Journal of Orthopaedic Science and Research

Open Access

Data Article

An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors

Alessandro Mariani[1*]

[1]Degree in Motor Science, University of Genoa, Italy

[*]**Corresponding Author:** Alessandro Mariani, Degree in Motor Science, University of Genoa, Italy; Email: alessandromari2004@libero.it

Received Date: 01-06-2022; **Accepted Date:** 28-06-2022; **Published Date:** 07-07-2022

Abstract

Moving on an evolutionary sight, this article individualizes three basic human causative factors in adolescent idiopathic scoliosis developing inspiration, bipedal locomotion and lateralities. The integrative approach considers the neuromechanical coupling in respiration, introducing the concept of pneumofascial competition (section one) as the loop that occurs between inspired air and pleural fasciae and then global myofascia. Affordances (possibilities) and constraints of respiratory system match positions and movements of whole body, where the links between spine and periphery (limbs and head) play a determinant part: these connections, the one that involves the spinal transverse plane, are worked out in section two. Therefore, section two appears a decisive step in trying to solve some questions about human bipedal locomotion and its proficiency, again in a neuromechanical coupling view, with totally original considerations about the role of scapula and about the spine as a treble torsion spring. Finally, it is possible to trace out a new adolescent idiopathic scoliosis etiology (section three), adding a third factor: laterality. What is only human is the hyper stressed lateralization (s) by means of cultural requirements. The motor hyper specialization is another form of energy saving (automatism). Thus, all the article is about the evolutionary principle of costs minimizing. Adolescent idiopathic scoliosis is here seen as an evolutionary mismatch disease between human nature and human culture and every curve can be explained in an integrative way, where causes and effects develop a mutual self-powering cycle.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

Keywords

Inspiration; Human Bipedal Locomotion; Laterality; Scapula; Adolescent Idiopathic Scoliosis Etiology

List of Abbreviations

AIS: Adolescent Idiopathic Scoliosis; APA: Anticipatory Postural Adjustments; CKC: Closed Kinetic Chain; CPGS: Central Pattern Generators; D LB-R C: Deep Lateral Bending-Rotation Coupling; DM: Deep Multifidus; DMD: Duchenne's Muscular Dystrophy; EIM: External Intercostal Muscles; EMG: Electromyographic; ES: Erectors Spinae; HBL: Human Bipedal Locomotion; IS: Idiopathic Scoliosis; ISB: International Society of Biomechanics; LD: Latissimus Dorsi; PM: Pectoralis Maior; QL: Quadratus Lumborum; SM: Superficial Multifidus; SPI: Serratus Postero Inferior

Introduction

Starting from the Nottingham concept of "vicious cycle" till the recent "multifactorial cascade concept", in the studies about Adolescent Idiopathic Scoliosis (AIS) it is generally accepted that the actors in play are several [1-7]. The latest researches are more and more addressed to genetic and epigenetic factors [2,3] regarding heritable factors less or more and earlier or later expressed. It seems correct, therefore, to debate about a familiar predisposition, but predisposition is not condemnation, therefore this seems not to be a strictly causative factor [8-10]. This article points out the presence of a motor loop that is able to explain the scoliotic curves at every level of spine, only considering three basic phenomena:

1. Inspiration act and how it can be organized
2. Connections between limbs movements (or assumed positions of the limbs) and spinal motion on the transverse plane, justified by gait evolution in a phylogenetical sight
3. The specialized behaviours of human motor system known as laterality and how these behaviours influence the expression of inspiratory act and the subjective posture forming. These three factors must be seen in a way where causes and effects change continuously in a circular way with a self-powering result

This is the meaning for a cycle which can become vicious and lead to spinal deformities, but which remains in a physiological range in the majority. In section one it will be briefly introduced the concept of "pneumofascial competition", considering the most basic and repeated act of life (inspiration act) in which it is possible to find a basic loop between air necessity and affordances or constraints of whole human fascial system, with consequences on

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

lungs formation (variability of pleurae compliance). Then, in section two, it will be treated the strict motor connections between limbs and vertebrae, introducing the meaning of Deep Lateral Bending-Rotation Coupling (DLB-RC), coming from Human Bipedal Locomotion (HBL). In section three it will be explained how the peculiarity of human laterality enters in loop with the two preceding factors, drawing an original and rational pathway able to explain all different AIS, considering always the same three factors, only these three factors, for every curve: it will be explained how connections between human nature and human culture, at certain conditions, can provoke AIS, in terms that an evolutionary scientist could name as “mismatch disease”. This perspective implies new insights, not only about rehabilitation approach, with potentially more powerful and careful exercises than the existing ones, but even about an increased possibility of prevention, particularly in the delicate developmental age. Finally, the connections limbs-vertebrae can interest men and women of science who try to solve some unknown links to explain the so-smooth and so-efficient mechanism of HBL in walking and running and its uniqueness, with heavy implications about gait evolution.

Discussion

Section One- The basic inspiration act linked to affordances and constraints offered by global fascial system: Concept of ‘pneumofascial competition’

The interactions between the global myofascial design and the different inspiratory muscles can conduct to reconsider the concept of breathing kinetics, deciding not to stop at the classical differentiation between principal and accessory inspiratory muscles, but rebuilding the opportunities of breathing, where the assumed position (or the movement) is a constraint for some inspiratory muscles and, at the same time, an affordance (here the meaning is ‘opportunity’) for others (pneumofascial competition). What it is interesting, at the end, is how visceral pleurae change (and therefore how posture changes). Since the early moments of life, humans breathe. Chemical-physical shock, caused by air contact, stimulates the nervous respiratory centres and phrenic nerve. Diaphragm starts its work. It is the first moment of competition between the inspired air internal pressure and connective tissue, globally intended. Upon this basic biological mechanics, every motor act will be gradually learned. If rest frequency of inspiratory act is 15/min (in early childhood over 20/min), in one hour it is 900/min and in one day 21600. It is possible to say about 20000 because, in non-REM phases of sleep, there is a sensible decrease (but, during the day, some actions induce augmentation). This number well represents the strength of “the” act, in terms of load law. Humans, as any other biological organism, respect the law of surviving. For essentially aerobic organism this means the need of air insufflating. It is possible to investigate in which ways the breathing act works in different postures. A study of evaluation of diaphragm mobility by Yamaguti et al. [11] reports the greater excursion of right hemidiaphragm in right decubitus and this is

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

consistent with the idea of fascial interactions, here with myofascial structure named 'lateral line' by Myers that, being more stretched on right side in right decubitus, allows the right hemidiaphragm excursion express itself more than it can in left decubitus, where the right myofascial lateral line is more shortened [12]. Another study reveals how the recruitment of levator costae muscles changes in presence of a lateral bend: a contralateral flexion of thoracolumbar spine increases EMG activity of levator costae muscles in concave side while ipsilateral flexion decreases it (in convex side); moreover it is useful to study inspiratory accessory muscles from a quantitative point of view: during an increasing effort which are their sharing plays (with same posture)? [13]. The resting breathe kinetics during inspiration is generally accepted as something that involves, above all, diaphragm and External Intercostal Muscles (EIM). Levatores costae muscles and iliocostalis (lumborum, dorsi, cervicis) often are not cited. Then there are other accessory ones: scalene muscles, serratus anterior, serratus postero superior (Serratus Postero Inferior (SPI) is not commonly cited among inspiratory muscles but in Busquet, Latissimus Dorsi (LD) in caudal part, Pectoralis Maior (PM) sternocleidomastoid, inphrahyoid and suprahyoid muscles [14]. The studies connecting inspiration and involved muscles analyse when the accessory muscles work. The usual question is: when the respiratory effort increases (augmented energetic requests), at which point of ventilation is the requirement of added muscles necessary (quantitative point of view)? The focus can be shifted to a qualitative sight. In fact, the inspiratory motor pattern is subjective, and it depends on the assumed position, primarily on positions held for a long time (study and work, but also repeated sport movements, if early practised). It means that, for example, in the evolving of a habitus asthenic posture the most important factor is in habits that gradually prevent a normal work of anterior thoracic expansion. The inspiratory function is influenced by forces of anterior closing applied by myofasciae more superficially (anterior positioning of the arms). Consequently, diaphragm is not able to express the increase of antero-posterior diameter of rib cage that would exist bidirectionally in a physiological action. The impediment causes an “air hunger” that the system can solve with the inspiratory muscles that, at these conditions, are able to work. Serratus anterior can become an actor in the play: this is because here it tends losing the adduction-abduction action on scapula and it emphasizes the inspiratory affordance of thorax backwards and to lateral direction. The absence of myofascial constraints of the high dorsum may also emphasize the inspiratory possibilities of serratus postero superior, increasing dorsal kyphosis again (here higher). The vicious cycle causes a gradual hypo functionality of diaphragm: the more involved serratus anterior reduces the range of cupolas movement, because cupolas go towards a major tension latero-lateral with an increase of the relative diameter of low thorax on frontal plane. The forward positioning of the head inhibits the scalenus affordance of inspiration: air cannot push out the anterosuperior pleura because scalene muscles are not able to raise the first two costae (another factor of chest depression). Other back muscles (levatores costae and iliocostalis cervicis and dorsi) concur towards same posture (they can work). The lumbar passive hyper lordosis, with iliac bone in closing position enters in vicious process because its progressive augmentation causes a progressive disfunction

