# MILAN ROTH: OSTEONEURAL GROWTH RELATIONS, THE BIOMECHANIC AND NEURODYNAMIC PROCESSES OF PHYSICAL BODY GROWTH IN VERTEBRATES WITH TENSION AS ITS TOOL TO OVERCOME GRAVITY. CLINICAL IMPLICATIONS OF DISCONGRUENT OSTEONEURAL GROWTH.

*Contemporary biomedical science and neuroscience do lack knowledge on how the intrinsic characteristics of growth in morphogenesis and pathogenesis are governed by the Central Nervous System (Neurotrophism). Skeletal deformation and carcinogenesis in a un unexpected new etiologic framework.*

*The concise concepts on morphogenesis and the growth by stretch of the "Nervous Skeleton" by Prof. Milan Roth of Brno (1926–2006) and all its consequences for etiology, pathogenesis, prevention and diagnostics in, at first, orthopaedic and neurologic disorders are disclosed. His scientific journey is revisited: from his early observations in scoliosis by pneumomyelography to understandable explanation why the human body is at risk for many exclusive human disorders in form and function in case of discongruent osteo-neural growth under influence of well knowned intrinsic and external factors.*

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## 1. INTRODUCTION

In orthopaedic literature an understandable biomechanical etiology of scoliosis and many other spine- and not spine related musculoskeletal conditions, thus the set of causative factors needed for that, is still lacking. But looking into recent literature on musculoskeletal conditions without direct trauma, genetic defects or infection, there are only few without the proverb "Idiopathic" in its name or description. Where for more than two centuries in European Orthopaedics the spinal deformities in healthy children were explained exclusively as load dependant deformities as an effect of sitting of children during long periods (school, embroidery, sitting child labour, or heavy labour on farms or in construction before the skeleton was matured, from the seventies in the last century "idiopathic" is popping up round many musculoskeletal conditions out of Anglo-American medical societies. Knowledge under what kind of circumstances bone, cartilage and spinal discs will be formed properly or can be deformed was however already sought out in the field of biomechanics and addressed in classic Orthopedics, including the preventive power of body exercises in "(school) gymnastics", all around the basic biomechanic knowledge on posture (Haltung, Leibeshaltung or Alignement in German). Wolff's Law on remodelling of bone in response to loading achieved via mechanotransduction, is an undisputed base in science on a growing skeleton. But how deformation of the total spinal structure, centre part of our body posture, is actually achieved is nowadays said unknown and called "idiopathic" in Anglo-American literature. The main black box on "how Nature works" in a growing individual to reach optimal end results had to lead at a given moment to the important role the nervous system plays, by its own growth, and on its role in morphogenesis and in patho-anatomy of all other organ-systems( Neurotropism), fist of all the locomotor system. Just because endo-, ecto-and mesodermal tissues during growth become all firmly attached on cellular level with those billions of nervous cells, gives us a clue about the importance of nervous cells in creating and maintaining "health". The formation of billions of synaptic connections during the growth, all new somatic cells had to be connected with one of more nervous cell or dendrites attached to their stem cells, means an intriguing piece of neuroscience. The well-known fact, that all those billion nerve cells in the world of vertebrates are already formed about three months after gestation is a major fundament on the concepts here to be discussed. That neurogenic part of morphogenesis was never researched in depth till Milan Roth started this after his unexpected observations on central cord and roots in pneumomyelography in scoliotic patients.

In a process of reversed engineering by the first author on getting scientific evidence behind the effectiveness of a new found brace technique in spinal deformities as scoliosis and kyphosis (TLI: Thoracolumbar Lordotic Intervention) the vast research of the neuroscientist Prof. Milan Roth, neuroradiologist in Brno, in (then) Czechoslovakia was revealed in extenso. The original search was headed for explanations in the found relationship between abnormal form and abnormal function (bad posture and decreased sagittal flexibility) in thorough clinical examination of the locomotor apparatus in adolescents. A relation between spinal deformities, including "bad postures" and increased tension (thightness) in the neuromuscular structures (highly innervated myofascial structures as now commonly seen in "tight hamstrings") in the legs of adolescents was consequently found in practice (PvL).

Roth found, researched and delivered the first concept ever on basic natural principles to explain how a growing organism can come to its final form under guidance and control of the Central Nervous System. He found answers why only the human spine can easily deform into scoliosis as a result of asymmetric tension in the CNS, that has a hard job to balance a heavy weight of our skull on a flexible, but because of our bipedality and human specific motion intriguing spine. As a consequence of obeying all Natural Laws of a growing organism a further proof of "Form follows Function", as a nondisputed axiom in Biology, become supported by his work.

His most intriguing step in biology and Medicine is that in which he brings us towards understanding the most malignant and life-threatening condition in modern man, cancer, is his concept on the loss of neural control of those somatic cells, that lost or never had synaptic contact with the neighbouring neural cells in case of too fast activity, as can be expected in children with high velocity growth spurt.

There is no better introduction to his legacy than to copy the first part of Milan Roth's own introduction in his book "Neurovertebral and Osteoneural Growth Relations" out of 1985:

***"The progress of modern biology and medicine is associated with the unfavourable phenomenon known as the interdisciplinary barrier. By the steady increase of the latter the constructive communication between the representatives of individual branches of science is rendered ever more difficult. This communication is however, vitally desirable for synthesis and exploitation of knowledge accumulated in in vast and frequently very remote fields of research. With this object in mind the present author has undertaken an attempt to correlate, on the basis of own specific approach and of knowledge acquired by study of extensive literature, some facts concerning fields as remote as developmental anatomy and physiology, experimental embryology and teratology on the one hand with those of clinical disciplines as roentgen morphology and pathology of the skeleton as well as oncology at the other hand. Such a project may appear far too ambitious to be realizable but the author is confident of being able to disclose for the reader a principle common to all the above-mentioned branches of biological science."***

## 2. BIOGRAPHY

Professor Milan Roth died on April 4 2006, due to complications of a second CVA, on the same day his concepts were presented extensively for the first time on an international symposium on scoliosis in Oxford.[4] He was a professor of neuro-radiology of the J.Ev.Purkyně-University (now: Masaryk-University) in Brno, capital of Moravia in Czechoslovakia, now the Czech Republic, but dedicated his scientific career to explore the "black box" in biomedical knowledge.

Milan Roth was born on October 6, 1923 in Lelekovice, a small village north of Brno, in a local schoolmaster's family. After completing his grammar school studies in Brno in 1942, he spent a year improving his language skills because the Czech universities were closed at the wartime. Since 1943 till the end of World War II, he was forced to work for the German occupiers in an armament factory in Kurim near Brno as part of the "Totaleinsatz" in warfare of the Nazi's. After the war, he studied at the Medical Faculty of (now) Masaryk University in Brno, completing his studies on September 29,1949. First, he was assigned to the department of surgery at the local hospital in Brunntal in northern Moravia (till January 31, 1950). During 1950-1952 he served in the army, most of the time at the Department of Radiology of the Military Hospital in Plzen (Pilsen). After completing his military service, he spent a short time at the pulmonary department of the local hospital in Prerov, and then at the Central Department of Radiology of the Medical Faculty in Olomouc (now Palacky University). Since November 1, 1954, he has been with the Central Department of Radiology of the Medical Faculty in Brno (now Masaryk University) that became Department of Radiology and Nuclear Medicine in 1960, and this was his workplace till his retirement in August 1989. Only in his early career he worked as a fellow, not accompanied by his young family as that was forbidden under the communistic regime, at the Karolinska Institute of the University of Stockholm, Sweden.

After this scientific fellowship abroad, he got an appointment in Brno in basic research too, in the field of anatomy. In that research trail on finding the biomedical explanation on the role of the CNS

**Fig. 1.** Prof. Milan Roth at the age of 80

in spinal deformities, he could extend his findings to a much more important level: the explanation of growth of natural bodies to overcome gravity and come to species specific morphogenesis and deformities, like scoliosis in men. His first observations with pneumomyelography started his endless interest in what is going on during morphogenesis and how you could understand the role of the nervous tissue in macroscopic features, which in his concepts brought us the explanation on cellular level, always on a Socratic way asking himself the question if the steps he made in building his theory could be denied by others.

By all sorts of restrictions and censorship under the communistic repressive rules, he could not get access to meetings and societies in the free world. He wrote a lot of articles in Czech, German and English language, all with Russian summaries, and almost all inaccessible for the "Western" mainstream medical science, before he wrote down his legacy in his Opus magnum, a book (in English): Neurovertebral and Osteoneural Growth relations, published by the University of Brno in 1985. After the Velvet Revolution he managed to publish abroad on his extended thoughts on etiology of all growth dependant musculoskeletal and spinal cord conditions even into more common lifestyle related conditions, that can now be seen as one of the biggest socio-economic burden of diseases:

herniated discs, disc degeneration and spinal stenosis. His concepted etiology of cancer can be the game changing theory in oncology, because of its simplicity, that will not so much bring curing therapies, but certainly can bring back the huge power of preventive Medicine, as cancer is world-wide seen as a consequence of our way of life (Zivilizationskrankheiten).

After his retirement on the University he stayed a part-time radiologist of the Radiodiagnostic Clinic of the hospital in Brno - Bohunice. He suffered a brain stroke early in 1999, became seriously aphasic. Just before the planned visit of the first author, his medical condition detoriated quickly because of a second CVA. Milan Roth passed away peacefully amidst his family on April 4 2006.

His work remained largely unnoticed in the mainstream of the international world of neuroscience, orthopaedics, neurology or neurosurgery and had only some influence in Anatomy and Embryology. But in his own country he was recognised and honoured by the Society for Connective Tissues, CMA J.E. Purkyně. He also was for a long time in the redaction of journal Pohybové ústrojí (Locomotor system). It is a true honour to give this support to give him posthumous the chance to be recognised forever as a scientific leader in Medicine.

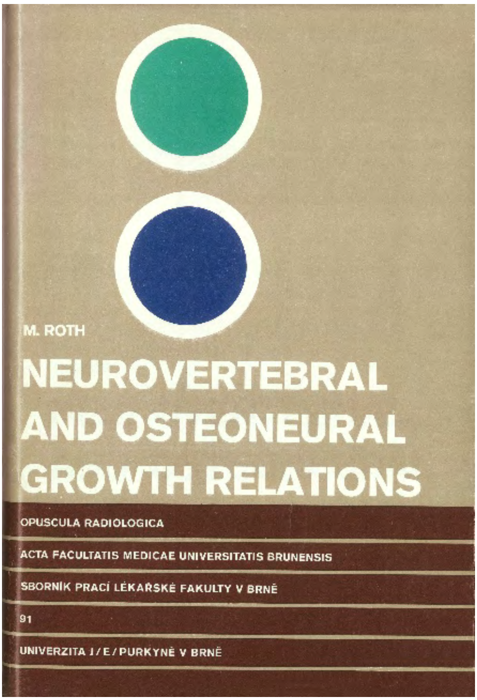


**Fig. 2.** Picture of the title and the front of his book (1985)

At the end of this contribution a bibliography of selected articles and a summary of his book is added with the main purpose to disclose them to a wider audience.

His main concept is the concept on skeletal morphogenesis and the way the billions of not connected nerve cells are capable of developing an extremely interconnected "Nervous Skeleton" and create and maintain contact with all the many billion new somatic cells that grow by mitosis in a centrifugal wave from the axial spine-cord complex. The overall concept he developed is based on the existence of 2 different types of growth of the spinal column, viz., the cellular-divisional (mitotic) growth of bone and soft tissues and the extensive (stretch) growth of the nervous structures. The neural extensive growth proceeds at a slower rate than the bone growth. Which is manifested most conspicuously in the ascent of the spinal cord. In his concept a number of normal as well as pathological features of the skeletal morphogenesis- above all the gross deformities of the body-parts which grow rapidly in length such as the spine, the extremities or the facial skeleton – are explained by the disturbed relation of the two growth types caused by an insufficiency of the vulnerable neural extensive growth.

## 3. OVERVIEW OF THE RESEARCH WORK OF MILAN ROTH

His biomedical scientific legacy is of such a wide scope that it is difficult to specify, discuss or review all his work in this contribution. It can however be divided it in four main chapters:

1. Analytical work, undertaken mainly during the decade 1960-1970, in which he laid the fundaments of the research into the suspected interdependency in growth of the skeleton and the CNS. It was supported by examining and integrating his interpretation of older work in the fields of biology, embryology, anatomy and physiology.
2. Creation of mechanical models of the spine and the central cord roots complex, to mimic the processes of spinal growth and the pathway of deformations. Creation of intelligent "infographics" in drawings of the macroscopic growth as an extrapolation of the suspected processes on cellular level. With this drawings he could explain and visualise the processes of interrelated types of growth in the growing body in regard of the time relapsed and the existing tensile forces, that are needed to "mould" the volume increase by mitosis of somatic cells into species and families related adult anatomy .The moulding is done by muscular actions which also depicts in midterm embryological stage the places where joints will be formed.
3. Proposing the integrated concept of neuro-osseous growth relations and the causes of possible discongruency between the two types and its role in explaining the normal development of tissues creating the organs and organic systems, viewing the thoracolumbar spine as a crucial primary part in formation and functionality of the skeleton and nervous tissue.
4. Publishing articles from 1970 till 1998 in which he consequently built upon his earlier integrated concepts. This included papers on topics such as scoliosis, Scheuermann's disease, the Arnold Chiari malformation and Syringomyelia, the role and development of the neural foramen in order to get better understanding of the pathoanatomy of stenosis.

Unhappily, there is no clue in reading his work, or any mentioning in discussions by himself, that he was aware of the research done on the clinical part of growth in healthy schoolchildren. This was sought out in the German speaking world of orthopaedics in the 19$^{th}$ century, that reached its zenith of knowledge on healthy growth around 1914. At that time there was much emphasis on the relationship between (bad) sitting positions in early childhood at home and on schools with the occurrence of scoliosis and hyperkyphosis.

