

# Scoliosis Idiopathic? The Etiologic Factors in Scoliosis Will Affect Preventive and Conservative Therapeutic Strategies

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## 1. Introduction

Scoliosis is a three dimensional deformation of the complete spine and trunk, only present in humans, with its start and progress occurring during childhood. It still puzzles the medical world.

All medical (=human) conditions that lack a clear set of etiological factors will suffer ongoing discussions if the existing or new therapeutic measurements will be the right ones. Of course a massive change in form of the spine like in scoliosis or hyperkyphosis must be related to multiple causative factors inside and outside the afflicted body. In the last six decades very little attention is given to the variability in sequence in presentation of these factors in time and the severity of their action in otherwise healthy children. Also the fact that, besides in clear neurological diseases, deforming forces are exogenous or under influence (by muscles) of external circumstances stayed widely underestimated. With the wish to erase the pronoun "idiopathic", used in scoliosis for sixty years, there should be awareness of these shortcomings in knowledge among orthopedic and related scientists.

There is ongoing discussion and research in the modern scientific world of Orthopedics on causes and thus on strategies of therapy in idiopathic spinal deformities (Wang et al., 2011). The discussion on pathogenesis is evolving quickly towards more physiologic neuromuscular events. Looking into genetic aspects is also popular, but the fact that the unique genome of an animal effects all cells and tissues makes that genes cannot be directly related to a gross asymmetric deformation of half a body in otherwise healthy children. This focus on chromosomal blueprints and concomitant biochemical substrates can prevent the discovery of practical solutions in spinal deformities.

There was quit common knowledge in the nineteenth century, that most spinal deformities were caused by children's labor in industry and on farms and accelerated by tuberculosis or rachitis (Hohmann et al, 1957). For phycisians looking to girls and young tailors it was obvious that prolonged sitting is a strong deforming factor, but all this basic observations disappeared out of the academic point of view in the search for etiologic factors. Because of known differences in qualities of tissues for girls (lower mean weight, lesser mean muscle strength, increased mean ligament and capsular laxity, earlier spurt of growth) in concordance with a different neurohormonale system compared to boys, a preference for the

occurrence of scoliosis in girls is clear and only in that way as causative “genetic” factor foreseen by clinicians (Jansen, 1912).

Especially on the conservative pathways, like bracing, orthopedics are apparently on a crossroad (Negrini et al., 2010; de Mauroy et al., 2010). Is the fact most physicians still try to brace under discussion, or are there reasons to look specifically to the way or technique we do it? Does the three point correction with pushing forces on the apical ribs, like in contemporary bracing techniques, correspond with the pathogenesis of deformities and patient specific type of curves? Dealing with a multitude of factors and theories and the lack of a plausible (and correctable) factor in etiology is troublesome and not helpful in all day practice and transparency towards patients. Scoliosis and kyphotic deformities are no radiological events for children and parents, but are in general still “products” of complex clinical processes (fig. 1.). Most value and attention is given by patients and doctors to what can be seen and measured in standing X-rays.

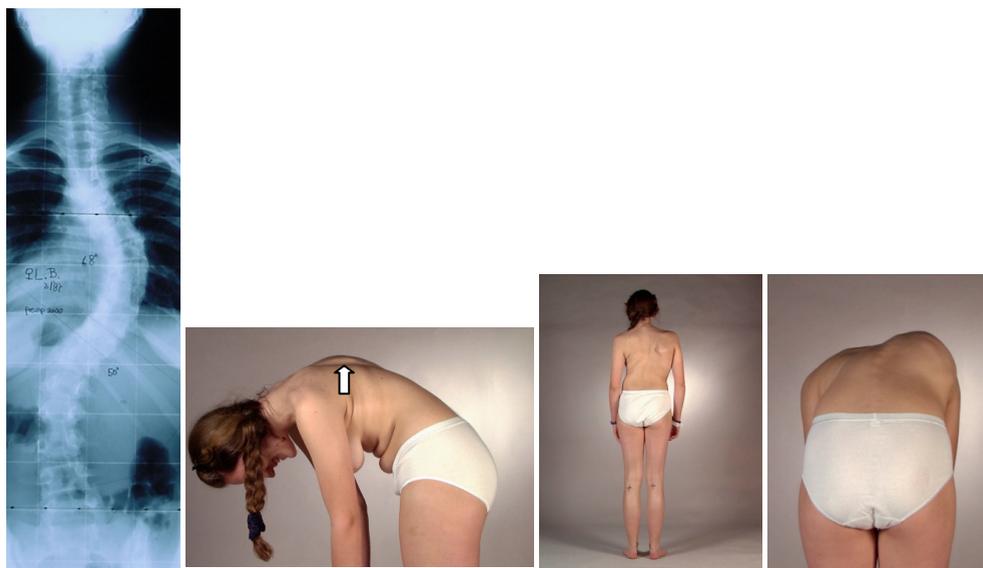


Fig. 1. Normally used radiological and clinical studies in scoliosis. The AP whole-spine radiograph (gold standard since Cobb) shows a serious right sided thoracic curve of  $68^\circ$  in a girl of almost fourteen year with an early menarche at 11.6 year. No other afflictions. Very late referral and a short period of TLSO before surgery in 2000. The typical clinical manifestations (on the day before surgery) show a right sided thoracic gibbus by bending (left and right), waist asymmetry and very pronounced right scapula in stance (middle). Not mentioned in textbooks is the shown inability to bend further from the hips, because of thigh hamstrings. The aggravation of mainly the thoracolumbar kyphotic curve is responsible for the visible creases at the higher abdominal wall (left). A small part of the thoracic spine itself still looks hypokyphotic (according to Dickson’s axiom) in bending on the level of the apex of the gibbus (arrow).

Even upgrading the imaging of the deformation from two dimensional radiographic to three dimensional proportions, like in modern CT scanning or EOS is not enough to understand the full clinical and morphologic presentation.

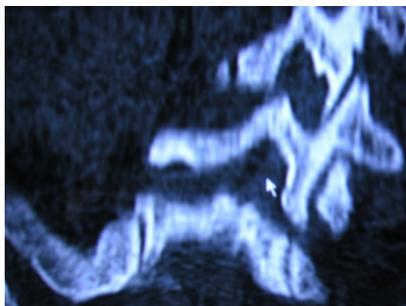


Fig. 2. AP slice of a spiral CT scan in scoliosis. In this 18 year old girl with a painful left lumbar curve the surplus value of CT scanning above plain X-ray shows details of the rotated pars interarticularis L4, sequelae of prolonged compressive forces as arthritic changes and subluxation in the facet joints in the concavity under the left sided thoracolumbar curve. It is important to state that the final configuration of any piece of bone is achieved by all (mainly muscular) forces on it during childhood (Wolff's Law), so that the morphology (also the radiologic) we see in adulthood is the resultant of all compressive and tensile forces during growth (Hohmann et al., 1957).

MRI brought even a lot more: imaging of the soft tissues and its relationships with bone. MRI can show the intriguing cohabitation and reciprocal influence of neural and skeletal tissues in all deformities in a more advanced way. But the fourth dimension, time, and the sequence of morphogenetic events in time and the level of penetration of their causative factors, so important in understanding any affliction during growth, is not visible, but can be deduced. Even MRI shows only the resultant of previous processes.

