of forces acting on the normal spine‖, [159, 160].

14.1 Experiments on ribs
Sevastik et al 1990, reported that ―Elongation of one rib on the right side by 1 cm was achieved in two groups of adult rabbits of different age, by osteotomy and application of a metallic expander. The procedure resulted in immediate deviation of the spine in the frontal and sagittal planes, with moderate scoliosis, convex to the left, and a significant decrease in the normal cervicothoracic lordosis and thoracolumbar kyphosis‖ [161].

Sevastik Bo, et al 1995 in his pig specimen experiments described ―it was concluded that gradual elongation of one rib affects the position of the numerically corresponding vertebra in relation to the suprajacent and subjacent vertebrae in the three cardinal planes in the same way as the apex vertebra is affected in IS. Moreover, the registered tilt, i.e., the rotational movement of the central vertebra in the coronal plane, could explain the wedging of the disc space, and the ventral translation in combination with the tilt in the sagittal plane could account for the lordotic tendency of the scoliotic segment‖, [162].

14.2 Correction of experimentally produced scoliosis
Sevastik et al 1990, [163], reported that resecting partially three intercostal nerves on the right side of growing rabbits were, moderate left-convex thoracic scoliosis with rotation of vertebrae had developed from one to three months later. A further resection of three intercostal nerves, this time on the left convex side, one and two months after the first operation, resulted in regression of scoliosis or halted its progression. These results further support the concept that the asymmetric longitudinal growth of the ribs cause scoliosis. They also proposed that regulation of the rib length could be an approach to the effective correction of progressive IS at an early stage in man‖, [163].

14.3 Suggested surgical intervention on the ribs
Gréalou et al 2002, [164], reported on simulations of RC surgery for the management of scoliotic deformities. They simulated and evaluated concave side rib shortening and convex side rib lengthening have been. Slight post-operative immediate geometrical correction of the spine was found in any of the simulations. This biomechanical analysis showed that proper rib surgery may counteract the progression of the spine deformity depending on the remaining growth potential. These findings support the concept of early interventions on the RC that may be an approach of treatment to prevent curve progression in small to moderate IS, [164].

Xiong and Sevastik 1998, [165], reported the results of an operation on a 7-year-old girl with right convex thoracolumbar IS with 46° Cobb angle, who was operated upon by 2-cm shortening of three concave ribs. 27 months after the operation the curves were reduced to 21°. They concluded that this approach is a harmless intervention and may have vast beneficial implications for the young patients with early onset thoracic IS‖, [165].

14.4 Experiments on nerves
Sevastik et al 1990, [166, 167], reported that resecting three intercostal nerves on the right side of growing rabbits after one to three months later, moderate left-convex thoracic scoliosis with rotation of vertebrae had developed, and the sagittal curvatures of the spine had diminished. A further resection of three intercostal nerves, on the left convex side, one and two months after the first operation, resulted in regression of scoliosis or halted its progression. These experimental results further support the view that asymmetric longitudinal growth of the ribs, I the causative scoliosis factor, [166, 167].

14.5 Vascular Changes in the Chest Wall After Unilateral Resection of the Intercostal Nerves
Agadir et al, 1990, [168], reported that ―right side intercostal nerves resection in young, growing rabbits developed structural left convex scoliosis. The vascular structure changes of their anterior RC were evaluated. Their results demonstrated that unilateral resection of the intercostal nerves significantly increases the vascularity of the structures on the denervated side of the thorax. This development may account for the greater longitudinal growth of the ribs on this side and for the development of the scoliosis observed in earlier studies, [168].

14.6 The John Sevastik thoracospinal concept of aetiopathogenesis of AIS
According to this concept which applies only to girls with right thoracic AIS, increased asymmetric longitudinal growth of the left periapical ribs around the apex of the vertebral curve, triggers the thoracic curve simultaneously in

the three cardinal planes. The concept does predict curve progression. Sevastik suggested operation on the ribs as a treatment for early progressive thoracic curves, [169,170, 171], and hypothesized that the dysfunction of the ANS is considered responsible for the scoliogeny of AIS, [169], see fig. 31.

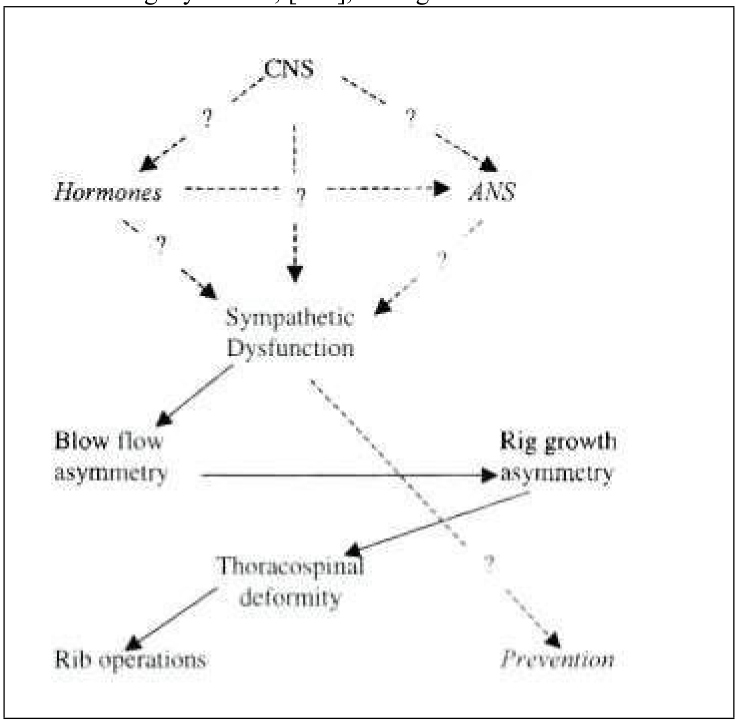


Fig 31: - The hypothesis of the dysfunction of the ANS as responsible for the AIS scoliogeny, (modified from Sevastic 2002, [169]).

Iliopoulos et al 2007, [172], reported also on the dysfunction of the ANS which results in asymmetric blood supply evolution of the anterior RC wall in female AIS with progressive right convex thoracic IS, confirming what Prof. Sevastik hypothesized.

14.7 Breast asymmetries in females suffering AIS.

There is evidence for developmental disruption of anterior chest wall blood supply in AIS girls with progressive right thoracic scoliosis, [172].

Normally et al 1988, [173], stated that the left breast was significantly more often larger in the scoliotic series of girls. Additionally, Normelli et al 1986, [174], assessed the vascularity of the breasts using thermographic and diaphanographic methods in normal and scoliotic girls. They found that the vascularity of the left breast was significantly greater for the girls with a right convex thoracic curve than for the control group. They propose d that unilateral stimulation of rib growth due to a greater vascularity of the left breast and the underlying costosternal junctions might be one initiating factor in the development of right convex thoracic AIS in girls‖.

Denoel et al 2008, [175], assessed of breast asymmetry in the presence of IS. Twenty-four women with right IS were evaluated. In 20 girls they found a smaller right breast.

Cruz and Korchin 2013, [176], in their clinical study assessed 54 female patients suffering IS. Breast volume was calculated using anatomic measurements.IS women consistently presented breast asymmetry with this of the convex thoracic IS being always smaller in volume. The affected side also presents a smaller areola, a higher position of the nipple and a higher position of the inframammary fold. However, the degree of asymmetry does not correlate with the severity of the scoliosis. The authors assumed that the breast asymmetry even though it denotes an underling scoliosis is indicative of curve progression, as Prof. Sevastic stated as well. Other factors probably are responsible for curve worsening, [176].

15. Different Cobb angle and RH correction using a biomechanical model

Closkey and Schultz 1993, [177], in a computer-implemented biomechanical model of a thoracolumbar spine and deformable RC, investigated: a) the influence of spine morphology and RC stiffness properties on the RC deformities that arise from scoliosis and b) the relationship of actual rib distortions with those seen on CT scans. They reported that these model-obtained findings mirror the clinical findings that correction of the Cobb angle leads to correction of the lateral offset of the RC but interestingly does not correlate well with correction of the RC axial rotation. They admitted that correction of only the lateral curvature will reduce the lateral offset of the RC but will minimally affect the derotation of it‖.

16. Thoracic kyphosis and hypokyphosis, the impact of LSP

The thoracic spine participates posteriorly in the formation of the RC. In some older publications it was suggested that in IS, hypokyphosis is the triggering feature to the development of IS, [178, 179, 180]. This view was formulated because almost all publications, endorsing this view, included and studied children with progressed IS and not children with initiating IS. For example, in the Dickson et al 1984 paper, [178], the mean Cobb angle of the examined cases is referred to be 39 degrees of Cobb angle, which is not a mild one. Moreover, Deacon et al. 1984, [180], stated that the apical deformation in IS is characterized by apical lordosis and alters the regional and global sagittal profile, which is quite true, but this cannot be used for mild or moderate IS. All of Deacon's scoliotic spines are severely deformed up to 184 Cobb degrees, except for one, with a severe rotation, which is not the case, for mild or moderate IS. When mild IS children were analyzed, [181, 182], the above statement that resulted from the study of severe IS patients seems to be inaccurate.