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

of potentiality of diaphragm pillars (they would work provoking lumbar lordosis but here they are not able to work because of short fixation). Quadratus lumborum (QL), iliocostalis lumborum and SPI feel too a short fixation as the caudal part of LD [15]. The superficial PM and the deeper pectoralis minor prevent an anterior expansion of chest with constraints parasternal intercostals leading to a shortening of transversus thoracis muscle and the lower possibility of vertical expansion of rib cage is justified by gradual restrictions on rectus abdominis excursion because of its attachments on 5th rib. The increasing dysfunctionality of diaphragm can exhaust linea alba and compromise the coordination between diaphragm and transversus abdominis (abdominal prominence). The picture is often completed by knees in flexum and valgus and foot in pronus and valgus. The concise analysis of this frequent posture allows to introduce the general idea: already in this part of the script, the concept of cycle appears (vicious or virtuous). Already in the basic act of life, we find a recurrence of mutual causes and effects. The organism inspires air where he can, at the existing conditions: the visceral pleura can assume its compliance, topographically peculiar for everyone, with the possible concurrence of located sensory structures of tension variation in pleura (visceral and parietal). The existence of this kind of sensory structures in pleura (lung stretch receptors) is well known, mediating the Hering-Breuer reflex and the Head reflex [16]. Anyway, it is now considered more probable that afferences are mediated by signals coming from spindles and/or tendinous Golgi organs of which inspiratory muscles are rich and that these signals integrate central commands, introducing the principle of neuromechanical matching as regards the distribution of neural drive to human respiratory muscles [17,18]. In this basic cycle, another important biologic law is clear: economy of effort. When a way of breathing starts to be the usual one, it can be expected it will be confirmed and this will occur because of a gradual adaptation of involved motor units together with a located increase of visceral pleura compliance that decreases the effort of protagonist muscles. The cycle is self-confirming, if air is enough. Here it is talking about inspiratory act because this is “the act” while expiratory act, almost always, is an elastic return of rib cage and thus not crucial. Studies have already reported the idea of a neural drive to inspiratory muscles matched to a mechanical advantage [18,19]. This minimal- work hypotheses to minimize metabolic cost has been demonstrated for EIM (and indirectly for levatores costae) at different interspaces in according with dorsoventral and rostro caudal gradients and for parasternal intercostal muscles too [19,20]. Furthermore, it appears how reduced is the classical difference between principal or accessory muscles; in fact, also in resting breathe, there is activity in scalene and sternocleidomastoid and genioglossus [18,21]. These results confirm that inspiration could be a global wave that travels through all the body from the tongue to the feet, according to the fascial design done by Myers (deep front line): the study by Butler underlies that respiratory drive can be observed in limb muscles under certain circumstances [12,17].

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

Section Two- Spinal motion connected to limbs behaviours: DLB-RC in HBL

Here it will be considered the connections between periphery (limbs) and centre (spine) when the trunk seems not to be involved in any task. For this reason, the implications of this section are directly related to spinal motion during HBL, where, at self-selected speed, there are minimal motions on the transverse plane regarding the iliac and acromial axis, a unique peculiarity even respect to non-human primates that sometimes move bipedally [22,23]. By Witte et al., the overall impression is, especially in comparison with other mammals, that rotations are reduced [24]. It is surprising that connections between limbs and spine, above all regarding the transverse plane, seem to remain a black box, using words as 'poorly understood' [25]. Observations *in-vivo* and palpations of spinous processes on many subjects during last years leaded who wrote this article towards a possible explanation, where it is present again a neuro mechanical matching. Thus, it appears essential to try to establish which is the language spoken between limbs and spine in HBL. In spine, if there is a signal of lateral bending to the right, it is arguable that there is rotation to the left (spinous processes to the right), with the probable aim of distributing the intra joint pressures (joint facets and discs) and potentially favouring an elastic storage. The anatomy of paraspinal muscles (Erectors Spinae, ES) concerns various myofascial structures from lateral ones to medial ones [22,26]. In the most medial and deep ones there are, besides interspinous ligaments and muscles and intertransverse ligaments and muscles, also ligaments and muscles of the transversus spinalis system (semispinalis, multifidus, rotators) which play their smoothly coordinate work, in according to DLB-RC, with the small muscles nearest to the spine which have a higher density of muscle spindles [26]. The medial and deeper part of the so-called ES is biomechanically connected to other more lateral and more superficial muscles as iliocostalis, longissimus dorsi and spinalis in the meaning that a shortening at any level of the more lateral iliocostalis propagates towards the more medial longissimus dorsi and semispinalis and till every structure of intertransverse and transversus spinalis system (in upper thoracic-lower cervical part it will be evaluated too the splenii muscles). It is appropriate to notice that these changes modify inspiration kinetics too, because this implies different affordances for rib cage expansion, in fact the described motion “affects” ipsilaterally levatores costae and EIM too [13,19]. Where are the human “interplays” vertebrae/limbs in HBL? It appears that scapula is the interplay for different behaviours of upper limbs, with located and different influences on lower cervical and thoracic vertebrae. This flat bone allows different pressure at different levels of spine depending on fine motion of arms (human fine handedness). It will be treated the scapula motion considering the anatomical landmarks recommended by the International Society of Biomechanics (ISB), as it is in an article where it is tested that, in presence of forward movement of the arm (shoulder flexion with arm in neutral position), the scapula has an upward motion [27]. From the kinetic results: the inferior angle of scapula goes away from spine, the trigonum spinae goes towards the spine and the acromial angle raises by a global action of the whole trapezius. The kinematics of the medial border of scapula is the key factor to lead to a well located lower or higher

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

pressure on the ES. Where pressure increases there is an increasing of d LB signal, where pressure decreases there is an opposite signal. The cycle (or loop) goes on the transversus spinalis system and, if the right arm raises in the preceding way and left arm is passive, vertebrae from C3 to T4 seem to rotate to the trigonum spinae (mutual approach): spinous apophysis rotate to the right. Vertebrae from T5 to T12 rotate away the inferior angle (mutual distancing): spinous apophysis rotate to the left. The effect is obviously more appreciable if the arms work simultaneously in opposite direction as in HBL. By Abiko, et al., 'The deep multifidus are rich in proprioceptors sensitive to pressure and deviation of the intervertebral joint' [28]. It is important to notice that this specific effect shows itself as regards the simple arm forward elevation without further movements (arm in neutral position) as the opposite effect shows itself in backwards movement (always in neutral position) where the biomechanics effect on inferior angle scapulae is strengthened by LD fibres that cross on the inferior angle, counterbalancing the physiological posterior tilt of it and warranting the adequate pressure on the mid-lower thoracic tract of ES [27]. Further movements change scapula motion and the relationships between medial border of scapula and spine. If right arm raises and goes to an adduction too through PM action, all the medial border goes away from spine and the spine answer will be uniform for all the tracts just seen (all the considered vertebrae rotate in a way that spinous processes go to the left). Here it is determinant to analyse asymmetrical movements (or positions) where the DLB-RC is different for each side and now it is possible to say rationally that asymmetrical conditions lead the spine in a “more lordotic status” together with a “more kyphotic status” at the same spinal level through the d LB-R coupling. More the border of scapula moves, in any directions, more the effect increases (to the right or to the left). Scapula here appears to be a selective vectoral direction exchanger because a mediolateral-oblique strength is translated into a signal for a selective variation of tension of longitudinal muscles. Regarding lower limbs and lumbar zone, the principles are the same. The mechanism is less refined than the scapular one and this is consistent with a minor necessity of fine motion by lower limbs that must warrant stability above all. The lower limb movement (or position) causes an effect on hip joint (well discernible) and on fine sacroiliac joint. It is possible to underline that coupled pelvic and hip flexion and extension are determinant in setting up lordosis and kyphosis of lower spine, as well pelvic motion upon the hip joints in rotation and abduction/adduction influences lumbar and spine movements, with consequences again on DLB-RC system. If there is hip flexion there is the iliac bone in posteriority and this means a global signal of ipsilateral increasing kyphosis (or decreasing lordosis) of lumbar tract regarding the same side, through elongation of sacrotuberous ligament and its strict connection to sacrolumbar fascia [29,15]. By Lee and Vleeming, it is known that the sacroiliac joints warrant 'sufficient flexibility for the intra-pelvic forces to be transferred effectively to and from the lumbar spine and lower extremities', contributing to a kinetic chain and that 'the erector spinae/multifidus is the pivotal muscle group that loads and extends the spine and pelvis' [30]. The lumbar Erector Spinae (ES) undergoes a necessary elongation to let the hip joint flex. In presence of asymmetrical action, as now it is considered, the wave arrives