The processes of growth are not only to increase volumes and masses, but it also copes with energy and asks for storage of energy by incorporating elastic properties in any part of a body, from cell to the complete loco motor system. Movement isn't possible without these properties in energy- processing. Only one organ is capable of multidimensional control of these processes: the central nervous system (CNS). As part of obvious natural manifestations of human growth, in the absence of diseases, spinal deformations will have their biology based explanation in a deviation or adaptation of the natural arrangement of forces, masses and energy during growth. There is no modern biomedical scientific field around the neuromuscular skeletal system, in which the natural tendency of any organism towards optimisation in form and function, broadly accepted in evolutionary biology, are starting points. But it is just what every growing organism, so even the human species, strives for. It is the observed variation that is called "natural". Inherited variation as can be seen in color of hair and eyes or elasticity of the skin is only indirectly related to the wide variation in the visible end stages of the phenotype. Environmental / external factors should be the most influential factors in individual deviations of growth and phenotype as they are in all evolutionary changes in form and function. The human species creates its own environmental factors by its constant and rapidly changing lifestyle (sedentation,

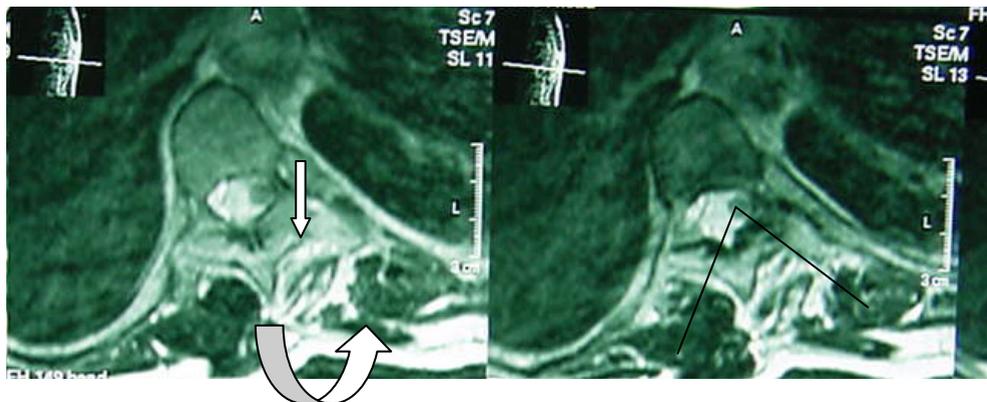


Fig. 3. MRI (transverse slides) in scoliosis. According to the findings of Milan Roth with pneumomyelographic studies, on MRI in the lower thoracic spine in an otherwise healthy female patient of 38 year with a never treated scoliosis, the very asymmetric position of the central cord is seen in the concavity of the curve. Also the slender caliber of the cord is not normal, as is the contact zone of the cord to the bony boundaries of the spinal canal. The picture of a bony canal that spiralizes around the precious cord (Roth), that stays by itself in the middle of the total body has in MRI its modern way of assessing concomitant features of the neural tissue in scoliosis. Of paramount importance to understand the message of Roth's work and taken consequences in TLI is the flattening of the vertebral groove at the left, concave, side ( arrow) and the luxated erecting musculature (curved arrow) out of it, compared to the right side. The rope is dislodged from its groove in the trolley. The right muscle shows already some fatty disuse degeneration. The estimated distance from the centre of the cord to the centre of the muscles still show an equilateral triangle (right).As a fact the musculature (dynamic stays) balance the cord (the regulator) via the flexible spine (mast).

urbanization, industrialization and mechanization) in which unnatural tools and circumstances are repulsing the natural ones. Its structural body has to follow in phenotypical alterations, not in genotypical changes. In the lifestyle of the human species prolonged sitting on chairs is a novel circumstance for the majority of people since less than a century. The availability of chairs and the explosive habit of prolonged sitting in childhood started its demographic "normalization" or "incorporation" only in the second half in the nineteenth century (schooling, school laws) and shows its foreseen effects in our spines (fig.4).

## 2. Goal

Our goal is to support the development of etiology related therapeutics in spinal deformities with help of forgotten or apparently neglected science and some own observations.

In this chapter, we follow a way back to our predecessors whose results are still undisputed. Then we try to look for more original thoughts and existing science on scoliosis and growth nowadays. We go first back to the (guiding) article of Robert Dickson where the presence of lordosis in the thoracic spine got its place as causative factor and a factor to be addressed in therapeutic strategies in scoliosis. It seems a firm starting point (after a standstill in science

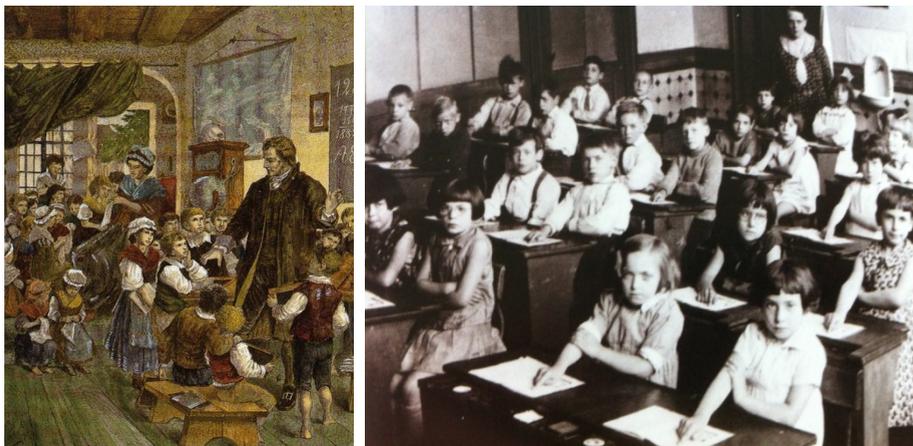


Fig. 4. Two pictures on schooling and the role of sitting with a century in between. On the left an idealized portrait of Georg Fröbel, a pioneer in guiding proper development of physical and cognitive capacities even in the youngest children by organized playing (Kindergarten). On the right just a class in an elementary school around 1950 showing the furniture once advised by the Swiss orthopedic W. Schulthess around 1850. It is obvious care is taken by teachers to look after a good posture for everybody. First in the Montessori and Dalton school systems and later on generalized by introducing loose chairs again, this discipline on posture was loosened and faded completely.

on scoliosis during and between the World Wars) were the most used biomechanical models and techniques of modern bracing and surgical procedures got their scientific background (Dickson, 1988). Had all what was investigated or used in the centuries before lost its value? Was looking to deformities of the human spine as understandable disfeatures of natural growth, as Andry already did in looking to trees (fig.5), a false start (Andry,1741) ? There came awareness in the nineteenth century, that in mechanical structures, certainly living ones with autonomic loco motor functions, all events or processes will have to respect the Natural Laws (Gordon, 1991). Besides those initiated by Isaac Newton on dynamics, the modern (extended) laws of Robert Hooke ( on energy and springs)dealing with conservation of energy, momentum and angular momentum leading to regulation of equilibrium (mainly by torque or rotational forces) are part of this. This homoeostatic process in balancing masses and energy should nowadays be taken into account in understanding deformations in a given body during its developing period.

Till the research of Milan Roth came unexpected in the medical world, knowledge on how the, also growing, nervous system ( in all “higher” forms of life) regulates the interrelated processes of skeletal growth was ( and is?) a blind spot in Medicine(van Loon P,2008b). Homoeostasis (important in growth) combines static (anatomical and functional posture) and dynamic muscle-actions (movement), and the spring like functions (energy preservation) of joints and discs in stance and voluntary locomotion. The osseous spine is only part of the complete neuro-loco motor system but is the most important and has an understandable construction in the view of mechanical engineers if they recognize the original functions. Only in living creatures there are natural developing processes in which form follows function.



Fig. 5. Young trees connected with straight poles. As Andry took a young deformed tree as an allegory for the orthopedic way of looking towards human growth, it must be emphasized that the only reason for placing poles attached to trees by gardeners is to protect them for deforming forces like winds. By guiding branches of a young tree tied to sticks almost any form can be obtained. In old anatomic textbooks the morphology of bones is attributed to the ever moulding action of the intrauterine pressures and the postnatal action of muscles in movement. The logo of Orthopedics is more about protection, forces, growth and time, not so much on a technique of correction of deformities.