Grivas et al 2022, [181], stated that ―it would be useful to examine the definitions of the severity of IS as there is not full agreement on what is mild and moderate IS. Mild IS is characterized by a Cobb angle [112], of more than 10 and less than 30 degrees, of more than 10 but less than 25 degrees [184], and of more than 10 but less than 20 degrees [62]. Moderate IS is considered when Cobb angle is 25–40 degrees, which is indicated for non-operative treatment [184, 185], and a Cobb angle is greater than 21 to 35 degrees [62]. We consider as mild IS those with a Cobb angle 10 to 20 degrees and as moderate those with a Cobb angle 21 to 35–40 degrees. In these curves, especially in the mild ones, the apical vertebral rotation is not large [169, 171]. This morphology is very important for the measurements of a true LSP, which is minimally affected. This fact results in more reliable measurements, and it is very important‖.

Grivas et al 2002, [181], addressed the thoracic spine morphology importance in mild and moderate IS. The aim of their study was a) to study the LSP, in SSS referrals with and without LOS of mild curves 10°-20° Cobb angle and b) to validate LSP's aetiological importance in scoliogenesis. They examined the spinal radiographs of 133 children, 47 boys and 86 girls with a mean age of13.28 and 13.39 years respectively and ATI ≥ 7°. They concluded that the minor hypokyphosis of the thoracic spine and its minimal differences observed in the studied small curves with nonscoliotics in their report add to the view that the reduced kyphosis, by facilitating axial rotation, could be viewed as being permissive, rather than as aetiological, in the scoliogenesis, [181].

Pizones et al 2016, [146], analyzed the sagittal thoracic parameters of different types of progressive thoracic AIS patients and compared them with healthy peers. They found that in their 2D analysis of moderate AIS, Lenke 1 curves of AIS exhibited normal thoracic sagittal parameters, which brings into question the effect of lordosis on the development of single thoracic curves. Discussing the controversy arisen on the issue of the LSP of IS stated that by facilitating axial rotation, this reduced kyphosis could be viewed as being permissive to progression rather than an initiating factor, in the pathogenesis of IS‖ [181, 186, 187].

The Pizones et al 2016, [125], completed a cross-sectional study analyzing prospectively registered data of 113 AIS patients, with mean age 14.9 ± 1.9 years, suffering progressive main thoracic deformity. They found that sagittal variables were correlated the least to Mid Thoracic Cobb, (MT Cobb). In their discussion they wrote ―although hypokyphosis was theorized to be an important trigger factor for the vertebra to spin and rotate creating IS, [179], thoracic lordosis in their AIS curves was only seen clearly in Lenke type 3 curves. Thoracic hypokyphosis was also reported that is strongly related to curve progression, [188, 189, 190].

17. IS and evolution of thoracic shape: "The scars of evolution"

The evolutionary development of the human from quadrupedalism to bipedalism has involved many adaptive changes in the locomotor system, [62, 111]. Some of the skeletal changes have been observed in fossils: the neuromuscular changes can only be inferred. Four skeletal consequences of humans adopting upright posture, fig. 32, are: a) The creation of a lumbar lordosis (sagittal curve), b) The rounding of pelvic shape associated with bipedal gait, c) The rounding of rib cage shape, and d) Changes in the occipital bone. The inferred neuromuscular consequences of the human adopting upright posture are: e) Changes in trunk muscles for the upright posture and bipedal gait, f) Changes in the CNS associated with the upright posture and bipedal gait.

*17.1 Rib Cage and pelvic changes***.** Three million years ago, the adult human RC was funnel-shaped, fig. 32. The RC changed in 3 million years of bipedalism from' "Lucy" to modern man barrel shaped RC.

Likewise, the pelvis in the last three million years has dramatically shortened and turned in just the way one might expect if the mechanical requirement were to provide better muscular attachment or erect walking, [192]. These pelvic changes have the effect of both shortening the torso and bringing the center of pelvic mass much closer to the hip joint, [191]. The mechanisms for these changes may have involved the trunk musculature acting under the influence or the CNS. Such evolution would naturally select the more efficient individuals.

The rarity of scoliosis in quadrupeds. Typical "idiopathic" structural scoliosis occurs rarely in quadrupeds. This knowledge is consistent with the view that man is more vulnerable to scoliosis because of both his gait and weight bearing in the upright position.

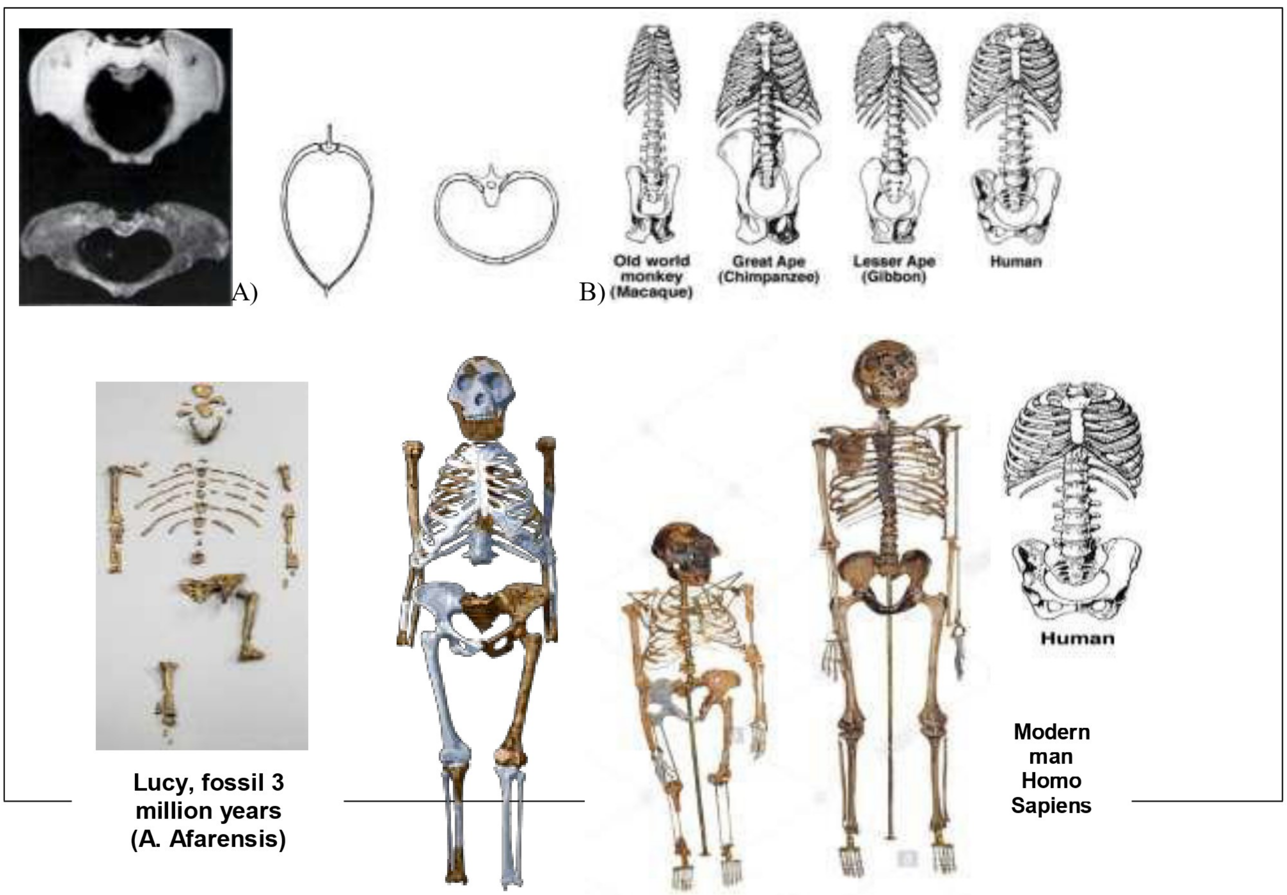


Fig. 32: - Evolutionary changes of the shape of thorax and pelvis. A. The Pelvis of modem human female (above) compared with "Luci‖ pelvis (below). The pelvis became more ovoid with a sagittal expansion, [191]. B. Changes of the funnel shaped thorax to a barrel form.

Elaine Morgan describes that idiopathic scoliosis may be considered as a 'scar of evolution'. In her book ‒The scars of evolution, what our bodies tell us about human origin‖, she offers a pioneering look about just where our earliest ancestors came from, and about the legacy--not always advantageous--that they left us, [193].