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

directly to the deeper ES muscle. The lowering of biomechanics pressure on ES chain, respect the contralateral side, causes a rotating effect on lumbar vertebrae: if there is flexion of right hip the lumbar spinous apophysis rotate to the left because right DLB-RC decreases intra joint pressure on the right side and DLB-RC strength of left side wins through a wave that affects iliocostalis lumborum, longissimus, medial and lateral intertransverse lumborum till to involve the transversus spinalis system. There are effects on QL (left shortens), hemidiaphragm (left pillar more lordotic and therefore with reduced range in inspiration), iliopsoas (left elongates) and SPI (left shortens). The opposite effect occurs on right side. At the same spinal level, a different situation of each side is born: one side goes to a “more lordotic status” together with a “less lordotic status” of other side. Leg motion in hip extension increases lumbar lordosis at the ipsilateral side because of asymmetrical movement (or position) and the result ends in vertebrae rotation. If the common last interplay is the ES chain, it is consequent that analogous effect occurs in a hip extra rotation or in a hip abduction, both inducing an ipsilateral increase of lumbar ES tension and then an ipsilateral increasing lordosis. As said about upper limbs movements, the complex hip joint movements can imply too multiple planes of motion and everyone must be considered regarding the described laws. Anyway, for the aim of this script, it is to suggest how the main behaviours of limbs might “talk” to spine motion (intervertebral motion) and how usual positions held for a long time, particularly in developmental age, can affect the human inspiratory expression till to cause strong asymmetries, as it is in scoliosis (see third section). If it is accepted that the proficiency of HBL was a key point for the homo sapiens imposing, it is arguable that the peculiarities here described played a strong part in an evolutionary perspective. The till now accepted theories on HBL imply the concept of legs “inverted pendulum” looking particularly at the limbs that are clearly protagonist in advancing [31-33]. The associated opposite pendulum of the arms was underestimated and only in the latest years studies on EMG of trunk and arms muscles appeared in global analysis of gait, both in walking and running [34]. Anyway, it is still not so clear the real meaning of arms swinging, although different studies demonstrated that, in a condition of inhibition of arms movements, the global energetic cost increases, but from this script it might appear clearer [35-37]. Gracovetsky, proposed 'a challenge to the current thinking' and his evolutionary perspective is summarized in this sentence: 'Locomotion was first achieved by the motion of the spine [38]. The limbs came after, as an improvement, not as a substitute'. The proposal of this script moves towards this direction that is present in Dickinson, et al., in a general evolutionary sight: 'viscoelastic behaviour produces responses to disturbance before the fastest neural reflexes [39]. This prereflexive mechanical feedback provides an additional component that functions in parallel with reflexive neural feedback and feedforward control from motor circuits. These authors used words as 'complementary pathways'. In another article, by Witte, et al., it is reported: 'A torsional twist around longitudinal axis seems to be the most important’, and 'The relative minimum of trunk torsion at energetically optimal speeds indicates an interplay between the trunk and limbs' and even more 'The locomotor meaning of the scapula is usually ignored' [24]. A few studies try to explain the complex role of paraspinal muscles. It was shown

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

that differences exist between Superficial Multifidus (SM) and Deep Multifidus (DM)/rotators [28,40-42]. The DM usually contains a higher percentage of type I fibres respect the SM and this is coherent with the necessity of its continuous rhythmic involvement in HBL [28]. It was shown a temporarily different activation of the two considered structures and DM exhibits a shorter latency in presence of arm movements suggesting a strict connection with the limbs [28]. Furthermore, the studies on Anticipatory Postural Adjustments (APA) reveal differences among paraspinal muscles if the arm moves [40]. Moreover, the SM is sensitive to forward leaning of arm and not to a backward leaning, with the probable aim of counterbalancing the forward variation of body centre of mass, while the DM is sensitive to both directions [28]. Generally, it appears how the DM which connects two-three vertebrae is more refined than SM which connects four-five vertebrae, because of a higher density in DM of muscles spindles [26]. The studies more dedicated to the nervous system in HBL in the latest years are generally shifted to the deepening of the so-called Central Pattern Generators (CPGs) involved in the rhythmical expression of gait and the related modules but it is increasing (and it seems necessary) the hypothesis of an interplay that strictly connects the limbs movement to the spine motion. An evolutionary view seems the most appropriate [43-45]. By Jung and Dasen, 'Both axial based undulatory and limb-based ambulatory locomotion rely on CPGs activity, and there is emerging evidence that limbs CPGs evolved from co-option of pre-existing undulatory motor circuits' [46]. By Murakami and Tanaka, 'Thus, limb muscles and their neuronal inputs appear to have evolved from a subset of hypaxial muscles and their neuronal inputs' [47]. By Lacquaniti, et al., 'The coupling of activation patterns and limb biomechanics then results in balanced net joint torques and smooth movements' [44]. Lacquaniti, et al., underlined the perspective of top-down and bottom-up approaches and Bianchi, et al., wrote ‘one might suggest that the specific tuning of limbs and body kinematics can be used by the nervous system when endurance needs to be maximized' [48,49]. This idea of minimizing metabolic cost as key factor of human evolution is present also in Lieberman who introduced the concept of endurance hunting allowed by a more efficient and economical bipedal gait of humans [50]. Other studies focused on biomechanical aspects and showed very interesting data on angular momentum in HBL, from which it appears an almost total side-to-side balancing that Herr and Popovic refer to be typically human [51]. Other consistent data report the probable metachronal mechanism of spine as inherited behaviours common to preceding species [52]. Now it is possible to try to summarize the preceding cited cues of the literature in consequences about HBL and to indicate possible evolutionary perspectives, following the design till now drawn. Considering one instant of gait cycle where there are clear differences between right and left sides and omitting other aspects as the balancing necessity, it is now possible to argue that at the right “heel-on” moment (and the left “toe-off” moment) there is the maximum of the physiological treble rotation of spine. Regarding the lumbar tract, this implies that right lumbar kyphosis accompanies to left lumbar lordosis with rotational consequences already explained for all the tract with connections that probably are mechanically related to iliopsoas elastic advantage in modulating gait cycle [44,45]. Moreover it is known how the hip extension, during

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

HBL, occurs together with slight hip abduction/extra rotation connected to the hip rotators complex (and iliac bone in active opening position), while hip flexion, in HBL, occurs together with slight hip adduction/intrarotation connected to adductor muscles and iliac bone in active closing position (see Allen and Neptune for this mediolateral module) [45]. Finally it is possible to say that it occurs a considerable alternating stretching-shortening cycle that amplifies the elastic storage in lower part of the body (till to T12, psoas attachments) where it is difficult to distinguish if the pattern generator starts centrally (spine) or in periphery (legs) or if there is a “loop” with signal copies that travel together in circular self-powering way and in which it is difficult also to discern nervous signals from mechanical aspects [39]. Anyway it is useful to notice that the elastic storage affects alternatively all the motor structures from the deepest ones (besides already cited also ES, transversus abdominis, oblique internal, rectus abdominis under arcuate line, QL, SPI, for instance) to the most superficial ones (besides already cited also oblique external, rectus femoris, biceps femoris, soleus, gastrocnemius, gluteus maximus for instance) because of the different situation of iliac bone that is in posterior position on right side together with an anterior position on left side. The analysed moment is obviously only a frame to which another opposite cycle follows, gradually changing the described motion, but with the global advantages coming from the elastic storage and the consequent energetic proficiency until the end of the opposite rotational movement, and so on, where the concept of nervous metachronal wave seems to extend itself at the biomechanical aspects [52]. Now it is necessary to shift the attention on the upper part of the body, considering the interactions between upper limbs and lower cervical-thoracic tract where there are present the other two physiological spine rotations. Coherently with the frame just seen, it is here evaluated the instant of HBL in which the right arm is at the end of backward leaning the instant of maximum left arm forward leaning. The scapular interplay, as already explained, produces a double spinal rotation. It is arguable from several observations that, from T5 to T12, in this situation, the spinous processes are rotated to the right. This is primarily a consequence of the involving of right LD that, intersecting inferior angle of scapula, pushes it toward the spine keeping it in pressure on ES, and so counterbalancing its natural posterior tilt and allowing a right wave on ES from lateral to medial. Trapezius globally elongates while deltoid posterior, teres maior and long head of triceps brachii are the synergic muscles. The selective pressure of scapula affects the T5-T12 tract while on other side (left) there is shoulder flexion with a global action by trapezius that provokes a motion towards the spine of trigonum spinae and away from the spine of inferior angle: the effect is the opposite of the right side one, lessening, in the same tract (T5/T12), pressure on ES from medial to lateral and so powering the rotation of spinous processes to the right; among peripherical synergic muscles there are deltoid anterior, serratus anterior and long head of biceps brachii. What is really noticed it is the opposite rotation that from T4 propagates till C3. At this level the mechanical scapular interplay provokes, at the given conditions, a rotation to the left of spinous processes that propagates till cervical vertebrae because of the strict myofascial connections between rhomboid and splenii muscles. The left rotation of spinous processes from C3 to T4, when left arm acts a forward leaning, is

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

probably caused by a well-located motion to the spine of the trigonum spinae. The fascial connection with splenii affects too semispinalis and cervical multifidus at least till C3 level but with a fine propagation to the head [53], where the splenii muscles involvement assumes a role of counterbalancing an excess of head movements contributing in gaze stabilization. In fact, it is reported in Kunin, et al., that 'the finding that incremental rotations of the head during locomotion were significantly lower than C2 supports the idea that lower vertebrae play a more significant role in moving the head during locomotion' [53]. Now it is possible to argue that regarding the spine, during HBL, there is a treble curvature on frontal plane coupled with a treble rotation on transverse plane. Thus, the spine act as a treble torsion-spring that, in coordination with the limbs and the whole myofascial system, addresses the gait advancing in a unique way among animal kingdom. This whole coordinated motion seems to imply the warrant of alternating, cyclic loads on intervertebral discs with obvious consequences on the health of discs and intervertebral joints. Starting from an evolutionary ancient C-shape escape responses, fishes gradually developed appendages that helped the sinusoidal way of body propulsion [54-56]. Then the amphibians had a locomotion braving the land contact with the first protraction-retraction cycle of pectoral fins on a solid surface, co-ordinated with the side-to-side whole-body bending [56] while snakes crept, maintaining a sinusoidal gait and neuronal modules may have been maintained from the swimming CPGs to the walking CPGs [57-59]. Therefore, the increasing development of limbs (also in reptiles as lizards) seems to have unavoidably evolved from an initial C-shape, where a lateral bending mechanism was fair, towards a multiplanar crossed mechanism that increased the motion affordances and the elastic storage together with a greater energetic proficiency, preserving the mechanism in tetrapods till to quadrupeds' mammals [60]. It is meaningful to report a consideration by Schilling and Carrier, et al., 'Considering its central role in locomotion, it is surprising how limited our understanding of the axial system is compared with our understanding of the limbs'. In the same article, about the evolution of epaxial muscles from tetrapods to quadrupeds mammals, it is underlined how the recruitment patterns in mammals resemble ancestral patterns of vertebrates, with the study focused on multifidus lumborum muscle and the longissimus thoracis et lumborum muscles of dogs. In the quadrupeds, anyway, the coronal plane sinusoid is pre-eminent in walking and trotting and the sagittal plane sinusoid in galloping with the fundamental help of tail and its possibility to increase number of curvatures and spring mechanisms [60]. The non-human primates began to gait sometimes bipedally and gradually lost tail, but the main way of land locomotion was not bipedal (knucklewalking) [61]. Finally, the first hominids appeared with a clear bipedal gait and a more erect posture and the thorax-pelvis out-of- phase phenomenon [23,62,63]. It is not sure that the early bipedal protohominids already had the economical spinal motion of homo sapiens described in this section because of a different shape of rib cage [64,65]. If the motion of spine here described became a homo sapiens peculiarity, it could have played a prominent part in his supremacy, also regarding other contemporary hominins, where a greater global elastic storage could have warranted advantages in hunting, escaping and even in world colonization and imposing. This was