The spine has unchanged capabilities in evolution between all vertebrate species, according to Gracovetsky, as primary engine in locomotion (Gracovetsky& Farfan, 1986). The main change in function of the spine between quadrupeds and bipedals is that the coupling mechanism at the thoracolumbar joint (cauda equina) changed. From coupling a pair of pendulums with ground contact steered by counter wise directed torsional movements at this joint towards the coupling of one pendulum with ground contact and a free moving reversed pendulum. Balancing the weight of (an impressive) skull connected on top of the same spring- like spine in between plays an important role. Homo erectus is the only animal with a conus-cauda at the thoracolumbar joint, and this had much to do with this evolution, which makes counterwise torques possible (Roth, 1985). Still by the use of torsional forces, men are amblers, not gallopers (Gracovetsky& Farfan, 1986). But men achieved a powerful and efficient locomotion in thousands of years. Thanks to the right evolution of their spines.

### 3. Method

We searched in older available studies and descriptions of deformities from the Renaissance on and followed the gradually developing knowledge in ethiopathogenesis by leading European institutions. By that we can now highlight some forgotten or misinterpreted pieces of evidence brought by researchers who brought biologic, evolutionary and biomechanical science in a proper sense together in the nineteenth century. As mentioned a missing link in underlying knowledge how a living animal or human actually grows persisted till our time. By the use of own observations in clinical practice (orthopedics) some connections between

clinic and underlying biology can be postulated along this older knowledge, which lost much of its value and penetration in modern Medicine. The ongoing science on ethiopathogenesis of scoliosis was apparently interrupted by the global social disturbances in the period 1914-1945. Traumatology attracted all focus and manpower in Orthopedics.

We under scribe evolutionary knowledge in which the human spine has the same origin, development (phylogenetic and ontogenetic) and functions in locomotion as any other vertebrate and will have to face the same (forming and deforming) forces to grow, to keep balance in stance and while moving. Walking of men is indeed bipedal, but balancing only on hind legs is shared with all birds, quadrupeds like kangaroo's and to a certain degree some other primates. On this point the search for proper knowledge which organ organizes all this features in individual development and how scoliosis as a deviation should be under control of the nervous system too, the work of Roth became disclosed. Further exposure of the work of Roth, who in a way attached the old knowledge in many biomedical fields into a comprehensive explanation how growth is organized and regulated by the oldest organ (phylogenetic and ontogenetic) of animal life: the central nervous system with its precious brainstem-cord-roots complex in vertebrates in his concept of the "Nervous Skeleton" and its very intriguing way of growth, is undertaken (Roth, 1985; van Loon, 2008b).

#### **4. "Lost" historic knowledge on spinal deformities and natural scientific evidence on morphogenesis in pre-Pubmed literature**

Only a few highlights in orthopedic history will be referred to in this chapter.

In 1792 the surgeon of the city of Amsterdam David Van Gesscher published his book on "Observations on Deformations of the Spine" (in Dutch and assigned to the German surgeon at the court of King George III of England). His clinical studies on form and function and postmortem observations in kyphosis and scoliosis are written down and seem a start for a concise system in understanding scoliosis. He postulated two important concepts in the non consumption (the old name for Tuberculosis was Consumption) deformed spine: the optimisation of the balancing forces towards a healthy posture in the human bipedal ways of standing and walking needs a certain optimal sagittal curvature. He even postulated a mathematical formula for the description. This optimal curvature is necessary to keep the weight of the head and the shoulders balanced in an energy saving way above the hips in stance and during walking. He postulated already that a long up-going lumbar lordosis to Th10 in the sagittal contour was the mainstay of a good posture. In postmortem studies he found the weakening and ventral deformations in discs, apophyses and wedging vertebrae mainly at the thoracolumbar area as was found in our days too in serious kyphosis and scoliosis. The second concept was on the role of prolonged sitting and the relation with the found changes around the discs at the thoracolumbar spine. He observed that (mainly) girls, especially those with "a weak constitution" who spent their days by knitting or with embroidery in a flexed position on chairs or stools can develop scoliosis more easily around their compressed and easily deformable thoracolumbar elements (van Gesscher, 1792). Looking afterwards this "weak constitution" was caused in some cases by rachitis (English disease), but even in those days, many girls were not allowed to play outside and was the nutrition quit badly. Van Gesscher invented an extending corrective corset. This was used for more than 100 years in The Netherlands and abroad before the use of Plaster of Paris (invented by A. Mathijsen) became popular (cheap, easy, changeable). This corset shows a lordotic configuration in its complete length.

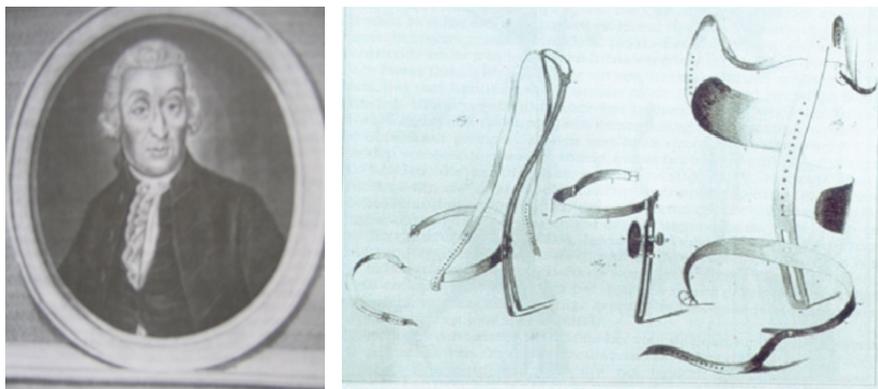


Fig. 6. Portrait of the surgeon of Amsterdam, David van Gesscher (1735-1810) and a picture of his successful brace for scoliosis out of his book from 1792.

In France Nicolas Andry already hypothesized in the same era the possibilities of guidance and correction young growing human spines and skeletons by using the moulding capability of muscular forces towards more optimized posture and function. As in tree-growing by gardeners his guidance by extending corsets was a proven method to withstand deforming external forces (like wind in young trees). With exercises and symmetrical extension at the thoracolumbar joint in corsets (for “weak” girls) he managed a good deal of deformities as scoliosis (Andry, 1741). This was followed by Vernel and later on popularized in many European orthopedic institutions. Extension of the spine and avoidance of sitting in flexed position (bad posture) became a mainstay in Orthopedics (and educational environments) until the mid twentieth century (Hohmann et al., 1957). When cosmetic aspects became popular for this guidance with corsets of posture in girls and young women, the scientific background of its original purpose faded quickly.



Fig. 6. Caricature from the early nineteenth century. At the time it became popular to put any young woman in higher classes in a constricting but extending corset, the original purpose or indication in children with deforming spines and a “weak constitution” according to Andry and Vernel was on its way to be forgotten. In countries like Germany and Sweden special gymnastics and postural exercises replaced these corsets in girls and young women.

In 1907 one of the first hospital surgeons in Germany treating scoliosis, L. Wüllstein described his animal experiments in young dogs to show how forced flexion can produce all now well known characteristics of kyphotic deformities in the midportion of the canine spine. Thorough macroscopic and microscopic investigations were done at sacrifice of these young dogs after a different amount of weeks. They functioned with the spine brought in forced flexion (Fig.7) All pathologic features ,afterwards describing the changes in Scheuermann's disease, were present in only a few weeks (from Hohmann et al.,1957)

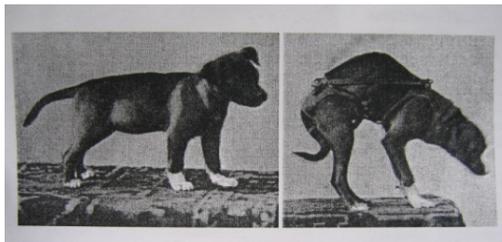


Fig. 7. Photograph from the described animal experiment to create serious spinal deformations in dogs by Wüllstein.