Abbreviations

AIS = Adolescent Idiopathic Scoliosis
ANS =Autonomic Nerve System
ATR = Angle of Trunk Rotation
ATI = Angle of Trunk Inclination
CMTR = Composite Muscle Trunk Rotator
CNS = Central Nervous System
CPG = central pattern generator
CS = Carnegie Stages
CT = Computerized Tomography
DRCI = Double Rib Contour Sign
EOS = Early Onset Scoliosis (EOS)
FVC = Forced Vital Capacity
HD= high density
ICP = Infancy, Childhood, Puberty
IIS = Infantile Idiopathic Scoliosis
IS = Idiopathic Scoliosis
JIS = Juvenile Idiopathic Scoliosis
LD = Low density,
LLC = Lateral Lumbar Curves
LOS = Late Onset Scoliosis
LSP = Lateral Spinal Profile
MRI = Magnetic Resonance Imaging
MTCobb = Mid Thoracic Cobb,
PSF = Posterior Spinal Fusion
RC = Rib Cage
RH = Rib Hump
RHD = Rib Hump Deformity
RI = Rib Index
RLD = Restrictive Lung Disease
RVA = Rib Vertebra Angle
RVASD = RVA Difference
RV = Residual Volume
STH = Selective Thoracic Fusion
SSS = School Scoliosis Screening
QL = Quadrates Lumborum
TA = Truncal Asymmetry
TI = Thoracic Index
TLC = Total Lung Capacity
TR = Thoracic Ratio

Acknowledgments

First of all, the author would like to express his gratitude to his teachers and especially, regarding the study of scoliosis, to Professor RG Burwell of Nottingham, Great Britain, where the author served clinically and academically in Queens Medical Center Orthopaedic Department, the Harlow Wood Orthopaedic Hospital and the University of Nottingham, Additionally the author would like to express his great appreciation and thanks to all his collaborators in his 25-years journey of the implementation of the School Scoliosis Screening program after his return from UK, while servicing clinically at the Thriasio and Tzaneio Hospitals, in Athens Greece, and where he carried out his published research work on scoliosis that is also presented in this article. All the names of these collaborators are shown in the References in this paper. Additionally, I express my appreciations and many thanks to Mrs. Elpiniki Griva for her help to the linguistic improvement of the text of this paper.

Funding:

This review paper received no funding.

Institutional Review Board Statement:
N/A

Informed Consent Statement:
N/A

Data Availability Statement:
N/A

Conflicts of Interest:
The author declare that have no conflict of interest concerning this article.

References:

1. Bisgard J. (1934). Thoracogenic scoliosis. Influence of thoracic disease and thoracic operations on the spine. Archives of Surgery 29, 417-445. Bisgard JD. Thoracogenic scoliosis: Influence of thoracic disease and thoracic operation on the spine. Arch Surg. 1934, 29:417–445. 1934.
2. Γρίβας ΘΒ, Burwell RG, Webb JK. (1991): Η κατά τμήματα μελέτη της διαμόρφωσης του θωρακικού κλωβού κατά την ανάπτυξη. Αλλαγές σχετιζόμενες με το σπονδυλικό επίπεδο, φύλο, πλευρά και σημασία για την ανάπτυξη των πνευμόνων και την σκολίωση. Πρακτικά 17ου Ετήσιου Πανελλήνιου Ιατρικού Συνεδρίου, 7-11 Μαΐου1991, Ξενοδοχείο Κάραβελ, Αθήνα. Αρ. Εργασίας 456, Τόμος Πρακτικών Συνεδρίου, σελ. 116.
3. (https://www.kenhub.com/en/library/anatomy/development-of-musculoskeletal-system
4. https://discovery.lifemapsc.com/in-vivo-development/lateral-plate-mesoderm/somatic-mesoderm
5. Keith, A. 1909 The Mechanism of Respiration in Man. Further Advances in Physiology. 1909.London: Arnold
6. Openshaw P, Edwards S, Helms P. 1984. Changes in rib cage geometry during childhood. 1984, Thorax 39: 624–627.
7. Bastir M, García Martínez D, Recheis W, Barash A, Coquerelle M, Rios L, Peña-Melián Á, García Río F, O'HigginsP. 2013. Differential growth and development of the upper and lower human thorax. 2013, PLoS One 8:e75128.
8. O'Rahilly R, Muller F. 1987. Developmental Stages in Human Embryos: Including a Revision of Streeter's Horizons and a Survey of the Carnegie Collection. Washington: Carnegie Institution of Washington, 1987.
9. O'Rahilly R, Müller F. 2001. The skeletal system and limbs. In: R O'Rahilly, F Müller, editors. Human Embryology& Teratology. 3rd ed. New York: Wiley-Liss. 2001, p 357– 394.
10. de Vries JI, Visser GH, Prechtl HF. 1982. The emergence of fetal behaviour. I. Qualitative aspects. Early Hum Dev.1982, 7: 301– 322.
11. de Vries JI, Fong BF. 2006. Normal fetal motility: an overview. Ultrasound Obstet Gynecol. 2006, 27: 701– 711.
12. Okuno, K., Ishizu, K., Matsubayashi, J., Fujii, S., Sakamoto, R., Ishikawa, A. et al. (2019) Rib cage morphogenesis in the human embryo: a detailed three-dimensional analysis. Anatomical Record, 302, 2211–2223. https://doi.org/10.1002/ar.24226.
13. https://en.wikipedia.org/wiki/Carnegie_stages.
14. Wells LJ, Boyden EA. 1954. The development of the bronchopulmonary segments in human embryos of horizons XVII to XIX. Am J Anat, 1954, 95: 163– 201.
15. Grivas TB, Burwell RG, Purdue M, Webb JK, Moulton A. A segmental analysis of thoracic shape in chest radiographs of children. Changes related to spinal level, age, sex, side and significance for lung growth and scoliosis. J Anat. 1991 Oct; 178:21-38.
16. Grivas TB, Burwell RG, Purdue M, Webb JK, Moulton A. 1992. Segmental patterns of rib-vertebra angles in chest radiographs of children: Changes related to rib level, age, sex, side and significance for scoliosis. Clin Anat 1992; 5(4):272-88
17. Canavese F, Dimeglio A, Bonnel F, Corradin M, Pereira B, Marcoul A, Charles YP. 2019 Thoracic cage volume and dimension assessment by optoelectronic molding in normal children and adolescents during growth. side and significance for scoliosis. Clin Anat 1992;5(4):272-88. Surg Radiol Anat. 2019 Mar;41(3):287-296. doi: 10.1007/s00276-018-2164-4. Epub 2018 Dec 17. PMID: 30560403
18. Vernon E. Krahl: Anatomy of the mammalian lung. In Handbook of Physiology, Section 3: Respiration, vol. 1 eds Fenn W0 & Rahn H, Baltimore: Williams & Wilkins, 1964, p. 229.
19. Schwend RM, Schmidt JA, Reigrut JL, Blakemore LC, Akbarnia BA. Patterns of Rib Growth in the Human Child. Spine Deform, 2015 Jul;3(4):297-302, doi: 10.1016/j.jspd.2015.01.007. Epub 2015 Jun 11.
20. Vernon E. Krahl: Anatomy of the mammalian lung. In Handbook of Physiology, Section 3: Respiration, vol. 1 (eds Fenn W0 & Rahn H, Baltimore: Williams & Wilkins, 1964, p. 229.

