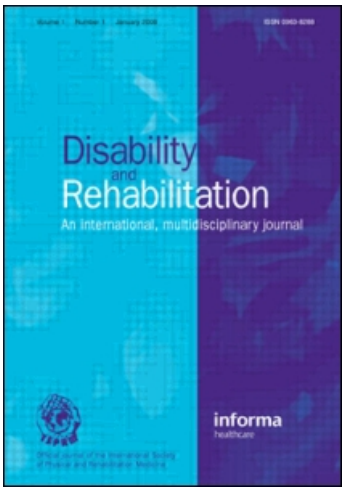

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What a school screening program could contribute in clinical research of idiopathic scoliosis aetiology

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What a school screening program could contribute in clinical research of idiopathic scoliosis aetiology

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Abstract

Purpose. Scoliosis school screening (SSS) programs have clinically benefited many children through early detection and treatment, as it is clearly stated in the Consensus Paper which has been published by the Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT). It is also through these SSS programs that almost all of our current knowledge on the natural history and curve progression of IS has been made known. The present study summarizes the contribution of SSS in research of IS aetiology.

Method. We reviewed all the reports in relation to research of IS aetiology, which were published in peer-review journals and were originated from the Thriasio SSS program.

Results. Analysis comprises of reports for (i) IS prevalence, (ii) aetiological studies originated from school screening referrals which implicate numerous environmental and biological factors in IS pathogenesis, (iii) suggestions for a more efficient screening, (iv) IS natural history, and (v) the evolving aim of SSS based on the reported research.

Conclusions. SSS should be adopted by policy makers, because its scope goes beyond the identification of IS at an early stage, contributing significantly into the research for IS aetiology.

Keywords: *Idiopathic scoliosis, aetiology, scoliosis school screening program*

Introduction

The cause of idiopathic scoliosis (IS) in humans remains obscure and probably multifactorial [1]. Until now IS aetiology suggestions and theories resulted mainly from studies of clinical results of scoliotics' treatment, genetics and physiology. It is now widely accepted that SSS programs contributed mainly to reveal the prevalence, the natural history and curve progression of IS [2–4].

The aim of the present study is to summarize the contribution of SSS in research of IS aetiology and to provide some useful suggestions for improvement of the screening process, by reviewing all the scientific papers which derived from our SSS program. A thoughtful review of the SSS outcomes is of great value and may benefit the medical research community with main interest in IS aetiology, together with suggestions and new ideas in the way scoliosis nowadays is screened for and treated.

Reports on IS prevalence

Documenting IS prevalence from school screening referrals

From 17 January 1997 to 25 January 1999, in the Thriasio SSS program, 3039 children (1506 boys and 1533 girls) aged between 5.5 to 17.5 years old were screened. This SSS program had been thoroughly organized, which enabled the examiners' team to obtain quickly the maximal amount of information about the examined population. The Adam's bending test was performed in standing and sitting position and the amount of Axial Trunk Inclination (ATI) was assessed using the Pruijs scoliometer. Scoliometer readings above 7° at any level of the lumbar, thoracolumbar or thoracic region during forward bending of the trunk, in a standing and sitting position, was used as a cut-off point for referral and radiological examination. A total of 262 pupils were referred to the hospital for further evaluation, 118 of which underwent radiological

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examination. Scoliosis was measured by the Cobb method [5–7] (Tables I and II) This number represents 3.9% of the examined population [5,6].

Influence of industrial environment on IS prevalence

The screened area of Thriasio Pedio is a heavy industrialized area and is a place of particular interest because it experienced considerable environmental pollution during the last decades. Furthermore, this area is inhabited by a quite diverse population in relation to its occupation and its ethnic origin. These reasons make Thriasio Pedio a particularly interesting region for descriptive research. The scoliosis prevalence, found in this area was similar to the prevalence reported from other non-industrialized geographical districts of Greece (2.9%), suggesting that industrial pollution does not play a role in IS prevalence [7,8].

Study of national SSS program results. National prevalence of IS and estimation of the number of children who will require conservative or surgical treatment

The results of 17 Greek SSS programs were reviewed and the national scoliosis prevalence was calculated together with estimations on the number of children who eventually will need conservative or surgical treatment.