As we see nowadays in most countries, the sedentary lifestyle of children must be responsible for the huge increase in musculoskeletal conditions in absence of any preventive or hygienic knowledge on the importance of a healthy natural posture (alignment) of the growing body. Two World Wars took care of permanent distraction of focus of mainstream medicine on this part of health as part of classic orthopaedics. There is ample evidence that from 1914 on the complete Anglo-

American scientific and medical world cut all influence out of the German speaking world, leading to a huge loss of knowledge on prevention that could be provided to the growing child. The passive deformation of discs cartilage and bone by external and lifestyle dependant pathologic loading patterns caused by sitting is a fast-increasing feature in modern youth with its sedentary lifestyle from the start. The authors stress, that the classic orthopaedic knowledge on healthy growth and the found disturbing factors are completely explained in its deepest biomedical background of Natures capabilities how growth (morphogenesis and physiogenesis) could be optimised, by the research of Roth. If there is a lack of mobility and exercise by which the nervous tissue will be stretched (grows) the skeleton and its easily deformable parts (discs and cartilage) will show deformations. It is important to emphasise, that in his days the physical education of the mean growing child in his country and the knowledge on prevention in the proper care for good postures out of the European Orthopedics and schools of gymnastics still existed and was provided. Obviously, he therefore focussed on the pathologic cases he encountered in his work as neuroradiologist.

## 3.1 Analytical work

Roth's knowledge of the superb work of European scientists on the deformed spine, gross morphology-anatomists, embryologists, biologists and orthopaedics which he often quoted, was prodigious, being aware about the grounds of their disputes on certain earlier concepts, mainly on scoliosis. An increasing number of anatomists and orthopaedics were investigating skeletal problems in Europe in the late nineteenth century, which included spinal deformations with its topic scoliosis, with names such as Lorenz, Nicolodani, Albert and Schulthess noted. Wolff's Law on Bone formation and the principle named after Hueter and Volkmann are leading until today. But both lack any clue on the role of the nervous system during growth. They conducted anatomical studies, mainly on cadaver spines and details in vertebrae and discs. Roth was the first to step into the black box between visible changes in posture and the intriguing role of the nervous tissue in its bony housing by his own discoveries and observations resulting from his expertise in pneumencephalo- and myelography. As one of the first with expertise in creating contrast X-rays of the spinal canal by inflating air in the intradural space he made new observations on unknown pathologic features of the position, calibre, asymmetries leading to a suspected presence of tension in the central cord and vertebral roots in especially scoliotic spines. He stated: *"The traction effect of the spinal nerves is of decisive influence upon the position of the spinal cord within the spinal canal as well as upon the shaping of the vertebral foraminae, a conclusion we reached in our own radiographic studies, published in 1965 and 1966"*.

## Phylogenetic work

The hypothesis that the tensionless position of the central nervous system matures into the adult skull and spine was demonstrated in worms and other, higher developed animals as well as in radiological and cadaver human studies. He stresses the phylogenetical criteria incorporated in Holzer's Neuroprotective mechanism, in which all vertebrates should grow in such a way, that the central cord, the brain and the nerve roots dwell in rest completely free of contact, are equally surrounded by liquor cerebrospinalis and can move freely in the bony "house" that protect them by

1. The growth in length of the vertebrate body including man proceeds, together with differentiation, in the *craniocaudal direction* (Fig. 2). This biological law has not been adequately appreciated in human biology and medicine. In the anatomical, anthropological, paediatric or orthopaedic monographs the growth in length of the human body is consistently designed as though it proceeded from the feet to the head, i.e. with the feet at the same level in the schematic drawings.

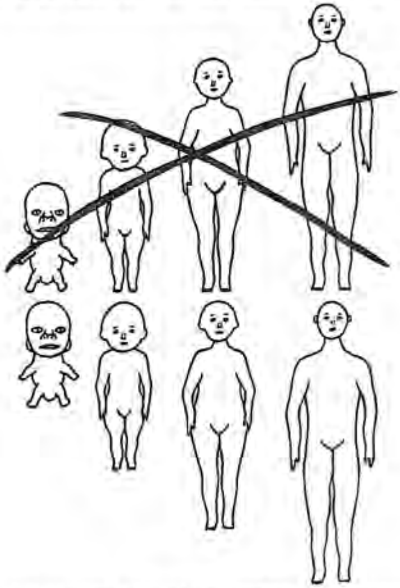

*Fig. 2.* The correct *(below)* and incorrect *(above)* conception of the growth in length of the vertebrate body.

**Fig. 3.** Drawing and explanation of a more neuroscientific view on growth in vertebrates, based on the principles by Kingsbury of cephalo-caudad growth (Book, 1985, page 12)

enough circumferential space for the liquor cerebrospinalis. This must be even be true in maximal range of motions of the spine and big joints. By applying study to the normal state and growth he allowed us to develop understanding of the requirements of the central nervous tissues during growth into adult anatomy.

**Experimental teratogenic work on the role of the nervous system and disconnected Osteoneural Growth Relations in Carcinogenesis.**

The concepts of Roth on the possibility to get cancer in many humans' organs is of a never seen intelligence and imagination to understand what cells, or islands of cells can do in the case of escaping the constant control in function by nervous cells. This escape by insufficient quantitative

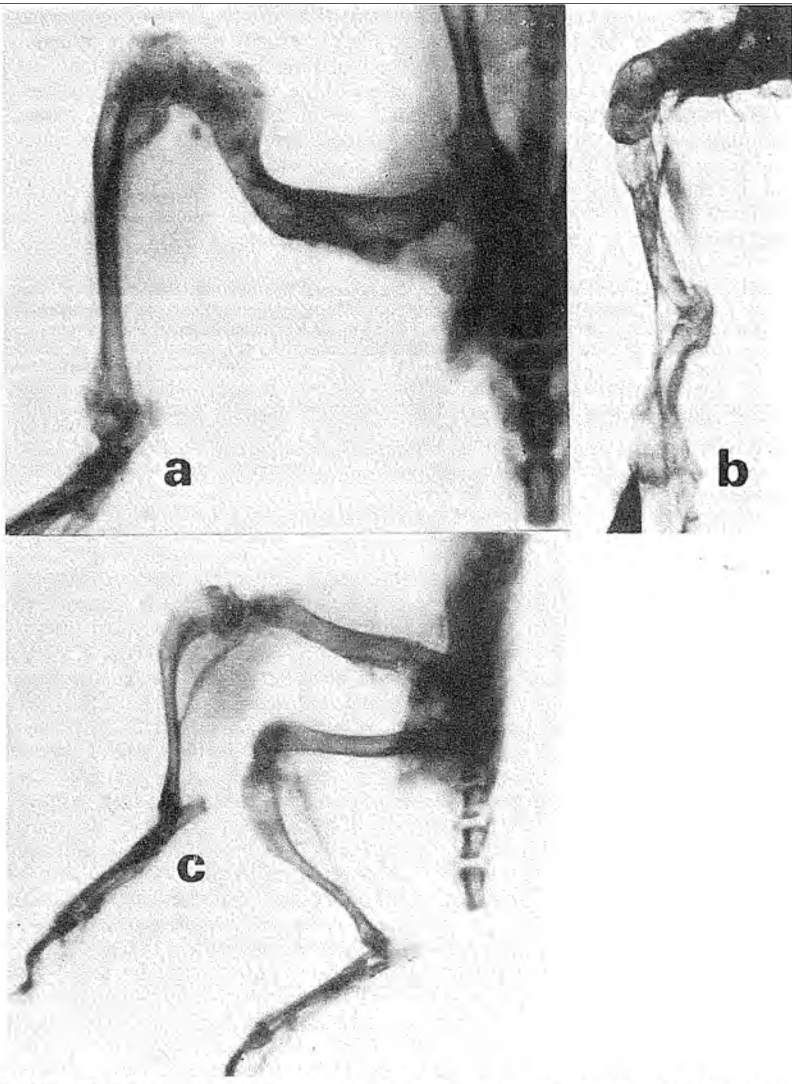


*Fig. 62a–c.* Roentgenograms of the hind limbs of adult osteolathyric rats (a, c), hind limb of an osteolathyric frog tadpole (cleared with the Williams' technique and photographed in full extension) in (b). Femoro-tibial "sticking out" with excessive varus deformity of the tibia in (a) is related to the same cause like the cruro-tarsal deformity in the tadpole (b), viz., to the excessive growth insufficiency of the sciatic nerve. Sciatic nerve section performed at the beginning of the experiment (*lower* placed limb) has an important preventive effect upon the osteolathyric bone changes (c).

**Fig. 4.** Some examples of animal extremities (a. rat; b. tadpole) in which the effect of lathyrus injected in the amnion shows postnatal bowstring effect of the N. Ischiadicus) and bowing and varus of bones.

synapse-formation between nerve cells and their attached somatic cells in a period of growth that shows discongruency, can lead to undifferentiated cell division and autonomous, but malignant behaviour. He postulated firmly, that if groups of cells miss any control by the nervous cells, they will grow in all directions as a "tumour" in many forms can spread as metastases and behave on malign way quit easily. In order to understand the role biochemistry plays (and still plays) in the development of a range of deformities of the spine, extremities and jaw, Roth conducted experimental studies on teratogenesis to clarify the role of the up to then neglected osteo-neural growth patterns, an area in which the growth by stretch of the nervous system interacts with other tissues. Roth was able to impair the stretching properties of the nervous system by exposing it (intra-uterine) to either teratogenic substances or by lowering the level of oxygen (as in Cerebral Palsy) within it. In these experiments, he was able to create spinal deformities as scoliosis in animals like chicken, ducks, tadpole and rats.

His experiments demonstrated that the so-called passive role of neurogenic tissue, especially in the central cord, was transformed into a major, active role during the development and growth of the spine and the extremities. This ability of nervous tissue to grow by extension is phylogenetically determinate. Growth and errors of growth of the vertebrate spinal skeleton was depicted by his concepts, allowing the "intimate relation existing from the very beginning of development between the nervous and the bony tissue to continue working incessantly during the whole growth period of life".

## 3.2 Mechanical models of the spine, spinal growth and deformations

After concluding that in scoliosis (as the first deformity he investigated) there is a mismatch or discongruency in growth of length between the skeleton and the nerve cells, Roth developed and made his own mechanical models for different issues in a quest for an better understanding of the development of the normal, as well as the distorted or deformed spine (and skeleton). He was fully aware that forces in nature are often invisible, such as the forces of growth and tensions within the body. He realised that only the consequences of these forces on a body can be seen and thus a conceptual clarification of the universally adopted relationship between form and function (i.e. acting forces) is essential in order to understand these important processes in nature.

In a paper on the models of neuro-vertebral relations, Roth described an elastic model which could dynamically reproduce the physiological relationships of the growth of osseous structures with that of nervous tissue. Using Plexiglas, rubber, textile and metal he was able to construct an accurate model representing all the components of his concept of proportioned and disproportional growth between different tissues. The dynamics of locomotion, but also of the intrinsic tension by balancing or produced by growth were visualised in all sorts of mechanical models. Roth created all his models himself. He fully realised in accordance with the gross morphologists like Volkmann, Hueter, Nicolodani, that there were changes in form of bones and joints between the embryological stages and the later adult state just because of the always present patterns of locomotion in the womb and in postnatal life. And that all these changes are reflecting the individual development of the phenotype, our ontogenesis.

Radiographs were made of these models in different stages of applied forces of tension, using different planes in order to demonstrate the close similarities with the radiographic images of living individuals. The model also explained the ascent of the conus medullaris during growth, widely seen then as a passive displacement. In some pathological conditions, like myelomeningocele, the ascent is said to be hindered by a tight string of fibrous tissue, the filum terminale, causing a "tethered cord". Roth claimed that the less intrinsic loss of stretch ability tense spinal cord and associated attached roots would explain the impossibility of it "ascending" properly into the position of the conus at the T12-L1 area whereas in other animals the conus still remains at a lower level in the lumbar spine. The ascent was thus seen as an adaptation to the prevailing upright position of the body in mankind. The so-called "tethering" is thus not a passive binding by strings, but an intrinsic quality of nervous tissue. The stressed lordotic component of the thoracolumbar spine required in order to create optimal biomechanical and neuromechanical conditions is also a very interesting aspect of his models.

For his concept of the osteoneural growth concept, Roth devised a very simple model, made from beads on a string. This "necklace" model, which can be easily copied today with materials such as slightly deformable beads, gives an insight in what can happen when nervous tissue is unable to keep up to the extending energy growing bone is delivering. The tension within the bones or the counteracting energy of muscle actions occurring as a result of activity act as supercharged engine dictated by nervous tissue itself.

Normal growth leads to the development of slender and long bones, but as the trend towards lengthening of bones takes place, the resulting retardation of extension of nervous tissue leads to the beads becoming compressed and thereby deformed.

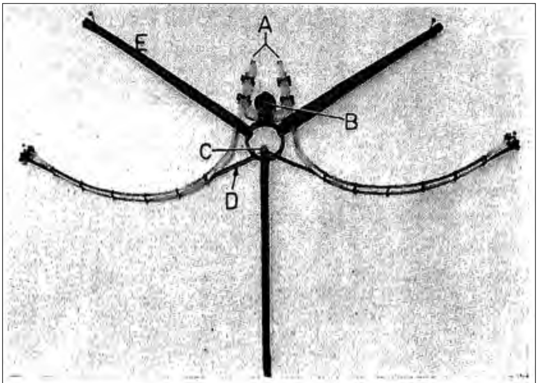


Fig. 1. A thoracic segment in the elastic model, viewed from above and slightly behind. A — vertebral body, B — longitudinal axis of spine, C — spinal cord, D — spinal nerve, E — rubber strip.

**Fig. 5a.** Photograph of a single segment of the thoracic spine in the transversal plane with modelling of the ribs, roots and cord. From: Roth M. [Models of vertebro neural relations]. Czesk Radiol 1970 Sep; 24(5): 189-94. (Courtesy of Roth's heirs).