21. Dansereau J, Stokes IAF: 1988. Measurements of three-dimensional shape of the rib cage. J Biomech1988.21: 893–901.
22. Stokes IAF, Dansereau J, Moreland MS (1989). Rib cage asymmetry in idiopathic scoliosis. Journal of OrthopaedicResearch 7,1989, 599- 606. PMID: **2738774**DOI: 10.1002/jor.1100070419
23. Schwend RM, Geiger J. (1998). Outpatient pediatric orthopedics. Common and important conditions. Pediatr ClinNorth Am. 1998 Aug;45(4):943-71. doi: 10.1016/s0031-3955(05)70054-7. PMID: 9728195
24. Schwend RM, Akbarnia BA, Schmidt JA, Blakemore LC. 2022. Normal Growth of the Thorax, , in ―The Growing Spine , Management of Spinal Disorders in Young Children‖, (Eds Akbarnia BA, Thompson GH, Yazici M, El- Hawary R), Springer Publisher, 2022, Pages 75-90, ISBN: 978-3-030-84393-9
25. Simon G, Reid L, Tanner JM, Goldstein H, Benjamin B (1972). Growth of radiologically determined heart diameter,lung width and lung length from 5- 19 years, with standards for clinical use. Archives of Disease in Childhood.1972, 47, 373- 381. DOI: 10.1136/adc.47.253.373 .
26. Openshaw P, Edwards S, Helms P. Changes in rib cage geometry during childhood Thorax. 1984 Aug;39(8):624-7. doi: 10.1136/thx.39.8.624. PMID: 6474391.
27. Jellema LM, Latimer B, Walker A. 1993. The rib cage. The Nariokotome Homo Erectus Skeleton. Cambridge: Harvard University Press. p 294– 325.
28. LoMauro A, Pochintesta S, Romei M, D'Angelo MG, Pedotti A, Turconi AC, Aliverti A. 2012. Rib cage deformities alter respiratory muscle action and chest wall function in patients with severe osteogenesis imperfect. PLOS One7:e35965.
29. Bastir M, García Martínez D, Recheis W, Barash A, Coquerelle M, Rios L, Peña-Melián Á, García Río F, O'HigginsP. 2013. Differential growth and development of the upper and lower human thorax. PLoS One 8:e75128.
30. García-Martínez D, Recheis W, Bastir M. 2016. Ontogeny of 3D rib curvature and its importance for theunderstanding of human thorax development. Am J Phys Anthropol 159: 423– 431.
31. Grivas TB. 1984. Survey for the lower limbs of early school age children. Thesis, University of Athens, p. 93 (in Greek), p 74 and 91. https://www.didaktorika.gr/eadd/handle/10442/3440, https://phdtheses.ekt.gr/eadd/handle/10442/3440?locale=en, DOI 10.12681/eadd/3440
32. Dimeglio A, Canavese F. 2012.The growing spine: how spinal deformities influence normal spine and thoracic cage growth. Eur Spine J. 2012 Jan; 21(1): 64–70. Published online 2011 Aug 30. doi:10.1007/s00586-011-1983-3,PMCID: PMC3252439, PMID: 21874626
33. Dimeglio A, Bonnel F. 1990. Le rachis en croissance. 1990, Springer, Paris
34. Dunnill MS. 1962.Thorax. Quantitative methods in the study of pulmonary pathology. 1962 Dec;17(4):320-28. doi:10.1136/thx.17.4.320. PMID: 25269161
35. Davies G, Reid L. 1970. Growth of the alveoli and pulmonary arteries in childhood. Thorax. 1970 Nov;25(6):669-81. doi: 10.1136/thx.25.6.669. PMID: 5533319.
36. Thurlbeck WM. 1975. Postnatal growth and development of the lung. Am Rev Respir Dis. 1975 Jun;111(6):803-44. doi: 10.1164/arrd.1975.111.6.803. PMID: 1094872 Review.
37. Zeltner TB, Caduff JH, Gehr P, Pfenninger J, Burri PH. 1987. The postnatal development and growth of the human lung. I. Morphometry. Respir Physiol. 1987 Mar;67(3):247-67. doi: 10.1016/0034-5687(87)90057-0. PMID: 3575905
38. Zeltner TB, Burri PH. 1987. The postnatal development and growth of the human lung. II. Morphology. Respir Physiol. 1987 Mar;67(3):269-82. doi: 10.1016/0034-5687(87)90058-2. PMID: 3575906
39. Dimeglio A, Bonnel F, Canavese F. 2009. Normal growth of the spine and thorax. In: Akbarnia B, Yazici M, Thompson GH (eds). The growing spine. Springer, New York, pp 11–41.
40. Meredith HV, Knott VB. 1937. Changes in body proportion s during infancy and the preschool years. 1. The thorax index. Child Development 8, 173- 190.
41. Sinclair D. 1969. Human Growth after Birth. London, Oxford University Press.
42. Burwell RG, Vernon CL, Dangerfield PH. 1980. ln OWEN's et al. Scientific Foundation of Orthopaedics and Traumatology. London, pages 317-328.
43. Burwell RG, James N, Johnson F, Webb JK, Wilson YG. 1983. Standardized trunk asymmetry scores: a study of back contour in healthy schoolchildren. Journal of Bone and Joint Surgery 65B. 452-463.
44. Hieronymi G. 1961. Über den durch das Alter bedingten Formwandel menschlicher Lungen. Ergebnisse der allgemeinen Pathologie und pathologischen Anatomie 41, 1- 62.
45. Keith, Sir Arthur. 1923. Man's posture: its evolution and disorders. Lecture III. The postural adaptations of the shoulders and thorax. British Medical Journal 1, 545- 548. doi: https://doi.org/10.1136/bmj.1.3248.545
46. Andriacchi T, Schultz A, Belytschko T, Galante J. 1974. A model for studies of mechanical interactions between the human spine and rib cage. J Biomech 1974; 7:497–507.

47. Brasiliense LB, Lazaro BC, Reyes PM, Dogan S, Theodore N, Crawford NR. 2011. Biomechanical contribution of the rib cage to thoracic stability. Spine (Phila Pa 1976). 2011 Dec 15;36(26): E1686-93. doi: 10.1097/BRS.0b013e318219ce84.PMID: 22138782
48. Richard L. Drake, A. Wayne Vogl, Adam W. M. 2019. Mitchell Gray's Anatomy for Students, 4th Edition – January 15, 2019, Paperback ISBN: 9780323393041, ISBN: 9780323611053
49. Karlberg, J. 1989. A biologically-oriented mathematical model (ICP) for human growth. Acta Paediatrica, Supplementum, 1989, 350,70-94.
50. Grivas TB, Burwell RG, Purdue M, Webb JK, Moulton A. 1992. The rib cage deformity in infantile idiopathic scoliosis -The funnel-shaped upper chest in relation to specific rotation as a prognostic factor: An evaluation of thoracic shape in progressive scoliosis and control children during growth. In Alberti I Drerup I Hierholzer Eds: Surface Topography and Spinal Deformity VI, Gustav Fischer Stuttgart New York 1992, 93-109.
51. Harris JA, Shah SA, Campbell Jr RM, Balasubramanian S. 2014. A comprehensive review of thoracic deformityparameters in scoliosis. Eur Spine J 2014 Dec;23(12):2594-602. doi: 10.1007/s00586-014-3580-8. Epub 2014 Sep 20.
52. Hierholzer E, Hackenberg L. 2002.Three-dimensional shape analysis of the scoliotic spine using MR tomography and rasterstereography. Stud Health Technol Inform. 2002; 91: 184-9, PMID: 15457720
53. Sangole AP, Aubin CE, Labelle H, Stokes IA, Lenke LG, Jackson R, Newton P Three-dimensional classification of thoracic scoliotic curves. . Spine (Phila Pa 1976). 2009 Jan 1;34(1):91-9. doi: 10.1097/BRS.0b013e3181877bbb. PMID: 19127167.
54. Donzelli S, Poma S, Balzarini L, Borboni A, Respizzi S, Villafane JH, Zaina F, Negrini S 2015. State of the art of current 3-D scoliosis classifications: a systematic review from a clinical perspective. . J Neuroeng Rehabil. 2015 Oct 16;12:91. doi: 10.1186/s12984-015-0083-8. PMID: 26475324.
55. Dansereau J, Stokes IAF, Moreland MS 1987. Radiographic reconstruction of 3D human rib cage. In Surface Topography and Spinal Deformity Edited by: Stokes IAF, Pekelsky JR, Moreland MS. Stuttgart: Gustav Fischer; 1987:67-76.
56. Yuichi Kasai, Kenji Takegami Atsumasa Uchida. 2002. Length of the ribs in patients with idiopathic scoliosis. Arch Orthop Trauma Surg (2002) 122 : 161–162. Arch Orthop Trauma Surg (2002) 122 : 161–162
57. https://www.researchgate.net/publication/317929622_The_Laryngeal_Aspects_of_Infant_Language_Acquisition/figures?lo=1
58. Meredith HV, Knott VB. (1937). Changes in body proportion s during infancy and the preschool years. 1. The thorax index. Child Development 8, 173- 190.
59. Mehta MH. 1972. The rib-vertebra angle in the early diagnosis between resolving and progressive infantile scoliosis. J Bone Joint Surg Br. 1972 May;54(2):230-43.PMID: 034823.
60. Wemyss-Holden SA, Jacobs KJ, Burwell RG, McNeill SA, Polak FJ, Webb JK, Moulton A 1991. The rib cage in adolescent idiopathic scoliosis (AIS): a segmental analysis of rib-vertebra angles (RVAs) revealing crossed RVA asymmetry with aetiological implications. Proceedings of a joint Meeting of the British Association of Clinical Anatomists and the American Association of Clinical Anatomists, Norwich, 8-11 July 1991. Clin. Anat.
61. Grivas TG, Burwell RG, Moulton A, Webb JK. 2015. Letter to the Editor concerning: "Patterns of Rib Growth in the Human Child" by Richard M. Schwend, John A. Schmidt, Julie L. Reigrut, Laurel C. Blakemore, Behrooz A. Akbarnia, Spine Deformity Volume 3, Issue 6, November 2015, Pages 608-610. Spine Deformity 3 (2015) 297-302, http://dx.doi.org/10.1016/j.jspd.2015.01.007.
62. Burwell RG, Cole AA, Cook TA, Grivas TB, Kiel AW, Moulton A, Thirlwall AS, Upadhyay SS, Webb JK, Wemyss-Holden SA, Whitwell DJ, Wojcik AS, Wythers DJ. 1991-1992. Pathogenesis of Idiopathic Scoliosis. The Nottingham Concept. Acta Orthop Belgica. Vol 58, Suppl. 1, 1992, 33-58.
63. Burwell RG, Cole AA, Cook TA, Grivas TB, Kiel AW, Moulton A, Thirlwall AS, Upadhyay SSs, Webb JK, Wemyss-Holden SA, Whitwell DJ, Wojcik AS, Wythers DJ (1991-1992): Pathogenesis of Idiopathic Scoliosis: The Nottingham Concept. J Bone Joint Surg (Br) 1992, 74-B:SUPP I, 88-89.
64. Grivas TB, Samelis P, Chadziargiropoulos T, Polyzois B. 2002. Study of the rib cage deformity in children with 10 degrees-20 degrees of Cobb angle late onset idiopathic scoliosis, using rib-vertebra angles--aetiologic implications. Stud Health Technol Inform. 2002; 91:20-24.
65. Carey J. 1932. Scoliosis etiology, pathogenesis and prevention of experimental rotary lateral curvature of the spine, Journal American Medical Association J.A.M.A 1932, 98, 104-110.
66. Cook TA, Burwell RG, Wemyss-Holden SA, Webb JK. 1991. A segmental study of iliocostalis: functional and clinical implications. Clin. Anat., 1991, 4:387.
67. Wemyss-Holden, SA, Burwell RG, Cook TA, Binch C, Webb JK, Moulton A. 1991. A spiral composite muscle trunk rotator in man? Relevance to gait, idiopathic and sportsman's scolioses and stroke. Clin. Anat., 4:386.