In 1912 one of the co-founders of the SICOT, the Dutch orthopedic surgeon Murk Jansen, published his book "The Physiologic Scoliosis and its causes "(in Dutch). Besides a thorough but also critical review of all available published knowledge on scoliosis and kyphosis by scientists like Lorenz, Schulthess, Nicolodani, Schanz, Volkmann and Hueter, own research was done. Out of postmortem studies (partly in Liverpool with Robert Jones) it was suggested strongly, that the anatomic and physiologic asymmetry in the left and right crurae diafragmaticae act as a creator of asymmetrical rotational forces at the thoracolumbar area in ventilation. This was seen as an explanation of the quit dominant presence of right sided thoracic and left sided lumbar curves in scoliosis. Moreover, he did in vivo tests with children to show the sometimes very early presentation of a thoracolumbar kyphosis with angular configuration if siblings are put too much and too soon in sitting positions. The stiffening of this area in kyphosis he observed and explained as contractures around the (later called) "neutral" vertebra creates a fulcrum (a functional bar of some vertebrae) to cantilever the now opposing rotational forces by the diaphragm in lateral curvatures. He did in vivo experiments with young children suspended under vertical head traction to show the right sided torsional movements of the ribcage in respiration. In animal experiments in hares (even so suspended, now on their ears), he performed intrathoracic pressure measurements and showed consequent lower intrathoracic pressure in the right pleural cavity.

In conclusion of all this, Jansen plead strongly for preventive measurements by restriction of passive sitting (flexed posture) in siblings and young children before their muscular strength to extend the spine was properly established ( by playing, crawling and sleeping in prone positions!) and the thoracolumbar lordosis has established itself firmly. All, to prevent the development of this early kyphotic deformity (Jansen, 1912). Alertness of parents and teachers, optimalisation of static and dynamic posture building by influencing lifestyle factors (school furniture designed by Schulthess and others) and exercises (gymnastics, reinforcement of the muscles extending the spine) were advised in those days. Some of this holistic approach and relation with gymnastics still survives or struggles for survival in parts of Europe (Weiss, 2008; Zahner et al., 2006; Bas et al., 2011).

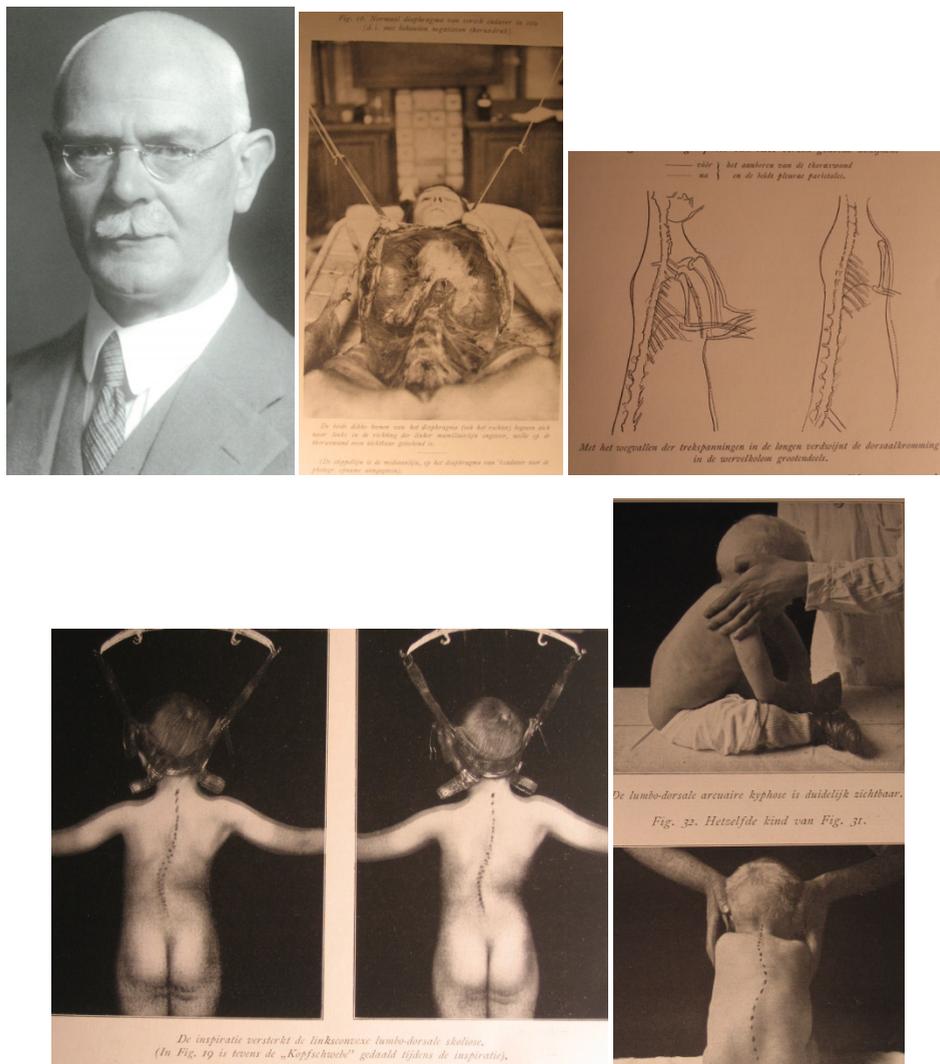


Fig. 8. Portrait of Murk Jansen (and the most illustrative figures in his monograph on scoliosis(1912).Clockwise: portrait of Murk Jansen (1867-1935); Ventrally opened cadaver with suspension of the asymmetric configuration of the left and right crux diaphragmatica; Drawing of the idea of his animal study in hares to confirm that almost the same asymmetry in the diaphragm in these mainly bipedal animals gives asymmetric but side-consequent higher intrathoracic pressures; A boy with a scoliosis, suspended on his head. The rotational movement in inspiration is visibly increasing the left lumbar curve; an in vivo demonstration of early kyphosis of the thoracolumbar spine in a young child in sitting position. Even at this age this is already a sign of structural changes in height and form of vertebrae and discs. The slight right sided coronal curve above this kyphosis is also depicted.

Unhappily the prevailing way of correcting structural and serious scoliosis in Jansen's time has changed in Europe to prolonged bedridden periods on corrective plaster shelves. Cobb mentioned it even as the "Murk Jansen plaster shelf". Sayre's method of corrective plastering in suspension, leaving mobility for walking was apparently overruled in Europe by Calot's corrections in prone position under anesthesia and plaster shelves (Gelbke, 1883). The corrective action was still a quit symmetrical thoracolumbar lordotic hyperextension. Only the gravity forces during stance were ruled out. In his review Jansen actually connected the various scientific knowledge brought by dozens of scientist and argued on the value of the discussion between Volkmann and Hueter. Their "principle" was never written down in one sentence by both of them, there was even an argue on the exact role of the resilience of the deformable structures in the spine, e.g. the discs, the apophyses, ligaments and the cartilage in the facet joints. But the "principle" reflects in retrospection to the Conservation Laws mentioned on which the deformation of growing cartilage in other joints is also theoretically based. Orthopedics knew, as generalists, around 1900 the way "the system" works, but were unaware of the exact role of the central nervous system as constructor and controller of its own housing. A black box.

Because of the World Wars and other political disturbances a longstanding gap in evolution of knowledge on spinal deformities is visible in produced literature. The sources in German language got dusted in libraries. When Cobb in the United States presented the value of radiographic measurements of curves he did warn seriously not to forget the clinical and physiological/ functional aspects of scoliosis, but such a fate seems to have happened for quit some time (Cobb, 1958).

