From the ECM to Posture

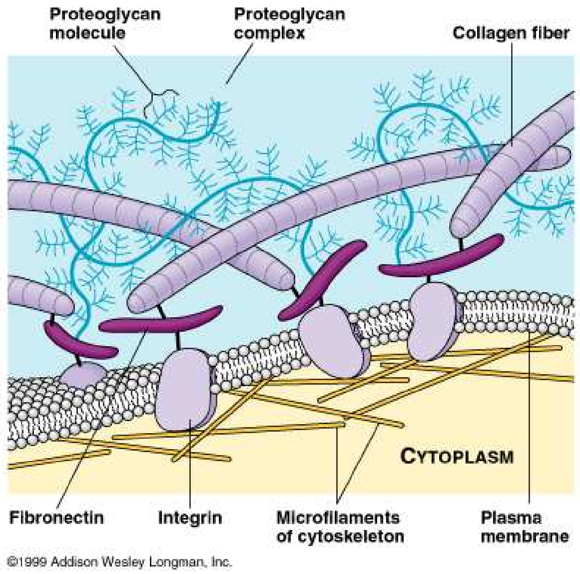
Is the connective system our real Deus ex machina?

Giovanni Chetta

Assumption

This work, which is the natural expansion, development, and examination of past efforts, is a result of daily clinical practice and the indispensable comparison between theory and practice with other specialists, including the following: Francesco Giovanni Albergati (angiologist), Melchiorre Crescente (dentist), Alfonso Manzotti (orthopedist), Serge Gracovetsky (bioengineer), Carlo Braida (physicist), Wolfgang Freesmeyer (dentist). I wholeheartedly dedicate this work to the last two, who unfortunately will not be able to see it completed unless from a parallel world.

Extracellular Matrix (ECM)



Introduction

In order to better understand the importance of the role of posture as part of our overall health, a description of the extracellular matrix (ECM) is necessary, even if it only includes the little that is known about the subject today. Every cell in our bodies, just like every other living multicellular organism, needs to "sense" its surroundings and interact with its environment in order to perform its vital functions and survive. In a multicellular organism cells need to coordinate their different functions, much like in a community of human beings. In multicellular organisms, cells make use of hundreds of extracellular molecules (proteins, peptides, amino acids, nucleotides, steroids, fatty acid derivatives, dissolved gases, etc.) for constant communication over short and long distances. In every multicellular organism each cell is exposed to hundreds of different signaling molecules that are located inside and outside of the cells, both free and linked to their surface or bound in the extracellular matrix. The cells come into contact with an extremely complicated external environment via their surfaces (the plasma membrane), and more specifically through numerous specialized areas located on their membranes (from several dozen to over 100,000 on each cell). The different membrane receptors are sensitive to many signals from the cell interior and from the ECM and are subject to significant changes over the course of the cell's life. Membrane receptors are capable of recognizing and bonding with signal molecules (for example: peptide hormones, neurotransmitters) to initiate specific reactions inside of the cell (for example: secretion, cell division, immune responses). The signal from a membrane receptor is transmitted inside of the cell by a series of intracellular components capable of producing different effects through "controlled signaling cascades" that vary based on the cell's specialization. Thus, different cells are able to respond to the same signal in different ways and at different times (for example: when myocardial cells are exposed to acetylcholine the result is a decrease in contractions, while in a parathyroid cell it stimulates the secretion of the components of saliva) – Gennis, 1989.
Cells are constantly combining, coordinating, controlling, activating, and stopping numerous and different signals from the inside of the cell and from the ECM, processing them at the right time and in the right way by activating specific reactions (live, die, divide, move, modify, secrete something into the ECM or store it inside of the cell, etc.). Responses that involve a change via the genetic code could require several minutes or hours (genes must be transcribed and the mRNA has to be translated into protein), but when cells need a response in a few minutes or seconds they use direct systems of activation through enzymes.

The ECM is generally described as being composed of several important classes of biomolecules:

- Structural proteins (collagen and elastin)
- Specialized proteins (fibrillin, fibronectin, laminin, etc.)
- Proteoglycans (aggrecans, syndecans) and glucosaminoglycans (hyaluronans, chondroitin sulphates, heparan sulphates, etc.)

Structural proteins

Collagens are the most common glycoproteins in the animal kingdom. They are the most abundant proteins present in the ECM (but not the most important) and are the fundamental elements of connective tissues (cartilage, bone, fascia, tendons, ligaments).
There are at least 16 different types of collagen, and types I, II, and III are most commonly found in ordinary fibrils (type IV forms a sort of network that is the major component in the basal laminae). Collagen is normally synthesized by fibroblasts, but epithelial cells are also capable of producing it. Collagen fibers constantly interact with an enormous quantity of other molecules in the ECM, forming a biological continuum that is essential for the life of the cell. The collagens associated into fibrils play a predominant role in forming and maintaining structures capable of resisting tensile forces, as they are nearly inelastic (glucosaminoglycans resist compressive forces).
Somehow collagen is produced and re-metabolized as a function of the mechanical load to which it is subjected, and its viscoelastic properties have a significant impact on posture in human beings, as we will see in the "Fascia viscoelastcity" paragraph. Another example of collagen's ability to modify itself based on environmental influences, for example, by assuming different degrees of rigidness, elasticity, and resistance, can be seen by looking at FACIT collagens (Fibril Associated Collagen with Interrupted Triple helices), which are capable of acting functionally as proteoglycans (described in the "Glucosaminoglycans and Proteoglycans" paragraph). Thanks to their PG/GAG (proteoglycan/glucosamoniglycan) coating they have biosensory and bioconductor properties: their electric charges provide them with a greater capacity to bind to water and exchange ions, and thus a greater electric capacity. We know that any mechanical force capable of generating a structural deformation stresses the intermolecular bonds producing a slight electrical charge known as a *piezoelectric current* (Athenstaedt, 1969). In such cases, the collagen fibers distribute positive charges on their convex surface and negative charges on their concave surface, turning them into semiconductors (allowing electrons to flow on their surface in a single direction). Since piezoelectric energy (similar to pyroelectric energy generated by thermal stress) is neutralized by circulating ions in an extremely short period of time (about $10^{-7} – 10^{-9}$ seconds), the availability of PGs/GAGs on the surface of the fibrils is decisive in signal propagation in order to act as "repeaters" of the electrical impulse. A longitudinal periodicity of about 64nm (which looks like a stripe when viewed under an optical microscope) allows for the impulse to propagate at a velocity of about 64 m/s (equivalent to the conduction speed of fast nerve fibers) – Rengling, 2001. The strong dipole moment of the collagen fibrils and their resonance capacity (properties present in all peptide structures) as well as the low dielectric constant of the ECM facilitate the transmission of electromagnetic signals. Therefore, the three-dimensional and ubiquitous collagen network also has the peculiar characteristic of conducting bioelectric signals in three-dimensional space, based on the relative availability between the collagen fibrils and the cells, in the afferent direction (from the ECM to the cells) or in the efferent direction.
This represents a real time ECM-cell communication system and these electromagnetic biosignals can cause important biochemical changes. For example, in bones, osteoclasts cannot "digest" piezoelectrically charged bones (Oschman, 2000).
Lastly, it is important to note that it is no coincidence that cells expend great amounts of energy (about 70%) constantly producing material that must be expelled generally through the exclusive storage of protocollagen (the biological precursor of collagen) in specific vesicles (Albergati, 2004).

In vertebrates, the overwhelming majority of tissues must have two qualities: strength and elasticity. A true network of **elastic fibers** located in the ECM of these tissues allows initial conditions to be restored after strong forces of traction are applied. Elastic fibers are capable of increasing the extensibility of an organ or a part of an organ by at least five times. Long, inelastic collagen fibrils alternate among elastic fibers and have the precise responsibility of limiting excessive tissue deformation as a result of traction.
Elastin is the major component of elastic fibers. It is an extremely hydrophobic protein composed of a string of about 750 amino acids, rich in proline and glycine like collagen, but different from collagen because it is not glycosylated and contains many hydroxyproline residues and not hydroxylysine. Elastin has the appearance of a true biochemical network, with an irregular three-dimensional shape, composed of fibers and thin layers that permeate the ECM of all connective tissues. It is particularly abundant in elastic blood vessels (it is the most common ECM protein in the arteries and makes up over 50% of the dry weight of the aorta), ligaments, lungs, and skin. Unlike collagen, in the dermis the density and volume of elastin tends to increase over time, while aging elastin appears to be enlarged, almost swollen, often with a fragmented appearance and with a reduction in the "amorphous" component (Pasquali Rochetti et al, 2004). Smooth muscle cells and fibroblasts are the major producers of its precursor, tropoelastin, secreted into the extracellular spaces.

Specialized proteins

The ECM contains an elevated (and still not well defined) number of non-collagen specialized proteins, which typically have multiple domains with specific bonding sites for other molecules present in the ECM and for receptors present on the cell surface. In this way, each single component of these proteins acts as an "amplifier" of contacts between similar and different molecules, creating an infinite biochemical network capable of generating, modulating, varying, and propagating millions and millions of pieces of biochemical (and energetic) information, even remotely.
An important specialized protein in the ECM is **fibronectin**, a high molecular weight glycoprotein that can be found in all vertebrates. It is a glycoprotein dimer composed of two large subunits joined by disulphide bridges. Fibronectin appears to be capable of influencing cellular growth, intercellular adhesion, and adhesion with the ECM (it is capable of bonding to cells and other ECM molecules; ex: collagen, fibrin, heparin) as well as cellular migration (cells can move up to 5 cm a day – Albergati, 2004) etc. in various ways. The most well known isoform, type III, bonds to integrins. Integrins are a family of transmembrane proteins that make cells adhere to the extracellular matrix through recognition of the RGD peptide sequence. RGD peptides are amino acid chains of varying lengths starting with simple tripeptide chains, characterized by an Arginine-Glycine-Aspartic Acid sequence. This sequence of amino acids is ubiquitous in the body and is involved in numerous physiological functions. This RGD sequence is one of the structures that bond to particular types of cells (example: inflammatory cells) so that they can carry out their functions. Integrin and RGD bonding induces a series of reactions in the cytoplasm that involve the cytoskeleton and other proteins that regulate cell adhesion, growth, and migration. Integrins therefore act as mechanoreceptors: they transduce tractions and mechanical pressure from the ECM inside of the cell and vice versa selectively and in a way that can be modulated (Alberts, 2002).

Glucosaminoglycans (GAGs) and proteoglycans (PGs)

Inside of connective tissues glucosaminoglycans (GAGs) and proteoglycans (PGs) form an "essential", highly hydrated, gel-like substance containing overlapping protein fibrils.
This polysaccharide gel is capable of allowing the ECM to resist significant compressive forces and allows for a rapid and constant diffusion of nutrients, metabolites, and hormones between the blood

and the tissues. GAGs normally bond covalently to a protein nucleus (core), which gives rise to a proteoglycan (PG). GAGs and PGs are capable of acting on their own or in groups as receptors for adhesion molecules or as catalysts for biochemical processes on circulating molecules such as growth factors, cytokines, and coagulation enzymes.

GAGs are made up of polysaccharide chains composed of disaccharide units that repeat many times. One of the two sugars is always an amino sugar (n-acetylglucosamine or n-acetylgalactosamine), which is almost always sulfated. The second sugar is usually glucuronic acid or its isomer L-iduronic acid. There are four major groups of GAGs: chondroitin sulphates, hyaluronic acid, dermatan sulfates, heparan sulfates, keratan sulfates.

The polysaccharide chains of glucosaminoglycans are too rigid volumetrically to fold into the compact globular structures typical of polypeptide chains, and they are also highly hydrophilic. For these reasons (and probably for others that are unknown to us) GAGs tend to assume extremely vast conformations that occupy a large volume for their mass, thus forming significant quantities of gel even when they are present in low concentrations. The high quantity of negative charges (GAGs, which are normally sulphated, are the most numerous anionic molecules produced by animal cells) attract numerous cations; among these, Na+ plays an important role, giving the structure osmotic capabilities and trapping a large amount of water in the ECM. This generates swelling (turgidity) that allows the ECM to resist to significant compressive forces (due to these characteristics, under physiological conditions, the cartilage in the hip is perfectly capable of resisting pressures of several hundred atmospheres)

In the connective tissue, GAGs account for less than 10-12% of the overall weight, but thanks to their characteristics, they fill many of the extracellular spaces, forming pores of aqueous gels of various sizes and charge densities, acting as key selective points or “servers” that regulate the traffic of molecules and cells in the ECM, based on their sizes, weights, and electric charges.

Hyaluronic acid (hyaluronans, hyaluronate) might be the simplest GAG. In humans it consists of about 25,000 nonsulfated disaccharide repeats and is not normally found connected to a “protein core”, giving it an atypical structure. Experimental and biological-molecular data confirm that this molecule plays a fundamental role in bones and joints, providing resistance to significant pressures. It also plays an extremely important role in filling spaces in the ECM during embryonic development: it creates empty spaces between the cells, which the cells migrate towards in subsequent phases (Albergati, 2004). When GAGs and PGs associate with each other they can give rise to enormous polymer complexes in the ECM. For example, the *aggrecan* molecules, which represent the majority of PGs in the joints, combine with each other through non-covalent bonds with hyaluronic acid, giving rise to aggregates that are the size of bacteria.

Not all PGs are secreted by the ECM; some are integral components of the plasma membrane. Among the most well known transmembrane PGs, *syndecans* have an extracellular domain consisting of three chains of GAGs, while the intracellular domain is believed to be capable of reacting with actin in the cytoskeleton (Alberts, 2002).