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

possible, together with other important anatomical changes, because of the "discovery" of posterior plane (affordances), that it means the crossed extension of both shoulder and hip joints, not allowed previously [64]. It is possible to say that the three questions done by Witte et al. in their article about HBL (why? why so? why not otherwise?) might find the answers [24]. Together with an out-of-phase pendulum of the limbs that is basic in maintaining stability and advancing, in the depth it occurs a treble spine rotation well located [66]. This treble rotation (torsion springs) is strictly integrated with limbs movements making them less energetically expensive because of the underlined elastic storage that involves every part of the human body by means direct attachments on spine and indirect fascial connections that run all through the system with synergic contributes in advancing [12,14]. The crossed kinetics of HBL, with out-of-phase coordination of limbs, posteriorly seems therefore to rise cranially from the foot (toe-off) through a posterior chain including, among others, soleus, gastrocnemius, biceps femoris till gluteus maximus and QL. Here, at the level of thoracolumbar junction, the wave switches to the other side where it meets the contralateral one coming from upper limb (caudally propagation) above all by means the LD action. The analysed role of scapula warrants the rotation of upper thoracic-lower cervical vertebrae with influences on head. At the same time, anteriorly, it occurs a swing phase during which a cranially directed wave (from tibialis anterior till, among others, rectus femoris, adductor longus, iliopsoas, oblique internal) switches to the other side, trough linea alba and it meets the other wave, caudally oriented. EMG data on human walking and running are coherent with this reconstruction [34]. It is meaningful to notice that the phylogenetical preservation of paraspinal muscles function, is clearly explained too in a study treating the evolution of the axial system in craniates [67]. Anyway, during the long travel to the conquest of a full orthogrady that drove towards the HBL, the transversus spinalis system seems to have added to its role of control and modulation of excessive vertebrae torsion all along body axis the role of essential propulsion system in horizontal advancing, strictly integrated, mechanically and nervously, with limbs [67]. It is important to notice that what it is here drawn can rationally explain the role of arm swinging and why every human begins to run bending his arms. In fact, at higher speed of gait, it is coherent that spine rotations increase and therefore scapula motion increases: the necessity of a greater backwards movement of elbow, involving LD, is solved by the reduction of lever arm of the arm that allows lower energetical cost of LD in posterior movement of the elbow, giving a higher amplitude signal to the spinal transversus spinalis system (in fact this is clearly appreciable in extreme elbow backwards movement of sprint athletes). At the same time it is explained the easier, if requested, head rotation to the side of arm in backwards movement: the caudal coming signal on cervical vertebrae goes towards a rotation to the right if the right arm is going backwards, although the fine human head control permits the opposite rotation too, if the situation of viewing requests it because of any reason, and this is because C1 and C2 vertebrae remain free: the evolutionary perspective, in hunting or escaping, remains preeminent. Another important consequence is about T12 vertebra that seems to feel both more cranial influences (upper limbs) and more caudal influences (lower limbs) and can therefore be

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

named as intermediate vertebra. What is till now reported (sections one and two) can be defined as basic natural qualities of mankind. Then there is cultural influences and it appears clear that, in a so-called civilized society, the lifestyles and the increase of sitting position in working and studying affect the HBL in the meaning of an increasing and worrying loss of extension movements regarding the shoulders and the hips. Anyway the next section starts from all the remarks till now drawn, having to add the analysis of the hyper-repeated and stereotyped acts of the human species with such a developed cortex, such a refined handedness and, finally, with hyper lateralized behaviours as never it happened (and it was not possible to happen) previously in evolutionary history. Now it is possible to suggest an innovative approach to the causes of every curve of the so-called AIS.

Section Three- An original etiology of AIS

All the considerations in this section must connect to the two preceding sections. At the end it will strongly appear the idea about AIS as a much more learned than genetic pathology, in according with the extraordinary peculiarity of human possibility of learning, specializing and transmitting (cultural factors). Therefore, in evolutionary terms, AIS will be a typical evolutionary “mismatch disease” [68]. The laterality phenomenon, which it is generally definable as an asymmetry of motor behaviour (or perceiving process) between the two sides of the body at different levels in acting functions (or in perceiving signals), is already present in previous species [69], but the anatomy and physiology of humans makes the process unique. The statistics already known in literature report a right-hand dominance about 90% and a less strong right leg dominance (in the meaning of leg more skilled): for data see the review in an article by Osborn and Homberger [70]. Homo sapiens is an asymmetric organism respect the organ anatomy, not only because of positioning of unpair organ (liver, spleen, heart) but even considering dimensions of pair organs as lungs, with the right three-lobed lung bigger than the left two-lobed lung. Regarding the spine, it is useful to notice that, at birth, all the vertebrae are rotated to the left, probably as residual of more frequent utero left side lie, and, at the end of spine maturation, the rotation remains generally the same for the cervical and upper thoracic tract and for the lumbar tract, with the early closure of neurocentral junctions of these tracts while the closure in mid-low thorax occurs later and the vertebrae rotation of this tract gradually turns to the right [71,72]. Schlösser, et al., noticed that 'Hueter-Volkmann's law implies accelerated closure of the epiphysis under compression and delayed closure under distractions. Therefore, the changes in the pre-existent rotation and NCJ asymmetry in the immature spine might be caused by another mechanism' [72]. Here it is suggested that the mechanism might be the inspiratory act where it is opportune to consider the coupling of Hueter-Volkmann's law and Pauwels' law [73]. The result for vertebrae shaping in AIS appears to be a pathogenetic pressure on one side that inhibits the enchondral longitudinal growth (Hueter-Volkmann) and on the other side an intermittent pressure (caused by respiration) that stimulates the growth

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

plates (Pauwels). Concordant data on this aspect come from Antoniou, et al., who consider the elevated synthetic activity in convex side in inter vertertebral discs too and Oliazadeh, et al., who consider the impaired mechanotransduction in IS subjects (molecular mechanism) [74,75]. Now it is useful to remember the repeated strength of inspiratory act and the different dimensions and positions of lungs: the right one is bigger and higher, with the right diaphragmatic cupola which has a physiological higher range than the left one, being even tempted to hypothize here that usually the right arm has consequently an easier affordance (less restrictions) in raising and tools manipulating (obviously frontally) and that the dominance handedness forming is more bottom-up than top-down, also considering studies on situs inversus totalis [76-78]. Furthermore, there are clear differences even in utero (probably again because of more time spent on left side lie) with right thumb more often sucked than the left one and right arm moved more, besides the head more often turned to the right [79]. All this loop seems to address to the increase of probability of right handedness. The thoracic spinal co-ordination, during this gradual development of tools handling, is the one described in section two. The tons of repetitions of a peripherical act drives the expression of inspiratory act because of increasing involvement of right EIM and levatores costae together with a decreasing involvement of left ones. Otherwise the diaphragmatic pillars have too an asymmetrical range with the right one more extended (attachments from L1 to L3) than the left one (L1-L2) and this difference seems to be enough to provoke, even though a bilateral lordotic status is present, a greater lordosis on right side than on left one during every inspiratory act. Because of links already explained, this means that the normal fine rotation of lumbar vertebrae towards the left is confirmed and a greater consequent freedom of right hip confirms the right leg dominance, in the meaning of higher range in hip extension, abduction and extra rotation, while the anatomic fascial connections of the pillars with iliopsoas (anteriorly and medially) and with QL (posteriorly and laterally) explains the influences till to T12. The left cervical-upper thoracic tract rotation is confirmed by the more frequent right arm dominance with the consequences caused by fine interplay of scapula motion on spine. At these conditions, it appears that the inspiration motor expression, considering the handedness and footedness factors, may be an enough condition to address the development of a so-called normal spine with slight treble rotation on transverse plane and slight related treble curve on frontal plane. Forcing the question, it is strong the temptation to define as “scoliotic” all the human spines: how much the situation deflagrates it is another matter and it is a consequence of habits, subjective learning of hyper stressed actions or positions, particularly during developmental age (cultural factors), never or seldom counterbalanced.

It is now very important to relate to a topographical classification of the idiopathic scoliotic curves that traces back to Wilhelm Schulthess and that, during last century, was revisited by Ponseti and Friedman and lately by Queneau and Stagnara [80,81].

The cervical-thoracic curve is in the majority left-sided convex and regards the lower cervical vertebrae together with the upper thoracic vertebrae: a greater involvement of left high

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

levatores costae and EIM besides left serratus postero superior in every inspiration (respect to the right side) is a consequence and an enforcing of the situation that can start from an exaggerated approach of trigonum spinae of right scapula to the spine (more caudal cause, on which it will be necessary to come back soon treating about double thoracic curves) or an extra residual head rotation to the right (more cranial cause): both causes communicate with the transvers spinalis system asymmetrically.