In 130,689 screened children, where IS was considered when Cobb angle $\geq 5^{\circ}$, the IS prevalence was 4.9% and in 85,210 children where IS was considered when Cobb angle $\geq 10^{\circ}$ IS prevalence was 2.9%. The right thoracic curves predominated. Among the total sample of 215,899 children, 7965 were identified with IS; 4.5% of them were treated conservatively while 0.19% of them were treated surgically [9–12]. From data of the 1998 Greek national census, the children population aged 8–14 years old numbered 751,000. With the above-mentioned datum and with a national scoliosis prevalence of 2.9% (Cobb angle $\geq 10^{\circ}$), it is estimated that 21781 children would be diagnosed with IS. According to the treatment indications for IS, 980 (4.04%) of Greek scoliotics would need conservative treatment, while 41 (1.88%) children would need operative treatment [9] (Figure 1).

Aetiological studies originated from school screening referrals

The cause of IS in humans remains obscure and probably multifactorial. At present, there is no proven method or test available to identify children or adolescents at risk of developing IS or identify which of the affected individuals are at risk of progression. Reported associations are linked in pathogenesis rather than aetiologic factors. A number of suggestions concerning its aetiology have been proposed including neuromuscular, connective tissue structure, vestibular dysfunction, melatonin levels, platelet microstructure, mechanical, growth related and developmental, asymmetry in the brainstem, genetic factors, equilibrium dysfunction and impairment of proprioception leading to the idea that a disturbance of postural control [1,30], but no single factor has been identified so far. Many authors suggest that a relation exists between the origin of scoliosis and balance troubles. Visual impairment has been shown to increase the prevalence of idiopathic scoliosis in human subjects when compared to the prevalence of the general population [13–18].

Why the prevalence of IS is reported differently in the peer-review published papers

The prevalence of IS is reported differently in different countries. In northern geographical lati-

Table I. The number of the scoliotic children depending on the size of the Cobb angle.

			Cobb angle									
			10–19°				20–40°					
			Male		Female		Male		Female		Scoliotic children	
			Left	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*	*Right*	Count	*% within curve*
Type of curve		DB	5	2	6	10			2	5	30	33.3
		L	5	1	5	2		1	3	1	18	20.0
		T	3	3	3	6				2	17	18.9
		TL	3	4	8	8			1	1	25	27.8
	Scoliotic children	Count	16	10	22	26		1	6	9	90	
			26		48		1		15			
		% within sex & Cobb angle	28.9		53.3		1.1		16.7			100

Table II. The steps of detecting and treating scoliotic children at Thriasio Pedio.

	Screened population	Children referred for further examination at Hospital (referrals)	Children who were finally examined at outpatients at Thriasio General Hospital	Children referred for radiological examination	Scoliotic children followed up	Scoliotics treated with Boston brace
Girls	1533	170	115	77	48	15
Boys	1506	92	63	41	26	1
Girls/Boys ratio	1.01	1.84	1.82	1.87	1.84	15
Total	3039 (100%)	262 (8.6%)	178 (5.8%)	118 (3.9%)	74 (2.4%)	16 (0.5%)

tudes the prevalence is higher than those of southern countries (Finland 9.2%, Greece 2.9%). Furthermore, age at menarche, which is considered a reliable prognostic factor for IS is also reported differently in various geographical latitudes. A study on epidemiological reports from the literature was conducted to investigate a possible association between the prevalence of IS and age at menarche among normal girls in various geographic latitudes. Twenty peer-reviewed published papers reporting IS prevalence and 33 peer-reviewed papers reporting age at menarche in normal girls from most geographic areas of the northern hemisphere were retrieved from the literature. The regression of prevalence of IS and age at menarche by latitude was statistically significant ($p < 0.001$) and were following a parallel declining course of their regression curves, especially in latitudes northern than 25°. Late age at menarche was parallel with higher prevalence of IS [19].

Geography may play a role in the pathogenesis of IS, as it appears that geographical latitude which differentiates the sunlight, influences melatonin secretion and modifies age at menarche, which is associated to the prevalence of IS. Puberty appears later in girls that live in northern latitudes and thus prolongs the period of spine vulnerability while other pre-existing or aetiological factors are contributing to the development of IS [19]. Later Montanaro et al. and Suh et al. referred to these new concepts [20,21].

IS prevalence in blind females and the role of different age at menarche

The hypothesis that light is implicated as an important factor in the modulation of IS prevalence is a major factor in the investigation of scoliosis prevalence in blind girls. The prevalence of IS in blind women in Greece is 42.3%, while the prevalence in the general population in the same regime is 2.9%. Blind women had a later age of menarche (13 versus 12.58 yrs) compared with normal girls. The postural aetiology of scoliosis in blind people has been reported. There may be a possible role of light in association to melatonin production, age at menarche and high prevalence of scoliosis in blind women. It could be hypothesized that the levels of melatonin in blind women causes delayed sexual maturation and render the growing immature spine of these women to longer exposure, until maturity, to detrimental causative factors of scoliosis, leading to the increased reported prevalence of IS [22].