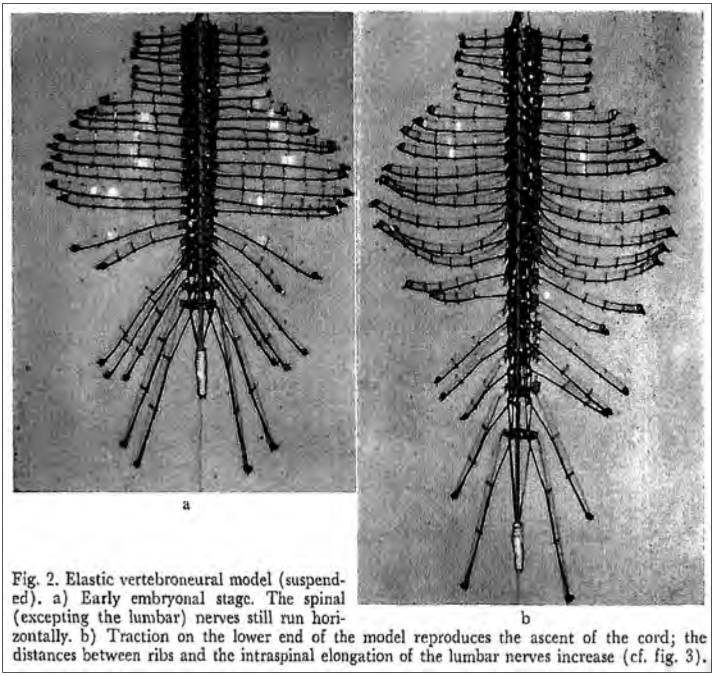


**Fig 5 b**. The whole construct of spine, inhabitants and ribs in two different positions distinguished by a certain amount of tension in the combined system of different tissues. From: Roth M. [Models of vertebra-neural relations]. Cesk Radiol 1970 Sep; 24(5): 189–94. *(Courtesy of Roth's heirs).*

## 3.3 The concept of osteo-neural growth

The existence of scoliotic curves in the human spine, not encountered in other animals, puzzled him as much as it still does today, especially when he found out that the central cord was distorted too. Furthermore, the biomechanical adagio that form always follows or reflects function was a mainstay in his thinking throughout his published work. The attention was drawn to the relationship between nervous tissues and the spinal canal by his pioneering work as a neuro-radiologist, employing the techniques of pneumoencephalography, myelography and positive contrast examinations of the scoliotic spine.

**Biological studies supporting these concepts**

The comparison of the growth of animal nervous tissue by extension and the growth of central fibres in plants on the same mechanism has already been fully explained and is undeniable. It is also a well-known fact, that there is no cell proliferation by mitosis of nervous tissue after birth in animals. All the billions neurocytes are present about three months after gestation. Nervous tissue, in vertebrates as in all other animals, must possess an alternate pattern of growth, to reach its adult length than all other tissues in the body. Somatic tissues grow or renew themselves at all stages of life by rapid and intensive cell proliferation, especially during growth. "As in trees, the growth pattern is by extension of the cells (extensive growth; German: Streckungswachstum). Roth compared

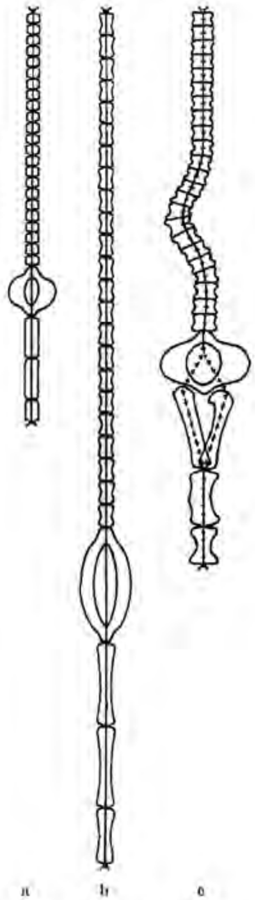


Fig. 1a–c. The "necklace" model of osteo-neural growth relations. The nervous structures are represented by the thread, the growing axial and extraaxial skeletal elements by the beads. Fetal stadium in (a). Skeletal morphogenesis in the quadruped (b) and in man (c), eventually with pathological features (platyspondyly, kyphoscoliosis, bone and joint dysplasias) according to the more or less evolved capacity of the thread to elongate. The gross shape of a bony element depends on the amount of space available along the nervous structures

**Fig 6**. A schematic drawing of the necklace model in which prolonged or progressive tension on the string gives deformation of the vertebrate skeleton like beads. From: Roth M.: The relative osteo-Neural growth; a concept of Normal and pathological (Teratogenic) skeletal Morphogenesis. Gegenbaur morph. Jahrb. Leipzig 119 (1973)2, S.250–274 (courtesy of Roth's heirs).

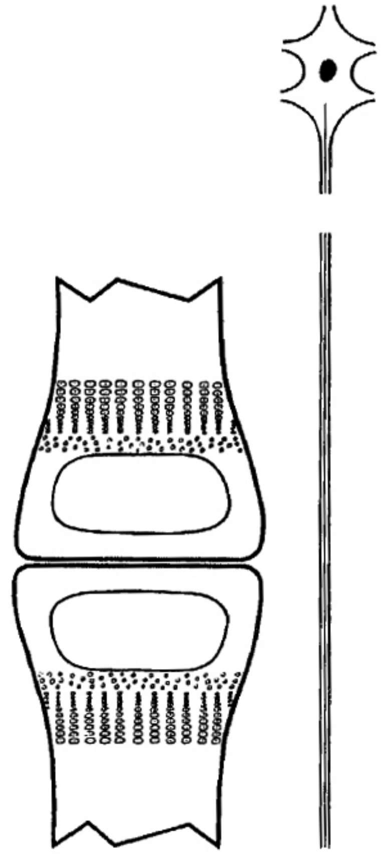


**Fig. 7.** A schematic drawing showing the difference in how tissues in vertebrate animals grow, namely by cell proliferation comparing the epiphyseal zones around a schematic joint at the left, and the elongation by stretching of a none proliferating nervous tissue cell. (From: Roth M. [Idiopathic scoliosis a special type of osteo-neural growth disproportion]. Z Orthop Ihre Grenzgeb 1969 Nov;107(1): 37–46). Courtesy of Roth's heirs.

the governing phytohormone auxin, a tryptophan derivate driving this type of growth in plants which is said to be highly susceptible to a number of growth inhibitors (Gutenberg, Lehrbuch der Botanik) with the role of serotonins in the growth of nerves in animals. The energy necessary to stretch cells is generated by tensile power in the surrounding tissues during growth. In the spine, the vertebrae and discoligamentary complex, growing by cell proliferation, is responsible for the energy needed to stretch associated nervous tissues: "tag on tow".

With great interest in biology and specially biological literature on plant and animal growth Roth adapted the law of cephalocaudal differential growth ( Kingsbury) in which growth in animals, just as in plants is found to be directed from the first existing and central parts of a living creature, in the

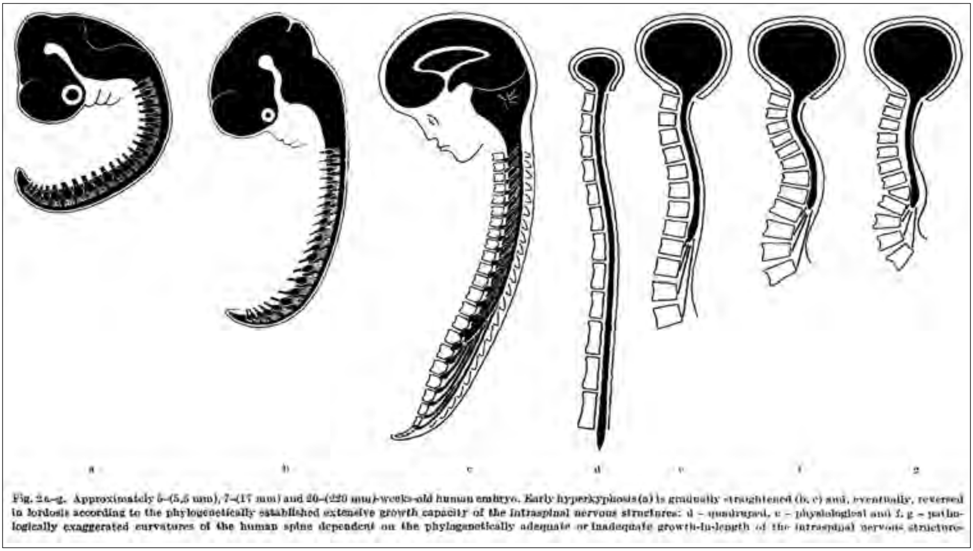

**Fig. 8.** Schematic drawing of embryological stages in which the enormous relative volume of the nervous system and the comma like shape is depicted, gradually changing to a stretched and slenderer configuration, before the biomechanical needed cervical and lumbar lordosis is created. From: Roth M.: The relative osteo-Neural growth; a concept of Normal and pathological (Teratogenic) skeletal Morphogenesis. Gegenbaur morph.Jahrb., Leipzig 119 (1973)2, S.250-274 (courtesy of Roth's heirs)

vertebrate the central cord, in his early embryological stages being in advance of the first segmentations of surrounding tissues. Although describing a leading role the osseous structures play as an acting part in the lengthening of the central nervous structures, by subscribing that intriguing law of cephalocaudal differential growth he put the phylogenetically and embryologically oldest part of the nervous organ, the central cord and brainstem, in a initiating, architectural and controlling role of the lay-out or construction of their own house, the surrounding tissues that form the biomechanical even more intriguing spine.

**The leading role of the nervous tissue in morphogenesis of the axial skeleton. Neurotropism explained.**

Roth stresses that till his time, and not much changed since then (authors remark), the primary role and place of the nervous tissue in development and growth of the body with the other systems, like the vascular, gastrointestinal and musculo-skeletal systems, was apparently left out of consideration in scientific work on the very complex and interrelated stages of maturing a single diploid cell to a full-grown animal or man.

For showing the exaggerated ventral-concave curvature (hyperkyphosis) of the early embryonic body Roth refers and used schematic drawings with examples taken out of earlier work of Blechschmidt.

As is the so-called ascensus of the conus-cauda, until now seen as a passive event, also the lengthening of the spinal nerve roots is widely considered as dragging them along by the fast-growing spinal column. Roth stated the opposite and reveals that there is also a controlling function of the central nervous system on the final form of the spine in adulthood. It is the need for a child to create lordosis and the in human's unique possibility of torque and counter torque at the TL junction that is maximal at the thoracolumbar spine to perform upright walking. He compares it with the leading role unrolling of the growing brain substances control the form of the skull (calva) at the end of growth. It gives an understandable explanation why the conus in man is present at the thoracolumbar joint while it is in the lower lumbar spine in almost all quadrupeds.

As a Leitmotiv in all his argumentation he follows Němeček et al. (1972): *"The neuron has two main functions: First to maintain its own integrity as well as the integrity of the organism innervated cells by it. The neuron is one of the important regulators of growth of other organs, of their metabolism and function. The complex of these functional aspects is called the "trophic role" of the nervous system. The other part of the neuron's functions, in general more accentuated, consists in mechanisms which give origin to impulses, make their regulated propagation possible and account for the integrated function of the nervous system. The nervous system is extraordinarily sensible to oxygen supply. A lack of the latter lasting more than one-minute sets the nerve cells out of function. The main energetic substratum of the brain is glucose".*

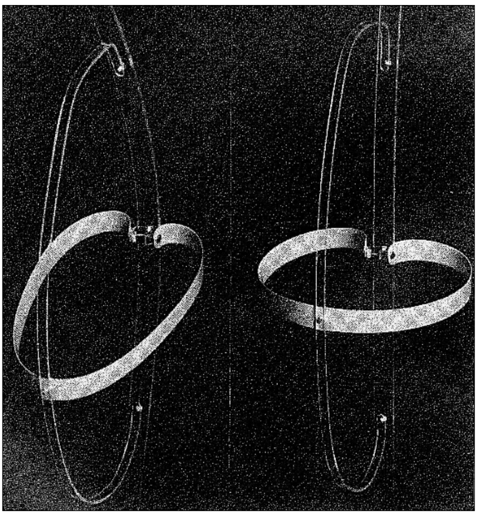

**Fig. 9**. A mechanical model showing the difference in shape of ribcage and diaphragm in a kyphotic posture and in full extension as in deep inhalation.

## Chapter 4. Summary

It is clear that Roth missed feeling or constant practical experience with the complete clinical picture of children with and without deformations of the spine. He clearly stated that a lordotic form of the lumbar and thoracolumbar spine is of great importance for proper function of this complex area of the most mobile part of the spine in childhood. He described the needed functional possibility of the lower thoracic ribs to elevate, but also to retro-pulse themselves and helping by that the impressive bellow function of the diaphragm. That tension on neuromuscular structures can be measured and that most of the mechanical laws of Robert Hooke on properties of tensile bodies like springs are of value to understand the complex mechanism between controlling nervous system was not foreseen by Roth. The deformation of discs and osseous elements of the spine is created by the same sort of forces that makes the ability to stand, sit, balance and motion, which is delivered by the muscular system, possible. No muscle acts without instruction by neurogenous signalling.

### The consequence: Roth on spinal and skeletal deformities during growth, the practical field of orthopaedics.

Roth was very consequent in applying his concepts in his explanation of the mechanism of the major deformity: scoliosis. The best we can do is citing Roth with his own words:

*"There exists the most intimate interrelation between the rapid craniocaudal growth-in-length of the axial skeleton and the slower proceeding extensive growth of the spinal cord and the nerve roots. The latter type of growth requires a higher supply with energy and, consequently, is more vulnerable than the former one. The vertebro-neural growth relation is similar to that existing between the developing brain and its bony case. The growth in length of the individual vertebrae and of the spine as a whole is adapted to the growth-potentiality of the intraspinal nervous structures, viz.; the former is determined by the availability of space among the latter. Idiopathic scoliosis may be interpreted as an adaptive morphogenetic reaction of the vertebral column upon the growth insufficiency of the intraspinal nervous structures: The growth process of the vertebral column, though continuing undisturbed at the cellular level, is adapted at the organ level by "waves" to the growth-insufficient cord-nerve complex. Morphological features of the scoliotic vertebra together with the typical position of the spinal cord within the spinal canal speak in favour of the suggested vertebro-neural concept which offers a plausible explanation of the congenital and experimental scoliosis as well".* End of quotation

Some of you might argue: what then about restoring the form e.g. by bracing where extension and lordosis are created instead of counteracted as in most available bracing techniques; isn't that harmful because it lengthens the spine, and thereby increases tension on the cord.