The mid-lower thoracic curve is right-sided convex for the 91% of individuals and usually affect 6 or 7 vertebrae: from T5 to T11 or from T6 to T12: the correlations with the statistics on handedness and with the vertebrae rotation of mid-lower thoracic tract, described in section two, appear strong and consistent besides very precise: an hyper stressed hand lateralization may be a sufficient condition to makes asymmetrical the expression of inspiration. This occurs because the located right levatores costae and EIM can increasingly work while the left ones are increasingly dormant; the right diaphragm starts its work regarding both pillars from phrenic nerve impulse, but it finds freedom of rib cage expansion in different ways for the two sides: on right side the expansion is favoured backwards but is inhibited forwards because of the contemporary action of PM, pectoralis minor and transversus thoracis with also the impossibility of right parasternal intercostals to contribute to inspiration act. Thus, it is explained the lower mechanical efficiency in convex side chest wall motion [82]. On left side it happens an opposite condition: the fascial constraints on left EIM and levatores costae, caused by gradual fixation till to immobilization of left deep paraspinals, prevent too the expression of left cupola of diaphragm that finds a residual possibility on the anterior part of rib cage together with the left parasternal intercostals here free and this explains a greater efficiency in concave side chest wall motion [82]. The change in ratio between concave and convex lung volume is another consequent feature [83]. The well-known shape of rib cage assumed by these scoliotic individuals is now explained and the thoracic right rib hump, visible in Adam's bending test, is a consequence. It is now appropriate to notice that, to become the causes, the mechanics here described must be accompanied by actions done during developmental age in a heavy, repeated and prolonged way, hyper stressing the spinal rotation and with poor compensatory actions. It appears clear that, in a so-called civilized society characterized by a mass compulsory scholarization, the first suspect goes to the handwriting, with various developments of sitting posture and paper orientation where is possible to find examples of the exaggerated forms of lateralization cued in the previous lines [84,85]. The absence or the insufficiency of general and alternating motor acts, in a such delicate age of life, plays another part in contributing to make the transversus spinalis system more and more fixed on concave side. The consequences in IS subjects is a gradual degeneration of fixed paraspinals in fatty tissue on concave side, besides a greater thickness [86-88]. Otherwise also sports movements, above all when early practised, can contribute to communicate a similar effect on spine as it was found in a study by Modi, et al., about volleyball players where the convexity of thoracic or thoracolumbar scoliosis is correlated to the hand dominance [89]. Among the large amount of publications on IS, there a few studies that went deep into possible direct connections between IS and laterality phenomenon, with statistical data enforcing the ideas of this script, although a common etiological scene is still absent. Regarding the right convex thoracic curve it is significant to report a study by Catanzariti, et al., in which it was shown a significant correlation between right thoracic IS and right handedness, finding that the most of scoliotic individuals are characterized by a right hand dominance together with a left eye dominance, till to get the authors at the hypothesis of a chiasmatic functional syndrome as primary cause [90]. If this was, it would remain anyway the problem of understanding if this would be a cause (top-down view) or an effect (bottom-up view). In a study dated by Goldberg, et al., the authors reported that the organization of the whole brain of IS subjects is more strongly lateralized than the non-scoliotic subjects but also in this study is clarified that it is not clear if the data must be considered causes or effects [91]. Similar conclusions about cortical abnormalities are present in other studies by Wang, et al., and Domenech, et al., [92,93]. In two other studies by Goldberg, et al., and Grivas, et al., the strong correlation between handedness and thoracic convexity is shown [94,95]. One of these studies Grivas, et al., is particularly meaningful because the research was developed studying 8245 school children. It is interesting to mention also two other studies treating a non-idiopathic scoliosis, deriving from Duchenne's Muscular Dystrophy (DMD) [96,97]. In the article by Ando, et al., it is clarified that, where it occurs a lateralized degeneration of paraspinal muscles, the muscles less affected are situated on the convex side of scoliosis, while on the concave side the muscles degenerate in fatty tissue, a result that matches the conclusions of the study already cited about IS process regarding rotators [86,96]. It could be possible now to suggest that what occurs in DMD subjects, by means of a genetical pathology that influences directly and asymmetrically the paraspinals muscles, it occurs too in IS subjects by means a stressed peripherical signal that makes increasingly asymmetric inspiratory act in developmental age. The article by Werner is a case report where two identical twin boys with DMD have opposite hand dominance and opposite convexity [97]. About handwriting it could be possible to investigate eventual statistical differences in society where the act is done leftwards, as in Arabic and Hebrew ones, and/or vertically as in Chinese and Japanese ones, to compare the data to the ones of the classical rightwards handwriting in western society. Coherently with this cue, it appears important that there are fewer right thoracic curves and more left thoracolumbar curves in Chinese scoliotic patients: the vertical handwriting, together with a probably more frequent clockwise paper orientation (for right hand dominance subjects this position is called by Hemmes as inverted position) causes a different scapula motion [84,98]. In the sight of this script the inferior angle of scapula on the side of the writing hand tends to remain nearer the spine than the inferior angle of the other side, justifying the statistical differences about the convexity respect to the data of different cultures as the western one. Anyway, it is also intriguing the assertions of Ponseti, fundable in a textbook on scoliosis, in whose opinion IS is almost unknown in some countries of Africa, South America and in India: presumably these assertions were made before, also in these countries, the mass compulsory scholarization became (fortunately) reality

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

[99]. But it is correct to say, coherently with the design of this script, that the beginning of located spinal rotations could be attributed too to juvenile work characterized by stereotyped motor acts, where the need is present and the scholarization still absent or rare. Furthermore, it is consistent to cite the datum reported in a textbook by Pivetta S and Pivetta M, in whose opinion IS is very probably unknown in so-called non-civilized people [99]. These factors can lead to a more frequent mid-lower thoracic curve or to a very less frequent double thoracic curve: if the adduction of right arm is accompanied to an extra raising of the arm, the spine approaching of trigonum spinae of scapula fires the answer of lower cervical-upper thoracic vertebrae (in handwriting this can happen because of too low chair or too high desk or a mix of these factors). The minor frequency of so-called double thoracic curves is consistent with the handwriting motricity. In fact, except more forced positions as the ones just mentioned, the adduction of right arm, necessary to handwriting, counterbalances the trigonum spinae approaching that is normal in a simple raising arm action as in HBL, because the arm adduction drags away from spine all the medial border of scapula and this means that the mid-lower tract is, in general, the only that is affected, because here there is the addiction of the effects of arm raising with arm adduction.

The lumbar curve is left-sided convex in most individuals, but not so strongly as for the thoracic curve, and this datum matches again to the statistical dominance data, in this case the so- called footedness that is directly related to a hip dominance. Because of this strict correlation with hip joint, it is extremely interesting to report two studies which relates different hip range of motion of two sides to scoliosis. In Karski, et al., it is treated about the right hip abduction contracture [100].

Cheung, et al., it is treated about the right hip adduction deficit, two aspects that, as already said, seem to be very related to utero left-side lie [101]. Anyway, in both studies it is strongly hypotized an etiological factor on IS: because of all said till now in this script, these two studies could be confirm on how the hip lateralization, related to footedness, can influence the lumbar zone till to cause lumbar scoliosis. As reported previously, the different attachments of diaphragmatic pillars between two sides and their interactions with iliopsoas and QL justify a different inspirational excursion of pillars, where the longer right one can provoke a greater lordosis than the shorter left one (the right one goes to a minor sagittal bending radius) [102]. Thus, the mechanism described in section two is again able to influence transversus spinalis system modifying the longitudinal signal in a rotational effect and the vertebrae rotate to the left till to arrive to a lumbar hump in Adam's bending test. The topographical development of lumbar scoliotic curves is typically located from D12 to L4 although D11 or L5 can be sometimes rotated. The pathological pathway seems to be the same of the physiological pathway of a so-called normal spine and the deflagration can link again to hyper stressed forms of lateralization derived from postural habits, also in sitting position where the non-dominant foot remains more fixed and the dominant one explores generally movements and positions of greater range, in abduction, extra rotation and extension of hip joint [71,103]. It is useful to

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

repeat that the scoliotic deformations have more probabilities to occur if other symmetrical movements are not regularly carried on. This single curve seems not to influence the expression of diaphragmatic cupolas (sternal and costal parts of diaphragm), where the phrenic nerve propagates its signal in a more symmetrical way, thus not causing thoracic curves.

The single thoracolumbar curve, an extended curve, is in the majority (81%) right-sided convex and is located from D6 or D7 till L2 or L3, involving 7/9 vertebrae. This ipsilateral curve, respect the thoracic and lumbar tract, is too imputable to the generic dominance phenomenon. If the postural habits, above all in a sitting scholar position, evolves towards a more lie-down position on the desk with the whole load of the body shifted on the same side, it appears at the cued levels a global curve with the convexity of spine on the loaded side. The rotational consequences, during handwriting, are the ones already described in mid-lower thoracic curve added to the ones already described in lumbar curve. The rotations are confirmed by the asymmetrical inspiration expression. In this situation (learned, in the meaning that it starts being assumed, probably with the aim of taking advantage of desk support and reducing efforts; then it becomes habitual), in most cases, the right thoracic tract is affected as reported previously, while the lumbar tract feels the more closed iliac positioning on the right side. This means a shortening of right iliopsoas associated to an affordance of elongation of right diaphragmatic pillar that becomes more powerful, while the left pillar undergoes the effect of deep paraspinals that lead the left side in a gradually more lordotic status (the arch of left pillar sees cut down its possibility to provoke lordosis during inspiration), lessening its potential and so confirming spinal rotations.