The role of melatonin in the pathogenesis of IS

Melatonin may play a role in the pathogenesis of scoliosis (neuroendocrine hypothesis) but at present, the data available cannot clearly show the role of melatonin in producing scoliosis in humans [22,23–30]. The biological relevance of melatonin in IS is controversial because: (a) No significant decrease in circulating melatonin level has been observed in a majority of studies, (b) experimental pinealectomy did not lead systematically to a scoliosis in all pinealectomized chickens, and (c) melatonin injections in pinealectomized animals did not always prevent the formation of scoliosis.

Melatonin acts in gonads indirectly, reducing the secretion of gonadotropines and mainly LH. The menarche is related with episodic secretion of LH during the night. Melatonin may play a role in the timing of puberty, and the onset of puberty in humans may be related to the decline in melatonin secretion that occurs as children grow. Late age at menarche is noted in northern geographic latitudes and in Inuits (Eskimos). The age of menarche decreases as the latitude is approaching the 30–25°, and then it increases again. The amount of sunlight and the quality of light may play a major role for the different initiation of menses in above-mentioned latitudes. Probably the increased levels of melatonin in countries with poor light environmental conditions, as in northern countries reduced the secretion

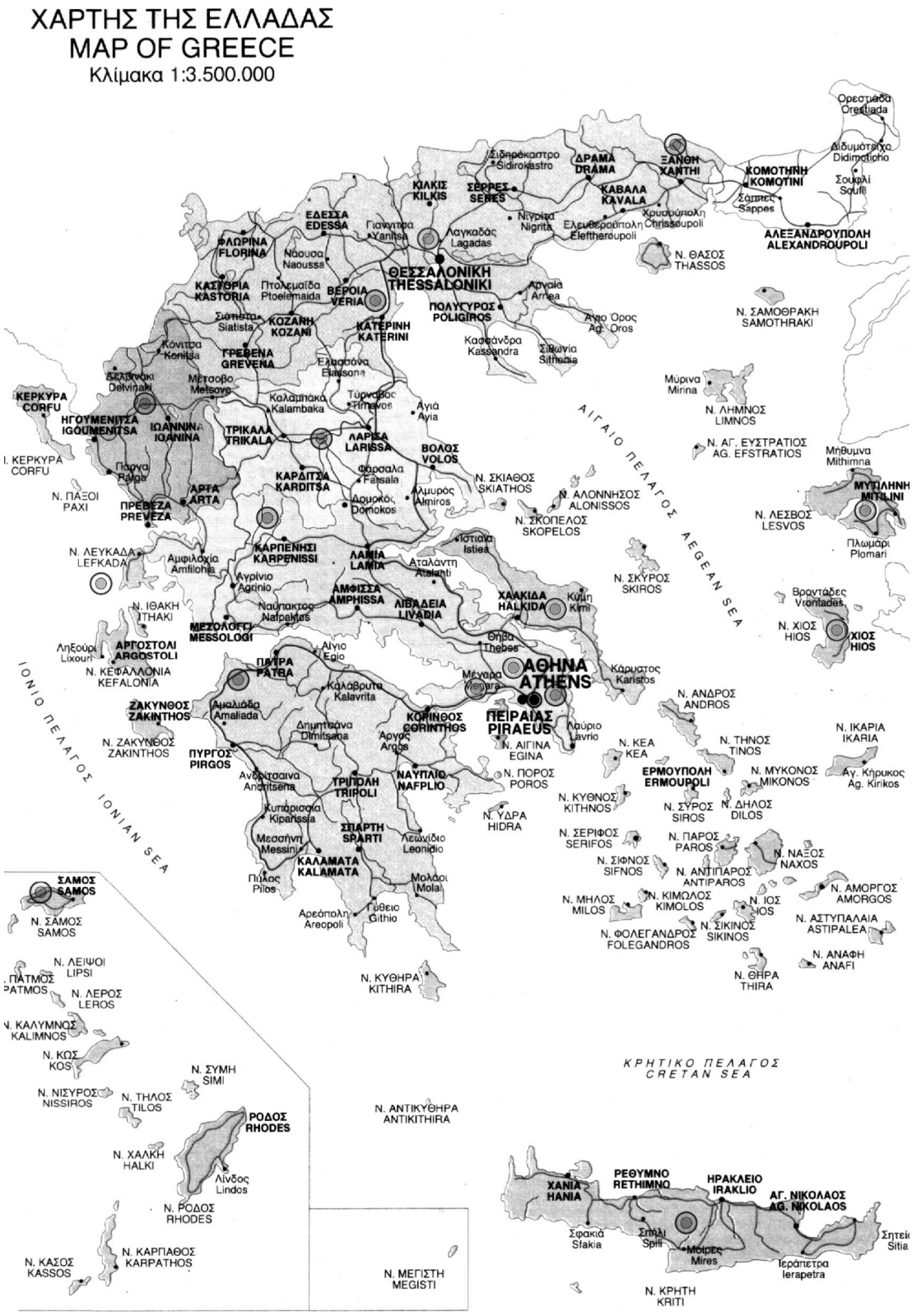

Figure 1. Map of Greece. Circles shows the regions were school screening programs were performed, as well as the total number (n) of participated children. The percentage of scoliosis is reported in parenthesis. Scoliosis was defined when Cobb angle $> 5^\circ$ for the 85,210 examined children in some school screening programs. More recently and according to SRS, scoliosis is defined when the Cobb angle of a lateral spinal curvature is $> 10^\circ$. (Athens $n = 3494$ (5.7%, Cobb $> 10^\circ$), Evia $n = 9537$ (9.5%, Cobb $> 5^\circ$), Chios $n = 4206$ (3.6%, Cobb $> 5^\circ$), Mitilini $n = 5380$ (4.1%, Cobb $> 5^\circ$), Samos $n = 2700$ (5.46%, Cobb $> 10^\circ$), Thessalia $n = 38{,}044$ (1.1%, Cobb $> 10^\circ$), Larissa $n = 22{,}148$ (2.7%, Cobb $> 5^\circ$), Epirus $n = 21{,}415$ (3.2%, Cobb $> 10^\circ$), Aitoloakarnania $n = 16{,}743$ (1.7%, Cobb $> 10^\circ$), Ionia Islands $n = 6699$ (1.1%, Cobb $> 10^\circ$), Patra $n = 10{,}000$ (2%, Cobb $> 10^\circ$), Thessaloniki $n = 7658$ (6.96%, Cobb $> 5^\circ$), Hemathia $n = 12490$ (7.12%, Cobb $> 5^\circ$), Xanthi $n = 26{,}612$ (2.7%, Cobb $> 5^\circ$), Crete $n = 21{,}220$ (1.7%, Cobb $> 10^\circ$), "St Sofia" Hospital, Athens $n = 3922$ (2%, Cobb $> 10^\circ$), Attica Thriasio Pedio $n = 3631$ (2.9%, Cobb $> 10^\circ$).

of LH and causes delayed age at menarche. The elevated levels of melatonin may also explains the inhibition of ovulation in the Inuits (Eskimos) during the months of winter night period [19,31].

Melatonin may play a role in the pathogenesis of scoliosis. It could be hypothesized that the levels of melatonin in females in northern latitude, causes delayed sexual maturation and render the growing immature spine of these women to longer exposure, until maturity, to detrimental causative factors of scoliosis [32].

Is the menarche in scoliotics and non-scoliotics different? Is there any relation between menarche and laterality of scoliotic curves? Studies in scoliosis school screening referrals

It is reported in the literature that the menarche in scoliotics appears later that in non-scoliotic girls. Given that there is a variety of a reported figure for age at menarche at different geographical latitudes, the above statement is rather inaccurate. In a study of Mediterranean girls there was not a statistically significant difference of the age at menarche between scoliotic and non-scoliotic girls [33]. However there was a significant difference between menarche positive and menarche negative scoliotic girls in relation to the laterality of scoliotic curves: The former showed predominantly right-sided primary curves, while the latter had mainly left-sided primary curves, patterns reflecting a developmental theory of scoliosis. This observation, which was implicating the aetiological role of age at menarche and laterality of the curve, would not be possible to be assessed without running a SSS program, and especially without screening younger children [33]. This new observation was referred later by Burwell, Guo et al. and Raggio [1,34,35].