The extracellular network

The ECM can therefore be viewed as an extremely complex network in which proteins, PGs, and GAGs carry out innumerable functions including the structural support and regulation of all tissue and organic activities. It is necessary to view overall cellular homeostasis as a group of mechanisms whose origin and development is found inside of the cell or externally in the ECM; in the latter case, the cell could be an intermediate or end target. Extracellular components, in addition to functioning as structures providing physical support to the cellular scaffolding, act as the actual sites of the start, development, and end of vital processes regarding the endocellular environment, including both cellular organelles and systems. This is an infinite biochemical network capable of generating, modulating, varying, and propagating, millions and millions of pieces of information, even remotely.

Each cell in the human body is constantly interacting with the ECM mechanically, chemically, and energetically, with "dramatic" effects on static and dynamic tissue architecture. For example, fibroblasts make important modifications to the collagen they produce, constantly altering it in order to be able to compact and prepare this material in the forms and quantities required depending on its specific function. When two small fragments of embryonic tissue are placed far away from one another, but still in the same culture of collagen gel, we first observe the formation of perfectly aligned neocollagen fibers that interconnect the two fragments. Subsequently, fibroblasts migrate out of the two embryonic tissue fragments along the neocollagen fibers, checking their deposition, and in turn, being monitored. This functional syncytium is most likely present during the regenerative processes of the ECM and constitutes a perpetual functional continuum capable of self-regulation and dealing with the constant variations required by the different vital functions in the tissues under physiological conditions (Albergati, 2004).

According to P.A. Bacci (2004), the interstitial matrix is truly the mother of vital reactions, the first site where exchanges of matter and energy occur. All of the tissues are connected and functionally integrated with each other in open systems; constant exchanges occur between them, which can initiate at both the local and systemic level, making use of biochemical, biophysical, and electromagnetic messages, or in other words, using different forms of energy. The ionic composition of the interstitial space makes up an essential substance that does not only allow exchanges and life, but affects gene expression in every cell.

According to F.G. Albergati (2004), the cell and the extracellular matrix are two worlds that only seem to be separate, which must interact at all times over the entire duration of life in order to be able to operate correctly and synergistically. This requires an extraordinary series of signals followed by an incredible series of molecular-biological activities.

ECM Remodeling

The ECM should be viewed as a structure that is in a perpetual and constant state of morphofunctional "remodeling", both in physiological and pathological conditions, based on functional requirements both internally (through the action of metalloproteases) and externally from the cells (through the action of numerous types of adhesion proteins). A reduced or lacking ECM remodeling capacity has lethal consequences on the cell. As we have seen, all cellular functions are expressed as a consequence of the corresponding function of the ECM structures, and pathological processes can precede or be a result of ECM modifications.

Clear examples of ECM remodeling include the repairing of the dermis-hypodermis (this process requires a precise chain of events including the degradation of the matrix, the migration of specific cells to the site, the synthesis of a temporary matrix composed of fibronectin, fibrins, and large quantities of type III collagen, a phase of temporary matrix remodeling essential for the functional restoration of its components and the structural restoration of the tissue itself as a result of this) and neoangiogenesis (the physiological process of forming new capillaries in tissues and organs in different pathological situations). Neoangiogenesis is being studied as a treatment with the goal of restoring the correct supply of blood to the ischemic tissues, for example, in cardiac muscle or in peripheral circulation, and to inhibit the process in tumors (Shishido et al, 2003).

Metalloproteases (MMPs) are a family of endopeptidases containing zinc and calcium, which have the potential capability of degrading all proteins and proteoglycan components of the ECM. They possess sequences that are similar to interstitial collagen and are located on the external part of the cellular membrane in an inactive form (and are activated when needed). Their activity is inhibited by specific agents known as TIMPs (Tissue Inhibitors of Metalloproteases). In the past they were known as collagenases or gelatinases due to their ability to denature native collagen or denatured collagen (gelatin) – Birkedal-Hansen (1993). These enzymes are implicated in numerous physiological and pathological processes including angiogenesis, embryogenesis, inflammatory responses, atherosclerosis, and numerous arthritic-rheumatic pathologies (including rheumatoid arthritis – Dieppe, 1995).

ECM and pathologies

Metalloprotease (MMP) activity is very precisely regulated during physiological tissue remodeling. This regulation seems to be lost or dramatically reduced in pathological conditions such as tumor growth. The protease-antiprotease balance is also “spatially” controlled; tissues organize themselves by creating a “wall” of inhibitors that surrounds the area where activated metalloproteases are present (therefore the cells that produce the proteases are different from those that produce their inhibitors). This system is obviously subject to numerous influences. Particularly, *oxidative stress* is capable of profoundly modifying the protease-antiprotease balance through free radicals (ROS – Reactive Oxygen Species, or ROTS – Reactive Oxygen Toxic Species) produced by unfavorable environmental and metabolic conditions and capable of resulting in widespread damages since they are not neutralized by the body’s normal defense system (scavengers), with some of the following consequences: damaging DNA (often due to repairs not being carried out by DNA-polymerase and through apoptosis), cell necrosis, lipid peroxidation, matrix disintegration leading to loss of receptor function (integrins), mitochondrial damage and damage to other organelles, blockage of the cell respiration chain and therefore energy production, cell death with collagen replacement/fibrosis (Izzo, 2001).

Oxidative stress → activation of MMPs and inhibition of TIMPs (MMP inhibitors) → Overall matrix damage

The ECM is an essential and vital substance for the cell’s metabolic exchanges. It is a type of heterogeneous and living material, which, although often changing its makeup from sol to gel, always remains a sort of rich and highly complex “internal sea” that is sensitive to basic phenomena such as intestinal toxicosis, alternating renal-hepatic phases of purification, vascular alterations, and acidification or alterations to systems of oxidation and reduction.
The structural and metabolic equilibrium of the extracellular compartment is essential in the regulation of vital, basic exchanges. It is through the alteration of these mechanisms of physiological homeostatic equilibrium that basically all chronic-degenerative diseases begin in the ECM. Many genetic diseases are the final result of primitive mutations to numerous molecules in the ECM (Albergati, Bacci, 2004).

Numerous chronic and degenerative pathologies (common diseases in our society) show a tendency towards acidosis and an increase in free radicals, showing the importance of maintaining the *body’s pH level* at around 7.4 (slightly alkaline), mainly through a correct diet. It is important to stress that it is not always a systemic problem, and can sometimes be related to a local state of acidosis and/or oxidation in the tissues. While in the large blood vessels changes in oxidation and pH are easily buffered, in the tissues and capillaries, acid is immediately moved out of the cell through specific pumps, altering the delicate exchanges of gas and nutrients (Worlitschek, 2002).

In the *neurons*, myelin provides nearly complete protection to the axon, except for short spaces called nodes of Ranvier, where the axon comes into direct contact with the ECM. Na^+ ion channels are almost exclusively present at the nodes, highlighting the importance of the extracellular pH for the health of the neuron also at this site. When present in the inter-synaptic space, neurotransmitters such as acetylcholine bond to Na^+ or K^+ channels; the hydrolysis of acetylcholine into choline and acetate by cholinesterase quickly frees the inter-synaptic space, allowing for the original state of the ECM to be restored. (Bloom, 1988).

The reduction of microcirculatory flow inhibits lipolysis and the release of free fats and glycerol, resulting, in other words, in lipogenesis. Ultrastructural observations make it easy to notice the structural and functional connection of adipocytes and fibroblasts with lymphatic precollector vessels. When lipolysis occurs, adipocytes decrease in volume and fibroblasts can contract, leaving space for the passage of water from metabolic processes, which together with protein macromolecules, fats, etc. form the lymph that cleans the cell and tissue. During lipogenesis or changes in tissue metabolism, fibroblasts and their associated fibrils decontract and the circulation

of lymph is slowed resulting in lipedema (characterized by high tissue pressure due to an increase in bound water) and lymphedema (characterized by high interstitial and blood vessel pressure from free water and proteins, or lymph, with higher levels of osmotic pressure) – (Campisi 1997).
It is therefore possible to define a "*cellular lympho-adipose system*", which could be the key to interpreting the etiology of all edematous alterations, which may originate from alterations to the ECM (Curri, 1990). This is all compounded by the excess sugar introduced into the body through our diets (which provokes a storage of lipids (lipogenesis) in the peripheral adipose tissue), as well as our modern lifestyles and habitats (with their postural implications described in the "Artificial life" paragraph) and the estrogens consumed in our diets (estrogens are used in the food industry and in treating land) and pharmaceuticals (for example, with the estrogen-progestin therapy widely used among young women). Exogenous estrogens enter into the body in pools, which do not bind to any hepatic proteins and which are not recognized by pituitary feedback mechanisms (therefore endogenous estrogens continue to be produced). These are transported in their free form by the vascular system and are normally distributed in the peripheral adipose tissue, provoking lipogenesis and water retention in the ECM, thus favoring superficial lipedema in well-known parts of the body (Fain & Sheperd, 1979). Intestinal fermentative-dysbiosis-related disturbances seem to play an additional role, which occur in the colon due to a poor diet. These conditions may produce toxins that accumulate in the ECM arriving through the vascular system. The toxins absorbed in the subcutaneous tissue may provoke metabolic alterations due to their effects, which include cellular acidification and oxidation, resulting in a slowdown of metabolic exchanges and interstitial water retention. The potential consequences are an increase in intracellular ions and macromolecules, and therefore, an increase in the material that needs to be drained through the lymphatic system (Bacci, 1997).

The term *Interstitial Heart Disease* (IDH) was coined to highlight the aspects of the genesis of several cardio-circulatory decompensations in which myocytes may be innocent bystanders compared to the hemodynamic events originating in the ECM cells in the heart. Cases of IDH could be due to structural anomalies in the cardiac interstitial space, which accounts for 40% of the myocardium (Gilbert & Wotton, 1997).

The ECM, and collagen in particular, play a vital role with regard to the *kidneys*. Chronic interstitial-tubule lesions are directly correlated to the decline in renal secretion activity and are often accompanied by an ECM deposition and a transformation of fibroblasts into myofibroblasts (see the "Myofibroblasts" paragraph below").

In case of *male hypofertility or sterility*, in the absence of evident endocrine-metabolic decompensations, the diameter of seminiferous tubules in the testis is greatly reduced in the presence or absence of sperm production since the wall is significantly thickened and the associated connective tissue produced by the ECM increases in proportion with the deterioration of testicular function (increase of vimentin, lamenin, and collagen IV) – Ikesen & Erdogru (2002).

Morphofunctional alterations in so-called "minor" cartilage collagen (III, IX, XI) occur during the aging process and in many pathologies such as *osteoarthritis, discopathies, detached retinas, and glaucoma* (Furth, 2001).

Today we know that many hepatic cells (hepatocytes responsible for fat storage, Kupfer cells, and endothelial cells) are capable of producing numerous components of the ECM when they are required to do so. *In the liver,* fibrosis is the most common response to hepatocellular insults (infections, disturbances to hepatic circulation, necrosis, etc).

In the *respiratory system*, studies are increasingly focused on the ECM. For example, in individuals with asthma there are structural modifications to several components of the ECM including collagen and glycoproteins (Boulet, 1999).

Every molecule and electron in the body has its own, typical physiological vibration, which is altered in pathological conditions, and even more so in chronic and degenerative diseases. The ECM is also subject to the laws of *electromagnetism* to preserve its own natural state, allowing the circulation of this type of energy which is the main driver of all basic cellular and tissue exchanges. Physical and energetic changes associated with biochemical changes initiate chronic and degenerative pathologies through a functional imbalance of metalloproteases. The best course of action is integrated treatment, making use of chemical-physical (nutritional-pharmacological) agents internally and mechanical-energetic (manual, movement, instrumental) agents externally (Pischinger, 1996).

Connective tissue

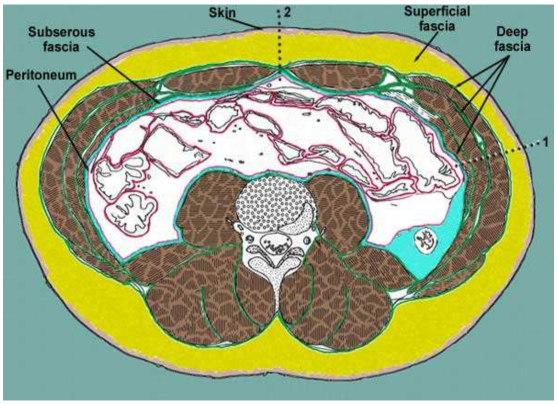
Introduction

The connective tissue is an integral part of the ECM. It is continuous: each tissue and organ contains connective tissue and their functions depend greatly on anatomical and functional interconnections. In terms of embryology, most connective tissue comes from the mesoderm, while some connective tissues in the cranium are derived directly from the neuroectoderm. What was considered a short while ago to be a "trivial" tissue whose role was to connect and fill space, in reality is a system or organ with numerous essential functions.

Functions of connective tissue

maintaining posture, connecting and protecting organs, acid-base equilibrium, hydrosaline metabolism, electric and osmotic equilibrium, blood circulation, nerve conduction, proprioception, motor coordination, barrier to invasion by bacteria and inert particles, immune (leukocytes, mastocytes, macrophages, plasma cells, inflammatory processes, repair and filling damaged areas, energy reserves (lipids), reserves of water and electrolytes, reserves of about 1/3 of plasma proteins, cell migration, intra and extracellular communication, etc. (Chetta, 2007).

Fascia



Among the different types of connective tissue (connective tissue in the strict sense, elastic tissue, reticular tissue, mucous tissue, endothelial tissue, adipose tissue, cartilage, bone, blood, and lymph), fascia is the "bridge" between the ECM to posture. Based on the design proposed by F. Willard (2007), the fascia can be divided into roughly four layers, which form concentric, longitudinal, and interconnected cylinders.