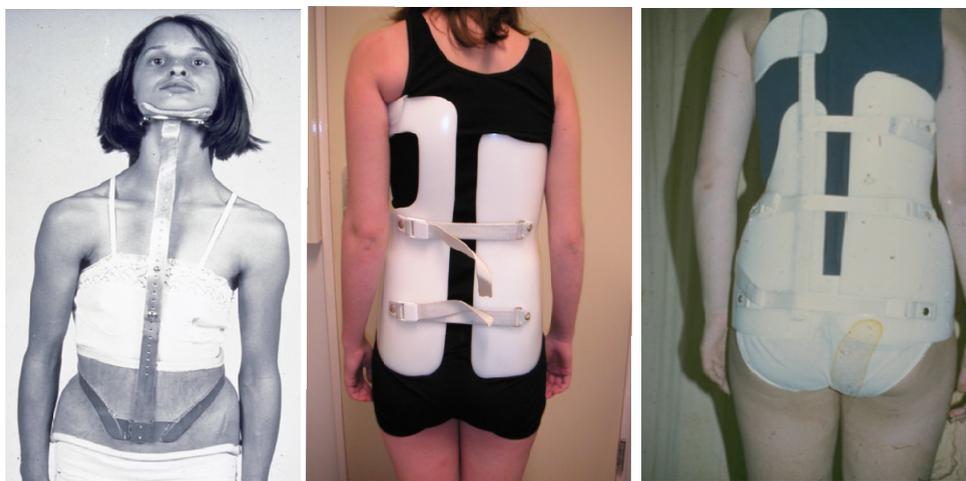


Fig. 9. Pictures of popularized braces. On the left an early Milwaukee brace based on a leather lumbar corset and the chin-head superstructure stretching the upper spine. In the middle a Boston brace with apparently orthotist dependent modifications. At the right a modified Boston brace with a so called Edlemann superstructure.

So the international research into causes of spinal deformities went away for a long time from the black box, the biological process of growth still was. This is also what hapens with

the known effects of lifestyle in terms of quantity and quality of movements and forces during all childhood (if you don't sit) and the role basic posture plays.

Maybe disconnected from this knowledge, from the USA two types of braces using distraction (Milwaukee brace) or thoracic flexion and lateral pressure on the apical zones (modular Boston brace) were globally popularized, and dozens of alternatives with their way of action following grossly the three point correction with pressure on apices of the different curves are also still in use.

### **5. Dyscongruency of neurovertebral growth relations in spinal deformity disclosed by Milan Roth**

Undetected till 2001 by the mainstream of orthopedic scientists Milan Roth of Brno developed between 1960 and 1985 his concepts on neurovertebral and neuro-osseous growth relations and the tension driven system of reciprocal influence between the two tissues. If this system is hindered by endogenous or exogenous influences, incongruence of growth can occur, leading to spinal deformities and alterations in morphology and function of the nervous system too. It was based on thorough knowledge of biological literature on growth in vertebrates, basic orthopedic knowledge and own research. Roth was a neuroradiologist and as professor in this field, he created a small research department with focus on spinal deformities and their background.

Roth returned for the orthopedic knowledge on scoliosis and the existing science on growth back to the gathered European science around 1900. Where concerning the way our loco motor system grows and functions and how pathways to run into trouble, the scientists involved were reaching each other quit well. Roth provided thoroughly revisited and new biological knowledge (in Czech, German and English) on how growth appears to happen on more conceptual scale for the parts doctors cannot see: the influence of time and all internal and external forces on an embryo or born vertebrate and how this is arranged. His main and most striking achievement is the discovery of the way the two different types of growth in Nature work together. The volume and mass increasing mitotic growth of all cells in all tissues during the whole process of growth, next to the extending type of growth of the neural tissues, whilst its amount of cells (billions) is already reached in the early stages of embryological life.



Fig. 10. Portrait of Prof. Milan Roth (1923-2006), neuroradiologist and scientist at the (now) Masaryk University of Brno, Cech Republic.

In this he supported the clinical observations on growing children made during the centuries before by orthopedics and gymnasts. Roth accepted the evolutionary theories completely and used them often by comparing the conditions of spine and cord in other animals. As is stated in anatomic science and embryology, the final form of bones is moulded by muscular action and the movement in joints. Roth proposed that all sorts of pulsating effects in the fluids around the embryo (heartbeat mother, respiration forces, intestinal mechanics and the motor activity of the mother are the first “moulders” of the early embryo. While the first differentiation in cells to occur is the formation of the neural stem cells organized in the notochord, the capacity of these cells will be the controlling and regulating tissue from that point on.

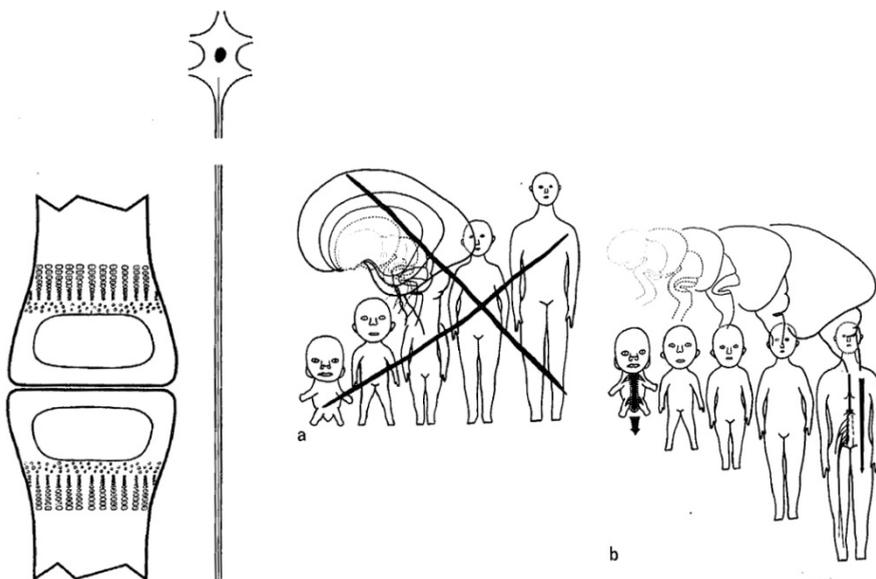


Fig. 11. Two drawings made by Roth on his most important researched issues and used in several publications on the way he learned to look to growth in vertebrates according to the discovered insights he brought into biomedical science. On the left a schematic drawing in which the osseous growth by cell division, mitosis, is depicted together with a simplified way to show, that a neural cell grows in the meantime by extension via continuous attachment to mitotic growing tissue cells under their “guidance”. An important dimension in growth is time. As Andry tried to catch time in his logo, Roth did this by drawing interruptions in the axons of the neural cell or in the peripheral nerves.

In a huge amount of publications on observations in pneumomyelographic studies in scoliosis, animal experiments, mechanical modeling and post mortem in vitro tests he depicted the crucial role that the type of growth (namely by stretching) of the whole nervous system, “the nervous skeleton”, has in the normal and abnormal formation of the spine. In teratogenic studies in animals, inhibitors of neural cell function and growth injected intrauterine, inevitably gave skeletal deformations. And the spines always spirialized into scoliosis.