The answer comes again from Roth himself:
*"Adjustment or rectification of the deformed structure like a scoliosis spine is not accompanied by lengthening, notwithstanding the fact that the scoliosis trunk is elongated; the curved spine is adjusted, not lengthened. The adjustment involves a contraction or reduction of the convex side of the intervertebral*

*discs. Consequently, in adjusting– paradoxally but irrefutably- the spinal canal is rather shortened."* End of quotation (see bibliography no.15).

**The work of Milan Roth: new challenges for future research**

Science is an ongoing process with its own dynamics. In biomedical science clarification of etiology is of paramount importance for the right diagnostic conclusions and the therapeutic consequences that can be taken. Roth took the challenge for many ailments the human locomotion apparatus and the Central Nervous System can show, by opening the black box of Medicine: how is growth in Nature arranged?

We are convinced that full disclosure, study and understanding of the work of Roth will inspire many of our present colleagues to start new research in different biomedical fields and clinical specialities around the locomotor system and the nervous system in children and adults. We think the challenges will be taken in different fields of (medical) science in order to create solutions in prevention and therapy for man.

1. Reproduce and clarify several of his analytical studies (pneumoencephalography and - myelography) by using modern technologies (MRI, Spiral CT-scan). Also, neurophysiologic studies (like SSEP and surface EMG) can be performed in situations with clear higher tensions in the neuromuscular structures. For instance, a publication of Cheng et al 2008 in Spine on short spinal cord with scoliosis is evidence that this kind of work is already in progress.
2. Research on what can causes the suspected differences in (the quality of) stretch growth of the cord-roots system to understand at last if this is the background of the misunderstood variation of spinal forms (like curvature, disc-height, vertebral height and shape). Can the basic genetic background be investigated behind the basic difference in resilience towards external deforming forces (like spectrum of laxity in boys and girls) reflecting the basic difference in elasticity of the cellmembrane? Clinical detectable tension in growing children is never investigated in the light of their spinal curvature.
3. A new coordinated effort between biophysics, like biomechanics and biochemistry to clarify the mechanism behind and between the growth (proportionate or disproportionate) of bone and tissues in relation with the stretch growth of the neural tissues. For biophysics this means, following Roth, the role of tension, tension patterns and tension regulation. For biochemics thorough research on the role of the transmitters, like serotonin, nowadays apparently important in all sorts of processes and diseases. What is their role, how do they work in the period of growth and is their function altered in body with deformations, even "light" ones? How is the process of distribution of the lava-like material surrounding the notochord as Roth calls it is organised, because following Roth it can give the clues on the final form of the body and the organs.
4. New concepts for treating patients by conservative or operative treatments with emphasis on the requirements for the nervous system as part of the complex "game" of compressive and tensile forces. Specific stretching exercises and brace techniques that extend the spine and apply lordosis to the thoracolumbar joint rearrange the tensile forces into natural postures.

**Bibliography of Milan Roth (incomplete list of his publications):**

This bibliography with all relevant publications by Roth consists of publications we collected. Some of the articles were acquired through Roth's family. Until 2006 only very few publications could be found on PubMed.

The publications are presented in chronological order.

To allow maximum disclosure all articles are presented in the following way:

- An English version of the title
- Statement of the language in which the original was published
- An English summary or abstract (mostly original, sometimes extended) is added

**1. Roth, M (1965),** ***Caudal end of the spinal cord,*** Acta Radiologica Diagnosis Vol. 3 (1965)

Original Language: English

**Abstract:** The normal position of the spinal cord with special emphasis on the "dorsolumbar junction" as the part of the spine lacking a detailed knowledge of gross anatomic features as demonstrated at negative contrast myelography is discussed. Material consisted of 34 adults and 8 children

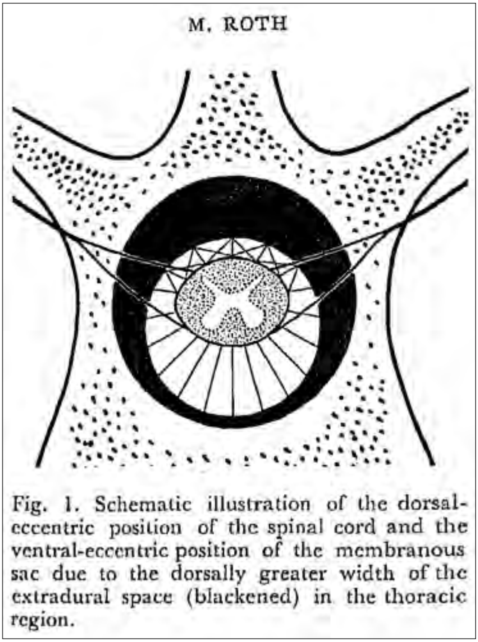


**Fig.10.** The most normal anatomic configuration of calibre, position and radiant fibrous band stabilisation of the cord. Roth found in all deformations of the spine, that this optimal configuration was never present. Instead the cord can be firmly attached or easily in contact with bony boundaries of the canal. Anterior attachment in the thoracic spine and elongation and posterior attachment or contact at the lumbosacral area. The well-known Neuroprotective mechanism of Holzer means that all vertebrates do grow in such a way, that in adulthood all neural tissues have a distinct distance to bony structures in rest and in locomotion.

without symptoms in this part or known remote disorders. The variation in position, the calibre and the intrinsic curvature of the cord at the different levels is explained by developmental factors, among which the morphology of the vertebrae is stressed. A cadaver study with fresh spinal cords specimen hanging freely showed a constant intrinsic curvature in the distal cord as a "reminder "of the embryological existent complete kyphotic configuration. Also, the eccentric "lodgement" of the roots in the neuroforaminae is depicted as a consequence of the ascent of the cord, as seen in humans.

2. **Roth, M. (1966), *Vertebro-medullary interrelations as observed in gas myelography,*** Acta Radiologica Diagnosis Vol. 4 (1966), p. 569–580

Original language: English
**Abstract:** The typical position of the spinal cord within the membranous sac, possibly derived from the close developmental relations between the neural tissue and the vertebral column, is described. The significance of the characteristic shape of the intervertebral foramina in predicting the depth of the ventral subarachnoid space is discussed. It is shown that small thoracic disk protrusions, with a narrow ventral subarachnoid space especially at the level of the lumbar intumescences, may give rise to myelopathy.

3. **Roth, M. (1968), *Idiopathic scoliosis caused by a short spinal cord,*** Acta Radiologica Diagnosis Vol. 7 (1968), p. 257–271.

Original language: English
**Abstract:** An explanation of the pathogenesis of idiopathic scoliosis based on the disturbance of the relative vertebro-neural growth is presented. This concept is supported by neuroradiologic, experimental and clinical observations.

4. **Roth, M. (1969), *Models of vertebro-neural relations,*** Acta Radiologica Diagnosis. Vol. 9 (1969)

Original Language: English
**Abstract:** The basic principles of vertebro-neural growth relations with special reference to the pathogenesis of idiopathic scoliosis are discussed. Plexiglas models, constructed to assist in the demonstration, are described. All models have in common that they do not only reflect a static three- dimensional condition but represent the incorporated forces in life and growth by visible movements and represent also a condensation of what happens in the fourth dimension: time.

5. **Roth, M. (1971), *The relative osteo-neural growth; some phylogenetic, ontogenetic and clinical aspects,*** ad. Diagn. 1971, 1, p 81–97

Original language: German
**Abstract:** The growth in length of the nervous structures necessitates a higher energetic level than that of the bones. A harmonic side-by-side growth course of the growth rates, cellular-divisional

and neural-extensive, is indispensable for the normal body growth in length. Comparisons are made with features of growth in different animals and embryological knowledge. The relative osteo-neural growth represents therefore an important factor in the phylogenetic and ontogenetic development of the skeleton as well as in the pathogenesis of bone dysplasia's.

### 6. Roth, M., *The relative osteo-neural growth*

Part I: Gegenbaur Morph. Jahrb., Leipzig 117 (1971) 2, S. 232–255
Part II: Gegenbaur Morph. Jahrb., Leipzig 117 (1972) 3, S. 312–334

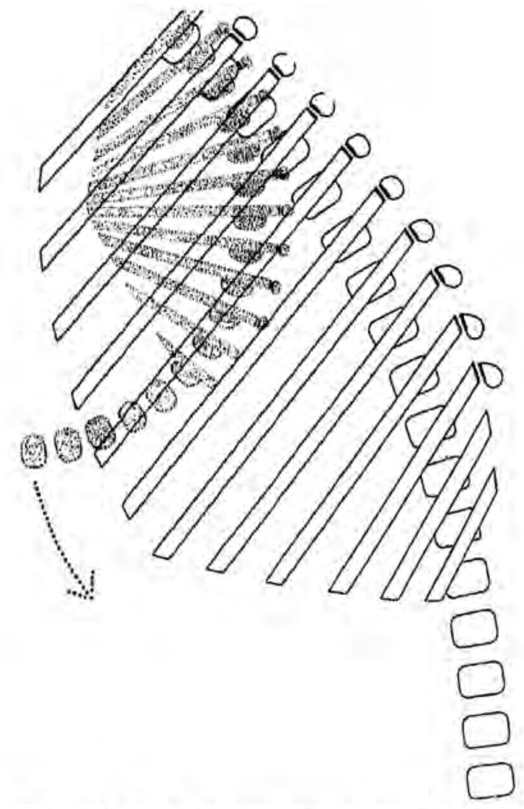

Abb. 3. Die Bildung der Lungenfurche hängt mit der Aufrichtung des ursprünglich zusammengerollten Embryonalkörpers (punktiert) zusammen

**Fig. 11**. The formation of the pulmonary groove depends on the extension of the completely kyphotic and rolled up configuration of the embryonic body. Roth created a beautiful mechanical model on the change of all dimensions and relationships initiated by the gradual extension of the body.

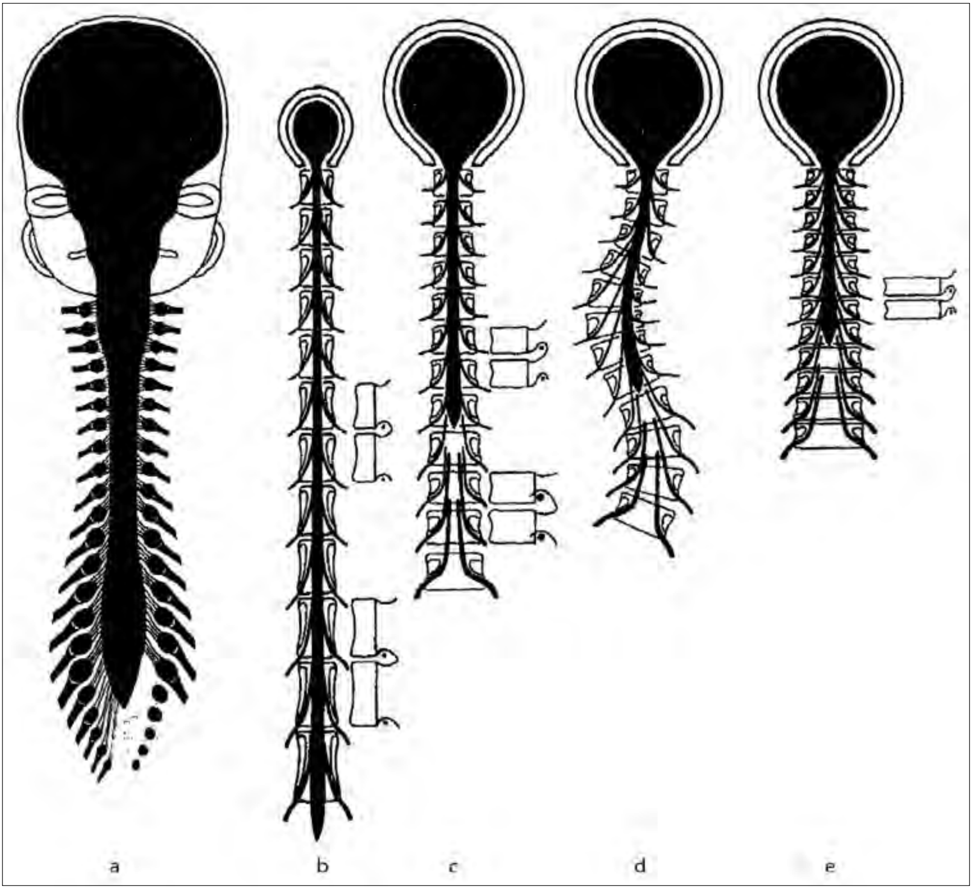


**Fig. 12.** The impressive relative change in proportions between cord and roots and vertebral bodies in animals, normal human spine, a scoliotic spine and a platyspondyly spine.

Part III:Gegenbaur Morph. Jahrb., Leipzig 117 (1972) 4, S. 421–440

Original language: German

**Abstract:** These three articles compose a total concept and explanation of the osteo-neural growth by extracting supporting evidence out of first class knowledge in biological, anatomical, embryological, histological and orthopaedic and neurological textbooks and literature. With own modelling, all sorts of research, and stepping over "scientific" boundaries, he tries to fit all visible formation and deformation of at least the skeletal development in his holistic explanation of how Nature "works". Skull and spine are in morphogenesis completely dependent on their neural countenances, but the spine and the bones of the extremities are "moulded" by the volume, condition and action of muscles in delivering 3-D movements.