68. Yuzeng Liu, Aixing Pan, Yong Hai, Wenjing Li, Li Yin, Ruijun Guo. 2019: Asymmetric biomechanical characteristics of the paravertebral muscle in adolescent idiopathic scoliosis. Clin Biomech (Bristol, Avon) . 2019 May; 65:81-86. doi: 10.1016/j.clinbiomech.2019.03.013. Epub 2019 Mar 19.
69. Grivas TB, Burwell RG, Kechagias V, Mazioti C, Fundas A, Kolovou D, Christodoulou E. (2015): Idiopathic and normal lateral lumbar curves: muscle effects interpreted by 12th rib length asymmetry with pathomechanic implications for lumbar idiopathic scoliosis. Eur Spine J. 2015;24(11): 2614–707.
70. Grivas TB, Burwell RG, Kechagias V, Mazioti C, Fundas A, Kolovou D, Christodoulou E. (2016) Idiopathic and normal lateral lumbar curves: muscle effects interpreted by 12th rib length asymmetry with pathomechanic implications for lumbar idiopathic scoliosis. Scoliosis Spinal Disord. 2016 Oct 14;11(Suppl 2):35. doi: 10.1186/s13013-016-0093-8. eCollection 2016.
71. Stokes IA, Burwell RG, Dangerfield PH. IBSE. Biomechanical spinal growth modulation and progressive adolescent scoliosis—a test of the ‗vicious cycle pathogenetic hypothesis: summary of an electronic focus group debate of the IBSE. Scoliosis. 2006;18(1):16.
72. Wolff J. The Law of Bone Remodeling. In: Maquet P, Furlong R, editors. Berlin: Springer-Verlag; 1986.
73. Wolff J. The Classic. Concerning the interrelationship between form and function of the individual parts of the organism. Clin Orthop. 1988; 228:2–11.
74. Golding JSR. The mechanical factors which influence bone growth. Eur J Clin Nutr. 1994;48 Suppl 1: S178–85.
75. Mau H. Specifizierung der korrespondierenden Wachstums-Gesetze von Hueter-Volkmann und Pauwels (Wachstumde-formitäten) und ihre Beziehung zu den Belasungsde-förmitäten. Z Orthop. 1984; 122:293–8.
76. Grivas TB, Vasiliadis ES, Koufopoulos G, Segos D, Triantafyllopoulos G, Mouzakis V.2006.Study of trunk asymmetry in normal children and adolescents. Scoliosis. 2006 Nov 30; 1:19. doi: 10.1186/1748-7161-1-19
77. Grivas TB, Vasiliadis ES, Mihas C, Triantafyllopoulos G, Kaspiris A.2008a. Scoliosis. Trunk asymmetry in juveniles.2008a Sep 23;3:13. doi: 10.1186/1748-7161-3-13.PMID: 18811937
78. Grivas TB, Vasiliadis ES, Mihasc Maziotou C, Triandafyllopoulos G.2008b. Back trunk morphology in 3301 children aged 3-9 years old. 2008b, Stud Health Technol Inform. 2008; 140:29-32. PMID: 18809994
79. Grivas TB, Vasiliadis ES, Polyzois VD, Mouzakis V. Trunk asymmetry and handedness in 8245 school children. Pediatr Rehabil. 2006 Jul-Sep;9(3):259-66. doi: 10.1080/10428190500343027. PMID: 17050403.
80. Grivas TB, Burwell RG, Webb JK, Moulton A. 1992. The funnel-shaped upper chest of progressive infantile idiopathic scoliosis (IIS): significance for rib growth patterns, rib dysplasia and aetiology of the spinal deformity. In Proceedings of European Spinal Deformities Society Meeting. Lyon-France, June 17-19, 1992, R Kohler and C Picault (ed), Sauramps Medical, 11, boulevard Henri IV, 34000 Montpellier, France, p. 74.
81. Perdriolle RJ, Vidal J: Thoracic idiopathic scoliosis curve evolution and prognosis. Spine. 1985, 10: 785-791. 10.1097/00007632-198511000-00001
82. Perdriolle RJ, Vidal J, Bechetti S, Alquier P: Torsion: the essential factor for progression in idiopathic scoliosis. Combined Meeting of Scoliosis Research Society and European Spinal Deformities Society, Amsterdam. 17–22 September 1989
83. Perdriolle RJ, Vidal J: Etudie de la courbure scoliotique. Importance de l'extension et de la rotation vertebrale. Revue de Chirurie Orthopedique. 1981, 67: 25-34.
84. Hodgett SG, Burwell RG, Upadhyay SS, Webb JK: Trunk height loss in idiopathic scoliosis in AP and oblique spinal radiographs. European Spinal Deformities Society First Congress. Scoliosis the Last 20 years 'Experience, Rome. April 16–19, 1986.
85. Jones FA, Burwell RG, Grivas TB, Webb. (1992). Ribcage deformity in resolving infantile idiopathic scoliosis.Does the thoracic shape contribute to the expression and resolution of the spinal deformity? Proceedings of European Spinal Deformities Society Meeting. Lyon - France, June 17-19, 1992. R Kohler and C Picault (ed), Sauramps Medical, 11, boulevard Henri IV, 34000 Montpellier, France, p. 271.
86. Grivas TB, Burwell GR, Vasiliadis ES, Webb JK. (2006). A segmental radiological study of the spine and rib--cage in children with progressive infantile idiopathic scoliosis. Scoliosis. 2006 Oct 18; 1:17. doi: 10.1186/1748-7161-1-17.PMID: 17049098.
87. Grivas TB, Samelis P, Pappa AS, Stavlas P, Polyzois D (2000-2002): Menarche in Scoliotic and Nonscoliotic Mediterranean Girls. Is There Any Relation between Menarche and Laterality of Scoliotic Curves? 2000 Meeting of the International Research Society of Spinal Deformities. Clermont, France, 23-26 May 2000, In proceedings p.7, In: Research into spinal deformities 3, Tanguy A and Peuchot B, (Eds), IOS Press, Amsterdam 2002, pp. 30-36. ISBN 0926-9630. Stud Health Technol Inform, 2002: 88: 3 0-36.
88. Pjanic S, Jevtic N, Grivas TB. (2022): Menarche in scoliotic and non-scoliotic balkan girls and relation between menarche and laterality of scoliotic curves. SOSORT Congress May 4-7, 2022, San Sebastian Donostia, Spain,Program book and Abstracts Proceedings, page 46.