1) The most external layer/cylinder, located below the dermis, is known as the *superficial fascia.* In the cranium, the superficial fascia extends in the galea aponeurotica (covering the upper part of the cranium, connecting posteriorly to the external protuberance of the occipital bone, through the nuchal line, and to the frontal bone anteriorly through a short and narrow extension), while it merges with the deep fascia at the sole of the feet (forming the retinacula of the foot). The superficial fascia is composed of loose connective tissue (subcutaneous, whose interior can contain a network of collagen fibers and mainly elastic fibers) and adipose (whose thickness depends on our diet in addition to its location). Fibers form a continuum between the fascia and the dermis and epidermis exteriorly, and at the same time the superficial fascia anchors itself to the underlying tissues and organs. It is an important storage site for water and fat, has a protective role against mechanical and thermal deformations and insults (insulating layer), is a passageway for nerves and blood vessels, and allows for the skin to run above the deep fascia. Similar to the deep fascia, it has little vascularization.

2) Beneath the superficial fascia lies the *deep fascia*, also called thoracolumbar or dorsolumbar (lumbodorsal) fascia, a cylindrical layer that is quite consistently present throughout the body (trunk and limbs). It is composed of dense irregular connective tissue formed from undulating collagen fibers and elastic fibers (arranged transversely, longitudinally, and obliquely) and forms a membrane that covers the external muscular area. This sheath, having developed around the notochord (which defines the medial axis in the embryo) covers the body, extending from the cranium at the edge of the jaw and at the base of the cranium with which it merges (and from which the cranium forms, which is part of the meningeal layer, as it has the same embryological origin). From here the deep fascia moves towards the upper limbs (until merging with the superficial fascia at the retinacula of the palm of the hand) and anteriorly it passes underneath the pectoral muscles, covering the intercostal muscles and the ribs, the abdominal aponeurosis and connecting to the pelvis. The deep fascia moves posteriorly connecting to the transverse processes, and then to the vertebral spinous processes, and then forms two compartments (right and left) containing the paravertebral muscles.
The deep fascia forms an inseparable connection with the sacrum (fused with the bone) where the different fascial compartments of the body converge and from where the portion of the deep fascia that covers the inferior limbs begins, until it merges with the superficial fascia at the soles of the feet in the retinacula of the foot.
A typical characteristic of the deep fascia is that it forms structural and functional compartments, which contain muscle groups with specific innervation. The compartment also provides specific morphofunctional characteristics to the muscle: a muscle that contracts inside of a sheath develops a pressure that sustains the contraction itself. The transverse abdominal muscles form the active part of the thoracolumbar fascia.
In individual muscles, the deep fascia continues via septums, aponeuroses and tendons (formed by parallel collagen fibers, which are almost completely inextensible), with the muscular fascia composed of the epimysium (fibro-elastic connective tissue covering the entire muscle), which extends into the belly of the muscle, forming the perimysium (loose connective tissue that covers the bundles of muscular fibers) and the endomysium (a delicate covering of the muscle fiber.
In physiological conditions, these septums and coverings allow for muscular fibers to slide and to receive nourishment. The deep fascia is directly connected both anatomically and functionally to the muscle spindles and the Golgi organs (Stecco, 2002). Similar to the superficial fascia, the deep fascia is not highly vascularized (often surgical incisions are performed where the fascia overlaps or merges since the strength of those areas allows for secure anchoring and easier scar repairs) and provides passageways for nerves and blood vessels.
As explained in-depth in the "Biomechanics of the deep fascia" chapter, this layer of fascia plays an extremely important role in posture.
The cylinder formed by the deep fascia contains two longitudinal cylinders placed one behind the other, forming the visceral fascia (anterior) and the meningeal fascia (posterior).

3) The anterior cylinder of the deep fascia, known as the *visceral or splanchnic fascia,* is the fascia that forms the mediastinum, extending from the mouth to the anus through several portions with similar structure and embryology: it begins at the base of the cranium and extends downwardly along the medial axis (endocervical, pharyngeal fascia), it forms the film covering the parietal pleura of the lungs (endothoracic fascia), it crosses the diaphragm, it surrounds several areas of the abdominal cavity, covering the peritoneal sac (endoabdominal fascia) and it extends to the pelvis (endopelvic fascia). The majority of this fascia is found around the thoracic organs on the medial axis, where it forms the mediastinal compartment of the thorax. The thoracic mediastinum then extends to the abdominal mediastinum, also acting as a large channel for fluids. In the abdomen, the endoabdominal fascia branches off from the axial column and completely covers the suspended organs and then returns to join back up with it (this fascia is abundant in the mesentery). The visceral fascia tends to specialize at several points (for example: it becomes thicker around the

kidneys in order to protect them).
The visceral fascia has the great advantage of having the ability to create compartments, but since it is also a deposit for fat, it can create problems by deforming the body cavity. For example, in obese individuals a structural and therefore functional alteration of the diaphragm can occur: if an increase of endothoracic mass is great enough to push the externally on the ribs, this causes the diaphragm to flatten out. When it contracts, rather than functioning as a vertical muscle that lowers and raises the ribs, it pulls on the costal margins internally, transforming itself into a expiratory muscle.
In this situation it will be impossible to perform a physiological deep respiration and the individual will only be able to take short, shallow, and frequent breaths resulting in a series of health consequences.
Several researchers consider the visceral fascia to be a single entity together with the deep fascia.

4) The posterior cylinder, contained in the deep fascia and located behind the visceral fascia, is the *meningeal fascia,* which encloses the entire central nervous system. The cranial bone, practically suspended on the meninges, originates from the neuroectoderm, developing from the cranial base through the differentiation of the cranial neural crest cells; this is part of the meningeal fascia (not the deep fascia which ends at the base of the skull, as we have already seen). Underneath the occipital bone is the dura mater, the highest point of the meningeal fascia, which extends downwardly until about the 2nd sacral vertebra through the dural sac (containing the arachnoid mater, pia mater, spinal cord, sacral spinal cord, spinal nerve roots, cauda equina nerves and cerebrospinal fluid). The meningeal fascia both protects and provides nutrients to the central nervous system.

Fascial Mechanoreceptors

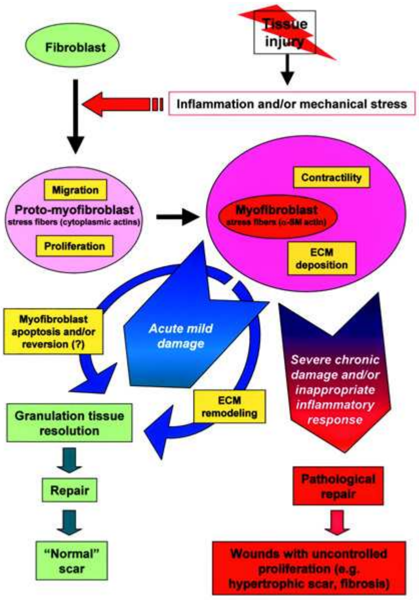
In reality it is the myofascial tissue that is the most extensive sensory organ in our body. It is from here that the central nervous system receives most of the afferent nerves (sensitive). An abundance of mechanoreceptors capable of creating effects at a local and general level have been found in the fascia in the visceral ligaments and the cephalic and spinal dura mater (dural sac). It is widely known that this feedback system is of extreme importance to the body. Often the number of sensory fibers in a mixed nerve is much greater than the amount of motor fibers. It is important to consider that in the muscular innervation of these sensitive fibers, only about 25% is accounted for by the well-known Golgi, Ruffini, Pacini, and Paciniform corpuscles (type I and II fibers), while the remaining part originates from "interstitial receptors" (type III and IV fibers). These small receptors, which mainly arise as free nerve endings, are the most numerous in our bodies and are ubiquitous (their highest concentration is in the periosteum) and therefore they are present both in the muscular interstice and in the fascia. About 90% of these are demyelinated (type IV) while the rest have a thick myelin sheath (type III). The "interstitial" receptors act more slowly compared to the type I and II receptors and in the past were mainly considered to be nociceptors, thermoreceptors, and chemoreceptors. In reality many of them are multimodal and the majority of them are mechanoreceptors, which can be divided into two groups based on their activation threshold from pressure stimulus: low-threshold pressure-sensitive (LTP) and high-threshold pressure-sensitive (HTP) – Mitchell & Schmidt, 1977. In certain pathological conditions, the activation of interstitial receptors sensitive to both pain and mechanical stimuli (mainly HTP) can generate painful conditions without the classic nerve irritations (for example, radicular compressions) – Chaitow & DeLany, 2000.
In addition to having the role of sensing the position and the movement of the body parts, this sensory network influences the autonomic nervous system through close connections in functions such as blood pressure regulation, heartbeat, and respiration, harmonizing them in an extremely precise manner with the requirements of the local tissues. The activation of the interstitial mechanoreceptors acts on the autonomic nervous system, causing it to modify the local pressure of the arterioles and capillaries in the fascia, thus influencing the transfer of plasma from the vessels to

the extracellular matrix, changing its viscosity locally (Kruger, 1987). Furthermore, the stimulation of the interstitial receptors, similar to the stimulation of the Ruffini corpuscles, is capable of increasing the vagal tone, generating overall neuromuscular, cortical, endocrine, and emotional changes associated with a deep and beneficial relaxation (Schleip, 2003).

Deep manual pressure applied statically or with slow movements stimulate Ruffini mechanoreceptors (especially through tangential forces such as lateral stretching) and some interstitial mechanoreceptors, causing an increase in vagal activity with associated effects on autonomic activity including an overall relaxation of all of the muscles and on the mind (van den Berg & Cabri, 1999) in addition to favoring the gel to sol transformation of the ground substance of the fascia (thanks to its thixotropic properties). The opposite result is obtained through vigorous and rapid pressure stimulating the Pacini and Paciniform corpuscles (Eble 1960).

Myofibroblasts

Discovered in 1970s, **myofibroblasts** are connective tissue cells found in the fascial collagen fibers and have an ability to contract like smooth muscle (they contain actin). These cells play a well-known and important role in healing wounds, tissue fibrosis, and pathological contractures.



Myofibroblasts actively contract during inflammation in Dupuytren's disease, rheumatoid arthritis, and cirrhosis of the liver. In physiological conditions they are found in the skin, spleen, uterus, ovaries, blood vessels, pulmonary septum, and periodontal ligaments (van den Berg & Cabri 1999). Their evolution is generally observed starting from normal fibroblasts to proto-myofibroblasts until they are completely differentiated into myofibroblasts and ends in apoptosis influenced by mechanical tension, cytokines, and specific proteins from the extracellular matrix. Considering the favorable configuration of the distribution of these contractile cells within the fascia, their role is most likely that of an accessory system of tension capable of acting in sync with muscular contractions, providing an advantage in survival situations (fight or flight). It is also highly probable that thanks to these muscular fibers, the autonomic nervous system can "pre-tension" the fascia independently from the muscles through interfascial nerves (Gabbiani, 2003, 2007). The presence of these cells in the capsules that cover the organs would explain how the spleen can shrink down to up to half of its volume in just a few minutes (a phenomenon that is observed in dogs in situations of extreme strain when the blood stored inside of this organ is required despite the fact that the capsule is rich in collagen fiber allowing for minimal variations in its length (Schleip, 2003).

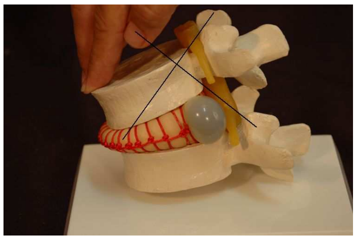
The smooth muscle fibers are able to contract through the activation of the sympathetic nervous system and vasoconstrictors such as serotonin and carbon dioxide (CO_2). The latter creates another link between the activity of the fascia and the body's pH. It is important to note that most patients with **fibromyalgia** or chronic fatigue suffer from chronic frank or borderline hyperventilation (with a resulting increase in alkalinity due to a lack of CO_2 in the blood) as well as unusually high levels of serotonin in the cerebrospinal liquid. Serotonin lowers the activation threshold of the type IV interstitial nociceptors. This would be an indication that fibromyalgia pain could be caused in part by the contraction of the fascia (motor dysfunction) and even more so by an alteration in pain receptor sensitivity (sensory dysfunction) – Mitchell & Schmidt, 1977.

"The soul of man with all the streams of pure living water seems to dwell in the fascia of his body. When you deal with the fascia you deal and do business with the branch offices of the brain, and under the general corporation law, the same as the brain itself, and why not treat it with the same degree of respect?" (Still, 1899)

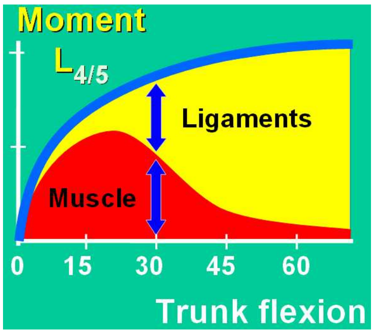
Biomechanics of the deep fascia

Overload + pinch + shear = risk for annulus fibrosus (hernia risk)

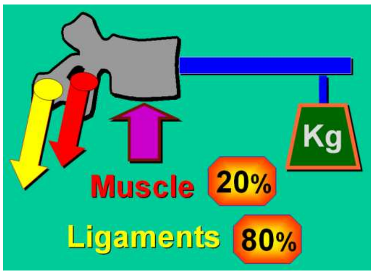
The thoracolumbar fascia has the essential biomechanical role of minimizing stress on the vertebral column and optimizing locomotion. Taking a close look at the fascia will allow us to discredit several common beliefs based on interesting hypotheses, but which have never truly been demonstrated. Studies show that **intervertebral discs** are rarely damaged by axial compression alone since the vertebral body is destroyed much sooner than the annulus fibrosus (Shirazi-Adl et al. 1984). The articular plate of the vertebral body breaks at an axial load (due to pure compression) of about 220kg (Nachemson, 1970): the pressure on the nucleus of the intervertebral disc causes the end plate to fracture after the migration of the nuclear material to this area (Schmorl's nodules). Since the damage affects spongy bone, it is capable of healing in a short period of time.