In **Part I** the function of the Ascensus Medullae in Homo erectus is discussed. The inhibitive ("breaking") power of the more energy asking stretch type of growth of the neural system on the growth by mitosis of the osseous and arthrogenic skeleton gives an insight in the complex system of tension regulation and strive for optimisation, that growth in nature should always be. The earlier discovered and described craniocaudal and posteroanterior directed growth in ante- and postnatal growth in animals (Kingsbury) is completely incorporated in Roth's conceptual thinking. The change in relative size of the primitive neural structures from huge to small is depicted and discussed as is

314 M. Roth: Das relative osteo-neurale Wachstum. II. Teil

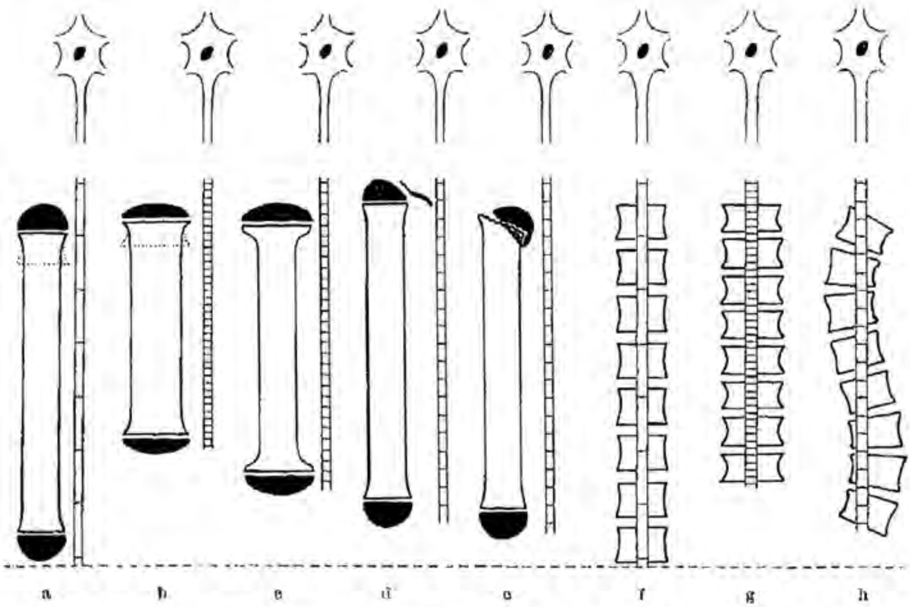


Abb. 20a–h. Verschiedene Anpassungstypen des Knochenwachstums an die pathologisch erhöhte Retardation des neuralen Streckungswachstums: a, f – harmonisches osteo-neurales Längenwachstum. Der physiologische neurale Bremseffekt macht sich in der Verbreiterung der Knochen- und Wirbelkörperenden bemerkbar; b, g – setzt die pathologische Inhibition des neuralen Streckungswachstums sehr früh ein, wird der noch weitgehend plastische heranwachsende Knochen bzw. Wirbel im ganzen kürzer und breiter, „zerfließt" seitlich; c – ist die Diaphyse bereits verknöchert, wenn die pathologische osteo-neurale Wachstumsdisproportion zur Geltung kommt, werden nur die Knochenenden von Verkürzung und Verbreiterung betroffen (Achondroplasie [= Chondrodystrophie], Kretinismus, Coxa plana); d, e – die adaptive Verkürzung des Knochens wird durch eine Gelenkluxation (d) oder Epiphyseolyse (e) bewerkstelligt. Kombinationen mit (c) sind sehr häufig; h – ist die Ossifikation der Wirbel bereits weitgehend fortgeschritten, wird durch die pathologische osteo- bzw. vertebro-neurale Wachstumsdisproportion die Wirbelsäule in Falten gelegt (Skoliose bzw. Kyphoskoliose), das Längenwachstum der Wirbelkörper wird in den Krümmungsscheiteln einseitig gehemmt (Keilwirbelbildung)

**Fig. 13.** Schematic drawing of different skeletal deformities with the suspected relation with the concomitant, but primary events in the stretching type of growth of the central cord.

the very clear present brachy-or Platyspondyly in siblings. The position, direction and calibre of the nerve roots in the neuroforaminae found at earlier pneumoencephalographic studies at all different levels are made understandable. Different morphologic features only present in the human spine, especially the caudalis (roof of the foramen) are clarified. Different affections like Scheuermann, Platy- (or better: brachy-) spondylie, Dysplasia spondyloepiphyseal tarda are according to Roth examples of clear "braking" power on growth in length by contracting muscles ordered in reflex by the neural cells that protects itself to overstretching. The formatted bone is like the narrow disc spaces diverged in horizontal directions.

Roth distilled out of his daily practice, that the thoracolumbar junction is the most inflicted in flattening of the discs and vertebrae in adolescent kyphotic deformities. Therefore, he ends with the statement that the length of the total spine is fixed by the capacity in growth by stretching of the intraspinal nerve structures.

**Part II.** Roth tries to come to a complete system of growth and formation of the body especially the complete skeleton based on earlier work of scientists and own studies. What seems true for the vertebra seems true for every piece of bone. It is the stretching forces and the stretch hindering forces that moulds the young bone in its cartilaginous stadium

**Part III.** On the form of the body and the physiological curvatures of the spine out of animal experiments in rats and frogs: “The nervous structures exert an influence on the morphogenesis of the skeleton even for the very reason of their existence in space, by their mass of a certain size and shape. The surrounding and /or accompanying skeletal masses adapt their general shape to that of the nervous structures. obviously under mediation of a “trophic” neural effect. Through this primary neural influence, the gross shape of the skeleton most appropriate for the given species in a given environment is elaborated. The stimuli and information reaching the organism by neural pathways are thus reflected in the morphogenesis of the skeleton. The role of the blood and the vessels (hormones-authors), of the physical stresses and of the hereditary (genetics- authors) appear only of secondary importance only in the light of osteo-neural growth relations”.

7. **Roth, M. (1973), *The relative Osteo-Neural growth: a concept of normal and pathological (Teratogenic) Skeletal Morphogenesis,*** Gegenbaur Morph. Jahrb. Leipzig 119 (1973) 2, S. 250–274

Original Language: German

**Abstract:** A concept of skeletal morphogenesis is proposed which is based on the existence of 2 different types of growth in the vertebrate body, viz., the cellular-divisional bone growth and the extensive (stretch-) growth of the nervous structures. The latter type requires a higher energy and oxygen supply than the former. Consequently, the neural extensive growth proceeds at a slower rate than the bone growth. Which is manifested most conspicuously in the ascent of the spinal cord. The slower growth rate, however, is a general feature of the nervous structures throughout the vertebrate body. A number of normal as well as pathological features of the skeletal morphogenesis-above all the gross deformities of the body-parts which grow rapidly in length such as the spine,

the extremities or the facial skeleton – can be readily explained by the disturbed relation of the two growth types caused by an insufficiency of the vulnerable neural extensive growth.

**8. Roth, M. (1975), *Spinal cord and Scoliosis. The cause and the Effect*,** Acta Chir. Orthop. Traumas. Czech. 42, 1975, no. 6, p. 507–517.

Original language: Czech

**Abstract:** There exist the most intimate interrelation between the rapid craniocaudal growth-in-length of the axial skeleton and the slower proceeding extensive growth of the spinal cord and the nerve roots. The latter type of growth requires a higher supply with energy and, consequently, is more vulnerable than the former one. The vertebro-neural growth relation is similar to that existing between the developing brain and its bony case. The growth in length of the individual vertebrae and of the spine as a whole is adapted to the growth-potentiality of the intraspinal nervous structures, viz.; the former is determined by the availability of space among the latter. Idiopathic scoliosis may be interpreted as an adaptive morphogenetic reaction of the vertebral column upon the growth insufficiency of the intraspinal nervous structures: The growth process of the vertebral column, though continuing undisturbed at the cellular level, is adapted at the organ level by "waves" to the growth-insufficient cord-nerve complex. Morphological features of the scoliotic vertebra together with the typical position of the spinal cord within the spinal canal speak in favour of the suggested vertebro-neural concept, which offers a plausible explanation of the congenital and experimental scoliosis as well.

**9. Roth, M., *The vertebral groove*, Acta Radiol.9; 1965 p. 740-745.**

Original language: English

**Abstract:** Roth shows the presence, and gives name to the peculiar anatomical bilateral groove at the posterior surface of the bony spine of the human adult. The development of the vertebral groove at the posterior side of the lamina as a unique feature in the human skeleton, absent in quadrupeds, is explained and its influence via the spinal nerves on the shape of the intervertebral foramina is described. It fits in Roth's view about the supposed working of the musculature to provide forces on bony structures that will add in their final shape as form is dictated by functional request. In the axiom that form follows function it is the far more posterior presence of the facet joints and processi mammillaria in human that is specific for the species and originates from the tremendous greater pulling forces of the musculus Erector Trunci in the osseous insertions in the upright man. The upright posture and the early development of a long lordosis let the extensor muscles "create" these grooves, at the TL-area very shallow or even absent if its stays kyphotic. The upright position creates thus a gutter or pulley-groove, in which a muscle can increase its pulling force by acting against a fulcrum.

**10. Roth, M. (1969), *Idiopathic scoliosis- A special form of osteo-neural growth disproportion*** Z Orthop Ihre Grenzgeb 1969 Nov;107(1):37-46)

Original language: German

**Abstract:** Idiopathic scoliosis is explained as a pathological increase of the vertebro-neural growth disproportion, the physiological degree of which is reflected in the ascent of the spinal cord. This disproportion roots in the two different types of growth occurring in vertebrates, viz., the cellular-divisional and the neural-extensive. The latter is generally encountered in plant-kingdom, where spiralization in case of tethering of a central structure is a very common morphologic feature. The morphological findings on scoliotic vertebrae as well as model experiments point to the primary growth insufficiency of the intraspinal nervous structures as the actual cause of the idiopathic scoliosis.it can be seen as a biomechanic solution to choose for the shortest distance between skull and sacrum by inducing spiralization with the locked thoracolumbar joint as a starting point.

**11. Roth, M., *The experimental Teratogenesis of the skeleton. An experimental disturbance of the relative osteo-neural growth.*** Gegenbaur Morph. Jahrb., Leipzig 122 (1976) 5, S. 686–730

Original language: German

**Abstract:** The previously suggested concept of the closest growth relations existing between the bony and the nervous tissue at the organ level of the spinal cord and the peripheral (including the facial) nervous trunks is experimentally buttressed. It is shown that the normal gross-morphological features of the vertebrae as well as of the tubular bones (viz., their length, physiological curvatures and terminal expansions) result from the adaptation of the bone growth to the slower proceeding and vulnerable neural extensive growth, viz., from a physiological osteo-neural growth disproportion. The more or less conspicuous growth in the length of the facial skeleton depends upon the phylogenetically established, more or less evolved extensive-growth potentially of the facial nervous trunks as well.

The growth relation existing between the developing brain and its bony case applies essentially even for the axial organ, the extremities as well as for the facial skeleton.

The experimental findings speak in favour of the theoretical expectation that the typical teratogenic deformities of the extremities (micromelia), of the spine (scoliosis, defects of the vertebrae and of the ribs) as well as of the beak (jaws) which may be produced by a great number of most diverse teratogens, result from the adaptation of the bone growth to the growth-insufficient nervous trunks, viz., from the pathologically enhanced osteo-neural growth disproportion. The cleft palate and the digital defects (syndactyly, oligodactyly) may be readily explained by the growth-inhibition of the palate and digital nervous structures as well.

The vertebrate body may be thus conceived as composed of 2 growth types, viz., the neural-extensive and the cellular-divisional (mitotic). The former is represented by an extremely dense felt work of nerve fibres and trunks (the Donaldson's "nervous skeleton"), which is "stuffed "with the other, mostly mitotic growing tissues. The 2 growth types are closely related partly at the macro-(organ-) level concerning the normal and teratogenic morphogenesis of the skeleton, partly at the micro-level of the utmost periphery, viz., of the terminal extensive meshwork and the individual cells or groups of cells. The cells which escape from the extensive felt work (i.e. from the "nervous skeleton") such as the superficial cells of the epidermis or mucous membranes and, in all probability,

the elements of the haemopoietic organs, perish under normal conditions, suffer a planned, highly purposeful death. With regard to the lack of normal nerves within malignant tumors, the malignant cell may be conceived as the one escaped from the limiting confines of the extensive felt work and, in spite of that, continues to live instead of "committing suicide".

**12. Roth, M., J. Krkoška and I. Toman *Morphogenesis of the spinal canal, normal and stenotic*,** Neuroradiology 10, 277–286 (1976)

Original language: English

Abstract: The shape of the canal in transverse view, the shape and the position of the facet joints and the foraminate are discussed in normal and pathological conditions, like the developmental of lumbosacral stenosis (Verbiest) and degenerative stenotic and degenerative changes are explained by the conductive role the neural tissues play in growth. In malignement of the spine the osseous structures of facet joints and laminae will be overloaded with hypertrophy and condensation (sclerosis) of bone as consequence, leaving the neural structures decreasingly less space to pass. Histological specimens are used. New models of the relationship between roots and vertebrae are introduced (fig). But nevertheless, the base of the early base of any deformation seems still orchestrated by the necessary normal or disturbs the developmental balance between the two tissues (neural and osseous- discoligamentary). Roth states firmly in this paper that the role of the Notochord, a prominent structure in fishes, amphibians and reptiles is vestigial in higher mammals and its morphogenetic role in the developmental events of the axial skeleton is grossly overestimated (The Dispensability of the Notochord).

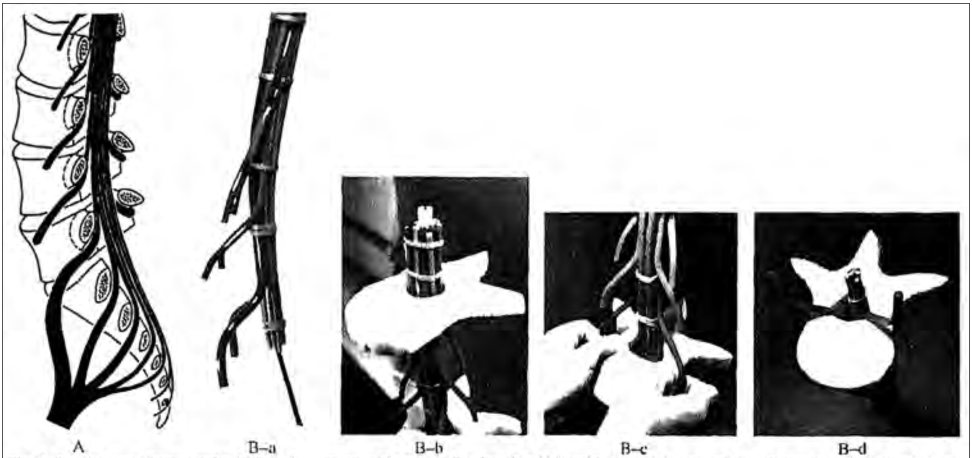


**Fig. 14.** Modelling of the relationship of the roots, their directions and the presumed tight contact between the roots and the bony surroundings in the lumbar spine.