89. Grivas TB, Burwell RG, Webb JK. (1991). The funnel-shaped upper chest of progressive infantile idiopathic scoliosis (lIS): significance for rib growth patterns, rib dysplasia and aetiology of the spinal deformity (IIS): Clinical Anatomy 1991, 4(1):73.
90. Agadir M, Burwell RG, Grivas TB, Moulton A, Webb JK, Wemyss-Holden SA (1991-1992): A segmental radiological study of resolving idiopathic scoliosis with aetiological implications. In Proceedings of British Scoliosis Society meeting, Newcastle upon Tyne, UK, 5-7 June 1991. J Bone Joint Surg (Br) 1992; 74-B: SUPP I, 88-89.
91. Agadir M, Burwell RG, Grivas TB, Moulton A, Webb JK, Wemyss-Holden SA (1991-1992): Resolving idiopathic scoliosis: a longitudinal radiological study with aetiological implications. In Proceedings of British Association of Clinical Anatomists, Winter Scientific Meeting and the Annual General Meeting 1991, Queen Mary and Westfield College, London, England, December 18, 1991.Clin Anat, 1992, 5(4): 326.
92. Agadir M, Burwell RG, Grivas TB, Moulton A, Webb JK, Wemyss-Holden SA (1991-1992): Progressive infantile idiopathic scoliosis: a longitudinal radiological study with aetiological implications: In Proceedings of British Association of Clinical Anatomists, Winter Scientific Meeting and the Annual General Meeting 1991, Queen Mary and Westfield College, London, England, Wednesday, 18 December 1991. Clin Anat, 1992, 5: 326
93. Agadir M, Burwell RG, Grivas TB, Moulton A, Webb JK (1992): Progressive infantile idiopathic scoliosis: a longitudinal radiological study with aetiological implications. Proceedings of British Scoliosis Society, 17th Annual Meeting at Slieve Donard Hotel. Newcastle, Co. Down, 19-21 March, UK 1992. J Bone Joint Surg, 1992, 74-B: Supp III, 303.
94. Pjanic S, Jevtic N, Grivas Tb. Menarche in scoliotic and non-scoliotic Balkan girls and relation between menarche and laterality of scoliotic curves. SOSORT Congress May 4-7, 2022, San Sebastian Donostia, Spain, Program book and Abstracts Proceedings, page 46.
95. Burwell RG, Dangerfield PH, Ames Nj: Anthropometric studies of normal and scoliotic children. Axial and appendicular skeletal asymmetry, sexual dimorphisms and age-related changes. In: R. R. Jacobs (editor) Pathogenesis of Idiopathic Scoliosis, Proceedings of an International Conference (Chicago: Scoliosis Research Society), 1984, pp. 27–44.
96. Goldberg CJ, Dowling, FE, Fogarty EE, Moore DP (1995): Adolescent idiopathic scoliosis as developmental instability. Genetica, 96: 247–255, 1995. GOLDBERG, C. J., FOGARTY, F. E., MOORE, D. P. et al.: Scoliosis and developmental theory: adolescent idiopathic scoliosis. Spine, 22: 2228–2238, 1997.
97. Bisgard J: Thoracogenic scoliosis. Influence of thoracic disease and thoracic operations on the spine. Archives of Surgery 1934, 29:417-45.
98. Damsin JP, C Cazeau, Carlioz H (1997) Scoliosis and fused ribs. A case report Spine, 1997 May 1;22(9):1030-1032.doi: 10.1097/00007632-199705010-00018.
99. Tsiligiannis T, Grivas TB Pulmonary function in children with idiopathic scoliosis 2012 Mar 23;7(1):7. doi: 10.1186/1748-7161-7-7
100. Mayer OH and Redding G. (2009). Early changes in pulmonary function after vertical expandable prosthetic titanium rib insertion in children with thoracic insufficiency syndrome J Pediatr Orthop, 2009 Jan-Feb;29(1):35-8, doi: 10.1097/BPO.0b013e3181929c8b.
101. Redding G (2013) The benefits and the bluster of biomechanical restoration of the t horacic cage on cardio-respiratory function in idiopathic scoliosis. 50thAnniversary Zorab Symposium, 20th– 21stJune, 2013, Royal College of Surgeons, London, UK
102. McPhail GL, Howells SA, Boesch RP, Wood RE, Ednick M, Chini BA, Jain V, Agabegi S, Sturm P, Wall E, Crawford A, Redding G Obstructive lung disease is common in children with syndromic and congenital scoliosis: a preliminary study.(2013 J Pediatr Orthop. 2013 Dec;33(8):781-5. doi: 10.1097/BPO.0000000000000078. PMID: 24172682
103. Robin GC 1990., The Aetiology of idiopathic scoliosis CRC Press Boca Raton, 1990, 1-259.
104. Grillner S, Mcclellan A, Sigvardt K, Wallen P, Wilen M. Activation of NMDA-receptors elicits ―Fictive locomotion‖ in lamprey spinal cord in vitro. Acta Physiol Scand 1981, 113: 549-551.
105. Burwell RG, AA Cole, TA Cook, T.B. Grivas, A.W. Kiel, A. Moulton, A.S. Thirlwall, S.S. Upadhyay, J. K. Webb, S.A. Wemyss-Holden, D.J. Whitwell, A.S. Wojcik, and D.J Wythers 1991. Pathogenesis of idiopathic scoliosis: The Nottingham concept. Proceedings of the Combined Meeting of the British Scoliosis Society and the Nordic Scoliosis Society, Newcastle upon Tyne, 5-6 June 1991.
106. Burwell RG, Upadhyay SS, Wojcik AS, Bacon NCM, Moulton A & Webb JK (1988). Ultrasound in evaluating scoliosis. In Proceedings of the Eighth Phillip Zorab Scoliosis Symposium, 26-28 October 1988, London (ed. D. Siegler, D. Harrison & M. Edgar), pp. 48-67. London: Phillip Zorab Scoliosis Research Fund.

107. Gregersen GG., and DB Lucas An in vivo study of the axial rotation of the human thoracolumbar spine. J. Bone Joint Surg. [Am], 1967, 49:247-262.
108. Schwend RM, Schmidt JA, Reigrut JL, Blakemore LC, Akbarnia BA Letter to the Editor: Response to Grivas et al.Spine Deform. 2015 Nov;3(6):610-611. doi: 10.1016/j.jspd.2015.09.003. Epub 2015 Oct 28. PMID: 27927565
109. Smithsonian National Museum of Natural History. http://humanorigins.si.edu/human-characteristics/bodies.Accessed August 20, 2015.
110. Dangerfield PH, Burwell RG, Vernon Cl. 1980. Anthropometry and scoliosis, In: Spinal Deformities (ed. R. Roaf). Pitman Medical, London. 1980. 259-280
111. Aiello L, Dean C. 1990. An introduction to human evolutionary anatomy. Academic Press, 1990, pp. 244. 275, 442
112. Cobb J. 1948.Outline for the study of scoliosis. Instr Course Lect. 1948; 5:261–275.
113. Nash CL Jr, Moe JH. 1969. A study of vertebral rotation. J Bone Joint Surg Am. 1969; 51:223–229.
114. Bunnell WP. An objective criterion for scoliosis screening. J Bone Joint Surg Am. 1984; 66:1381–1387.
115. Perdriolle R, Vidal J. Morphology of scoliosis: three-dimensional evolution. Orthopedics. 1987; 10:909–915.
116. Grivas TB, Dangas S, Polyzois BD, Dangas S, Samelis P. 2002. The double rib contour sign (DRCS) in lateral spinal radiographs: aetiologic implications for scoliosis. Stud Health Technol Inform. 2002; 88: 38–43.
117. Pratt RK, Burwell RG, Cole AA, Webb JK. 2002. Patient and parental perception of adolescent idiopathic scoliosis before and after surgery in comparison with surface and radiographic measurements. Spine (Phila Pa 1976). 2002; 27:1543–1550; discussion 1551–1552
118. Lykissas MG, Sharma V, Jain VV, Crawford AH: Assessment of rib hump deformity correction in adolescent idiopathic scoliosis with or without costoplasty using the double rib contour sign J Spinal Disord Tech. 2015 May;28(4):134-9. doi: 10.1097/BSD.0b013e3182745f51.
119. Γρίβας ΘΒ, Δάγκας Σ, Λαφογιάννη Σ, Σαμέλης Π, Πολυζώης Δ: Το σημείο της διπλής παρυφής των πλευρών των ημιθωρακίων στην πλάγια σπονδυλική ακτινογραφία. Υπάρχει αιτιολογική σχέση με την σκολίωση; 25ºΕπετειακό Συμπόσιο Παθήσεων Σπονδυλικής Στήλης «Ν. Γιαννέστρας, Π. Σμυρνής». Πάτρα: Hotel Porto Rio; 1999.
120. Grivas TB, Daggas S, Polyzois B, Samelis P. The Double Rib Contour Sign (DRCS) in lateral spinal radiographs: aetiologic implications for scoliosis. Clermont, France: International Research Society of Spinal Deformities meeting; 2000.
121. Grivas TB. 2014. : Rib index. Scoliosis. 2014; 9: 20. Nov 20. doi:10.1186/s13013-014-0020-9, PMCID: PMC4310037 PMID: 25635184
122. Haber LL, Adams TM, Briski DC, Celestre PC, Robbins DJ, Waldron SR. 2020. Long-term Results of Spine Stapling for AIS to Skeletal Maturity and Beyond. J Pediatr Orthop. 2020 Jan;40(1):e37-e41. doi: 10.1097/BPO.0000000000001389.PMID: 30973475
123. Maragkoudakis EG, Gelalis I, Grivas T, Burwell GR, Mazioti C, Tsilimidos G. Using the Scoliometer and a Surface Topography Apparatus to Check if Back Trunk Asymmetry Changes in Children and Adolescents in the Forward Flexion and Standing Erect Positions. Cureus. 2019 Dec 10;11(12): e6334. doi: 10.7759/cureus.6334. PMID: 31938623.
124. Grivas TB, Vasiliadis ES, Mihas C, Savvidou O. (2007): The effect of growth on the correlation between the spinal and rib cage deformity: implications on idiopathic scoliosis pathogenesis. Scoliosis 2007, 2:11 doi:10.1186/1748-7161-2-11.
125. Pizones J, Zuniga L, Sanchez-Mariscal F, Izquierdo E. (2016): Relationship between the different torsion-related thoracic deformity parameters of adolescent idiopathic scoliosis. Eur J Orthop Surg Traumatol. 2016 Oct;26(7):763-769. doi: 10.1007/s00590-016-1762-2. Epub 2016 Mar 21.
126. Grivas TB: 2012-2013. Chapter: Radiological appraisal of thoracic deformity - improvement or deterioration using the convex/concave rib-hump index („double rib contour sign") in curves Lenke Type 1, 3, 5 and 6. In Scoliosis Research Society • Half-Day Courses. Scoliosis Research Society, Editors: SRS 2012-2013 Education Committee; 29–30.
127. Thulbourne T, Gillespie R. 1976. The rib hump in idiopathic scoliosis. Measurement, analysis and response to treatment. . J Bone Joint Surg Br. 1976 Feb;58(1):64-71. doi: 10.1302/0301-620X.58B1.1270497. PMID: 1270497
128. Gaines RW, McKinley LM, Leatherman KD. 1981.Effect of the Harrington compression system on the correction of the rib hump in spinal instrumentation for idiopathic scoliosis. Spine (Phila Pa 1976). 1981 Sep-Oct;6(5):489-593. doi: 10.1097/00007632-198109000-00011.PMID: 7302683
129. Hefti FL, McMaster MJ. 1983: The effect of the adolescent growth spurt on early posterior spinal fusion in infantile and juvenile idiopathic scoliosis J Bone Joint Surg Br. 1983 May;65(3):247-54.doi: 10.1302/0301-620X.65B3.6841390.