The majority of this curves is again right-sided convex, but in little lower values respect the thoracic curve: it is arguable that, if generally wins the normal position just described with a normal paper orientation (counter clockwise for the right hand dominance subjects), in some individuals can win an inverted paper orientation (clockwise for the right hand dominance subjects), with the considerations already done in previous lines regards the changes that this behaviour causes [84].

The double thoracic and lumbar curve is constituted, in 93% of cases, by a right-sided convex thoracic curve (generally from D6 to D10), an intermediated neutral vertebra (D11) and a left-sided convex lumbar curve (D12/L4). The statistical data are easily explained by the consideration for which, given the data on human hand dominance, if this double curve is present can't help showing itself in this proportion: if the coupling (crossed) wasn't this, it would generate another curve type as the single thoracolumbar curve (ipsilateral coupling). The detailed explanation of this curve is not needed, because it is enough to add the explanation of a right-sided convex thoracic curve to the explanation of a left-sided convex lumbar curve. The same process can be used to justify the pattern of more rare treble curves. A consequence of this etiological design is the probable lack of foundation about the concept of "compensation curve" because the curve at different spine level might be simply the effect of a located hyper

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

lateralized motor habit and the compensation could be a chimera, as it is clear in thoracolumbar IS with subjects affected by a strong lateral projection. This etiological reconstruction must be able to explain coherently the actual unclarified aspects (associated abnormalities); this is done starting from the global review done by Schlösser, et al., in 2014 [104]. Among neuromuscular abnormalities, the impaired gait control can be explained by the perturbations on transversus spinalis system that affects directly the fine gait coordination as explained in section two [105,106]. The other data, with weak level of evidence in authors' opinion, might be more effect of the hyper lateralization which influences the development of nervous system, from thinner cortex right cerebrum to asymmetry of somatosensory evoked potentials till to a vestibular asymmetry [104]. Among the anthropometric abnormalities the most meaningful is the breast asymmetry and this aspect was already explained here. Among the metabolic abnormalities the decreased bone mineral density seems to be a risk factor while the impaired bone quality can be again a consequence of hyper lateralization. In another article, by Burwell, et al., several scientific observations and hypotheses are listed in an etiological perspective [3]. The relative anterior spinal overgrowth in AIS can be explained by the mechanism described in this script: rotational effect might be accompanied to a greater lordotic effect due to the located and continuous shortening on one side that push forward the affected vertebrae, considering also the posteriorly directed shear loads acting on a pre-rotated growing spine [107,108]. The impaired lumbo-sacral joint efforts during gait is another consequence related to the strict interactions between diaphragm, hip joints, sacroiliac joints and lumbar paraspinals, with consequences again on vertebral growth modulation [109]. Also, the pelvic axial rotation can be explained considering the lateralization perspective: if the right leg has a larger range of motion, as in right leg dominance subjects, there will be consequently a larger range in the right sacroiliac joint to allow the movements of the kinetic chains and this influences a stronger right iliac bone growth and its larger width, tending to cause a clockwise rotation of the pelvis, as it is reported by the cued studies [110,111]. Also the lengthening of the 12th rib on convex side in lumbar scoliosis can be included in the general sight here reported: the bigger affordance of the diaphragmatic pillar on convex side and the bigger affordance of SPI on the same side, together with the bigger affordance of excursion of QL, confirm in every inspiratory act a bone growth stimulus (Pauwel's law) on the 12th rib [112]. At the same time on concave side the same structures are more inhibited (shortened) in every inspiration act and, in according with Hueter-Volkmann's law, the bone growth of the 12th rib cannot be equal to the contralateral one. The studies on monozygotic twins seem to go to a learned hypothesis because of discordant results on scoliosis appearance [8,10,113]. The rapid pubertal growth spurt affects initially the discs and later the vertebrae forming, and the greater number of female scoliotic individuals can be related to the physiological preparation during puberty towards the menarche and, then, to the fertility age that is probably accompanied with global fascial releasing factors due to pregnancy possibility [114]. Coherently with these assertions, by Grivas, et al., it is known that the delay of the age at menarche prolongs the period of spine vulnerability [114]. The increasing fascial compliance affects probably all the fascial system,

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

and then the interactions between pleurae and more superficial myofasciae: if the subjective inspiration pattern is already hyper lateralized (learned), the fascial affordances become wide open, causing the pathological shape. The real causation is typically human and deriving from motor habits. In the latest years some studies investigated on hormonal or metabolic factors, trying to precise blood metabolic values with the aim of finding differences between scoliotic and non-scoliotic individuals but in the design here proposed, they can be evaluated as predisposing factors, probably able to increase fascial compliance, but not as strictly causative factors [2,3]. At the same time, also cerebral asymmetries already reported are here interpreted as consequences of excess of laterality. As regards the HBL, the proposed motion of spine might be the key to interpret the smoothness and the proficiency of human gait, with consequences (also rehabilitative) on hip and shoulder physiology, considering more carefully the role of scapula. As regards the AIS etiology, in this approach, it can't help being a "mismatch disease" between nature and culture: if it is accepted the superimposed act of HBL, that the whole human coordination is locomotion-based, thus any limbs-spine interactions move in this direction. Even the laterality process can be seen in a sight of costs minimizing fine motion (as handwriting) is repeated till to become automatic and this means to reach a subcortical control, with consequences on energy saving. According to Occam's razor principle, if these conclusions are accepted, it is consequent that a greater part of studies might be addressed to the development of human motricity and its biomechanical aspects, making genetical aspects less prominent (AIS as "learned" disease). This might lead to a more precise medical/rehabilitative perspective and even to the possibility of prevention. Regarding the already scoliotic subjects, corrective exercises could be addressed in a very personal way, with fine limbs movements or positions in according to the curve(s) pattern. The incessant inspiratory act closes the integrated circle (or opens it: impossibility to discriminate causes and effects). The limitations of this script, that has the ambition to be "a theory of the theories" for AIS, are the ones explained in the beginning and who wrote this article used observations and palpations of spinous processes to start the considerations, well conscious about the discussion on reliability of spinous processes palpation [115].

Conclusion

A fil rouge runs through all this script and it concerns the concept of affordances (possibilities) and constraints, the concept of minimization of costs and the concept of neuromechanical coupling: all these ones are present in every section of this script and they must be seen in an integrative self-powering way and in an evolutionary perspective (survey and advantages in reaching aims). This systemic approach of human ontogenesis considers the subjective inspiratory coordination (leading to subjective posture) in mutual relation with limbs-spine links that can be hyper stressed by a strong and not balanced lateralization. Thus, about 20000

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

inspiratory acts a day seem to be the sufficient cause that, at described conditions, can provoke scoliotic curves.

Author Contributions

M.A., L.G. and S.D.A. observed the case and contributed to the acquisition of data; M.A., M.C., D.D.V and G.M. performed the review of the literature and analyzed the data; M.A., M.C. and L.G. wrote the paper; F.P., S.D.S., G.T., S.P. and V.P. supervised the paper; all authors contributed to revision of the paper.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Stokes IA, Burwell RG, Dangerfield PH. 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;1:16.
2. Burwell RG, Clark EM, Dangerfield PH, Moulton A. Adolescent idiopathic scoliosis (AIS): a multifactorial cascade concept for pathogenesis and embryonic origin. Scoliosis Spinal Disord. 2016;11:8.
3. Burwell RG, Dangerfield PH, Moulton A, Grivas TB, Cheng JCY. Whither the etiopathogenesis (and scoliogeny) of adolescent idiopathic scoliosis? Incorporating presentations on scoliogeny at the 2012 IRSSD and SRS meetings. Active self-correction and task-orientated exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomized controlled trial. Scoliosis. 2013;8:4.
4. Wang WJ, Yeung HY, Chu WC. Top theories for the etiopathogenesis of adolescent idiopathic scoliosis. J Pediatr Orthop. 2011;31(1 Suppl):S14-27.
5. Kouwenhoven JW, Castelein RM. The pathogenesis of adolescent idiopathic scoliosis: review of the literature. 2008;33:2898-908.
6. Veldhuizen AG, Wever DJ, Webb PJ. The aetiology of idiopathic scoliosis: biomechanical and neuromuscular factors. Eur Spine J. 2000;9(3):178-84.
7. Hefti F. Pathogenesis and biomechanics of adolescent idiopathic scoliosis (AIS). J Child Orthop. 2013;7(1):17-24.
8. Gorman KF, Julien C, Moreau A. The genetic epidemiology of idiopathic scoliosis. Eur Spine J. 2012;21:1905-19.
9. Grauers A, Rahman I, Gerdhem P. Heritability of scoliosis. Eur Spine J. 2012;21(6):1069-74.
10. Bagnall KM. Using a synthesis of the research literature related to the aetiology of adolescent idiopathic scoliosis to provide ideas on future directions for success. Scoliosis. 2008;3:5.
11. Yamaguti WP dos Santos, Paulin E, Shibao S, Kodaira S, Chammas MC, Carvalho Celso RF. Ultrasound evaluation of diaphragmatic mobility in different postures in healthy subjects. J Bras Pneum. 2007;33(4):407-13.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