The brain: Trunk asymmetry and handedness. Studies in scoliosis school screening referrals

A study was conducted to find out a possible correlation of trunk asymmetry assessed with a scoliometer and lateralization of the brain as expressed by handedness in a school-aged population. A total of 8245 students (4173 girls and 4072 boys), 6–18 years of age were examined. A checklist was completed for each student including handedness and trunk asymmetry. The standing forward bending test was performed using the Pruijs scoliometer and the examined children were divided into three groups for each of the three examined regions (mid-thoracic, thoracolumbar and lumbar) according to the recorded asymmetry (no asymmetry, 2°–7° and more than 7°). A total of 91% of children were right-handed, while 9% were left-handed. A significant statistical correlation of trunk asymmetry and handedness was found both in boys and girls in the group of asymmetry 2–7° at mid-thoracic ($p < 0.038$), but not at thoracolumbar and at lumbar region. These findings showed that there is significant correlation of mild mid-thoracic asymmetry and the dominant brain hemisphere in terms of handedness, in children who are entitled at risk of developing scoliosis. These findings were implicating the possible aetiopathogenic role of cerebral cortex function in the determination of the thoracic surface morphology of the trunk [36,37]. Kouwenhoven et al. later commented on this observation [38].

The thorax: The double rib contour sign. The role of thoracic cage in the aetiology of IS. Studies in scoliosis school screening referrals

All lateral spinal radiographs in IS show a double rib contour (DRC) sign of the thoracic cage, a radiographic expression of the rib hump (Figure 2). A study was conducted to assess this DRC sign in IS children with 10–20° Cobb angle and to examine whether in IS the deformity of the thorax or that of the spine develops first.

The radiographs of 133 SSS referrals, 47 boys and 86 girls, with a mean age of 13.28 and 13.39 years old, respectively, were studied. The Cobb angle and DRC sign were measured. For quantification of the DRC sign, the 'rib index' was defined as d1/d2 ratio, where d1 expressed the distance from the most extended point of the most projecting rib contour (RC) to the posterior margin of the corresponding to that point vertebra, and d2 the distance from the posterior margin of the same vertebra to the most protruding point of the least projecting RC (Figure 2). According to statistical analysis there was no correlation of the Cobb angle to the 'rib index' of thoracic, thoracolumbar and lumbar scoliosis. The DRC sign was present in all referrals and scoliotics. The DRC sign results primarily due to rib deformation and secondarily to vertebral rotation, because DRC sign could be present in straight spines with no vertebral rotation. In all our school-screening referrals (having ATI $\geq 7°$) the thorax deformity, in terms of the DRC sign, had already been developed. Seventy percent of these children were scoliotics. The rest had a curvature of less than 9° of Cobb angle (10%) or they were children with straight spines (20%) who were followed up due to the existing rib hump. The non-scoliotics were 1.5–2 years younger than the ones who had already developed scoliosis, and they had both approximately a 'rib index' of 1.5. The DRC sign was present in all referrals. In contrary there was no scoliotic spine without it, as the DRC sign is always present in scoliotic lateral spinal radiographs with no exception.

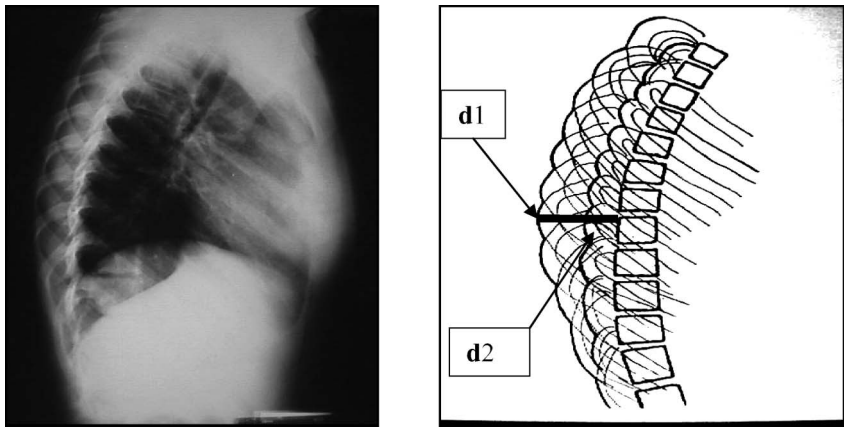

Figure 2. The double rib contour sign (DRCS) and the rib index. A drawing of a lateral spinal radiograph describing the rib-index is depicted. d1 expresses the distance between the most extended point of the most projecting rib contour (RC) and the posterior margin of the corresponding to that point vertebral body. d2 expresses the distance between the posterior margin of the same vertebral body and the most protruding point of the least projecting RC. *The rib-index* is the ratio d1/d2.

This observation supported our hypothesis that in IS the deformity of the thorax develops first and the deformity of the spine follows.