130. Weatherley CR, Draycott V, O'Brien JF, Benson DR, Gopalakrishnan KC, Evans JH, O'Brien JP. 1987. The rib deformity in adolescent idiopathic scoliosis. A prospective study to evaluate changes after Harr ington distraction and posterior fusion. J Bone Joint Surg Br. 1987 Mar;69(2):179-82. doi: 10.1302/0301-620X.69B2.3818745. PMID:3818745
131. Delorme S, Violas P, Dansereau J, de Guise J, Aubin CE, Labelle H. Preoperative and early postoperative three-dimensional changes of the rib cage after posterior instrumentation in adolescent idiopathic scoliosis. Eur Spine J (2000) 10: 101–106, DOI 10.1007/s005860000196
132. Pratt RK, Webb JK, Burwell RG, Cole AA. 2001, Changes in surface and radiographic deformity after Universal Spine System for right thoracic adolescent idiopathic scoliosis: is rib-hump reassertion a mechanical problem of the thoracic cage rather than an effect of relative anterior spinal overgrowth? Spine (Phila Pa 1976). 2001 Aug 15;26(16):1778-87. doi: 10.1097/00007632-200108150-00009. PMID: 11493850
133. Hwang SW, Samdani AF, Marks M, Bastrom T, Garg H, Lonner B, Bennett JT, Pahys J, Shah S, Miyanji F,Shufflebarger H, Newton P, Betz R. Five-year clinical and radiographic outcomes using pedicle screw only constructs in the treatment of adolescent idiopathic scoliosis. Eur Spine J. 2013 Jun;22(6):1292-9. doi: 10.1007/s00586-012-2625-0. Epub 2012 Dec 20. PMID: 23254863
134. Mattila M, Jalanko T, Helenius I. En bloc vertebral column derotation provides spinal derotation but no additional effect on thoracic rib hump correction as compared with no derotation in adolescents undergoing surgery for idiopathic scoliosis with total pedicle screw instrumentation. Spine (Phila Pa 1976). 2013 Aug 15;38(18):1576-83. doi: 10.1097/BRS.0b013e31829a6d37. PMID: 23680831
135. Soultanis KC, Stavropoulos NA, Grivas TB, Tsiavos K, Starantzis K, Papagelopoulos PJ Rib hump deformity assessment using the rib index in adolescent idiopathic scoliotics treated with full screw or hybrid constructs: aetiological implications. . Scoliosis. 2015 Feb 11;10(Suppl 2):S10. doi: 10.1186/1748-7161-10-S2-S10. eCollection 2015.
136. Haber LL, Adams TM, Briski DC, Celestre PC, Robbins DJ,Waldron SR. 2020. Long-term Results of Spine Stapling for AIS to Skeletal Maturity and Beyond J Pediatr Orthop. 2020 Jan;40(1):e37-e41.PMID: **30973475,**DOI: 10.1097/BPO.0000000000001389
137. Hamzaoglu A,·Karadereler S, Kahraman S, Akman YE, Mutlu A, Aslanturk O, Elsadig M, Sanli T, Enercan M (2020).Clinical, radiological and HRQoL outcomes after selective thoracic fusion with minimum 15‑ year follow-up. Spine Deformity, 2020, Spine Deform 2021 Sep;9(5):1323-1331. doi: 10.1007/s43390-021-00350-2. Epub 2021 Apr 27.
138. Igoumenou VG, Megaloikonomos PD, Tsiavos K, Georgopoulos G, Liontos M, Mavrogenis AF, Grivas TB, Soultanis K, Papagelopoulos PJ (2016): Postoperative rib hump deformity correction in patients with adolescent idiopathic scoliosis. Comparison of a three generations spinal fusion systems. Combined meeting of the International Research Society of Spinal Deformities and the Society on Scoliosis Orthopaedic and Rehabilitation Treatment. Banff, Canada 25-28 May 2016.
139. Igoumenou VG, Melamud E, Vazifehdan F, Megaloikonomos PD, Grivas TB, Mavrogenis AF, Papagelopoulos PJ, Soultanis K. (2021): Rib Hump Deformity Correction in Patients with Adolescent Idiopathic Scoliosis: A Comparison of Three Spinal Fusion Systems. J Long Term Eff Med Implants. 2021;31(4):81-87. doi: 10.1615/J Long Term Eff Med Implants.2021039387.PMID: 34587420
140. Easwar TR, Hong J-Y, Yang J-H, Suh S-W, Modi HN. 2011. Does lateral vertebral translation correspond to Cobb angle and relate in the same way to axial vertebral rotation and rib hump index? A radiographic analysis on idiopathic scoliosis. Eur Spine J. 2011 Jul; 20(7): 1095–1105. doi:10.1007/s00586-011-1702-0
141. Hong J-Y, Suh S-W, Easwar TR, Modi HN, Yang J-H, Par J-H. (2011) Evaluation of the Three-Dimensional Deformities in Scoliosis Surgery with Computed tomography. SPINE (2011) Volume 36, Number 19, pp E1259–E1265,
142. Tsirikos AI and McMillan TE (2022): All Pedicle Screw versus Hybrid Hook–Screw Instrumentation in the Treatment of Thoracic Adolescent Idiopathic Scoliosis (AIS): A Prospective Comparative Cohort Study Healthcare 2022, 10, 1455. https://doi.org/10.3390/ healthcare10081455
143. Lertudomphonwanit T, Berry CA, Jain VV, Sturm PF. 2022, Does Implant Density Impact Three-Dimensional Deformity Correction in Adolescent Idiopathic Scoliosis with Lenke 1 and 2 Curves Treated by Posterior Spinal Fusion without Ponte Osteotomies? Online first: May 10, 2021 Asian Spine Journal 2022;16(3):375-385. DOI: https://doi.org/10.31616/asj.2020.0398.
144. Yang S, Jones-Quaidoo SM, Eager M, et al. Right adolescent idiopathic thoracic curve (Lenke 1 A andB): does cost of instrumentation and implant density improve radiographic and cosmetic parameters? Eur Spine J 2011; 20:1039-47.