12. Myers TW. Anatomy trains. Myofascial meridians for manual & movement therapists, 3rd ed. Churchill Livingstone Elsiever. 2014.
13. Goldman MD, Loh L, Sears TA. The respiratory activity of human levator costae muscles and its modification by posture. J Physiol. 1985;362:189-204.
14. Busquet L. Les chaines musculaires-Tome I. Editions Frison-Roche, Paris. 2000.
15. Busquet L. Les chaines musculaires-Tome IV-Membres inférieurs. Editions Frison-Roche, Paris. 1995.
16. Guyton AC. Textbook of medical physiology, 8th Edt. W.B. Saunders Company, Philadelphia, PA. 1991.
17. Butler JE. Drive to the human respiratory muscles. Respir Physiol Neurobiol. 2007;159:115-26.
18. Butler JE, Gandevia SC. The output from human inspiratory motoneurone pools. J Physiol. 2008;586:1257-64.
19. De Troyer A, Kirkwood PA, Wilson TA. Respiratory action of the intercostal muscles. Physiol Rev. 2005;85:717-56.
20. Butler JE, Hudson AL, Gandevia SC. "The neural control of human inspiratory muscles," in Vol. 29, Chap. 15, Progress in Brain Research, eds Gert Holstege CMB, Hari HS, editors. Oxford: Elsevier. 2014;295-308.
21. Hudson AL, Gandevia SC, Butler JE. The effect of lung volume on the co-ordinated recruitment of scalene and sternomastoid muscles in humans. J Physiol. 2007;584:261-70.
22. Ceccato JC, de Sèze M, Azevedo C, Cazalets JR. Comparison of trunk activity during gait initiation and walking in humans. PLoS One. 2009;4:e8193.
23. Thompson NE, Demes B, O'Neill MC, Holowka NB, Larson SG. Surprising trunk rotational capabilities in chimpanzees and implications for bipedal walking proficiency in early hominins. Nat Commu. 2015;6:8416.
24. Witte H, Hoffmann H, Hackert R, Schilling C, Fischer MS, Preuschoft H. Biomimetic robotics should be based on functional morphology. J Anat. 2004;204(5):331-42.
25. Kumar S. Ergonomics and biology of spinal rotation. Ergonomics. 2004;47:370-415.
26. Willard FH, Vleeming A, Schuenke MD, Danneels L, Schleip R. The thoracolumbar fascia: anatomy, function and clinical considerations. J Anat. 2012;221(6):507-36.
27. Warner BM, Chappell PH, Stokes MJ. Measurements of dynamic scapular kinematics using an acromion marker cluster to minimize skin movement artifact. J Vis Exp. 2015;(96):51717.
28. Abiko T, Shimamura R, Ogawa D. Difference in the electromyographic onset of the deep and superficial multifidus during shoulder movement while standing. Sueur C PLoS ONE. 2015;10(4):e0122303.
29. Vleeming A, Schuenke MD, Masi AT, Carreiro JE, Danneels L, Willard FH. The sacroiliac joint: an overview of its anatomy, function and potential clinical implications. J Anat. 2012;221(6):537-67.
30. Lee D, Vleeming A. An integrated therapeutic approach to the treatment of the pelvic girdle. Movement, Stability and Lumbopelvic Pain: Integration of Research and Therapy. 2007:621-38.
31. Cavagna GA, Willems PA, Heglund NC. The role of gravity in human walking: pendular energy exchange, external work and optimal speed. J Physiology. 2000;528(Pt 3):657-68.
32. Saibene F. The mechanisms for minimizing energy expenditure in human locomotion. Eur J Clin Nutr. 1990;44(Suppl 1):65-71.
33. McGrath M, Howard D, Baker R. The strengths and weaknesses of inverted pendulum models of human walking. Gait & Posture. 2015;41(2):389-94.
34. Cappellini G, Ivanenko YP, Poppele RE, Lacquaniti F. Motor patterns in human walking and running. J Neurophysiol. 2006. 95:3426-37.
35. Meyns P, Bruijn SM, Duysens J. The how and why of arm swing during human walking. Gait & Posture. 2013;38(4):555-62.
36. Massaad F, Levin O, Meyns P, Drijkoningen D, Swinnen SP, Duysens J. Arm sway holds sway: locomotor-like modulation of leg reflexes when arms swing in alternation. Neuroscience. 2014;258:34-46.
37. Umberger BR. Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. J Biomech. 2008;41:2575-80.
38. Gracovetsky S. An hypothesis for the role of the spine in human locomotion: a challenge to current thinking. J Biomed Eng. 1985;7:205-16.
39. Dickinson MH. How animals move: an integrative view. Science. 2000;288:100-6.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

40. Lee LJ, Coppieters MW, Hodges PW. Anticipatory postural adjustments to arm movement reveal complex control of paraspinal muscles in the thorax. J Electromyogr Kinesiol. 2009;19:46-54.
41. Moseley GL Hodges PW Gandevia SC. Deep and superficial fibers of the lumbar multifidus muscle are differentialy active during voluntary arm movements. Spine. 2002;27(2): E29-3.
42. Sato T, Koizumi M, Kim JH. Fetal development of deep back muscles in the human thoracic region with a focus on transversospinalis muscles and the medial branch of the spinal nerve posterior ramus. J Anat. 2011;219(6):756-65.
43. Ivanenko YP, Poppele RE, Lacquaniti F. Five basic muscle activation patterns account for muscle activity during human locomotion. J Physiol. 2002;556:267-82.
44. Lacquaniti F, Ivanenko YP, Zago M. Patterned control of human locomotion. J Physiol. 2012;590:2189-99.
45. Allen JL, Neptune RR. Three-dimensional modular control of human walking. J Biomech. 2012;45:2157-63.
46. Jung H, Dasen JS. Evolution of patterning systems and circuit elements for locomotion. Dev Cell. 2015;32:408-22.
47. Murakami Y, Tanaka M. Evolution of motor innervation to vertebrate fins and limbs. Developmental biology. 2011;355:164-72.
48. Lacquaniti F, Ivanenko YP, DAvella A, Zelik KE, Zago M. Evolutionary and developmental modules. Front Comput Neurosci. 2013;7:6149.
49. Bianchi L, Angelini D, Orani GP, Lacquaniti F. Kinematic coordination in human gait: relation to mechanical energy cost. J Neurophysiol. 1998;79:2155-70.
50. Lieberman DE. Human locomotion and heat loss: an evolutionary perspective. Compr. Physiol. 2015;5:99-117.
51. Herr H, Popovic M. Angular momentum in human walking. J Exp Biol. 2008;211:467-81.
52. Falgairolle M, Cazalets JR. Metachronal coupling between spinal neuronal networks during locomotor activity in newborn rat. J Physiol. 2007;580:87-102.
53. Kunin M, Osaki Y, Cohen B, Raphan T. Rotation axes of the head during positioning, head shaking, and locomotion. J Neurophysiol. 2007;98:3095-108.
54. Horner AM, Jayne BC. Lungfish axial muscle function and the vertebrate water to land transition. PLoS ONE. 2014;9(5):e96516.
55. Ijspeert AJ, Crespi A, Ryczko D, Cabelguen JM. From swimming to walking with a salamander robot driven by a spinal cord model. Science. 2007:1416-20.
56. Pace CM, Gibb AC. Sustained periodic terrestrial locomotion in air-breathing fishes. J Fish Biol. 2014;84(3):639-60.
57. Goulding M. Circuits controlling vertebrate locomotion: moving in a new direction. Nat Rev Neurosci. 2009;10:507-18.
58. Altringham JD, Ellerby DJ. Fish swimming: patterns in muscle function. J Exp Biol. 1999;202:3397-403.
59. Delvolvé I, Bem T, Cabelguen JM. Epaxial and limb muscle activity during swimming and terrestrial stepping in the adult newt, Pleurodeles waltl. J Neurophysiol. 1997;78:638-50.
60. Schilling N, Carrier DR. Function of the epaxial muscles in walking, trotting and galloping dogs: implications for the evolution of epaxial muscle function in tetrapods. J Exp Biol. 2010;213:1490-502.
61. Nakatsukasa M. Acquisition of bipedalism: the Miocene hominoid record and modern analogues for bipedal protohominids. J Anat. 2004;204(5):385-402.
62. Lovejoy CO, McCollum MA. Spinopelvic pathways to bipedality: why no hominids ever relied on a bent-hip-bent-knee gait. Philos Trans R Soc Lond B Biol Sci. 2010;365:3289-99.
63. Zehr EP, Barss TS, Dragert K. Neuromechanical interactions between the limbs during human locomotion-an evolutionary perspective and translation to rehabilitation. Exp Brain Res. 2016;234;3059-81.
64. Crompton RH, Vereecke EE, Thorpe SKS. Locomotion and posture from the common hominoid ancestor to fully modern hominins, with special reference to the last common panin/hominin ancestor. J Anat. 2008:501-43.
65. Preuschoff H. Mechanisms for the acquisition of habitual bipedality: are there biomechanical reasons for the acquisition of upright bipedal posture? J Anat. 2004;204:363-84.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