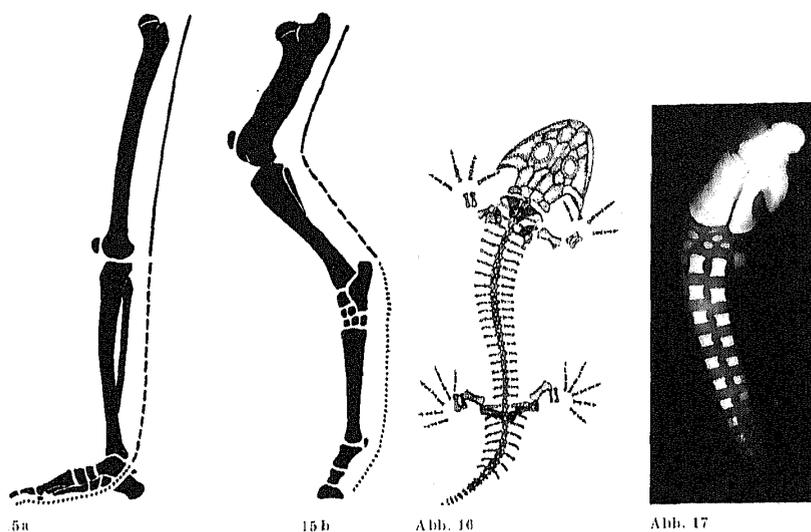


Fig. 12. Set of figures out of Roth's original articles in German. In a comparison between a hind leg of a man and a horse he illustrates the secondary length and width of bones to the primary lengthening of the nerves by stretching, on its turn induced by hormonal regulated increase in volume of the other tissues. In the two other pictures, a drawing of an extinct amphibian and an X-ray of a baby-whale with the similar skeletal build up of the cranial extremity, his vision on phylogenetic and ontogenetic morphogenesis around the nervous tissue is depicted.

A "short cord" can indeed cause scoliosis. Roth deduced the way Wolff's Law and the Volkmann Hueter principle works. Growth has to create flat (Platyspondylie) or wedged vertebral bodies in hindered stretch growth of the cord, in absence of too much torsional changes leading to kyphotic deformities. By this, he put Scheuermann's disease under the same etiological factors that are responsible for scoliosis (Roth 1968, 1969, 1981, 1985; van Loon, 2008b). And he conceived the existence of a mechanical force like tension to be assessed from the outside to represent these interconnected subsystems. If there is increased tension in the cord, there must be increased tension in muscles to, if the energy is not used to deform the soft connecting parts (Volkmann Hueter principle) or the bones (Wolff's Law) of the spine.

Recently, the Hong Kong group lead by Chang and Chu published supportive reproducing studies with MRI in idiopathic scoliosis (Chu et al, 2008). Own, not published observations on clinical investigation and whole spine MRI in children who develop a hyperkyphosis are astonishing affirmative to Roth's research and mechanical models (van Loon 2008c).

In personal observations the presence of neuromuscular tightness or tension, well-known in hyperkyphosis (as Scheuermann's disease) is also present in the rapidly progressive scoliosis and bad postures (like flat spines). These are the clinical representants of the spine deforming and neuroprotective forces. Several tests can be done to assess this neuromuscular

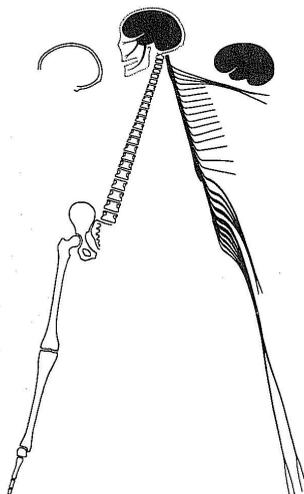


Fig. 13. Caricatured picture by Roth in the introduction of his book: Neurovertebral and neuro-osseous growth relations (1985). In this picture he satirized the greatest problem, in his eyes, existing in the biomedical and medical scientific fields with their diversity of developments and research: "The unfavorable existence of the interdisciplinary barrier". In case of his topic, the spine and its contents, with this caricature he complained over the complete barrier between orthopedics and neurology and neurosurgery to look to each others tissues in its developments and research into etiology. It looked if the two systems develop and function completely separated. He restored holistic knowledge.

tension (van Loon, 2008c). Like blood pressure in the cardiovascular system, this tension seems under influence of increasing (spurts, bad postures) and decreasing (sleep, stretching exercises, TLI bracing) factors.

The spring like storage of energy in these conditions can theoretically be a deforming force by itself. In a way Roth put these tensile forces in some of his mechanical models. Roth's only drawback (he was a radio neurologist) was a lack of clinical experience with healthy children with scoliosis or hyperkyphosis and thus a fruitful collaboration with orthopedics in a broader way. The ever existing and observed presence of neuromuscular tightness in children with deformities (well described for Scheuermann's disease) can be used in these proposed tests to evaluate increasing tension in the musculoskeletal system during growth of healthy children. They will give a further clue to the question of the chance of progression. Roth called it the growth in length inhibiting muscular forces if the mitotic increase of volume exceeds the speed of growth of the central neural tissues (brainstem, cord and cauda equina). It is the background between gross external body types as asthenia, athletic or pycnic. But also between children that are "lean" or "stiff" in their locomotion. Much of this can be understand by his plea to understand that any abnormal circumstance in the neural tissue has its effects in the musculoskeletal system. Is the cord tense, the muscles, especially those responsible for extension and balance, will be too?

These signs of neuromuscular tightness rapidly increases during growth spurts and can be addressed by physical therapy or gymnastics as neurodynamic tools. It fits in the radio

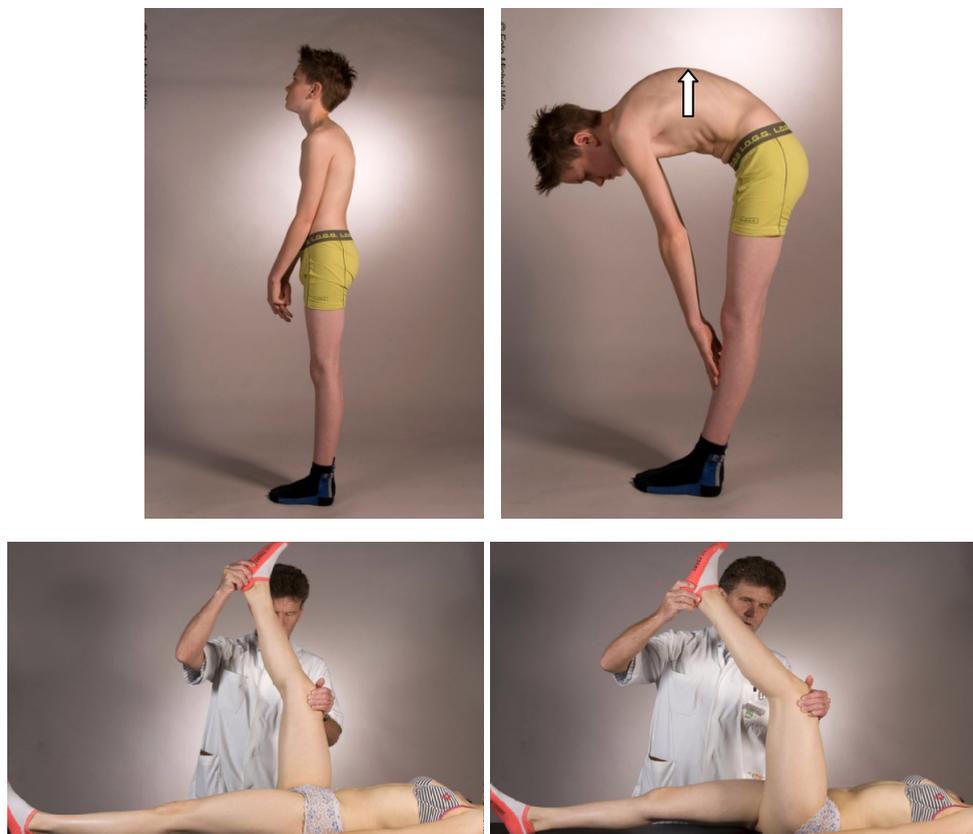


Fig. 14. Clinical test of neuromuscular tension. Above a boy of 12 presented with bad posture and muscular pains. From lateral an increased and long kyphosis can be seen. In bending because of “short hamstrings” and triceps surae a start of angulation in the kyphosis (arrow), leaning backwards in the ankles and a long finger ground distance can be seen. With his ankles in  $90^\circ$  he will loose balance. Below: healthy children with scoliosis as here in this girl show asymmetric straight leg raising or Femorotibiale angles. During growth spurts this is even more obvious.

diagnostic findings of a stretched, obvious tense central cord by Roth in his pneumencephalographic studies and the MRI findings recently published by Chu (Chu, 2008). In this publication observations are described on the relationship with Arnold Chiari malformations and scoliosis, by Roth already clearly stated (Roth, 1986). A nervous system that is stretched will have also have different clinical manifestations during life, all with secondary compensations and adaptations around it.