The clinical implications of this hypothesis, which was augmented by the findings of our study related to the role of intervertebral disc in mild scoliosis [56], were related to the conservative treatment of IS using braces. Brace's action on the ribs effectively corrects the deformity, prevent further deformation and alter the natural history of conservatively treated idiopathic scoliotics. The importance of the rib cage is also highlighted in the follow-up of younger operated (fused and instrumented) scoliotics in whom the surface deformity (thoracic deformity) is re-appearing. The rib hump is not wholly a secondary effect, as the ribs are themselves asymmetric and the hump may continue to increase, especially in immature patients even following a secure surgical spinal fusion [39]. This phenomenon is well documented, and this implies also that the deforming forces are still working after the operation and especially on the thoracic cage [39–42].

The authors postulated that the central axis (spine) fusion is not addressing the total deformity problem of scoliosis, but partially, straightening only the spine [43]. Later Burwell et al., Sucato et al., Weiss, and Campbell and Smith referred to these ideas and their clinical implications [44–48].

The thorax: The rib cage deformity in mild scoliosis compared with normals. Studies in school screening referrals

It has been reported that rib vertebra angles (RVAs) is an expression of the resultant muscle forces, which act on each rib. It was also suggested that RVA asymmetries by weakening the spinal rotation-defending system were aetiological factors for IS [49]. A study was carried out that showed that scoliotic children with small curves had under developed thoracic cage compared to non-scoliotic counterparts. The differences were more apparent in the scoliotic children with thoracic curves. It was suggested that the differences of the RVAs between right and left side in this group were an expression of asymmetric muscle forces acting on the thoracic cage. It was concluded that asymmetric muscle forces participate in the pathogenesis of IS on the thoracic cage, which early deforms. It was believed that an extraspinal factor, for instance asymmetric muscle forces precede and then the curve formation initiates and possibly progresses. It is noteworthy to mention the disclosure of asymptomatic underlying syringomyelia in cases with idiopathic thoracic scoliosis [50]. Asymptomatic neurologic abnormality may exert asymmetric forces on the spine. These forces are transmitted to spine mainly through the ribs. After the curve becomes structural, other factors may contribute to further deterioration of the deformity [49–51].

The spine: The role of the later spinal profile in the aetiology of IS. Studies in school screening referrals

A study was carried out addressing the problem whether the sagittal shape deformity or the lateral spinal curve (scoliosis) comes first. It is evident from this report that hypokyphosis is not a predisposing factor of the commencing of small scoliotic curve because there was no difference of the lateral spinal profile (LSP) in these curves with the LSP of the respective curves of their healthy counterparts [52]. The minor hypokyphosis of the thoracic spine and its minimal differences observed in the studied small curves when compared with the non-scoliotics in the

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 pathogenesis of IS [52–54] (Figure 3). Mauricienė and Bačiulienė later referred and commented on this hypothesis and idea [55].

The role of intervertebral disc in IS pathogenesis

A study was conducted for investigation of the deformation of the intervertebral disc. In the standing posteroanterior X-rays of 92 scoliotic curves, the following readings were obtained: Cobb angle (CA), apical vertebral rotation (AVR), apical vertebral wedging (AVW) and the adjacent to the apical vertebra upper (UIVDW) and lower (LIVDW) intervertebral discs wedging. Both thoracic and lumbar CA regressed statistically significant with lumbar LIVDW, lumbar UIVDW, thoracic LIVDW and thoracic AVW. Lumbar LIVDW correlated statistically significant with thoracic CA, lumbar CA and thoracic LIVDW [56].

The eccentric intervertebral disc in the scoliotic spine, through variation in its water concentration (through the asymmetrically imbibed water, with the so called Gibbs-Donnan mechanism) produces asymmetrically cyclical load during the 24-hour period and an asymmetrical growth of the vertebral body (Hueter-Volkman's law). The statistical analysis revealed that AVW appears later when already CA increases, the IVDW is more important than AVW and the LIVDW, which is greater than UIVDW, is the most frequent correlated radiographic parameter. The spine is deformed first at the level of the IVD, due to the increased plasticity of the IVD, in the way of either torsion or wedging, as an expression of other initiating factors that may result in IS. The deformation of the apical intervertebral disc seems to be an important contributory factor in the progression of a scoliotic curve [56].

The clinical implications of the above observation could be associated with the night-time brace treatment. The beneficial effect on scoliotic curve correction of this conservative treatment could be attributed on the following described mechanism. The nighttime brace correcting or overcorrecting the mild or moderate scoliotic curve, simulating gravity, acting also on the apical and adjacent wedged IVDs, reduces the asymmetrically imbibed water (greater amount in the convex side rather that in the concave). Therefore the diurnal variation in the water content of IVD is functioning under more normal conditions. The convex side of the apical IVD, which has now been corrected by the action of the nighttime brace, sustains no further greater amount of expansion than the concave side (stopping the asymmetrical application of Hueter-Volkman law) reversing the deleterious described hypothesis of progression of IS curves and consequently the growth of the apical and adjacent immature vertebrae turns more normal, in a close to normal biomechanical environment [56].