Risk only in case of previous annular fissure and initial nuclear herniation

This is the case even though the vertebra breaks at about 1,200kg (Hutton, 1982) and the annulus fibrosus suffers only a 10% deformation at an axial compression of at least 400kg (Gracovetsky, 1988).
Therefore axial compression is not capable of creating annular fissures (and damaging the articular facets) unless in the case of a violent impact. On the other hand, compression associated with torsion has proven to be capable of damaging the fibers of the annulus fibrosus and the capsular ligaments of the articular facets, causing herniation in extreme cases. The damage affects the outer portions of the disc, and since it is ligament damage, it requires time to repair itself. A *hernia of the disc* is truly caused by shear forces associated with compression, except in rare cases (Shirazi-Adl et al. 1986). This leads to the belief that the intervertebral disc is not a sufficient system of weight transmission and absorption, but in reality an *energy converter* (Gracovetsky, 1986).
However, there is no doubt that the load of vertebral compression can reach 700kg when lifting heavy weights (the force applied on L5-S1 while lifting a weight while in flexion at 45 degrees can be about 12 times greater than the weight itself).
In the 1940s, Bartelink proposed the idea, which is still commonly accepted today, that in order to lift a weight, the erector spinae muscles act on the spinous process of their associated vertebrae, assisted by intra-abdominal pressure (IAP), which pushes on the diaphragm (Bartelink, 1957).



Since it has been proven that the maximum force that can be sustained by the erector spinae muscles is 50kg (McNeill, 1979), a simple calculation demonstrates that according to this hypothesis, when lifting a load of 200kg the intra-abdominal pressure should be about 15 times greater than the blood pressure (the maximum IAP value, calculated on a surface of 0.2m^2 is 500m Hg (Granhel, 1987). Bartelink's model gains meaning if the fascia is introduced into it. When lifting weight while bending the spine with a posterior pelvic tilt (or tensioning the fascia as best as possible), the spine erector muscles have little need to activate. The object is mainly lifted due to the action of the thigh extensor muscles on the hips (ischiocrural and gluteus maximus) and the fascia. Studies show that in Olympic athletes, the stress is divided into 80% fascia and 20% muscles (Gracovetsky, 1988). Therefore, collagen is performing a large portion of



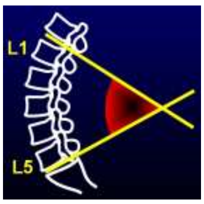
the work, since it acts as a cable and practically consumes no energy, and, thanks to its connections with the iliac crest-spinous processes, it is almost situated outside of the body, with the advantage of being far from the fulcrum of the lever (the arm). This was a necessary evolutionary choice because in order for the erector spinae muscles to be capable of lifting over 50kg, they would have needed to increase their mass to the point that they would have occupied the entire abdominal cavity. Therefore, the additional forces (muscles and fascia) were placed outside of the abdominal cavity.

The erector spinae muscles (multifidus) and intra-abdominal pressure, together with the psoas muscles, regulate lumbar lordosis from a three-dimensional perspective, thus assuming an important role as modulators of the transfer of force between the muscles and the fascia. Internal abdominal pressure does not put significant pressure on the diaphragm itself, but actually acts on lumbar lordosis and therefore the transmission of forces between the muscles and the fascia. Intra-abdominal pressure flattens the fascia so that the transverse abdominal muscles (which make up the active part of the dorsolumbar fascia, since its free ends are attached to its fibers) exert a force of traction on the same plane as the fascia. When intra-abdominal pressure is low, this mechanism is disabled and all abdominal muscle action (the rectus abdominis in particular) causes the trunk to bend.

In other words, if the pressure of the internal abdominal muscles is high, the lumbar region goes into hyperlordosis, while if the pressure in the abdomen is low, the vertebral column can bend with pelvis tilted posteriorly, thus stretching the fascia (a posterior pelvic tilt before bending to lift an object is typical of people who lift weights without any problems). In this circumstance there is less opposition to the systolic blood pressure and therefore the blood flows better to the extremities (somehow our muscular and skeletal system acts so that there is not excessive internal abdominal pressure in order to maintain peripheral blood circulation).

Thus the fascia can provide its significant contribution when the vertebral column bends if abdominal tension is reduced (Gracovetsky, 1985).

In a lifting experiment of 530N (about 52kg) with two different lumbosacral angles (lordotic angles) of 20 and 50 degrees, it was shown that less stress on the muscles and ligaments is observed in total bending by reducing lordosis and by increasing it (greater lordosis) when upright. In the 30-50 degree range of bending, the difference in lordosis is irrelevant (the optimal condition of balance was observed at 30 degrees). A posterior pelvic tilt is advantageous at the start of lifting, while physiological lordosis is preferable when erect. If the weight must be held for a long period of time, it is preferable to bend the limbs and reduce lordosis. Therefore, there is no optimal universal lordosis, since lordosis depends on the bending angle and the weight being supported (Gracovetsky, 1988).



Hyperlordosis occurs when the angle formed by intersecting tangent lines at disc T12-L1 and L5-S1 is greater than 40 degrees (Gracovetsky, 1986).

It is a good idea to teach the bending technique for heavy weight lifting, while it is not useful for lifting lighter weights. Also, this technique could create problems in the presence of intense myofascial contractions and/or retractions of the posterior chain (mainly the lumbar zone) due to the risk of "triggering" a myotatic reflex and a possible related muscular "block".

When carrying a backpack, changing the bending of the truck with each step creates an alternating role between the muscles and ligaments that could result in greater resistance (Gracovetsky, 1986). Similarly, when carrying heavy bags with one or both hands a slight bending of the trunk with small oscillations during each step is more convenient than the traditionally recommended posture (which involves greater lumbar lordosis and a fixed trunk). These methods also take another significant characteristic of the connective tissue (its viscoelasticity) into account.

Viscoelasticity of the fascia

We have seen that lifting heavy weights with the deep fascia in tension is the safest way to carry out these types of movements. However, these movements must also be done quickly, because when doing these same movements slowly, it is possible to lift only one-fourth of the weight that can be lifted when moving quickly (Gracovetsky, 1988). This is due to the **viscoelastic properties** of the collagen fibers, which cause the fascia to elongate if kept stretched for longer periods of time; when elongated, the collagen fibers remain in their new state for a long period of time (Viidik, 1973). Due to its viscoelasticity, the fascia deforms under stress in a short period of time, and therefore it is necessary to constantly alternate the structures that are subject to the stress. The amount of force needed to elongate the fascia even further depends on how much it has already been stretched, as greater forces will be required to elongate it further (the more elongated the fascia is, the more difficult it is to elongate it further), in a non-linear relationship (according to Kazarian's studies in 1968, collagen's response to the loads applied has at least two time constants: about 20 min. and about one-third of a second). The limit that should not be exceeded in order to avoid breaking the fibers of the fascia is two-thirds of the maximum elongation.

Posture and tensegrity

Dynamic equilibrium

The search for universal solutions regarding posture is mistaken because it ignores the fundamental property of connective tissue: viscoelasticity. We are not statues. Postural stability is assured in the gravitational field by constant movement, the alternating use of fascia and muscles, or in other words, their functional oscillation. The myofascial-skeletal system is a structure that is not stable; rather, it is in constant dynamic equilibrium. We are a redundant system, meaning that changing the internal distribution of weights does not necessarily entail postural modification; the control and efficiency of this system is essential first and foremost for the wellness of the vertebral column. As mentioned previously, the periosteum has a maximum concentration of stress sensors (interstitial receptors) that rapidly bring information (and not only regarding pain) to the brain. The dorsolumbar fascia is therefore more than an agent of transmission; without it we would not have efficient control over our muscles. The "enemy" is the split of the fascia from the periosteum (which occurs by exceeding 2/3 of the maximum elongation); when the fascia is damaged, rehabilitation is very difficult, and results in an imbalance in functional biomechanics and coordination. In children the fascia is immature, because the ossification of the vertebrae is incomplete, and therefore nerve impulses are not transmitted efficiently. Consequently, children move similarly to people who suffer from back injuries caused by damage to the collagen (forced to increase muscular activity).

Function and structure

Function precedes and molds structure, and postural coordination is more important than structure.

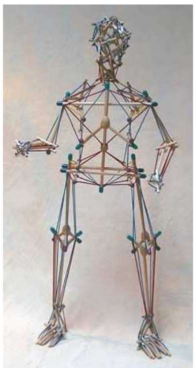
Reality Check: 76% of asymptomatic workers have herniated discs (Boos et al., 1995)

The half-life of collagen fibers in healthy tissue is 300-500 days. The half-life of the "ground substance" (the soluble portion of the ECM made up of PGs/GAGs and specialized proteins) is from 1.7-7 days (Cantu & Grodin 1992). The characteristics and arrangement of the new collagen fibers and the ground substance depend on the mechanical stress applied to the tissue.

It is no coincidence that man represents the ultimate cybernetic system: 97% of the motor fibers active in the spinal cord are involved in cybernetic processing activities and only 3% are used for intentional activities (Galzigna, 1976). Cybernetics is the science of feedback. The body must always know its environmental conditions in order to instantaneously and properly organize itself in order to carry out its necessary processes. Senses can never be separated from the motor function: the environment is constantly being sensed and assessed, highlighting the need for gravity, synesthesia, and proprioception. "Being and functioning are inseparable," Morin (1987). Reflexes are the main road.

Human beings need to move for their own survival and state of wellbeing. This is why locomotion is the activity that takes precedence over all others. In the living world, specific human motion is of the utmost importance and represents the most complex natural process. The traditional idea that human beings distinguished themselves due to their intellectual qualities has been discarded and at this point it is well-known that these qualities originated with the acquisition of the morpho-mechanical achievement of bipedalism (the freedom of the hands is a consequence of this). The current human body is mainly the result of the need for ambulation with maximum efficiency on two feet in a stable gravitational field. In agreement with this theory, man must be able to move with a minimal consumption of energy within a constant gravitational field and while subjecting its various structures (muscles, bones, ligaments, tendons, etc.) to a minimal amount of stress during walking.

Tensegrity



The English word "Tensegrity" coined in 1955 by the architect Richard Buckminster-Fuller, combining the words "tensile" and "integrity", describes the capability of a system of mechanically stabilizing itself through forces of tension and decompression that are divided and distributed amongst one another. Compression and traction forces balance each other within a closed system vectorially.

Tensegrity structures are divided into two categories:

1) those made up of rigid bars arranged into triangles, pentagons, or hexagons;
2) those made up of rigid bars and flexible cables. The cables make up a continuous configuration that compresses the bars organized discontinuously within itself. The bars push the cables externally.

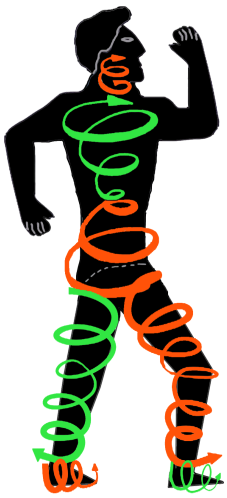
The advantages of tensegrity are:

-*resistance:* the resistance of the whole greatly exceeds the sum of the resistance of the single components;

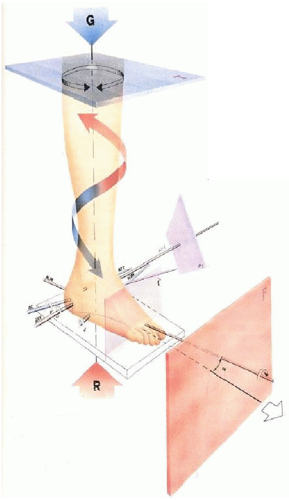
- *lightness:* with an equal capacity for mechanical resistance, a tensegrity structure weighs half of a structure relying on compression;

-the *flexibility* of the system is similar to that of a pneumatic system. This allows for a great capacity to reversibly adapt to changes in form in dynamic equilibrium. Furthermore, the effect of a local deformation created by an external force is modulated by the entire structure, thus minimizing its effect.

- the mechanical and functional *interconnection* of all of the constituent elements allows for constant bidirectional communication just like a real network.



Starting with the cytoskeleton (Ingber, 1998), the structure of the human body is characterized by tensegrity. Macroscopically, the rigid axes (bars) are the bones and flexible structures (cables) of the myofascial system (Myers, 2002). A unique quality of "human tensegrity" is that it functions like a *"variable pitch propeller"* or vortex (spiral) system. Man's cybernetic system to counteract gravity mainly acts on the transverse plane, thanks to a sophisticated neuro-biomechanical system.



The “human spiral” moves from the horizontal plane to the frontal plane thanks to the *talus-calcaneus “mortar”* in the feet when there is a sufficient coefficient of friction (without friction the winding motion of the foot becomes difficult). At the same time, grounds and surfaces that are too soft are inappropriate because the excessively disperse the compressive force from the impact of the heel when walking, which is indispensable for the execution and transmission of torsion forces to the spine and the pelvis (Snel et al., 1983).
Therefore, the foot is not a system or arches or vaults, it is a highly sophisticated sensory-motor helical system (Paparelli Treccia, 1978).

The **foot**: sensory-motor organ, a bridge between a system and the environment, composed of a variable pitch propeller made of 26 bones, 33 joints, and 20 muscles that influences the entire body.

The "specific human motion", a process involving multiple planes, is a combination of single-plane rotations. In essence, it is the periodic transferral of rotations from the transverse plane to the plane of progression (frontal plane). The ratio between rotations on the transverse and frontal plane nears the golden ratio, as well as the ratio of lengths between the various parts of the skeletal system (for example, hindfoot/forefoot lengths).