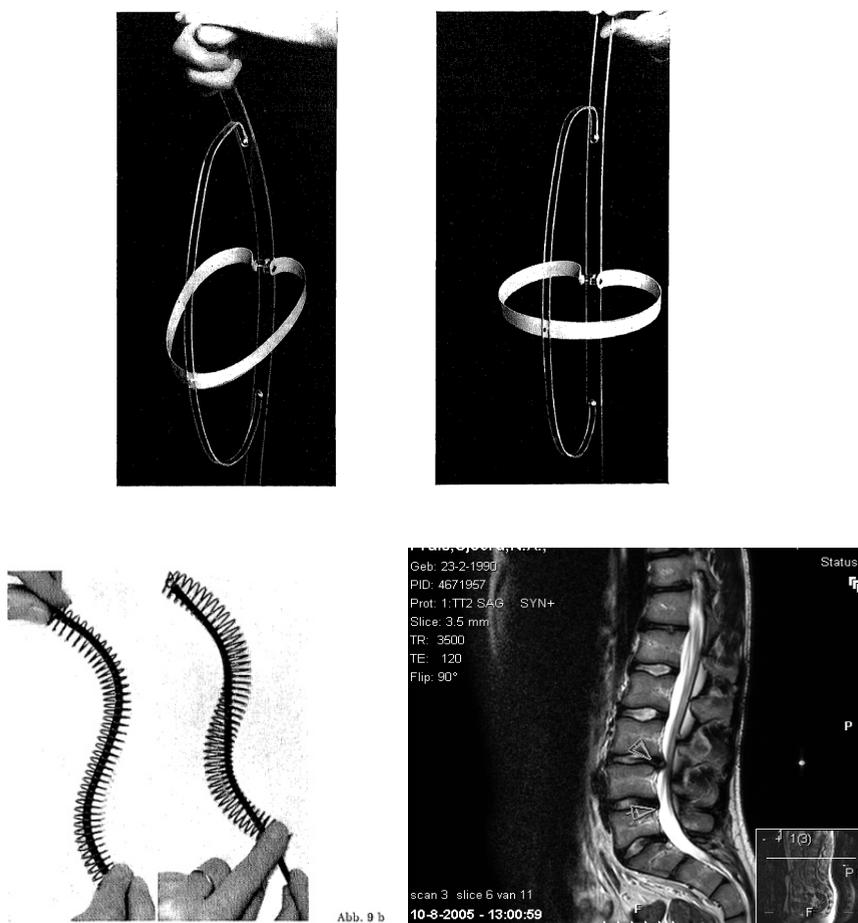


Fig. 15. For educational reasons and to show how tension between to systems can have consequences for both, Roth made different mechanical models. Above an eloquent model in which the relationship of creating the human lordosis, its concomitant vertebral grooves and the tensile forces to create and to hold this are condensed to mimic what happens in growth. The time factor and the increase in size cannot be shown. Below the most simple and illustrative model: a spring with a small rope inside. If the rope is shortened the curved spring shortens to but mainly by compressing the spirals in the concavities. To correlate with modern imaging at the right from own practice a sagittal T2 MRI from Th10 down. It is of a 15(!) year old boy who was seen for a bad sitting posture and low back pain. Straight leg raising was only 40° bilateral. Note the early changes as seen in Scheuermann at the TL joint and compressed discs at the posterior side lumbosacral. The complete posterior contact of the cauda in the canal and the stretched aspects looks similar to the spring model of Roth and were described already in his pneumomyelographies in Scoliosis and Scheuermann.

## 6. New facts on natural events around and deformations at the thoracolumbar joint and practical consequences in the evolution to proper treatment of scoliosis

The acceptance of the importance of all the events that take place, or evolves itself in the sagittal curvature in humans during growth gathered before 1914 helped us in the urge to go further than others to disclose the work of Roth. The acceptance of Roth's concepts because of their plausibility and their obvious representants in the all-day clinical practice with children and adolescents with postural and other spinal problems stimulated new ways of assessing and treating deformities like scoliosis in these children.

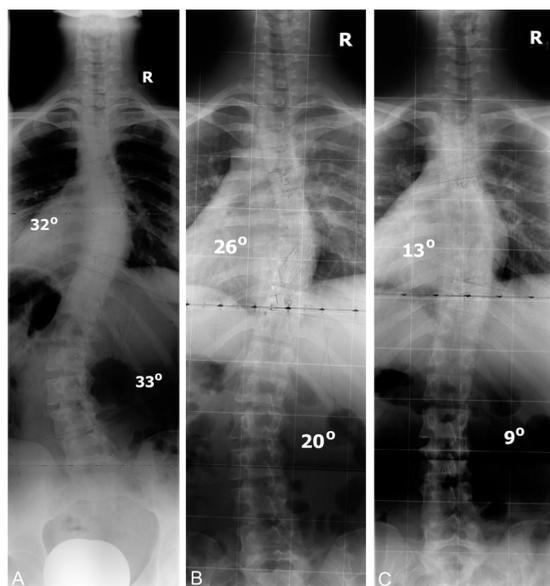


Fig. 16. Figures from the experimental study in Spine to proof the potential of correction by TLI principles in double major scoliosis. In 40 children with double major scoliosis (one curve at least 25°) the Cobb angles in standing position (left X-ray) were compared with those in supine position on a lordotic fulcrum under the thoracolumbar joint (picture left and right X-ray). In all cases both curves reduced very significantly. In a subgroup a third x-ray was made (middle X-ray) in just supine position, because of the well-known reduction of coronal curves if gravity is ruled out (van Loon et al., 2008)

In the found relation with the early events at the thoracolumbar joint (kyphosis in morphology, contracture in kinematics) and the possibility to come to etiology related therapeutic measurements the Thoracolumbar Lordotic Intervention (TLI) was developed. At first a brace technique with a new, unexpected way of successful correction in all deformities got into practice. In 2008 we presented in Spine a radiological study, demonstrating that forceful restoration of lordosis with a fulcrum under the thoracolumbar spine in supine children with double major scoliosis can correct instantaneous both curves significantly (van Loon, 2008a).

Its way of action of a TLI brace can be explained as to redirect the trunk extending long muscles in their original trail. The human spine is the only one that has such a trail in the form of the "vertebral groove", the concavities at each side of the spinal process in the vertebral lamina (Roth, 1969b). Also, for the first time, a consequent kyphotic curve in stead of the expected lordosis (in scoliosis) was found and described between the two coronal curves at the thoracolumbar spine in standing lateral radiographs. This finding is reproduced very recently by the study group of Sjanghai (Ni et al, 2010). With the, on these findings based corrective technique TLI (Thoracolumbar Lordotic Intervention) in braces, we brought promising results in a pilot study (van Loon et al, 2011).