IS and cavus foot. Studies in school screening referrals

It is well known that in a number of certain neuromuscular diseases cavus foot and scoliosis are presented together. Having in mind this observation many authors studied the relationship between foot morphology (especially pes cavus) and scoliosis, as it is thought these pathologic conditions may share a common origin. All of them pointed out that there is such a relationship and also that patients with scoliosis are more likely to have cavus foot than the people without scoliosis [57].

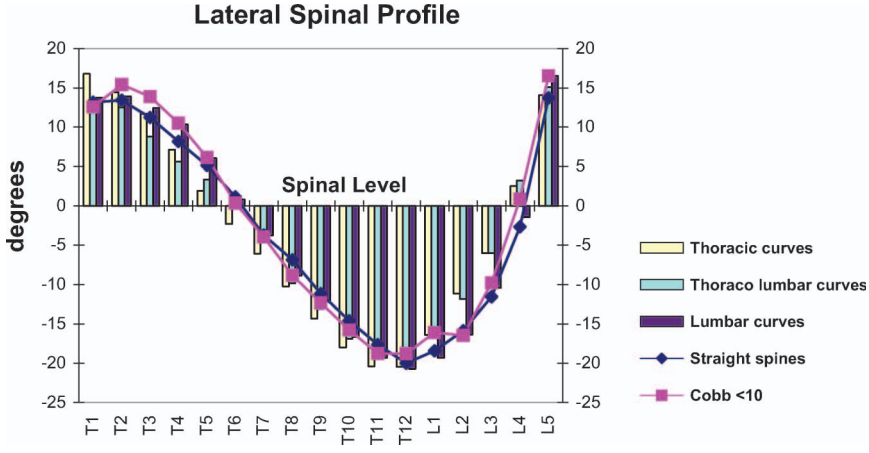

Figure 3. The Lateral Spinal Profile for the various groups of children, boys and girls. Yellow bars = thoracic curves, azure bars = thoracolumbar curves, mauve bars = lumbar curves, line with blue diamonds = straight spines, line with red rectangles = curves with Cobb $< 10^{\circ}$. (See online for the colour version of this figure.)

The authors investigated whether there is such a relationship in a large Greek children population derived from the SSS program. The significant correlation between IS and cavus foot as it has been reported elsewhere was not verified in our study. On the contrary, it was emphasized that the percentage of cavus foot was traced higher in the general healthy population than that in the small and moderate scoliotic curves studied [58].

It has also been reported that the scoliotic patients present increased joint laxity [59], which may predispose in flat foot rather than in cavus foot. This issue was also examined in the above study. Only three children were found to suffer flat foot among the 53 scoliotics. These findings do not support the former view [58].

Somatometric data resulted from the study of school screening data

A variety of findings regarding the stature and weight of IS children has been published. In a Mediterranean study sample of population, the somatometric parameters of height and weight in children with scoliosis, regardless of curve type and site were not statistically different from their non-scoliotic counterparts [60].

Suggestions for a more efficient screening

The scoliometer readings in both standing and sitting positions of 2071 children and adolescents (1099 boys and 972 girls) aged from 5–18 years old were studied. ATI was measured, in order to quantify the existing trunk asymmetry. Children and adolescents were divided in two groups with asymmetry 1–6° and $\geq 7°$ respectively. Some 67.06% of boys and 65.01% of girls were symmetric in the standing screening position while 76.5% of boys and 75.1% of girls were symmetric in the sitting position. A total of 3.23% of boys and 3.92% of girls had an asymmetry $\geq 7°$ in the standing and 1.62% and 2.21% in the sitting forward bending position. From the above study it was concluded that the sitting position is the preferred screening position for examining the rib or loin hump during school screening, as it demonstrates the best correlation with the spinal deformity, exposing the real trunk asymmetry [61]. Later Kotwicki et al. stated that back asymmetries in children can be successfully measured in the sitting forward bending position [62]. Sitting forward bending, providing more stable posture and eliminating lower limbs discrepancy, may be considered a recommended position for scoliosis exam using scoliometer or surface topography [61,62].