“The specific human motion, one of the most marvelous processes in nature, is founded upon vertical pillars, repositories of the golden number, in itself and in its reciprocal connections” (Paparella Treccia, 1988).

Praise to the helix

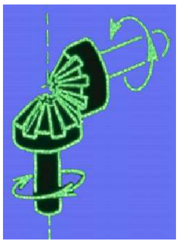
Gravity, in the long path of morphogenesis, shapes **helical forms**, which in movement take on the meaning of "constraints", producing helical paths. It is the same gravity that over long periods of time (morphogenesis) molds shapes, which during movement (short periods of time), take on the meaning of constraints. The helical paths introduced into the morphogenetic movements of the gravitational field with the contribution of the intra-tissue connections converge in the genesis of shapes (femur, tibia, astragalus, etc. as well as DNA have helical shapes). The shapes in nature are nothing other than solidified vortical movements. The helical trajectories of movement are echoed in helical shapes whose great symmetry favors structural stability (Paparella Treccia, 1988). Evolution has selected helical configurations because in movement they evolve while preserving dynamic stability (angular momentum), energy (potential and kinetic), and information (topology). Stability, understood as resistance to disturbances, is the objective that is always pursued by nature. Helixes are curves that grow without changing shape, their repetitive qualities and stability make them outstanding expressions of the geometry that underlies natural movements.

“*If a figure were to be chosen by God as the dynamic foundation of his immanence in shapes, this figure would be the helix” (Goethe)*

The *force of gravity,* both from a structural and functional perspective, should not be seen as an enemy; without it man would not exist.

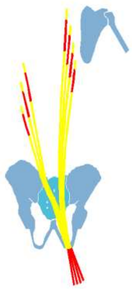
The engine of specific human motion

In 1970 Farfan was the first to propose the idea that movement advances from the pelvis to the upper extremities, or in other words, that movement starts from the iliac crest and proceeds to the upper extremities. In the 1980s Bogduk explained the anatomy of the soft tissues that surround the vertebral column, and in the 1990s, Vleeming clarified the association of the pelvis with the lower limbs. Finally, Gracovetsky (1988) demonstrated that the vertebral column is the primary engine of movement, “*the spine engine*”. This role of the backbone is still evident in our "ancestors", fish and reptiles, but a man whose lower limbs have been completely amputated is capable of walking on the ischial tuberosities without significant alterations in movement, or in other words, without interfering in the primary movement of the pelvis. This essentially demonstrates two things:



1) The *intervertebral facets and discs* do not prevent rotation, they favor it; the vertebrae were not built for static structural stability. In fact, lumbar lordosis together with lateral flexion induces torsion of the vertebral column mechanically through a mechanical "coupled motion".

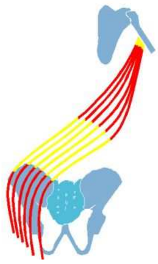
2) The role of the *lower limbs* is secondary to that of the vertebral column. By themselves they are not capable of rotating the pelvis to allow movement, but can amplify movement. The lower limbs are a result of the evolutionary necessity of increasing the speed of our movement. The greater power required for this purpose could not have come from the muscles of the trunk, which would have had to develop to be impossibly large and cumbersome. Therefore, evolution prepared other muscles, positioning them outside of the trunk on the lower limbs for functional and spatial purposes. The first responsibility of the lower limbs is to provide energy that allows us to move at high speeds. Thanks to the lower limbs, intervertebral movements and rotations on the transverse plane in particular can harness the complementary contribution of the hip extensor muscles (gluteus maximus, biceps femoris, semitendinosus, and semimembranosus) to which the spine is connected through specific and substantial myofascial chains:



a) sacrotuberous ligament – longissimus lumborum muscle (located on the sides of the spinal column)

b) sacrotuberous ligament and iliocostalis thoracis (allowing the right ischiocrural muscles control some of the left thoracic muscles and vice versa)

c) gluteus maximus muscles – latissimus dorsi (which controls the movement of the upper limbs).



All of these ischiocrural-vertebral column connections form a pyramid that assures strong mechanical integrity for the upper and lower limbs. The fascia is necessary to transmit this complementary force for specific human motion from the lower limbs to the upper limbs. The energy rises along the lower limb and is "filtered" by them (the ankle, knee, and hip are critical steps in this process) to reach the vertebral column in the appropriate phase and amplitude. In this way the trunk can use this energy by rotating each vertebrae and the pelvis appropriately (Gracovetsky, 1987).

Nonetheless, the rotation of the pelvis around the vertical axis during walking by the muscles that exert a force of traction downwardly creates an efficiency problem.

This problem is resolved by using the gravitational field as a temporary warehouse in which the energy released by the lower limbs with every step is accumulated: during the rise of the center of gravity (phase of deceleration) kinetic energy is stored as potential energy and subsequently transformed back into kinetic energy to accelerate the body (the body is lifted using the kinetic energy acquired while falling).

The associated curves are therefore in phase opposition: the increase in potential energy occurs as the kinetic energy is consumed and vice versa. In standard deambulation (7 km/h), muscular activity is required only to maintain the ratio between the two forms of energy in accordance with the specificity of the process. In other words, the muscular factor is not required to deal with the periodic rise in the center of gravity, but to control the contribution of the environment by modulating the instantaneous relationship between potential and kinetic energy, containing it within the limits of the construction of specific motion. As this responsibility is delegated to the red skeletal muscle fibers (aerobic), they consume small amounts of energy (Cavagna, 1973): an individual weighing 70kg walking on flat ground for 4km spends an amount of energy covered by consuming 35g of sugar (Margaria, 1975). For this reason, man is a tireless walker, differently from quadrupeds, whose motion requires a greater expenditure of internal energy (Basmajian, 1971). Thanks to the myofascial system, specific human motion occurs with maximum efficiency in the gravitational field. Therefore, our initial hypothesis appears to have been demonstrated.

Static?

Specific human motion can be defined as the group of dynamic, energetic, and informational events that converge in alternating bipedal ambulation (movement with progression) and the upright position (movement without progression). The "static" standing state in reality is a special case of ambulation, characterized by postural oscillations that are visible and quantifiable through stabilometric exams, corresponding to rhythmic movements on the transverse and frontal plane. As for movement without progression, the standing posture includes the inhibition of moving with associated supplementary muscular action for deceleration. This can be more difficult and costly in terms of energy compared to normal locomotion: human beings are made to walk (on natural surfaces).

Posture should therefore be defined as part of a dynamic concept: posture is the personalized adaptation of each individual to the physical, mental, and emotional environment. In other words "*it is the way we react to the force of gravity and communicate*" (Morosini, 2003).

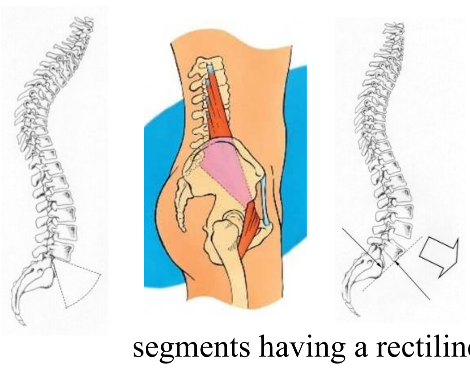
"Artificial" life

The cultural factor can affect normal postural physiology, modifying environmental information and interfering with the normal evolutionary process. Increasingly "artificial" habitats and lifestyles create postural changes in "civilized" human beings, which negatively influence their physical and mental health and beauty (Chetta, 2007, 2008).

We have seen how the control of *lumbar lordosis*, a typical characteristic exclusive to human beings, is a decisive factor: it allows stress to be minimized and for biomechanical efficiency to be optimized through a correct division of loads and functions between the fascia and muscles. Two factors have a special influence on this, and therefore on overall posture: foot support and "dental occlusion support".

Foot support

Just as Viennese architect, painter, and philosopher F. Hundertwasser (1991) perceived, *flat ground* is not suitable nor is it healthy for human beings. And as the French physiotherapist F. Mezieres correctly added, lumbar hyperlordosis is always a primary effect (Godelieve, 1995). Man normally reacts to flat ground by creating a position of lumbar hyperlordosis through the strong iliopsoas muscle (Myers, 2001). There are two types of this condition, as it is possible to test by analyzing X-rays of the sagittal plane (in the absence of antalgic reactions):



a) concentrated in the final lumbar vertebra with the upper segments having a rectilinear tendency

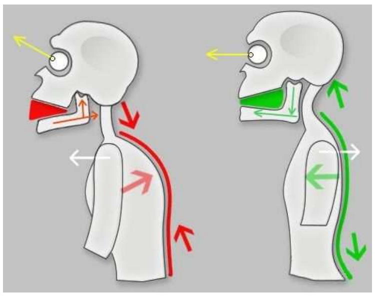
b) "spread" along the entire lumbar spine (Pacini, 2000).

This modification affects the entire body (including occlusion) and is compensated posturally, with an individual reaction.

> *"Flat ground was invented by architects. It is well-suited for machines, not for human beings. People do not only have eyes to enjoy the beauty that they see, ears to listen to music, and noses to smell pleasing aromas. People also have a sense of touch in their hands and feet. If human beings are forced to walk on asphalt and cement surfaces, as they have thoughtlessly been created in the*

offices of designers, cut off from the primordial relationship and contact with the ground, a crucially important element withers and dies. This has catastrophic consequences for the soul, balance, wellbeing, and health of human beings. Man has forgotten how to experiment with new things and becomes emotionally sick. An irregular and living surface helps humans re-conquer the mental balance and dignity, which has been violated in our unnatural and hostile "leveling" of the built environment. Irregular floors become a symphony, a melody for the feet, and bring natural vibrations back to human beings. Architecture must elevate humans and not subdue them. It is good to walk on unlevel floors and regain our human balance". F. Hundertwasser (April 1991).

Occlusion and stomatognathic system



The *head*, weighing 4-6kg in adults, is the body's heaviest extremity. The cranial-cervical-mandibular unit has a highly efficient and sensitive proprioceptive system considering the enormous importance of the organs and structures contained therein. Incorrect alignment on any level caused by stomatognathic and/or extra-stomatognathic problems (descending and/or ascending), inevitably creates reflex and mechanical-based postural compensations that affect the entire body to varying extents. The two mandibular arch quadrants (right and left), together with the cervical vertebrae (atlas) make up the "tripod" on which the cranium rests each time the teeth come into contact with each other (swallowing, chewing, etc). Thanks to this stable, temporary support, our system of balance is able to hold up the head though the neurosensory receptors and the myofascial system. The vertical dimension of occlusion is therefore a particularly critical parameter regarding correct cranial alignment, and for the general health of the body as a result (Formia, 2009).
It is also important to remember that the *tongue*, together with the foot, is the most important element in morpho-functional development. The functioning of the tongue directly influences mandibular and maxillary growth and the morphogenesis of the dental arches. For example, starting to give a baby a bottle too soon in life or improper positioning of a child's head can alter the functionality of the 17 muscles of the tongue (Ferrante, 2004).
There is also a small area (about 1 cubic cm) called the "spot" point, located between the base of the upper central incisors and the first palatine ruga, which is rich in exteroreceptors of the nasopalatine nerve (branch of the trigeminal nerve) involved in the mechanism of postural information (Halata & Baumann, 1999). In physiological conditions, the tongue lies on the palate in a state of rest, while during swallowing its tip rests right on the "spot" point performing as a sort of postural reprogramming (which can be affected in case of atypical swallowing). This is the same process of reprogramming or "re-convergence" between man and the environment, which takes place during every step thanks to the foot.
Dysfunctions in the stomatognathic system and foot support are therefore linked in a mutually dependent relationship and have an important influence on our posture and therefore our health.

Postural re-education

The study of posture is gaining increasing importance in our society, which forces people to live in habitats and with lifestyles that are unnatural and physiologically detrimental. Many more skeletal-muscular and organic problems are being linked to posture. Due to these circumstances, *posturology* has developed into a multidisciplinary science that encompasses numerous branches of medicine and many different techniques. Professional collaboration between specialists, technological evolution, and advances in scientific research on the extracellular matrix and connective tissues are the cornerstones of progress in this fascinating and versatile subject.

Conclusions

a) What exists outside the cell is as important as what is inside and both are mutually inseparable.

b) We are a "structuring function", neuro-biomechanically swinging vortically in dynamic equilibrium between connective tissue and muscles.

c) Functional alteration and therefore its re-education is crucial. Control and functionality of the joints where the "human vortex" develops specially, and those of the pelvis in particular, are the critical elements. These parameters should always be checked (precisely and measurable, meaning comparable over time) no matter what approach is used for postural re-education. Considering the results obtained only in a specific region of the body (for example, the stomatognathic system or foot support) without examining the overall postural effects creates a serious risk of moving a problem from one region of the body to another.