**13. Roth, M. (1981), *Idiopathic scoliosis from the point of view of the neuroradiologist,*** Neuroradiology (1981) 21: 133–138

Original language: English
**Abstract:** There is a simple morphological interrelation between the growing spinal cord-nerve root complex and the vertebral column, not unlike that between the growing brain and the skull. The shape of the enveloping vertebral skeleton mirrors the anatomical features of the enclosed neural contents. During the cranio-caudally directed growth, spurts of elongation of the vertebral column may be too rapid for the slower growth rate of the spinal cord and nerve roots. The smaller caliber and the conclusion, the cord root-system must be under increased tension are well described and explained. By this the Arnold Chiari malformation is made an understandable pathoanatomic feature and the serious complaints coming with the malformation can be explained. The resulting disproportion of growth between spine and nervous system can compensated for by adaptive scoliotic curvature of the otherwise normally growing spine. The proposed pathogenetic concept readily explains the main clinical features of the deformity and is supported by a spring model experiment.

**14. Roth, M. (1981), *Idiopathic scoliosis and Scheuermann "disease": Essentially identical manifestation of neuro-vertebral growth disproportion*.** Radiol. Diagn. 22 (1981), H.3, 380–391

Original language: German
Abstract: With the knowledge postulated on the disproportionate growth between the nervous tissue and the spine, Roth gives with his spring models a true to nature morphological presentation of the proportioned relations of the (tight or generally tethered) cord and roots and the deformed vertebrae (compression of the spring windings at the concavity, rope in the concavity). As the eccentric position of the cord and cauda was already known in literature (Lindgren 1941, Jirout 1964) Roth reverses this with arguments as it was seen as a secondary effect of the deformity towards a primary position with the deformity of the spine as a nervous tissue conducted developmental feature of the surrounding bony tissue. To Roth's finding the lower thoracic and thoracolumbar spine function as the most predilected area for the first dicongruencies between the two types of growth in otherwise healthy children in their growth. In his view the modificated muscular activity to keep the new posture with its relocated axial loading and unloading.

He also gives an understandable discussion in his concept of the existence of congenital scoliosis and kyphosis. More or less, he proposed scoliosis occurring mostly in flexible girls as an escape of becoming more and more kyphotic.

**15. Roth, M. (1985), *Once more spinal cord and scoliosis,*** Acta Chir. Orthop. Traum. Czech. 52, 1985, no. 6, p. 532–543

Original Language: Czech
**Abstract:** Morphogenesis of the spine as well as of the neurocranium cannot be understood from the growing bone tissue alone, regardless of the morphology and growth peculiarities of the neural content, the brain and the spinal cord-nerve roots complex. Idiopathic scoliosis may be explained as

a consequence of excessive discrepancy between the neural and the vertebral growth rates which will give especially the girl with more laxile joints the possibility to "escape" in a shortening, spiralizing way. Growth rate differential is a well-established factor of morphogenesis resulting, among others, in curvature of two adjacent structures growing in length at different rates. The periods of growth spurt are particularly prone to neurovertebral growth disproportionateness since the spinal cord-nerve roots complex may be unable to keep pace with the too rapidly growing spine. The latter is then laid in adaptive kyphoscoliotic curvatures along the growth insufficient neural content. The relative growth deficit of the "Wirbelbogenreihe" as compared with the "Wirbelkörperreihe", a feature characteristic for idiopathic scoliosis seems to result from the primary retarding effect of the spinal nerves, which run reins like along the pedicles. This neural retarding effect may be elicited either by excessive stimulation of the vertebral growth or by inhibition of the spinal neural growth, or by combination of both. The basic gross features of idiopathic scoliosis including the deformity of the thoracic cage and the concave sided eccentric position of the spinal cord may be reproduced by means of a neuro-costo-vertebral model.

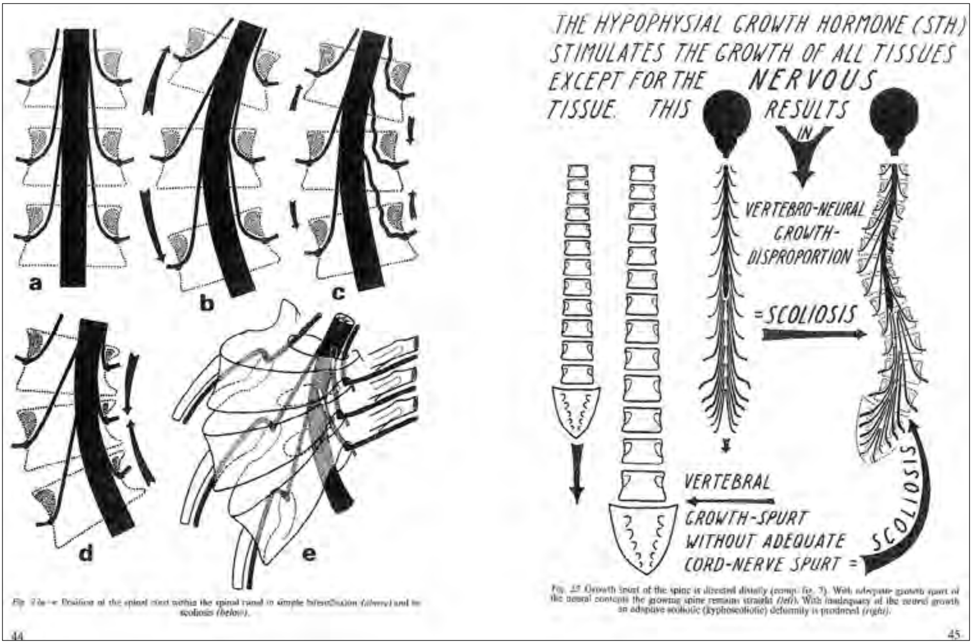


**Fig. 15.** Left: Drawing of the observations Roth did in bending a post mortem normal spine in which he removed all laminae and below the findings you can see in scoliosis in pneumomyelography (and MRI!!; PvL). Right: The schematic drawing of the result of growth spurt in normal and in scoliotic spines. He was not aware, that scoliosis always starts in spines with early kyphosis at the thoracolumbar spine and slight asymmetry at the TL spine because of asymmetric forces by the diaphragm (according to Murk Jansen, 1912)

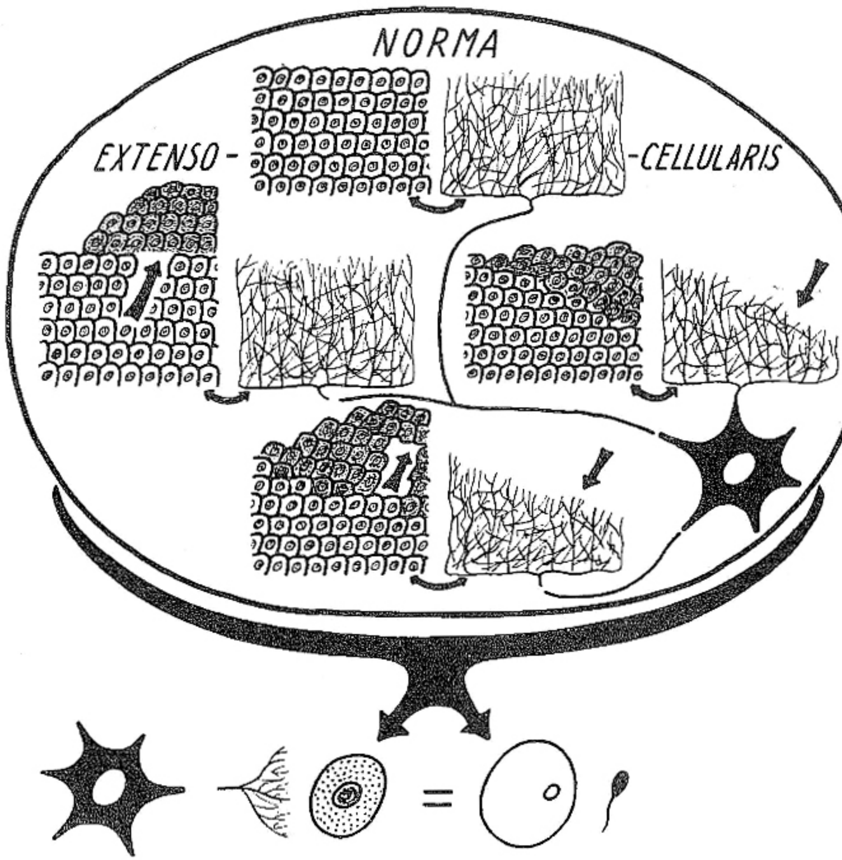


*Fig. 103.* The two-growth-types, extenso-cellular concept of cancerogenesis. Excessive and long lasting stimulation of cell proliferation *(left)*, inhibition of the neural extensive growth in the utmost periphery *(right)* or combination of both *(below)* results in extenso-cellular disjunction. The cells escaped from the two-growth-types system and remaining alive behave in a malignant way.

**Fig. 16.** Schematized origin of groups of cells, not attached or controlled by the nervous system (no connection nervous cells and new formed somatic cells during growth) and their capability to form tumours with malignant growth after initialization of cell proliferation by different types of exogen factors (tobacco, virus, mechanical forces, drugs, radiation etc.).

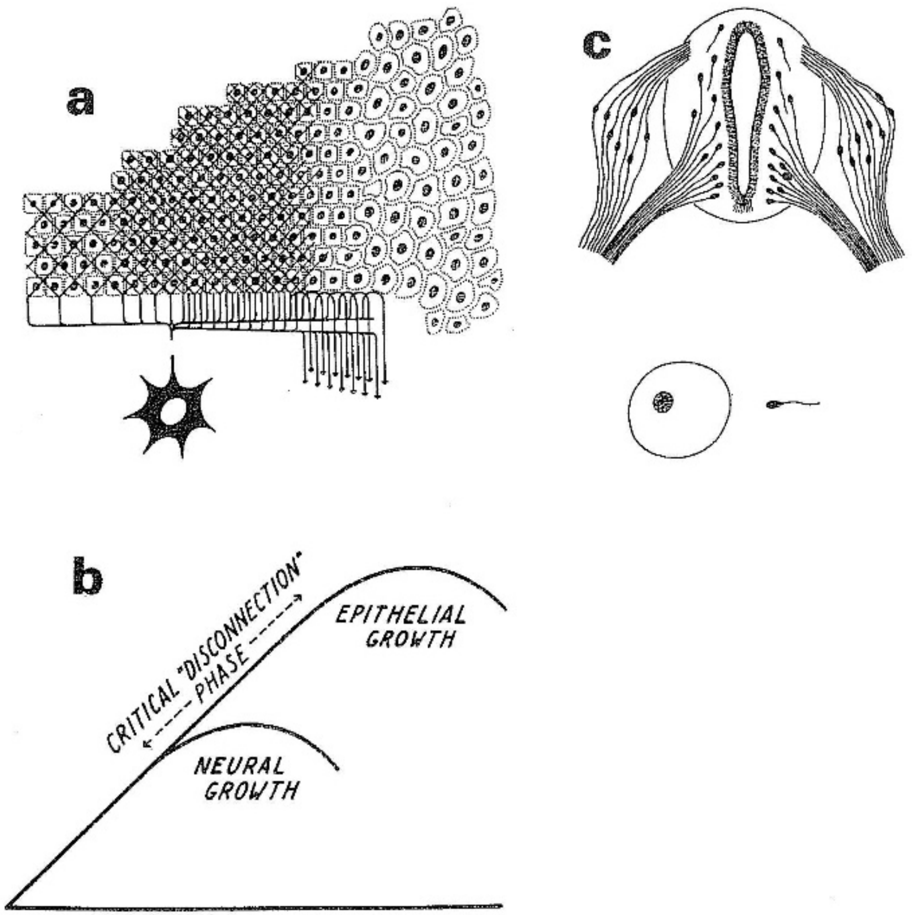


*Fig. 104a–c.* Schematic illustrations of the extenso-cellular relations in the tarred skin of mice. (Drawn according to *Julius'* findings (1930)) (a). Differential sensitivity of the epithelial and of the neural-extensive growth to stimulative factors: The vulnerable neural growth is impaired at concentrations of the cancerogenic agent still stimulating the epithelial growth (b). Schematic cross section of the human embryonic spinal cord with individual neuroblasts indicated (*above*–redrawn from *Villiger E. and Ludwig E.:* Gehirn und Rückenmark (Fig. 26). 14. Aufl., Benno Schwabe, Basel 1946). The outer resemblance, motility and some other features suggest a developmental relationship between the sperm *(below)* and the neuroblast (c).

**Fig.17.** Schematic drawings, based on earlier biomedical research on the neurotrophic background of malignant tumour growth.

There prevails a widespread tendency in cancerology to apply the *principle of infectiology*, viz., the penetrance of a pathogenic agens from outside into the body to the pathomechanism of tumours. According to the proposed concept and in sharp contrast to the principle of infectiology, the *principle of cancerogenesis* seems to consist, however, in *disconnection of the cellular-divisional and of the neural-extensive type of growth*. In addition to many other cancerogens, this fatal event may be brought about even by an infectious agens, above all by the oncoviruses which chronically and excessively stimulate cell proliferation and, possibly, impair the extensive neural growth. By both these effects the cellular "escape" is instigated.