Idiopathic scoliosis natural history study

In a 5-year prospective study on IS, an attempt was made to elucidate the natural history of the disease and to determine which factors contribute to curve progression. A total of 85,622 children were examined for scoliosis in a prospective school screening study carried out in north-western and central Greece. Curve progression was studied in 839 of the 1436 children with IS of at least 10° detected from the school screening program. In a 3.2 years mean follow-up, progression of the scoliotic curve was recorded in 14.7% of the children. Spontaneous improvement of at least 5° was observed in 27.4% of them, with 80 children (9.5%) demonstrating complete spontaneous resolution. Some 18% of the patients remained stable, while the remaining patients demonstrated no significant changes of less than 5° in curve magnitude. A strong association was observed between the incidence of progression and the sex of the child, curve pattern, maturity, and to a lesser extent age and curve magnitude. More specifically sex (girls); curve pattern (right thoracic and double curves in girls, and right lumbar curves in boys); maturity (girls before the onset of menses); age (time of pubertal growth spurt); and curve magnitude ($>$ or $= 30°$) were associated with a high risk of curve progression. On the other hand, left thoracic curves showed a weak tendency for progression. In conclusion, the findings of the study strongly suggested that only a small percentage of scoliotic curves will undergo progression. The pattern of the curve according to curve direction and sex of the child was found to be a key indicator of which curves will progress [63].

The aim of school screening based on the reported research

The goal of SSS is to detect scoliosis at an early stage when deformity is likely to go unnoticed and when there is opportunity for a less invasive method of treatment, or less surgery, than would otherwise be the case [64–67]. The present study provides an additional, different perspective of SSS, which is considered a research tool for IS aetiology. The SSS as a research tool is more efficient than single epidemiological studies, because it involves the whole population at risk, it is simple and can be performed in a rather economical mode, in contrary to other conditions where the cost of screening is enormous and therefore the only realistic approach for research is through epidemiological studies.

In a previous study, Grivas et al. reported that the economic information which should be used to estimate the cost of SSS programs should be the

direct cost and not the subsequent expenditures of follow-up, radiographs and treatment [68]. Therefore, the true cost of SSS programs is significantly low, while the benefits are meaningful.

What in reality the SSS program is doing, using the scoliometer or any other surface measuring devices, is sorting out children with surface and mainly thoracic surface deformity. It is not sorting out the scoliosis itself. Now, it is definitely ruled out that the surface deformity is not predicting accurately the scoliosis, especially in younger children [69]. Bunnell characteristically stated that it has become apparent from many reports that although there is a significant correlation between clinical deformity and radiographic measurement, the standard deviation is so high that it is not possible to reliably predict the degree of curvature from surface topography in any given patient by any technique [3]. It has also been reported that in typical screening settings where the prevalence and Positive Predictive Value are relatively low, for every curve $> 10^{\circ}$ detected, there are 1–5 false positives; and for every curve $> 20^{\circ}$ detected there are 3–24 false positives [3,4,66,67]. The above described phenomenon of over-referrals from the school screening programs is the cause of the burden and of the ongoing controversy over its application.

Therefore it must be widely accepted that with SSS programs, a chance is mainly given in the school-aged population to select not only children who have to be at risk, but also younger individuals who are entitled (due to surface asymmetry) to be at risk for scoliosis development. Consequently SSS is not only discovering children who definitely have scoliosis, based on a significant surface deformity, justifying the central axis (that is the spinal) deformity.

Additionally, it must be highlighted and clearly understood that the SSS programs identify the surface deformity and/or the existing number of IS cases among school-age children. It cannot predict which scoliotic curves will progress beyond a certain degree and will eventually need conservative or surgical treatment. The criteria used to predict progression of a small or moderate scoliotic curve are unfortunately not related to school screening programs. Therefore, all the asymmetric children who will be entitled to develop scoliosis will miss the opportunity to be picked up and they will probably be discovered when the only treatment option will be surgery. As it is expected, the outcome will be especially worse in poor societies.

Conclusion

In conclusion, the present study summarizes the contribution of SSS in the research of IS aetiology. Numerous factors that were implicated into IS aetiology were studied throughout the data which were collected from SSS programs. The role of biological factors such as the menarche, the lateralization of the brain, the handedness, the thoracic cage, the intervertebral disc, the role of melatonin, were studied in children referred from school screening. Moreover, the role of environmental factors such as the light, the impact of the geographical latitude in IS prevalence and its association with age at menarche were detected through reports from school screening programs. School screening should be adopted by policy-makers, because its aim goes beyond the identification of IS at an early stage, contributing significantly in research for IS aetiology.

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