Case studies

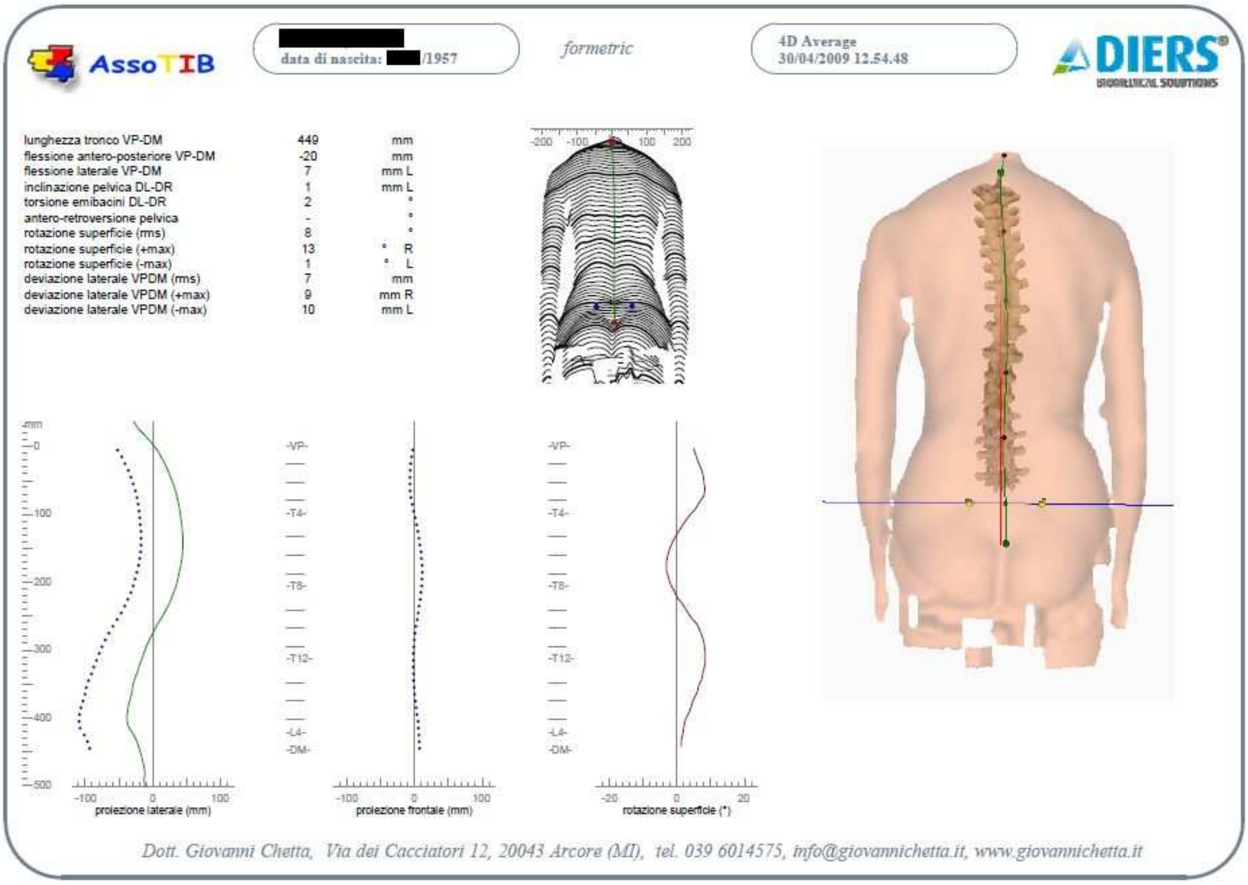
The clinical cases described below have been treated with the method that I called *TIBodywork*. Thanks to a team strategy, this method synergistically integrates a variety of specific techniques as part of a personalized program of postural re-education. The techniques used include the following: manual myofascial and articular techniques (bodywork – Chetta, 2004, 2010), postural exercises (Chetta -2008), ergonomics (insoles, shoes, occlusal splints etc. – Chetta, 2007), dietary education (Chetta, 2007) and mental education (Chetta, 2007). The objective of the postural re-education program is to restore/improve functionality, and as a result, postural structure and general physical-mental wellbeing according to the principles set forth in this publication.
In the following cases, the resolution of symptoms (completely or at least to allow for a return to a normal life) was accompanied by a decisive improvement of function and structure as shown by the Diers Formetric™ 4D+ analysis system.

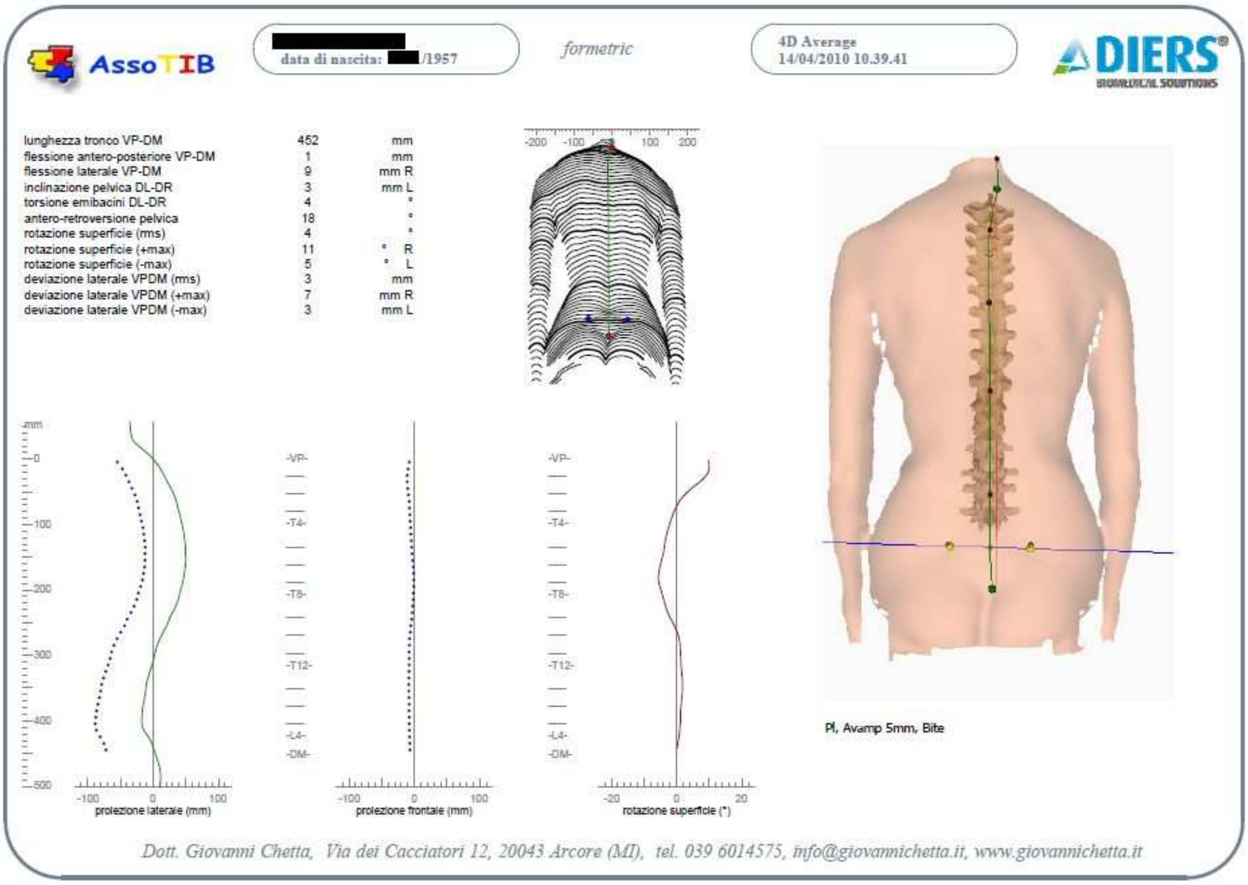
Case study: Migraine and cervicalgia

Female, born in 1957, with sharp left headaches (2-3 times per week) for the last 10 years associated with cervicalgia and back pain, balance problems and serious alterations to the vertebral column.

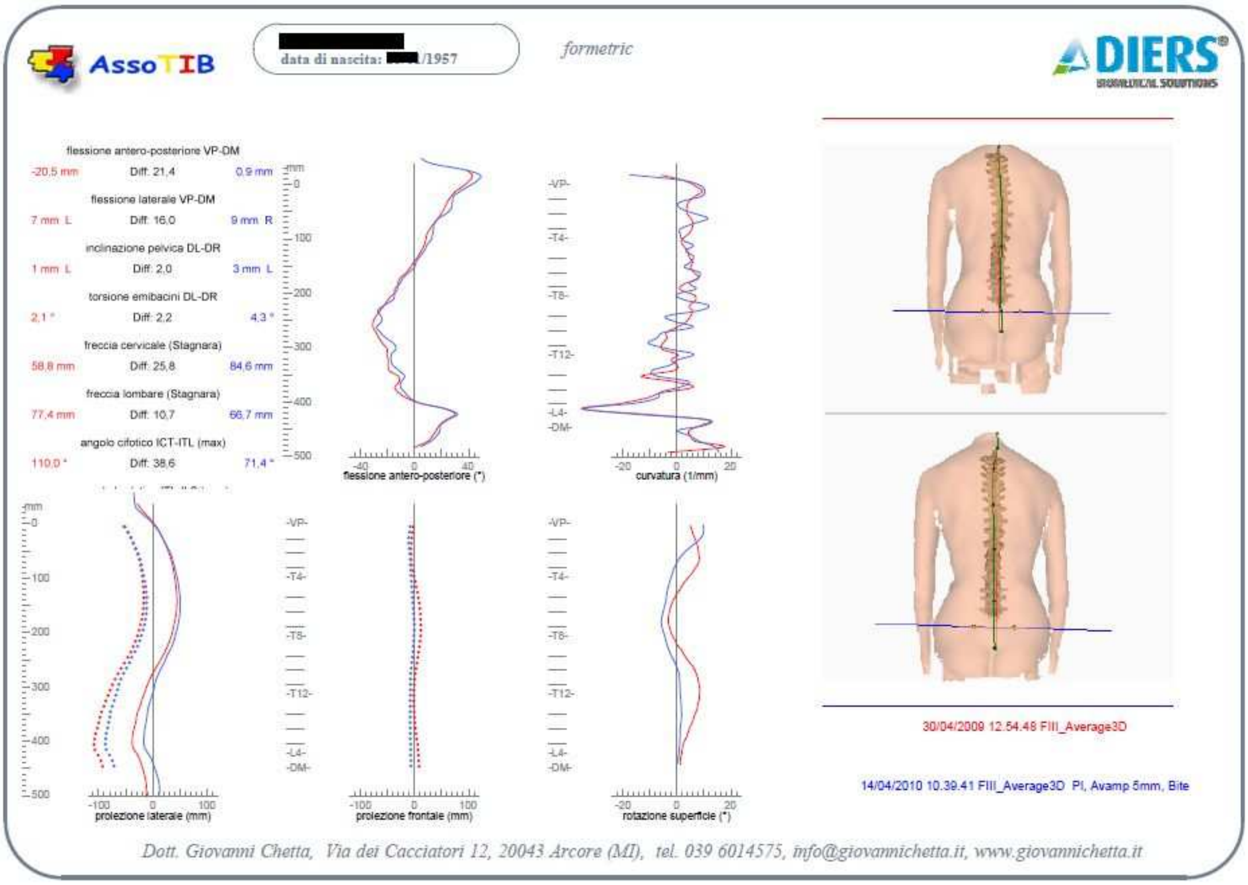
TIBodywork program: occlusal splint, customized ergonomic insoles, manual techniques (bodywork), postural exercises.

Results: clear improvement of symptoms, function and structure.





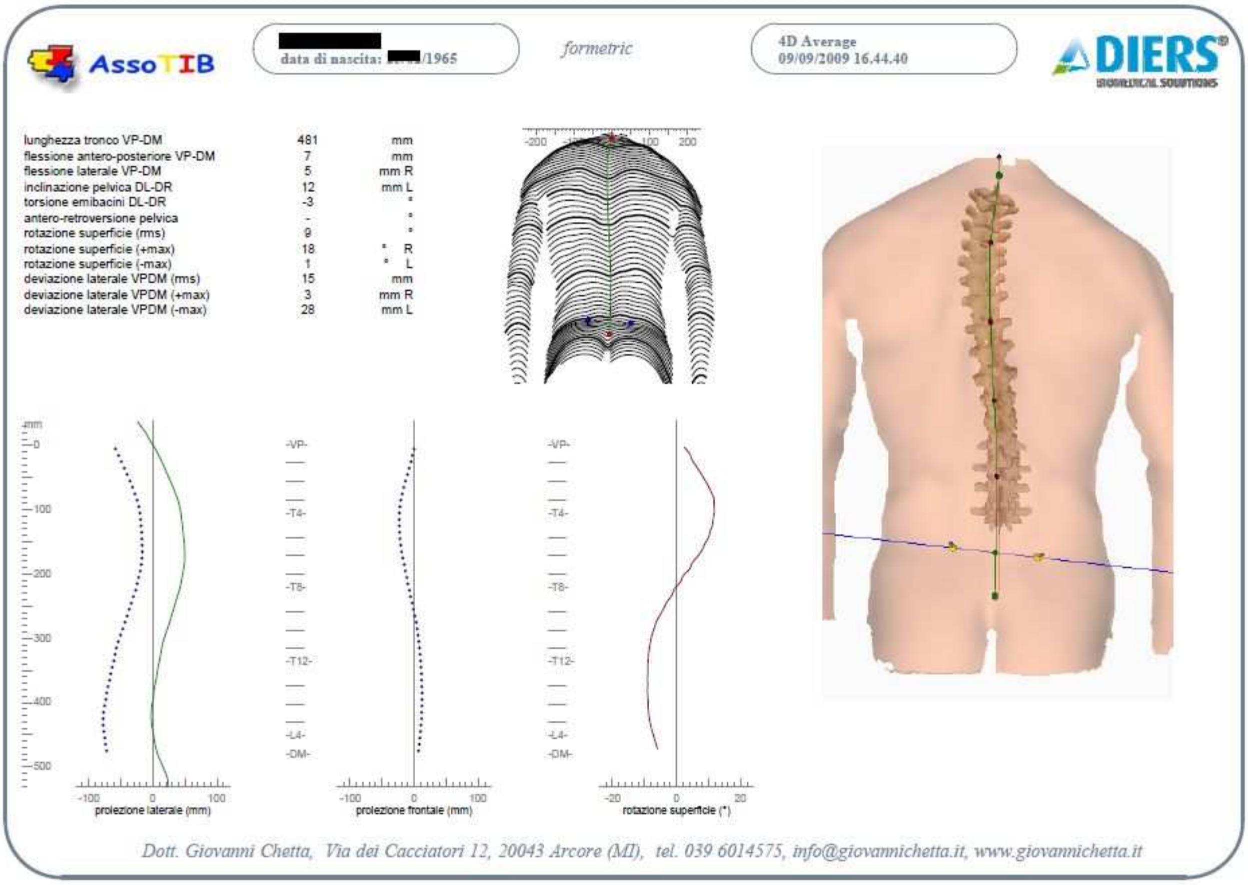
AssoTIB
[redacted]
data di nascita: [redacted]/1957
formetric
4D Average
14/04/2010 10.39.41
DIERS
BIOMEDICAL SOLUTIONS
lunghezza tronco VP-DM 452 mm
flessione antero-posteriore VP-DM 1 mm
flessione laterale VP-DM 9 mm R
inclinazione pelvica DL-DR 3 mm L
torsione emibacini DL-DR 4 °
antero-retroversione pelvica 18 °
rotazione superficie (rms) 4 °
rotazione superficie (+max) 11 ° R
rotazione superficie (-max) 5 ° L
deviazione laterale VPDM (rms) 3 mm
deviazione laterale VPDM (+max) 7 mm R
deviazione laterale VPDM (-max) 3 mm L
-VP-
-T4-
-T8-
-T12-
-L4-
-DM-
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
Pl, Avamp 5mm, Bite
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