TLI brings the older extending techniques back to stage and does not put the thoracic spine into flexion as is still advised based on Dickson's axiom. With the presence of any slight rotation in the spine or trunk, due to the asymmetric rotating forces of the diaphragm during respiration, a shortening and spiralisation will occur. This is according to Jansen and only proven by Dickson and his followers for the thoracic spine, because they overlooked apparently the events at the thoracolumbar spine. One of the main explanations can be that in developing kyphosis the proper deepening of the vertebral groove besides the spinal process become shallow, and only slight, but persistent torsional forces (Jansen) the erector trunci will slip gradually out of this pulley-groove (see also fig.3). The theory and experiments that dorsal shear forces are likely to be present in lordotic parts of a spine still holds. In our opinion they did not incorporate such a kyphosis in the thoracolumbar junction and this does not lean on older evidence in human spinal behavior and skeletal growth (Kouwenhoven et al, 2006; Kouwenhoven & Castelein, 2008). They describe the dorsal shear forces in fact in a "residual" - lordosis above a kyphotic change at the thoracolumbar joint. It does not say why it helps the M. erector trunci during growth spurts to force the spine and the complete trunk into an adaptive solution if the origin of the rotational forces that create even in non scoliotic a slight torsional aspect of the vertebrae. The location of the apices of sagittal curvatures is of paramount importance to assess if a human spine has developed along the ever present optimisation processes

In common sense there was/is knowledge of this "beautiful posture" coming with optimisation of the sagittal contour. Maybe because of developed aversion of the military and disciplinary aspects in "good posture", as not to speak of political abuse of this during the era's totalitarian regimes ruled peoples lives, discussions in academic Medicine on good and bad anatomical and physiological postures disappeared. For dealing with girls the fear not to be too much involved in "cosmesis" can be seen as a conflicting point of view to bring solutions. A more medieval acceptance of the presence of a good or a bad spinal posture slipped in, although tremendous efforts are done to cope in a very modern, increasingly "high tech" way, with our spinal problems.

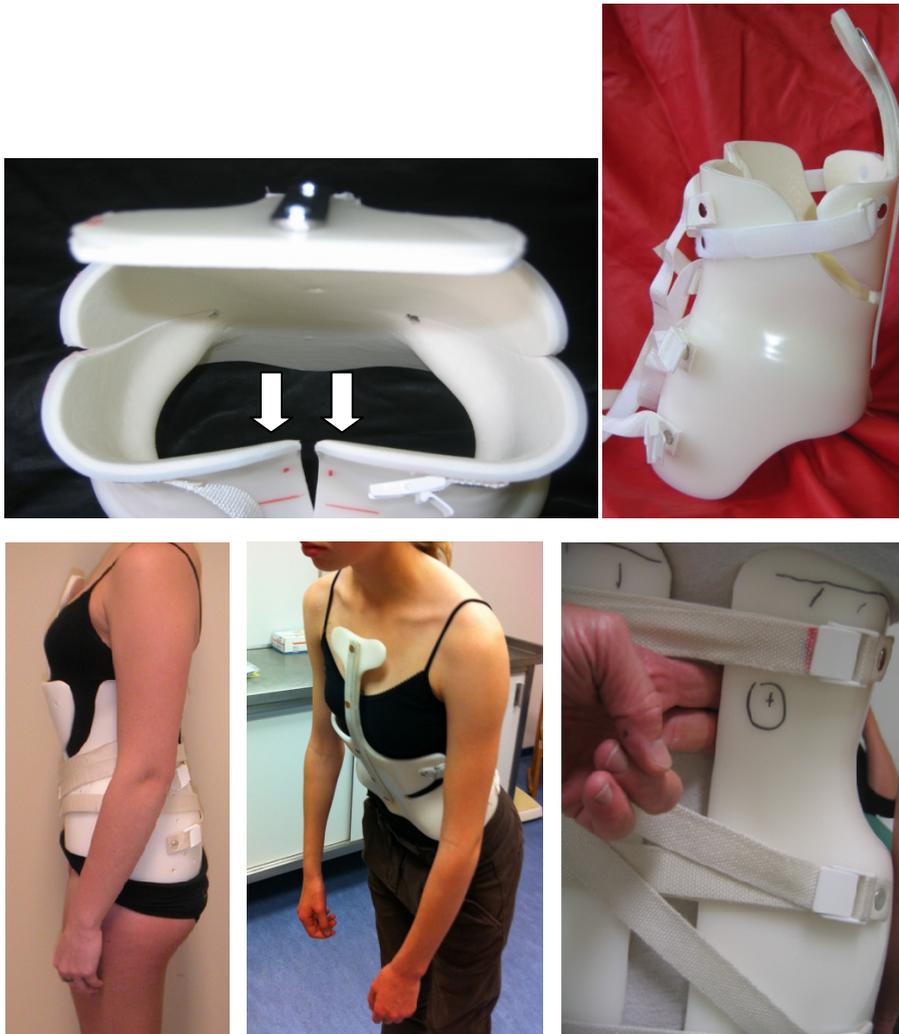


Fig. 17. Some aspects of Thoracolumbar Lordotic Intervention in a brace. Clockwise: A TLI brace seen from above with its backward bended sternal support. The places where pressure is applied on the paraspinal musculature at the thoracolumbar joint are symmetric and the same for all deformities (arrows); A TLI brace in lateral view. The short construction leaves a lot of freedom to move, except in flexion. a 15 year old girl wearing a TLI brace. The natural and cosmetic well accepted sagittal contour and normal balance are shown.; A girl with scoliosis in a TLI brace bending a little forward to show the extension that persist in the spine that leaves the sternum free.: By automatic further extension of the torso while wearing a TLI brace, at all controls the correction in lordosis can be augmented, whilst the upper and lower rims can be shortened with a positive effect on compliance. On the right the extra space after the first two months of wearing. The space will be filled up and the upper side shortened and bended backwards.

A functional interrelationship between curves in more than one plane was already shown in a study on bracing (van Rhijn,2002) In literature the sagittal contour of the spine in scoliosis is gaining more attention in the last decade because of severe problems that can be present in adulthood ( Glassman et al.,2005).



Fig. 18. The dynamic hypokyphosis in the thoracic spine above a thoracolumbar kyphosis. On the left a very well trained gymnastic girl of 16 after a (original, not TLI) Boston brace treatment for her scoliosis in a scoop test. The major asymmetric adaptations in muscular function and strength can be seen. On the right an 11 year old girl with a right sided thoracic scoliosis coming up from bending with the hands in the neck (scoop test) to achieve extension. Also here the hypokyphotic, almost lordotic spine at the level of the gibbus above the still kyphotic thoracolumbar spine is seen. In all children with deformations this scoop test shows a typical type of unrolling or coming up, with staged extension of the thoracic and lumbar spine.

## 7. Conclusions

Revitalization and combining older or dispersed knowledge on the causes of spinal deformities and on growth itself can bring an end to the "black box" or *Idiopathy*. Spinal growth can be seen as the result of a combination of neuro-osseous growth regulation in a very complex but understandable architecture of the loco motor system of all vertebrates. Three dimensional deformations are the result if any dyscongruency occurs between these two complete different types of growth in the neuro-osseous relationship. In scoliosis understanding of the meaning of the ever present torsional forces in the vertebrates and its special features in men is helpful. It seems that overlooking the work of Jansen, Roth and others kept the vision on the actual processes in the "black box" blurred.

In treating deformities with TLI principles we found an effective strategy in which the earliest etiologic moments and changes in functional anatomy of deformations is addressed. It applies a complete controlled lordosis, so normal growth forces and the proper function of the spine erecting muscles are being brought back in their anatomical tracts. And it prevents flexion, the rapidly increased and most prevailing "posture" in modern life of children. Much of these interventions can be done in a complete active way too by people themselves, guided by teachers, gymnasts or therapists that put development towards a good posture on the first place in their techniques.

This conjoined knowledge can also direct to new efforts in focused and dedicated research from unexpected etiologic view. New and possible better pathways can be developed for better preventive and conservative measurements in spinal deformities with progression during growth. Efforts to let children reach, from the start of their locomotion, a more optimal posture will increase the sustainability of the locomotor system as a whole and the durability of its functional parts.

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