145.Bharucha NJ, Lonner BS, Auerbach JD, Kean KE, Trobisch PD. Low-density versus high-density thoracic pedicle screw constructs in adolescent idiopathic scoliosis: do more screws lead to a better outcome? Spine J 2013; 13:375-381.
146.Pizones J, Núñez-Medina A, Sánchez-Mariscal F, Zúñiga L, Izquierdo E. Thoracic sagittal plane variations betweenpatients with thoracic adolescent idiopathic scoliosis and healthy adolescents. Eur Spine J. 2016 Oct;25(10):3095-3103. doi: 10.1007/s00586-016-4400-0. Epub 2016 Jan 28. PMID: 26821145.
147.Dubousset J, Herring JA, Shufflebarger H.The crankshaft phenomenon. J Pediatr Orthop. 1989 Sep-Oct;9(5):541-50. doi: 10.1097/01241398-198909010-00008.PMID: 2794027
148.Grivas TB, Vasiliadis ES, Rodopoulos G, Kovanis I. 2008. School screening as a research tool in epidemiology, natural history and aetiology of idiopathic scoliosis. Stud Health Technol Inform. 2008; 135:84-93.
149.Grivas TB, Vynichakis G, Chandrinos M, Mazioti C, Papagianni D, Mamzeri A, Mihas C.Morphology, Development and Deformation of the Spine in Mild and Moderate Scoliosis: Are Changes in the Spine Primary or Secondary? J Clin Med. 2021 Dec 16;10(24):5901. doi: 10.3390/jcm10245901.PMID: 34945197
150.Pruijs JE, W Keessen, R van der Meer, J C van Wieringen, M A Hageman. 1992. School screening for scoliosis: methodologic considerations. Part 1: External measurements Spine (Phila Pa 1976) 1992 Apr;17(4):431-436.
151.PruijsJE, W Keessen, R van der Meer, J C van Wieringen. 1995. School screening for scoliosis: the value of quantitative measurement Eur Spine J . 1995;4(4):226-30.doi: 10.1007/BF00303416.
152.Nissinen M, Heliovaara M, Tallroth K, Poussa M: (1989). Trunk asymmetry and scoliosis. Anthropometric measurements in prepubertal school children. Acta Paediatr Scand 78:747-753, 1989
153.Nissinen M, Heliovaara M, Seltsamo J, Poussa M. 1993. Trunk Asymmetry, Posture, Growth, and Risk of Scoliosis. A Three-Year Follow-Up of Finnish Prepubertal School Children. Spine Volume 18 Number 1 199
154.Willner S. 1984. Development of trunk asymmetries and structural scoliosis in prepubertal school children in Malmo: Follow up study of children 10-14 years of age. J Pediatr Orthop 4:452-55, 1984.
155.Willner S. 1979. Moiré topography-A method for school screening of scoliosis. Arch Orthrop Traumat Surg 1979; 95: 181 - 185.
156.Willner S. 1983. The efficiency of a combined clinical- moiré technique in school screening of scoliosis. In: Drerup, Frobin, Hierholzer, eds. Moiré fringe topography. Stuttgart, New York: Gustav Fischer, 1983: 175 -179.
157.Grivas TB, Vynichakis G, Chandrinos M, Mazioti C, Papagianni D, Mamzeri A, Mihas C. Reply to de Reuver et al. Comment on Grivas et al. Morphology, Development and Deformation of the Spine in Mild and Moderate Scoliosis: Are Changes in the Spine Primary or Secondary? J. Clin. Med. 2021, 10, 5901". J. Clin. Med. 2022, 11,2049. https://doi.org/10.3390/jcm11072049
158.Kenanidis E, Athanasiadis DI, Geropoulos G, Kakoulidis P, Potoupnis M, Tsiridis E. Does the sternum play a role in the aetiopathogenesis of adolescent idiopathic scoliosis? Preliminary data of a new theory. Hippokratia. 2018 Oct-Dec;22(4):173-177.PMID: 31695304
159.Sevastik JA, Aaro S, Normelli H. (1984): Scoliosis. Experimental and clinical studies Clin Orthop Relat Res 1984 Dec;(191):27-34.
160.Grivas TB. 2014. — 4th Educational Course. ed. SOSORT Educational Committee. 38–43.
161.Sevastik J, Agadir M, Sevastik B 1990.: Effects of rib elongation on the spine: I. Distortion of the vertebral alignment in the rabbit. Spine. 1990, 15: 822-825. 10.1097/00007632-199008010-00015.
162.Sevastik B, Xiong B, Lundberg A, Sevastik JA. 1995.In vitro opto-electronic analysis of 3-D segmental vertebral movements during gradual rib lengthening in the pig. Acta Orthop Belg. 1995;61(3):218-25. PMID: **8525819.**
163.Sevastik J, Agadir M, Sevastik B. 1990. Effects of rib elongation on the spine: II. Correction of scoliosis in the rabbit. Spine. 1990, 15: 826-829. 10.1097/00007632-199008010-00016. PMID: 2237634
164.Gréalou L, Aubin CE, Sevastik JA, Labelle H 2002.Simulations of rib cage surgery for the management of scoliotic deformities. .Stud Health Technol Inform. 2002; 88:345-9. PMID: 15456059
165.Xiong B, Sevastik JA. 1998. A physiological approach to surgical treatment of progressive early idiopathic scoliosis. Eur Spine J. 1998;7(6):505-8. doi: 10.1007/s005860050115.PMID: 9883961
166.Sevastik JA, Aaro S, Lindholm ST, Dalhborn M. 1987. Experimental scoliosis in growing rabbits by operations on the rib cage. Clinical Orthopaedics. 1987, 136: 282-86
167.Agadir M, Sevastik B, Sevastik JA, Persson A, Isberg B.1988. Induction of scoliosis in the growing rabbit by unilateral rib-growth stimulation. Spine. 1988, 13: 1065-1069. 10.1097/00007632-198809000-00016.
168.Agadir M, Sevastik B, Reinholt FP, Perbeck L, Sevastik J. 1990. Vascular Changes in the Chest Wall After Unilateral Resection of the Intercostal Nerves in the Growing Rabbit. Journal of Orthopaedic Research, 1990, 8: 283-290.
169.Sevastik JA 2002. Dysfunction of the autonomic nerve system (ANS) in the aetiopathogenesis of adolescent idiopathic scoliosis. .Stud Health Technol Inform. 2002; 88:20-3.PMID: 15455999.

170. Sevastik JA. 2006. Right convex thoracic female adolescent scoliosis in the light of the thoracospinal concept. Stud Health Technol Inform. 2006; 123:552-8.PMID: 17108486.
171. Sevastik JA, Burwell RG, Dangerfild PH. 2003. A new concept for the etiopathogenesis of the thoracospinal deformity of idiopathic scoliosis: summary of an electronic focus group debate of the IBSE. Eur Spine J (2003) 12: 440–450, DOI 10.1007/s00586-002-0489-4.
172. Iliopoulos P, Korovessis P, Koureas G, Zacharatos S, Stergiou P. b. Asymmetric evolution of anterior chest wall blood supply in female adolescents with progressive right-convex thoracic idiopathic scoliosis. Eur Spine J. 2007 Sep;16(9):1343-7. doi: 10.1007/s00586-007-0322-1. Epub 2007 Feb 9. PMID: 17294053.
173. Normelli H, Sevastik JA, Ljung, G, Jönsson-Söderström AM. 1988. The symmetry of the breasts in normal and scoliotic girls. Spine (Phila Pa 1976). 1986 Sep;11(7):749-52. doi: 10.1097/00007632-198609000-00016.
174. Normelli H, Sevastik J, Wallberg H. 1986. The thermal emission from the skin and the vascularity of the breasts in normal and scoliotic girls. Spine (Phila Pa 1976). 1986 Jun;11(5):405-8. doi: 10.1097/00007632-198606000-00001.
175. Denoel C, Aguirre MF, Bianco G, Mahaudens PH, Vanwijck R, Garson S, Sinna R, Debrun A. 2008. Idiopathic scoliosis and breast asymmetry. J Plast Reconstr Aesthet Surg. 2009 Oct;62(10):1303-8. doi: 10.1016/j.bjps.2008.04.031. Epub 2008 Aug 12.
176. Cruz NI, Korchin L. (2013) Breast asymmetry pattern in women with idiopathic scoliosis. Bol Asoc Med P R. 2013; 105(3):9-12
177. Closkey RF, Schultz AB. Rib cage deformities in scoliosis: spine morphology, rib cage stiffness, and tomography imaging. J Orthop Res. 1993 Sep;11(5): 730-737. doi: 10.1002/jor.1100110515.PMID: 8410473.
178. Dickson RA, Archer IA. 1984 Scoliosis in the community. In Butterworth's International Medical Reviews, Orthopaedics 2, Management of Spinal Deformities. R. A. Dickson and D. S. Bradford (ed.). London: Butterworths, pp. 77-100.
179. Dickson RA, Lawton JO, Archer IA, Butt WP. The pathogenesis of idiopathic scoliosis. Biplanar spinal asymmetry.J Bone Joint Surg [Br] 1984; 66:8-15.
180. Deacon P, Flood B, Dickson R. 1984. Idiopathic scoliosis in three dimensions. A radiographic and morphometric analysis. J. Bone Jt. Surg. Br. 1984, 66, 509–512.
181. Grivas TB, Dangas S, Samelis P, Mazioti C, Kandris K. 2002. Lateral spinal profile in school-screening referrals with and without late onset idiopathic scoliosis 10 degrees-20 degrees. Stud. Health Technol. Inform. 2002, 91, 25–31.
182. Schlösser TPC, Shah SA, Reichard SJ, Rogers K, Vincken KL, Castelein RM. Differences in early sagittal plane alignment between thoracic and lumbar adolescent idiopathic scoliosis. Spine J. 2014, 14, 282–290.
183. Zhu F, Chu WCW, Sun G, Zhu ZZ, Wang WJ, Cheng JCY, Qiu Y. 2011. Rib length asymmetry in thoracic adolescent idiopathic scoliosis: Is it primary or secondary? Eur. Spine J. 2011, 20, 254–259.
184. Qiu Y, Sun GQ, Zhu F, Wang WJ, Zhu ZZ. 2010. Rib length discrepancy in patients with adolescent idiopathic scoliosis. Stud. Health Technol. Inform. 2010, 158, 63–66.
185. Schlager B, Krump F, Boettinger J, Jonas R, Liebsch C, Ruf M, Beer M, Wilke HJ. 2021. Morphological patterns of the rib cage and lung in the healthy and adolescent idiopathic scoliosis. J. Anat. 2021, 240, 120–130.
186. Upasani VV, Tis J, Bastrom T, Pawelek J, Marks M, Lonner B, Crawford A, Newton PO. B. Analysis of sagittal alignment in thoracic and thoracolumbar curves in adolescent idiopathic scoliosis: how do these two curve types differ? Spine (Phila Pa 1976) 32(12):1355–1359
187. Rigo M, Quera-Salva´ G, Villagrasa M (2006) Sagittal configuration of the spine in girls with idiopathic scoliosis: progressing rather than initiating factor. Stud Health Technol Inform 123:90–94
188. Courvoisier A, Drevelle X, Dubousset J, Skalli W (2013) Transverse plane 3D analysis of mild scoliosis. Eur Spine J 22(11):2427–2432. doi:10.1007/s00586-013-2862-x
189. Zhang Y, Yang Y, Dang X, Zhao L, Ren J, Zhang L, Sun J (2014) Factors relating to curve progression in female patients with adolescent idiopathic scoliosis treated with a brace. Eur Spine J 24(2):244–248. doi:10.1007/s00586-014-3674-3
190. Carlson BB, Burton DC, Asher MA (2013) Comparison of trunk and spine deformity in adolescent idiopathic scoliosis. Scoliosis 8(1):2. doi:10.1186/1748-7161-8-2
191. Lovejoy CO. 1988. Evolution of human walking. Sci. Amer.1988. 259, 82-89.
192. Joharuon DC, Eday MA. 1981. Lucy The beginning of humankind. Penguin Rooks. London. 1981. 352.
193. Morgan E. 1991. ―The scars of evolution, what our bodies tell us about human origin‖. Penguin Press Science S.ISBN 10: 0140157573 / ISBN 13: 9780140157574 Published by Penguin Books Ltd, 1991.