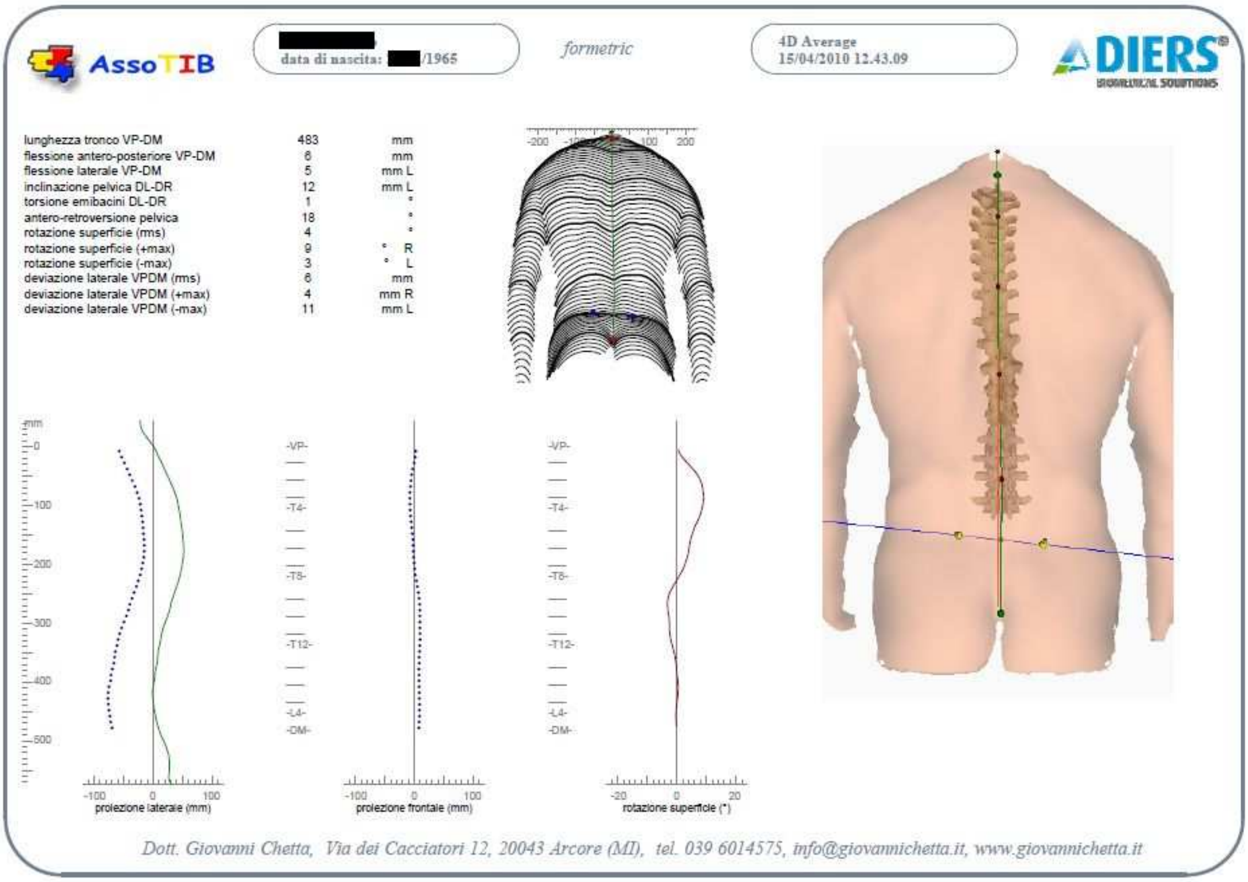


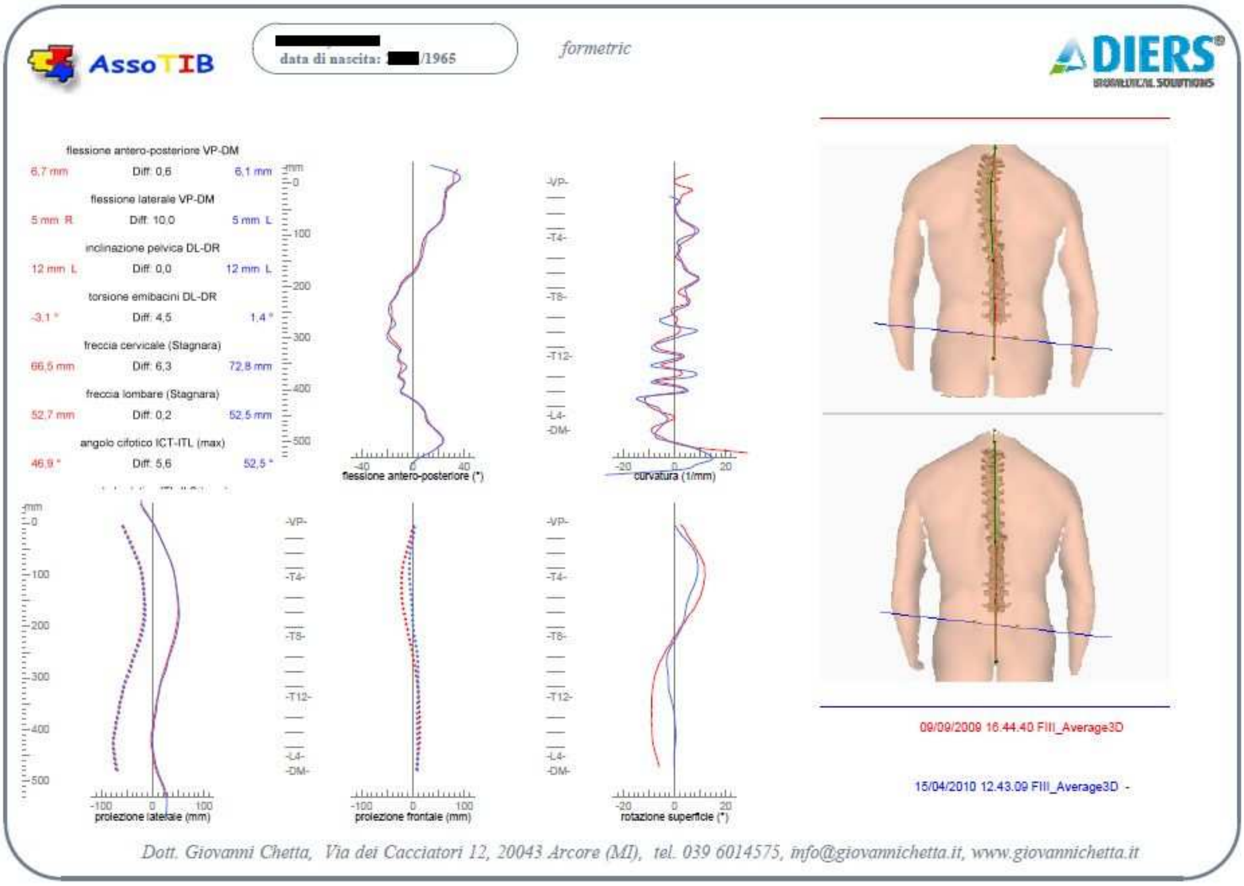
AssoTIB
[redacted]
data di nascita: [redacted]/1957
formetric
DIERS
BIOMEDICAL SOLUTIONS
flessione antero-posteriore VP-DM
-20,5 mm Diff: 21,4 0,9 mm
flessione laterale VP-DM
7 mm L Diff: 16,0 9 mm R
inclinazione pelvica DL-DR
1 mm L Diff: 2,0 3 mm L
torsione emibacini DL-DR
2,1 ° Diff: 2,2 4,3 °
freccia cervicale (Stagnara)
58,8 mm Diff: 25,8 84,6 mm
freccia lombare (Stagnara)
77,4 mm Diff: 10,7 66,7 mm
angolo cifotico ICT-ITL (max)
110,0 ° Diff: 38,6 71,4 °
flessione antero-posteriore (°)
curvatura (1/mm)
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
30/04/2009 12.54.48 FIII_Average3D
14/04/2010 10.39.41 FIII_Average3D Pl, Avamp 5mm, Bite
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

Case study: Groin pain

A 44-year-old athlete who has been suffering from pain in the left side of the pubis-ischium region. Scoliosis and after-effects from partial congenital dysplasia of the left hip for two years.
TIBodywork program: manual techniques (bodywork), postural exercises, ergonomic footwear.
Results: clear improvement of symptoms, function and structure.