As a matter of fact, the extenso-cellular concept of cancerogenesis postulates a *disturbance of the mechanism of physiological cellular death*. A cell, for instance the superficial cell in the epidermis or in any mucous membrane, when leaving the confines of the respective nervous skeleton, appears to be provided with something like *"lethal information"* by which the further existence of the cell is rendered

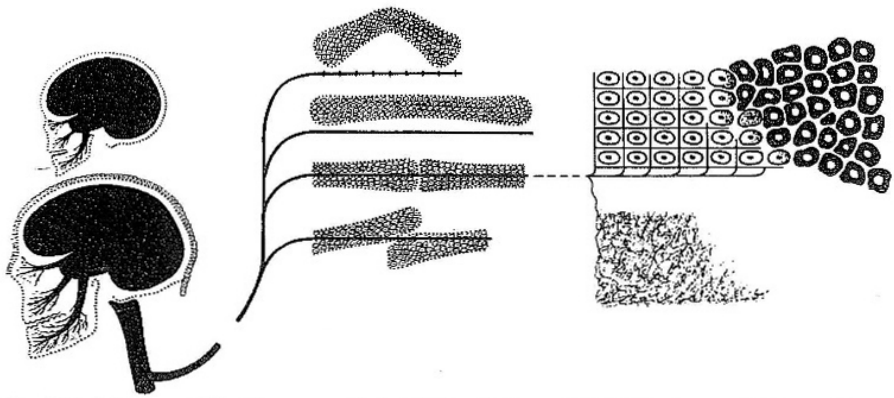

*Fig. 106.* Diagram of the "non-escape" *(middle)* and "escape" *(right)* extenso-cellular pathology. Both are based on a generalization of the neurocranial developmental relation *(left)* and result from the reduced availability of space—for individual bones or for epithelial cells—along or within the growth-insufficient nervous *macroskeleton* (scoliosis, bone deformities) or *microskeleton* (cancerogenesis).

impossible, the cell "commits suicide". Cancerogenesis means a *failure* of that mechanism, viz., the cell escaped from the confines of the nervous skeleton has "forgotten" or "refused" its physiological duty to die. The knowledge of this lethal mechanism possibly would make feasible to remind the malignant cell of its duty to die and to compel it to "commit suicide" by setting in function its own intrinsic lethal mechanisms.

**Fig. 18.** Part of the conclusive remarks of the chapter on carcinogenesis with its illustration on the way Roth concepted his idea's on how, by escaping of mitotic growing somatic cells to the individual but necessary synaptic attachment of every cell to a nervous cell or its dendrites. When these "escaped cells" in isolated groups are urged to proliferate to renew tissue, they stay uncontrolled by the nervous system and will behave in a malignant way.

**16. Roth M. (1985), Neurovertebral and Osteoneural Growth Relations. A concept of normal and pathological development of the skeleton,** Opuscula Radiologika; Acta facultatis medicae Universitatis Brunensis; Univerzita J.E. Purkyně v Brně

Original language: English
This **opus magnum reflects all his research** till then, brings his concepts of growth and discongruent growth under various experimental conditions and proposes well understandable etiologic pathways of many conditions that will have their origin in the period the organism forms itself by growth.

The designation "extenso-cellular escape growth pathology" that he proposed for the origin of cancer or malignant cell proliferation is discussed by Roth in the light of earlier "attempts at a neural explanation of cancerogenesis". In the Chapter: "The nervous skeleton- the missing link between skeletal teratogenesis and cancerogenesis? "

The complete summary of this book and summed up in 25 items of interest by Milan Roth himself is the best way to give an oversight of his thoughts, research and concepts.

1. There exist two diametrally different types of growth in vertebrates, viz., the *cellular-divisonal (mitotic)* and the *neural-extensive*. The latter, occurring otherwise in plants, requires a high supply with energy and oxygen. This accounts for its higher vulnerability as compared with the mitotic type of growth.

2. The notion is advocated that the neurocranial developmental relation (with the growing brain determining the gross shape of its skeletogenic envelope) represents just the most striking example of an *universal* osteoneural growth relation working throughout the entire body, viz., in the axial organ, in the limbs as well as in the facial area between the corresponding gross nervous structures and the respective skeletal parts.

3. Under normal conditions the spinal cord—nerve roots complex lags to a distinct degree behind the faster growing vertebral column. The growth in length of the axial organ proceeds in the *cranio-caudal* direction. Consequently, the neurovertebral growth differential is manifested in obliquity (caudal slanting) of the spinal nerve roots and in the cranially eccentric position of the spinal ganglia within the intervertebral foramina.

4. It has been shown (*Holtzer*, 1952) that skeletogenic tissue maintains a distinct distance from the surface of a nervous structure, probably by mediation of a negative chemotactic effect. By this *"neuroprotective mechanism"* the integrity of the neural contents is safeguarded, viz., its direct contact with the skeletogenic envelope is avoided. The formation of the subarachnoid space with the cerebrospinal fluid in the embryo appears to represent, among others, Holtzer's neuroprotective mechanism of the developing spinal cord.

5. By mediation of the neuroprotective mechanism, the vertebral skeletal envelope, not unlike the neurocranial, mirrors the anatomical features of the enclosed neural contents both in the embryo and in the adult, despite the important quantitative increase of the vertebral bone tissue and the relative decrease of the central nervous system taking place in the course of development. A vertebra is *"normal"* because it envelops a portion of the *normal* neural contents.

6. According to the more or less evolved phylogenetic capability of the spinal cord–nerve roots complex to grow extensively in length, the individual vertebrae grow either long and slender (dolichospondyly in quadrupeds) or short and broad (brachyspondyly in man). The craniocaudal length ("thickness") of the vertebral arch depends upon the length of the craniocaudal distances between the spinal ganglia. The caudal vertebral incisura (determining the shape of the intervertebral foramen) is produced by "cutting in" of the spinal ganglion (spinal nerve) from below into the vertebral arch.

7. Running ahead of the vertebral column in respect to the spinal cord–nerve roots complex means that every individual vertebral body disposes of a certain surplus of growth-energy which is realized in the transverse direction, viz., in spreading laterally of the skeletogenic material accumulating in the vicinity of the cranial and caudal growth plate. This transverse overgrowth, the onset of which fairly coincides with the first sings of the neurovertebral growth differential, remains lifelong manifest in the girth concavity of the vertebral body.

8. Concerning the "genetics" of the vertebral shape, it is under an indirect genetic control associated with the neural contents. The skeletal vertebral envelope is "carried with" and assumes the corresponding basic "neurovertebral" shape. The surface relief of the latter is just modified by the effect of muscles.

9. The rapid growth of the neural primordia is responsible for the kyphotic curvature of the early embryonic body. With the onset of the neurovertebral growth differential the spinal cord–nerve roots complex (from now on lagging behind the vertebral growth) imparts to the developing axial skeleton a tendency to straightening and, later, to lordotization, lumbar and cervical: The growing vertebral column is "laid in curvatures" along the somewhat shorter neural contents. Spinal curvatures established in this "neurovertebral" way are just modified by muscular action.

10. A disturbance of the relative neurovertebral growth, viz., an abnormally high difference between the neural and the vertebral growth rates may result from impairment of the vulnerable neural growth or from excessive stimulation of the vertebral growth or, possibly, from combination of both. The critical neurovertebral growth situation is then compensated for by adaptive deformities of the growing spine which has to "accomodate" along the inadequately growing, "too short" spinal cord–nerve roots complex. This adaptive reaction of the spine consists either in platyspondyly ("brachyspondyly", i.e. in formation of still shorter and still broader vertebrae than under normal conditions) or in abnormal kypho-lordo-scoliotic curvatures, isolated or in combination.

11. In contrast to a normal vertebra, specific features of the scoliotic vertebra result from its enveloping a portion of the more or less growth retarded spinal cord–nerve roots complex. Enhanced neurovertebral growth differential seems to account for other developmental spinal deformities as well, such as Scheuermann's kyphosis, deformities associated with dysraphic conditions and those occurring in various bone "dysplasias".

12. Primordial vertebral arch originates as a tongue-like process of skeletogenic tissue penetrating from in front into the interganglionic space. With an early coalescence of neighbouring ganglia this is rendered impossible and aplasia of the pedicle, usually considered as some primary derangement of the bone growth, results therefrom. A milder form of that abnormality, viz., an interganglionic space narrower than usual results in "dysplastic" thinning of the vertebral arch which is then predisposed to spondylolysis. Doubled spinal nerve roots often demonstrated by myelography in these conditions point to the early embryonic disturbance of neuromorphogenesis as the actual cause of them.

13. The vertebral body may be conceived as a very "short" long bone lacking the diaphysis. The neurovertebral growth differential should thus work–as osteoneural differential–even in the limbs where it is manifested in, essentially, the same features like in the spine, viz., 1. in physiological incurvations of long bones and 2. in terminal epi-metaphyseal widenings ("modeling") corresponding with the exuberant margins of the vertebral body.

14. The peripheral nervous system in its entirety represents an extremely dense feltwork of nervous trunks, branches and fibres, the "nervous skeleton" of Donaldson (1937) which is the product of postembryonic extensive neural growth of tremendous extent, which permeates throughout the entire body and forms, for instance, a feltlike neural envelope on the surface of every limb bone. Not unlike in the neurocranial area, various functional aspects of the peripheral nervous system should be disregarded in connection with the osteoneural relations: Just its *growth* should be taken in consideration.

15. Macromorphological osteoneural analysis of experimental deformities of the limb skeleton produced in rats, in chick and duck embryos and in frog tadpoles by various skeletal teratogens such as thallium, osteolathyrogens, cholinomimetics, hypothyroidism or roentgen irradiation and studied in specimens cleared with the Williams' technique (1943) suggests that the extensive growth of the limb nerves has been more severely interfered with by the administered teratogens than the bone growth in length. The produced skeletal deformities (bending, angulation, achondroplasia-like shortening, joint dislocations) appear as adaptations of the growing bones to the growth insufficiency of the nervous trunks, viz., the former had to "accomodate", even at the cost of a deformity, along the "too short" nervous trunks.

16. Two different "neural" mechanisms of the experimental and clinical developmental deformities of the limb skeleton are suggested. 1. The *early embryonic*, related to a disturbance of the primordial neuroskeletal relations within the forming limb bud and resulting in defects of whole bones or of their greater parts and in bone fusions. The sequelae of thalidomide disaster or of early irradiation of the pregnant uterus represent classic examples of that early neuroskeletal damage. 2. The *postembryonic*, resulting from enhancement of the physiological osteoneural growth rate differential to pathological levels and leading not to defects but just to adaptive deformities of otherwise normally growing limb bones.

17. The neurovertebral and osteoneural mechanism of the experimental deformities appears to work even in the analogous clinical deformities such as those of the spine mentioned above as well as in achondroplasia, in congenital dysplasia of the hip and in other bone "dysplasias" the causative mechanism of which is searched for in vain within the involved skeletal parts proper.

18. Micromelia in the chick embryo with characteristic "buckling" of the tibia, i.e. with its excessively sharp angulation resulting from treatment with the most variable teratogens, is associated with bones of essentially normal length, just with the distal (postperoneal) portion of the tibia growing in an opposite (proximal) direction. This specific osteoneural growth feature accompanied by hyperextension in the knee joint is analyzed and applied to explanation of clinical conditions associated with increased excursibility of joints such as the Marfan and the Ehlers-Danlos syndromes. The hyperextensibility of joints and of the skin together with increased length of bones (arachnodactyly) in these conditions appear to be related to the primary enhancement of the extensive neural growth.

19. "Curled toes" in the duck embryo treated with syntostigmine or with thallium show a striking outer resemblance with the "flaglike" deformity of the human hand in chronic rheumatoid arthritis. The possible relation of that mysterious condition to an osteoneural disturbance is discussed.

20. Facial skeleton and corresponding nerves do not escape from the universal osteoneural growth principle. Shortening of the mandible with production of the chin is related to a primary reduction of growth of the mandibular nervous skeleton which took place in the course of hominization. The classic experimental-teratogenic deformities of the beak in the chick embryo ("parrot" upper beak, shortening and angulation of the lower beak) are related, not unlike the deformities of the limb bones, to a primary growth impairment of the maxillo-mandibular nervous trunks.

21. Micrognathia and cleft palate are characteristic features of the Pierre-Robin syndrome. Micrognathia may be referred to a growth insufficiency of the mandibular nerves, the inability of the palatal shelves to grow adequately towards the midline to a primary growth insufficiency of the palatal nervous skeleton.

22. Osteolathyrism, a laboratory condition of growing animals produced by ingestion of peas of Lathyrus odoratus or by chemical osteolathyrogens, is held for a primary disorder of the skeleton in contrast to neurolathyrism characterized by spastic spinal paralysis. Osteolathyrogens have been shown, however, to work by the same indirect osteoneural mechanism upon the growing skeleton as the classic skeletal teratogens, viz., by a primary growth impairment of the spinal cord–nerve roots complex and of the peripheral nervous trunks. Accordingly, disturbances of collagen maturation and structure typical of osteolathyrism represent nothing but a secondary finding without any direct bearing upon the origin of skeletal deformities. Osteolathyrism represents just a variety of neurolathyrism: Whereas in the latter the neural *functions* are compromised, the former interferes with the neural *growth*.

23. The limiting role of the gross neural growth upon the growth in length of bones should apply to the entire nervous skeleton including the utmost neural periphery. Isolation ("carving") of individual digits from the compact hand or foot plate in the embryo may be conceived as related to the early nervous skeleton established for every individual finger and toe. The cells lying outside the nervous skeleton, i.e. those occupying the prospective interdigital spaces, succumb to necrosis, they "commit suicide". In webbed limbs the nervous skeleton extends into the interdigital spaces so that the cells occupying them remain viable. Polydactyly and syndactyly appear to represent the sequel of the primarily faulty arrangement of the digital nervous skeleton.

24. Taking into account the utmost peripheral nervous skeleton within the mucosal and cutaneous coverings of the body as limiting–under normal intravital conditions–the proliferation of epithelial cells, the malignant cell may be conceived as an essentially *normal* cell which escaped from the limiting feltwork of extensive neural growth and, instead of obeying the physiological duty to die, continues with its one-growth-type existence and proliferation autonomously, i.e. without any relation to the other, extensive type of growth. Various facets of malignant growth may be readily explained by the two-growth-types concept of cancerogenesis.