66. Bruijn SM, Meijer OG, Beek PJ, van Dieën JH. The effects of arm swing on human gait stability. J Exp Biol. 2010;213:3945-52.
67. Schilling N. Evolution of the axial system in craniates: morphology and function of the perivertebral musculature. Front Zool. 2011;8:4-23.
68. Lieberman DE. The Story of the Human Body: Evolution, Health, and Disease. Pantheon books, New York. 2013.
69. Rogers LJ, Vallortigara G, Andrew RJ. The Biology and Behaviour of Brain Asymmetries. Cambridge University Press. 2013.
70. Osborn ML, Homberger DG. The human shoulder suspension apparatus: a causal explanation for bilateral asymmetry and a fresh look of human bipedality. Anat Rec. 2015;298:1572-88.
71. Janssen MM, Kouwenhoven JW, Schlösser TP. Analysis of preexistent vertebral rotation in the normal infantile, juvenile, and adolescent spine. Spine (Phila Pa 1976). 2011;36(7):E486-91.
72. Schlösser TP, Vincken KL, Attrach H. Quantitative analysis of the closure pattern of the neurocentral junction as related to pre-existent rotation in the normal immature spine. Spine J. 2013;13(7):756-63.
73. 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.
74. Antoniou J, Arlet V, Goswami T, Aebi M, Alini M. Elevated synthetic activity in the convex side of scoliotic intervertebral discs and endplates compared with normal tissues. Spine. 2001;26(10):E198-206.
75. Oliazadeh N, Gorman KF, Eveleigh R, Bourque G, Moreau A. Identification of Elongated Primary Cilia with Impaired Mechanotransduction in Idiopathic Scoliosis Patients. Sci Rep. 2017;7:44260.
76. Schlösser TP, Semple T, Carr SB. Scoliosis convexity and organ anatomy are related. Eur Spine J. 2017.
77. Ihara A, Hirata M, Fujimaki N. Neuroimaging study on brain asymmetries in situs inversus totalis. J Neurol Sci. 288:72-8.
78. Kouwenhoven JW, Bartels LW, Vincken KL. The relation between organ anatomy and pre- existent vertebral rotation in the normal spine: magnetic resonance imaging study in humans with situs inversus totalis. Spine. 2007;32(10):1123-8.
79. Gutwinski S, Löscher A, Mahler L, Kalbitzer J, Heinz A, Bermpohl F. Understanding left- handedness. Dtsch Arztebl Int. 2011;108(50):849-53.
80. Ponseti IV, Friedman B. Prognosis in idiopathic scoliosis. J Bone Joint Surg Am. 1950;32A(2):381-95.
81. Stagnara P, Queneau P. Developmental scolioses during the period of growth; clinical and radiological aspects and therapeutic considerations. Rev Chir Orthop Reparatrice Appar Mot. 1953;39(3-4):378-452.
82. Kotani T, Minami S, Takahashi K. An analysis of chest wall and diaphragm motions in patients with idiopathic scoliosis using dynamic breathing MRI. Spine. 2004;29(3):298-302.
83. Chun EM, Suh SW, Modi HN, Kang EY, Hong SJ, Song HR. The change in ratio of convex and concave lung volume in adolescent idiopathic scoliosis: a 3D CT scan based cross sectional study of effect of severity of curve on concave and convex lung volumes in 99 cases. Eur Spine J. 2008;17(2):224-9.
84. Hemmes NS. Writing posture and paper orientation. Science. 1977;195(4277):441.
85. Van Loon P. Ever-present factors in healthy children that can deform their spines. opposition to dickinson's paradigm on lordosis. In Research into Spinal Deformities. Edited by T. Kotwicki TG, TB:IOS Presss. 2012;2012:63-7.
86. Wajchenberg M, Martins DE, Luciano RP. Histochemical analysis of paraspinal rotator muscles from patients with adolescent idiopathic scoliosis. Medicine (Baltimore). 2015;94(8):e598.
87. Zapata KA, Wang-Price SS, Sucato DJ, Dempsey-Robertson M. Ultrasonographic measurements of paraspinal muscle thickness in adolescent idiopathic scoliosis: a comparison and reliability study. Pediatric Physical Therapy. 2015;27(2):119-25.
88. Jiang H, Meng Y, Jin X. Volumetric and fatty infiltration imbalance of deep paravertebral muscles in adolescent idiopathic scoliosis. Med Sci Monit. 2017;23:2089-95.
89. Modi H, Srinivasalu S, SMehta S, Yang J-H, Song H-R, Suh SW. Muscle imbalance in volleyball players initiates scoliosis in immature spines: a screening analysis. Asian Spine J. 2008;2(1):38-43.
90. Catanzariti JF, Guyot MA, Agnani O, Demaille S, Kolanowski E, Donze C. Eye-hand laterality and right thoracic idiopathic scoliosis. Eur Spine J. 2014;23(6):1232-6.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

91. Goldberg CJ, Dowling FE, Fogarty EE, Moore DP. Adolescent idiopathic scoliosis and cerebral asymmetry: An examination of a nonspinal perceptual system. Spine. 1976;20:1685-91.
92. Wang D, Shi L, Liu S. Altered topological organization of cortical network in adolescent girls with idiopathic scoliosis. PLoS ONE. 2013;8:e83767.
93. Domenech J, Garcia-Marti G, Marti-Bonmati L, Barrios C, Tormos JM, Pascual-Leone A. Abnormal activation of the motor cortical network in idiopathic scoliosis demonstrated by functional MRI. Eur Spine J. 2011;20(7):1069-78.
94. Goldberg CJ, Moore DP, Fogarty EE, Dowling FE. Handedness and spinal deformity. Stud Health Technol Inform. 2006;123:442-8.
95. Grivas TB, Vasiliadis ES, Polyzois VD, Mouzakis V. Trunk asymmetry and handedness in 8245 school children. Pediatr Rehabil. 2006;9(3):259-66.
96. Ando N, Takayanagi T, Fujimoto Y, Mano Y. Mechanism to induce scoliosis in Duchenne Muscular Dystrophy-a study of paraspinal muscle by X-ray computed tomography. Rinsho Shinkeigaku. 1992;32(9):956-61.
97. Werner BC, Skalsky AJ, McDonald CM, Han JJ. Convexity of scoliosis relate to handedness in identical twin boys with Duchenne's muscular dystrophy: a case report. Arch Phys Med Rehabil. 2008;89(10):2021-4.
98. Du Q, Zhou X, Negrini S. Scoliosis epidemiology is not similar all over the world: a study from a scoliosis school screening on Chongming Island (China). BMC Musculoskelet Disord. 2016;17:303.
99. Pivetta S, Pivetta M. Tecnica della ginnastica medica. Scoliosi a indicazione chirurgica ortopedica conservativa, 2002. Edi.Ermes s.r.l., Milano.
100. Karski T, Kalakucki J, Karski J. "Syndrome of contractures" (according to Mau) with the abduction contracture of the right hip as causative factor for development of the so-called idiopathic scoliosis. In: Uyttendaele D, Dangerfield PH, editor. Research into Spinal Deformities 5, Studies in Health Technology and Informatics. Vol. 123. Amsterdam, IOS Press. 2006:34-9.
101. Cheung KM, Cheng AC, Cheung WY, Chooi YS, Wong YW, Luk KD. Right hip adduction deficit and adolescent idiopathic scoliosis. J Orthop Surg (Hong Kong). 2008;16:24-6.
102. Bruggi M, Lisi C, Rodigari A, Nava M, Carlisi E, Dalla Toffola E. Monitoring iliopsoas muscle contraction in idiopathic lumbar scoliosis patients. G Ital Med Lav Ergon. 2014;36(3):186-91.
103. Lee BJ, Cha HG, Lee WH. The effect of sitting with the right leg crossed on the trunk lenght and pelvic torsion of healthy individuals. J Phys Ther Sci. 2016;28(11):3162-4.
104. Schlösser TP, van der Heijden GJ, Versteeg AL, Castelein RM. How 'idiopathic' is adolescent idiopathic scoliosis? A systematic review on associated abnormalities. PLoS One. 2014;9(5):e97461.
105. Kramers-de Quervain IA, Müller R, Stacoff A, Grob D, Stüssi E. Gait analysis in patients with idiopathic scoliosis. Eur Spine J. 2004;13(5):449-56.
106. Yang JH, Suh SW, Sung PS, Park WH. Asymmetrical gait in adolescents with idiopathic scoliosis. Eur Spine J. 2013;22(11):2407-13.
107. Guo X, Chau WW, Chang YL, Cheng JC, Burwell RG, Dangerfield PH. Relative anterior spinal overgrowth in adolescent idiopathic scoliosis -result of disproportionate endochondral-membranous bone growth? Summary of an electronic focus group debate of the IBSE. Eur Spine J. 2005;14(9):862-73.
108. Janssen MM, Kouwenhoven JW, Castelein RM. The role of posteriorly directed shear loads acting on a pre-rotated growing spine: a hypothesis on the pathogenesis of idiopathic scoliosis. Stud Health Technol Inform. 2010;158:112-7.
109. Raison M, Ballaz L, Detrembleur C. Lombo-sacral joint efforts during gait: comparison between healthy and scoliotic subjects. Stud Health Technol Inform. 2012;176:113-6.
110. Zhao Y, Qi L, Yang J, Zhu X, Yang C, Li M. Factors affecting pelvic rotation in idiopathic scoliosis: analysis of 85 cases in a single center. Medicine (Baltimore). 2016;95(46):e5458.
111. Gum JL, Asher MA, Burton DC. Transverse plane pelvic rotation in adolescent idiopathic scoliosis: primary or compensatory? Eur Spine J. 2007;16:1579-86.
112. Grivas TB, Burwell RG, Kechagias V. Idiopathic and normal lateral lumbar curves: muscle effects interpreted by 12th rib lenght asymmetry with pathomechanic implications for lumbar idiopathic scoliosis. Scoliosis Spinal Disord. 2016;11(Suppl 2):35.

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212

113. Inoue M, Minami S, Kitahara H. Idiopathic scoliosis in twins studied by DNA fingerprinting: the incidence and type of scoliosis. J Bone Joint Surg Br. 1998;80(2):212-7
114. Grivas TB, Vasiliadis E, Mouzakis V, Mihas C, Koufopoulos G. Association between adolescent idiopathic scoliosis prevalence and age at menarche in different geographic latitudes. Scoliosis. 2006;1:9.
115. Harlick JC, Milosavljevic S, Milburn PD. Palpation identification of spinous processes in the lumbar spine. Man Ther. 2007;12(1):56-62.

Mariani A | Volume 3; Issue 2 (2022) | JOSR-3(2)-035 | Data Article

Citation: Mariani A, et al. An Evolutionary Adolescent Idiopathic Scoliosis Etiology Spine-Limbs Links, Inspiration and Laterality as Basic Factors. J Ortho Sci Res. 2022;3(2):1-26.

DOI: https://doi.org/10.46889/JOSR.2022.3212