Lack of adequate "availability of space" *along* the nervous macrostructures and *within* the utmost microstructural nervous skeleton is advocated as the common pathogenetic denominator of skeletal teratogenesis and of cancerogenesis. In the former instance, the shape of otherwise normally growing bones is just adapted to the inadequately growing nervous macrostructures (the spinal cord and/or the spinal nerves) without any disjunction of the two tissues closely interrelated at the organ level. Scoliosis and various "dysplastic" conditions of the skeleton are typical examples of what has been designated *"non-escape extenso-cellular growth pathology"*. In the latter instance, the individual epithelial cells escape from the extensive neural feltwork, continue proliferating outside its limiting confines and acquire malignant features. A fatal disjunction of the two growth types takes place resulting in the *"escape extenso-cellular growth pathology"*, viz., in the nerveless malignant growth. Cancerogenic factors seem to influence upon the two-growth system in the most variable combinations of stimulation and inhibition with unpredictable sequelae for their cohesivity.

> 25. The striking outer resemblance of the sperm and of the neuroblast together with some other features common to both (concerning the motility and, above all, the resistance of the embryonic cell once innervated to further innervation suggestive of the egg-sperm interaction) point to some phylogenetic relationship established probably at the very beginnings of the animal kingdom. The nervous system of animals would arise as a branch of the pre-existent plant ("archplant") kingdom and this initial event were recapitulated in the egg-sperm interaction at the onset of every individual ontogenesis as well as in the identical growth type of plants and of nervous structures, viz., in the extensive growth following after the embryonic stage of mitotic proliferation of cells. The purpose of fertilization were not only to bring together the maternal and paternal genetic equippment but also to induce the "two-growth-types" composition of the animal and human body.

**17. Roth, M. (1986), *Cranio-cervical growth collision: another explanation of the Arnold Chiari malformation and of basilar impression,*** Neuroradiology (1986) 28: 187–194

Original language: English
**Abstract:** Analysis of neuro-cranio-spinal development suggests a cranio-cervical growth conflict as the cause of the Arnold Chiari malformation and of basilar impression. Impaired cantilevering of the skull to accommodate the enrolling content and the hindered growth of the cervical skeleton gives rise the a "pulled out" configuration of brainstem and cerebellum that comes easily in contact with bony boundaries, giving rise to painful conditions and neural dysfunction. In gross (Meningomyelocele) and slight (adolescent deformities) impairment of distal spinal growth, a reversal of cervical growth occurs, the initial descent (uncoiling) of the primordial brain curvatures is compromised owing to the growth collision with the ascending cervical spine. The availability of space is subject of the struggle in which the cervical spine stays shorter and the foramen magnum relatively smaller, whilst the stem-cerebellum complex is pulled against it because of the tightness of the cord-roots complex in the vast growing axial skeleton.

**18. Roth, M (1989), *The `Enveloping` versus the Biomechanical function of the spine,*** Cs. Radiology 43, 1989, No. 1, c. 1–13.

Original language: Czech
**Abstract:** As a continuation of argumentation presented in a number of previous communications, the author advocates the view according to which the developing spine and its neural content ("spinal cord-nerve roots complex") are linked by an equally intimate morphogenetic relation like that existing between the brain and its skeletogenic envelope. A specific feature of the neurovertebral developmental relation consists in the fact that the elongated spinal cord-nerve roots complex is enveloped by its skeletogenic case both in the transversal and in the longitudinal direction. The matter is further complicated by lagging of the spinal neural growth behind that of the vertebral column. The development of the basic anatomical features of the individual vertebrae such as their length and width, the girth of the vertebral body as well as the shape of the intervertebral foramina

cannot be understood without taking into account the gross developmental dynamics of the two main components of the axial organ, viz., of the spinal cord-nerve roots complex and of the vertebral column.

**19. Roth, M. (1994),** ***Traumatic Spondylolysis in the hedgehog. A contribution to the Problem of Dysplasia of the Isthmus*****,** Z. Orthop. 132 (1994), p. 33–37

Original language: German
Traumatic Spondylolysis in a hedgehog is reported. On the basis of that rare thinning of the vertebral isthmus frequently associated with Spondylolysis in man is claimed to be related to the "neuro-enveloping "function of the spine shared with that of the neurocranium. Dysplasia of the isthmus results from abnormal ganglio-foraminal interrelation in the embryo rather than from any primary derangement of the proper vertebral bone growth. In humans the compressive forces on

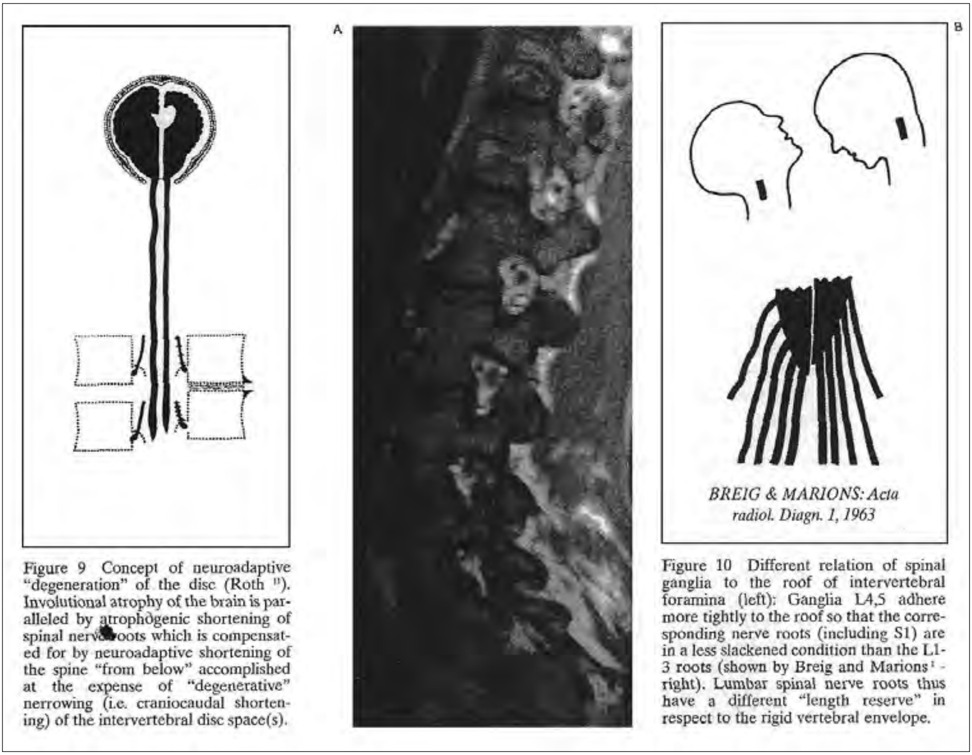


**Fig.19.** Schematic drawing of the obviously always present concomitant involution of cerebral volume (atrophy) and shortened tight cord and roots in the degenerative process that at the same time occur in the spine. A sedentary lifestyle and heavy labour can enhance these degenerative changes in case of already discongruent osteoneural growth.

the posterior elements in case of a low ending (hyper-) kyphosis can give rise to stress fractures of the pars intra-articularis.

**20. Roth M.** (1995) ***Role of neural growth in the pathomechanism of skeletal dysplasia's: an experimental study.*** Locomotor System, 2, 1995, No. 3, pp. 85–111

**21. Roth M**. (1996) ***Macroneurotrophic features of growth hormone effects upon the spine and hip.*** Locomotor System, 3, 1996, No. 2, pp. 72–108.

**22. Roth M.** (1998) ***Rheumatoid Deformities of the Skeleton: Animal Models and Neuroadaptive Pathomechanism.*** Locomotor System, 5, 1998, No. 1–2, pp. 40–49.

**23. Roth M. (1998)** ***Neuroadaptive Pathomechanism of Bone Dysplasia's.*** **(in Czech).** Locomotor System, 5, 1998, No. 3–4, pp. 127–132
In a number of instances experimental "osteoneural" findings pattern what happened in the course of evolution and hominization, viz., primary shortening of the nervous skeleton reflected in corresponding transfonnations of the bony skeleton. Shortening of the human mandible with appearance of the chin is one of the most striking examples of such an (experimentally reproducible) "phylogenetic neuroadaptive deformity".

**24. Roth M. (1998*****) Morphology and Development of the Spine: Plea for a doubt.*** Rivista di Neuroradiology 11:313–320.

Against the evident present "macroneurotrophism" effect that can be seen in the period of growth of both skeleton and nervous tissue, leading to gross morphological changes in the skeleton (deformities) he places the more "microneurotrophisme" effects, that can be seen in adulthood. This can explain the "degenerative" shortening of the spine and structural chances as seen in the lower spine can be related to similar degenerative (involution) processes that at the same time takes place in the neurocranium.

**25. Roth M.** ***Disc Degeneration: A Sort of Neuroadaptive Skeletal Dysplasia in the Adult and Aged Essay on "Macroneurotrophism" of the Skeleton, Pathology and Developmental Biology of Gross Neural Growth,*** April 1, 1999 Research Article, Volume: 12 issue: 2, page(s): 281-302
Radio diagnostic Clinic, Medical Faculty Hospital, Masaryk University; Brno-Bohunice, Czech Republic

Owing to the craniocaudally proceeding bodily growth, "neuroadaptive" shortening of the skeleton is accomplished as though "from below" since the too short spinal nerve roots and/or peripheral nerves hinder the spine and /or limb bones from growing straight forward in length. The concept is buttressed by experimentation on laboratory animals which suggests a common neuroadaptive pathomechanism of experimental as well as clinical skeletal "dysplasia's". Vertebroneural and/ or osteoneural length disproportion may take place even in the adult and aged as a result of involutional-atrophogenic shortening of spinal nerve roots and/or of peripheral nerves. Also, that disproportion must be compensated by the skeleton since otherwise the shortened nervous elements would be exposed to undue stretching. In the spine this "neuroprotective" measure is accomplished by degenerative narrowing (i.e. shortening) of the disc comparable with "cerebroprotective" dehiscence of cranial sutures under the effect of the expanding brain in obstructive hydrocephalus. Herniation of the disc is just a mechanical complication of the essentially purposeful "degenerative" process. Degenerative "arthrotic" narrowing (shortening) of the joint spaces in the limbs may be ascribed to analogous primary atrophogenic shortening of peripheral nerves.

**25. Roth M. *Macroneurotrophism in the development of the vertebrate skeleton.*** Anthropology XXXII/1 (1994) 1-24

Motto: "It is sometimes held that no real progress has been made until a biological mechanism is placed on a firm molecular basis. Such a view denies the existence of different levels of organization at which one can meaningfully investigate biological processes."

**Abstract:** … Against the petrified belief that the growth of the extracerebral nervous structures is mere passive "innervation follower" of the other tissues to be innervated, the view is defended and experimentally supported that growth in length of the bony skeleton depends upon and is governed by the active co-growth of the nervous skeleton (ten by Donaldson 1937). Variable length of the vertebral column as well as of the limb bones in animals and man mirrors the variable growth-in-length potentiality of the spinal and peripheral nervous structures. The nervous skeleton perceives, along exteroceptive and proprioceptive path ways, the conditions prevailing in the environmental niche and provides, by mediation of the more or less extensive neural growth, for the appropriate shape and length of the bony skeleton. Impairment of the vulnerable neural growth results in "neuroadaptive" deformities of the skeleton consisting in various types of its shortening, i.e. accumulation of the proliferating skeletogenic material along and within the too short nervous skeleton. If the two types of growth evolve in a congruent way than you can speak (in accordance with Holzer) of the Neuroprotective mechanism: The indispensable "Osteoneural balancer".

It is argued that egg and sperm appear to be sources of the two basic growth types of the vertebrate body, the cellular-divisional and the neural-extensive. The possible repercussions of that developmental interrelation upon some problems of general biology are discussed.

## Acknowledgments

We thank Milan Roth's widow, the late Mrs. Milada Rothova and their sons Tomas and Michal for their initial help in providing his biographical material and photographs and their approval to use all his published work to be brought under attention of the present medical world interested in unanswered questions on skeletal growth and spinal deformities as scoliosis.

Also, thanks to Dr. Kayo Styblo PhD, now orthopedic surgeon in Zaandam the Netherlands, who originates from Czechoslovakia, for translating the Czech articles of Milan Roth into Dutch.

Thanks to Prof. Ivo Marik and the Czech Society for Connective tissues J.E. Purkynë to give us the opportunity at the different Prague-Lublin-Sydney-St. Petersburg Symposia to bring our knowledge on the importance of the concepts of Roth in the light of many ailments modern man has to suffer.

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The PDF of his book is placed under the Research Gate profile of Piet van Loon https://www.researchgate.net/publication/23275347 The_central_cord-nervous_roots_complex_and_the_formation_and_deformation_of_the_spine_the_scientific_work_on_systematic_body_growth_by_Milan_Roth_of_Brno_1926–2006

## List of articles with reference to spinal growth and Roth's work

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3. PORTER R. W. **Comment to "The pathogenesis of idiopathic scoliosis:uncoupled neuro-osseous growth?"** ;Eur Spine J (2001) 10 :482–487
4. CHU WC et al. **A detailed morphologic and functional magnetic resonance imaging study of the craniocervical junction in adolescent idiopathic scoliosis**. Spine (Phila Pa 1976). 2007 Jul 1; 32(15):1667-74.
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6. CHU WC, MAN GC, LAM WW, YEUNG BH, CHAU WW, NG BK, et al. **A detailed morphologic and functional magnetic resonance imaging study of the craniocervical junction in adolescent idiopathic scoliosis.** Spine 2007 Jul 1;32(15):1667–74.
7. GIGLIO CA, VOLPON JB**: Development and evaluation of thoracic kyphosis and lumbar lordosis during growth**. J Child Orthop**.** 2007 Sep; 1(3):187-93. Epub 2007 Jul 28

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