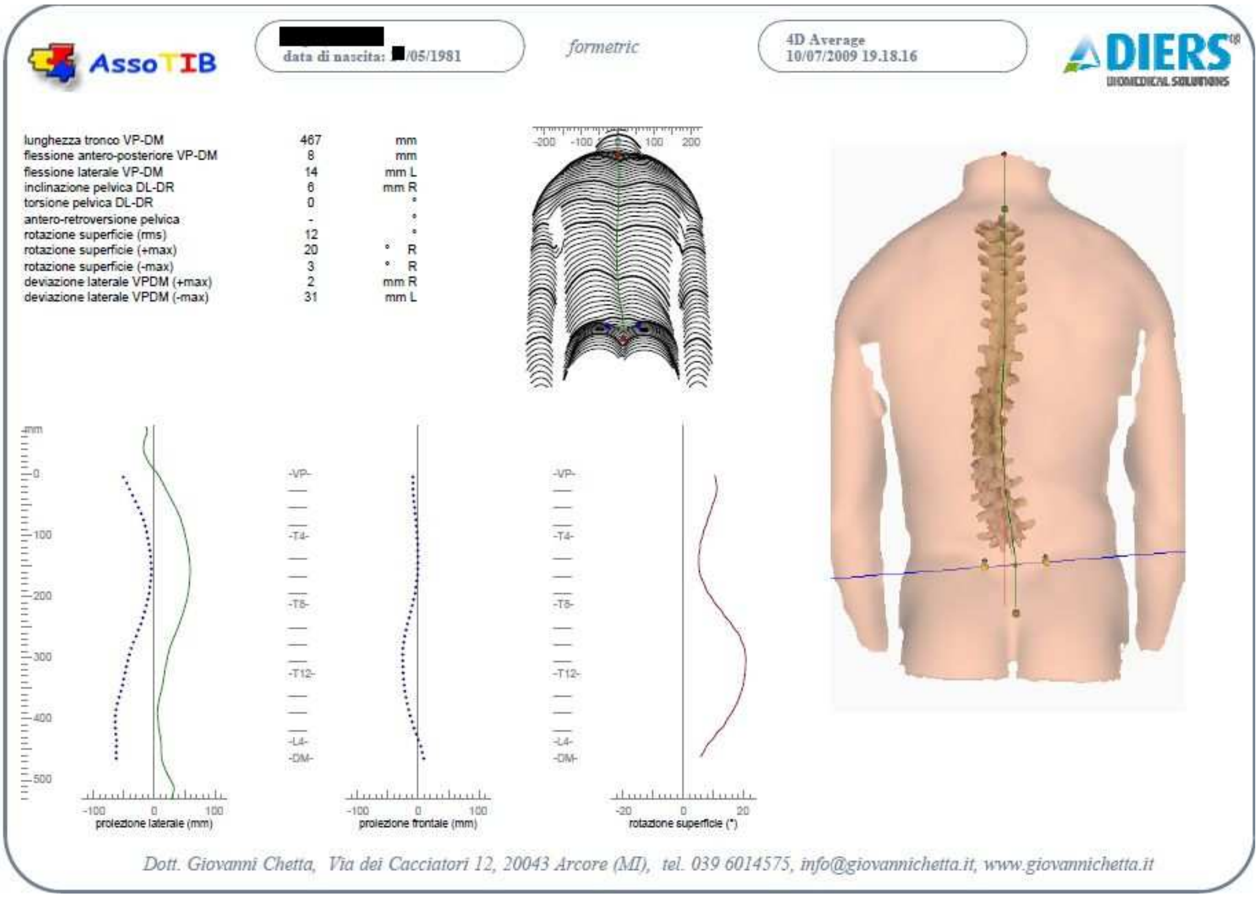


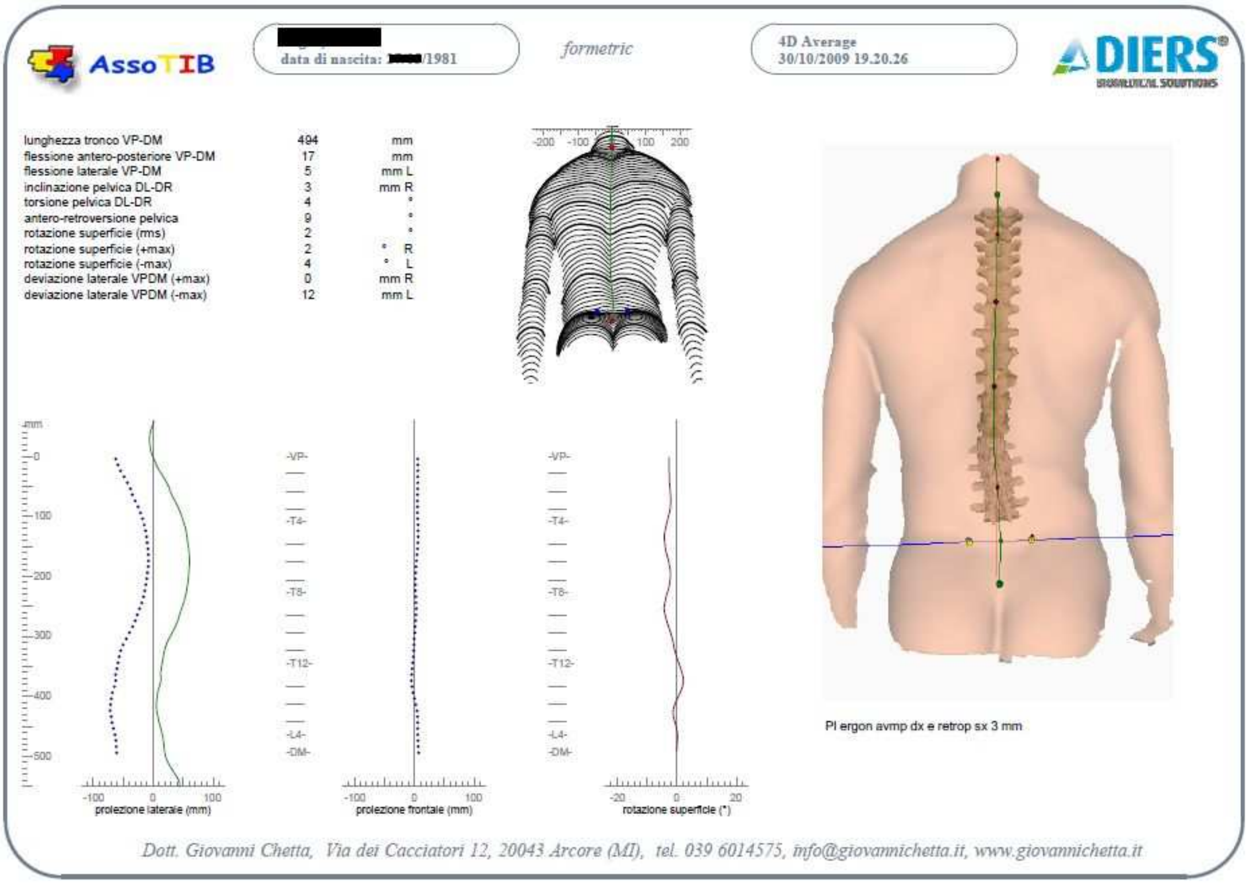

AssoTIB
[redacted]
data di nascita: [redacted]/1965
formetric
4D Average
15/04/2010 12.43.09
DIERS
lunghezza tronco VP-DM 483 mm
flessione antero-posteriore VP-DM 6 mm
flessione laterale VP-DM 5 mm L
inclinazione pelvica DL-DR 12 mm L
torsione emibacini DL-DR 1 °
antero-retroversione pelvica 18 °
rotazione superficie (rms) 4 °
rotazione superficie (+max) 9 ° R
rotazione superficie (-max) 3 ° L
deviazione laterale VPDM (rms) 6 mm
deviazione laterale VPDM (+max) 4 mm R
deviazione laterale VPDM (-max) 11 mm L
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

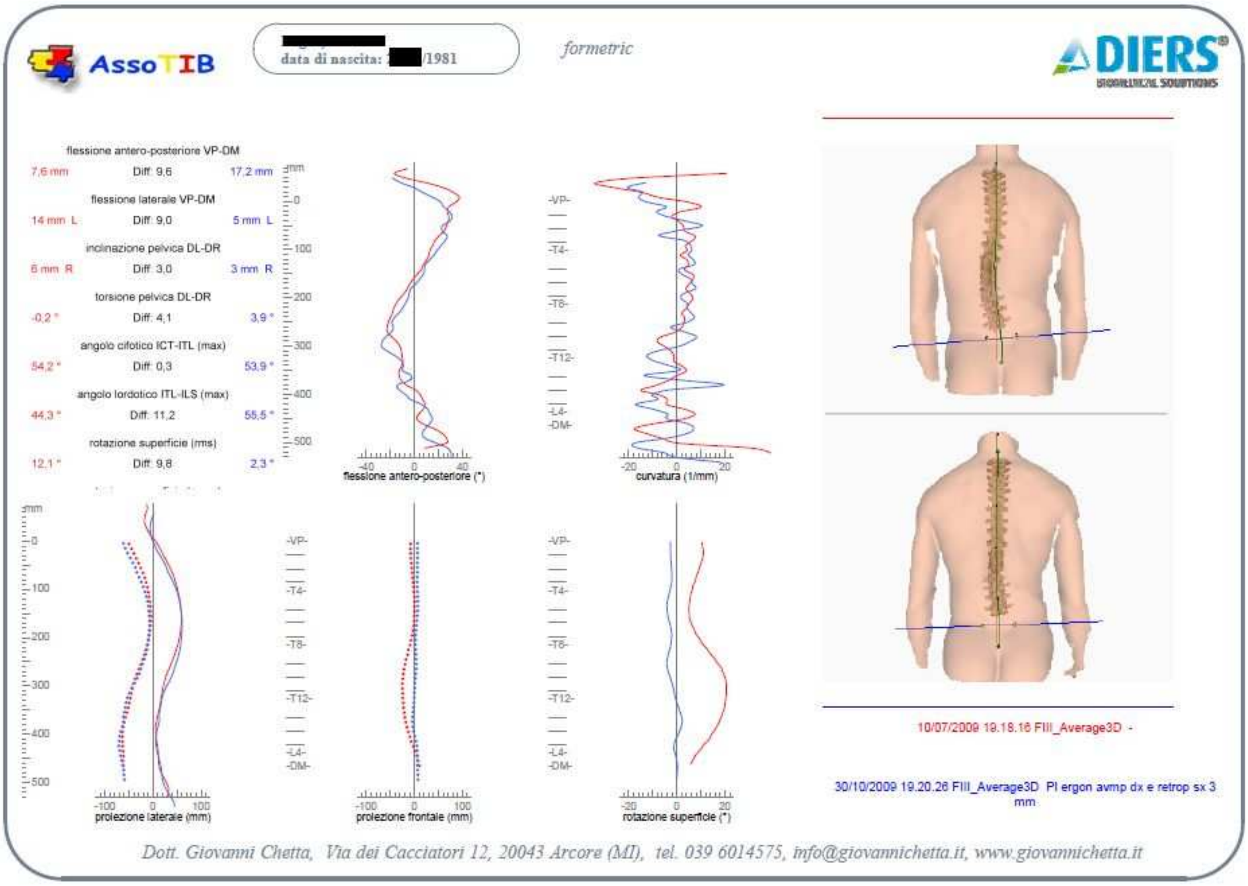

AssoTIB
[redacted]
data di nascita: [redacted]/1965
formetric
DIERS
flessione antero-posteriore VP-DM
6,7 mm Diff. 0,6 6,1 mm
flessione laterale VP-DM
5 mm R Diff. 10,0 5 mm L
inclinazione pelvica DL-DR
12 mm L Diff. 0,0 12 mm L
torsione emibacini DL-DR
-3,1 ° Diff. 4,5 1,4 °
freccia cervicale (Stagnara)
66,5 mm Diff. 6,3 72,8 mm
freccia lombare (Stagnara)
52,7 mm Diff. 0,2 52,5 mm
angolo cifotico ICT-ITL (max)
46,9 ° Diff. 5,6 52,5 °
flessione antero-posteriore (°)
curvatura (1/mm)
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
09/09/2009 16.44.40 FIII_Average3D
15/04/2010 12.43.09 FIII_Average3D
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

Case study: Scoliosis

Male born in 1981 with significant "structural" scoliosis.
TIBodywork program: postural exercises and customized ergonomic insoles.
Results: clear functional, structural and aesthetic improvement.




AssoTIB
[redacted]
data di nascita: [redacted]/1981
formetric
4D Average
30/10/2009 19.20.26
DIERS
BIOMEDICAL SOLUTIONS
lunghezza tronco VP-DM 494 mm
flessione antero-posteriore VP-DM 17 mm
flessione laterale VP-DM 5 mm L
inclinazione pelvica DL-DR 3 mm R
torsione pelvica DL-DR 4 °
antero-retroversione pelvica 9 °
rotazione superficie (rms) 2 °
rotazione superficie (+max) 2 ° R
rotazione superficie (-max) 4 ° L
deviazione laterale VPDM (+max) 0 mm R
deviazione laterale VPDM (-max) 12 mm L
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
Pl ergon avmp dx e retrop sx 3 mm
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

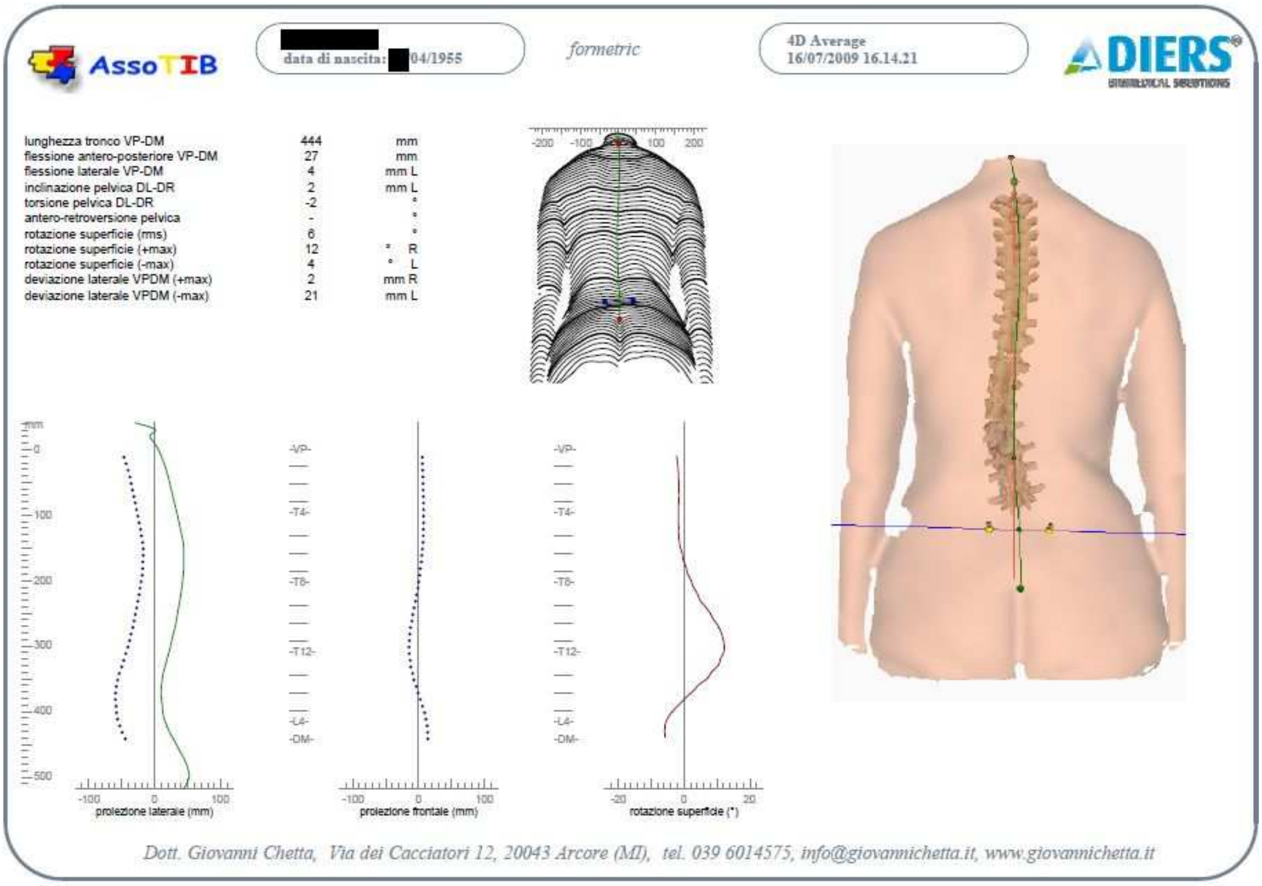

AssoTIB
[redacted]
data di nascita: [redacted]/1981
formetric
DIERS
BIOMEDICAL SOLUTIONS
flessione antero-posteriore VP-DM
7,6 mm Diff. 9,6 17,2 mm
flessione laterale VP-DM
14 mm L Diff. 9,0 5 mm L
inclinazione pelvica DL-DR
6 mm R Diff. 3,0 3 mm R
torsione pelvica DL-DR
-0,2 ° Diff. 4,1 3,9 °
angolo cifotico ICT-ITL (max)
54,2 ° Diff. 0,3 53,9 °
angolo lordotico ITL-ILS (max)
44,3 ° Diff. 11,2 55,5 °
rotazione superficie (rms)
12,1 ° Diff. 9,8 2,3 °
flessione antero-posteriore (°)
curvatura (1/mm)
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
10/07/2009 19.18.16 FIII_Average3D -
30/10/2009 19.20.26 FIII_Average3D Pl ergon avmp dx e retrop sx 3 mm
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

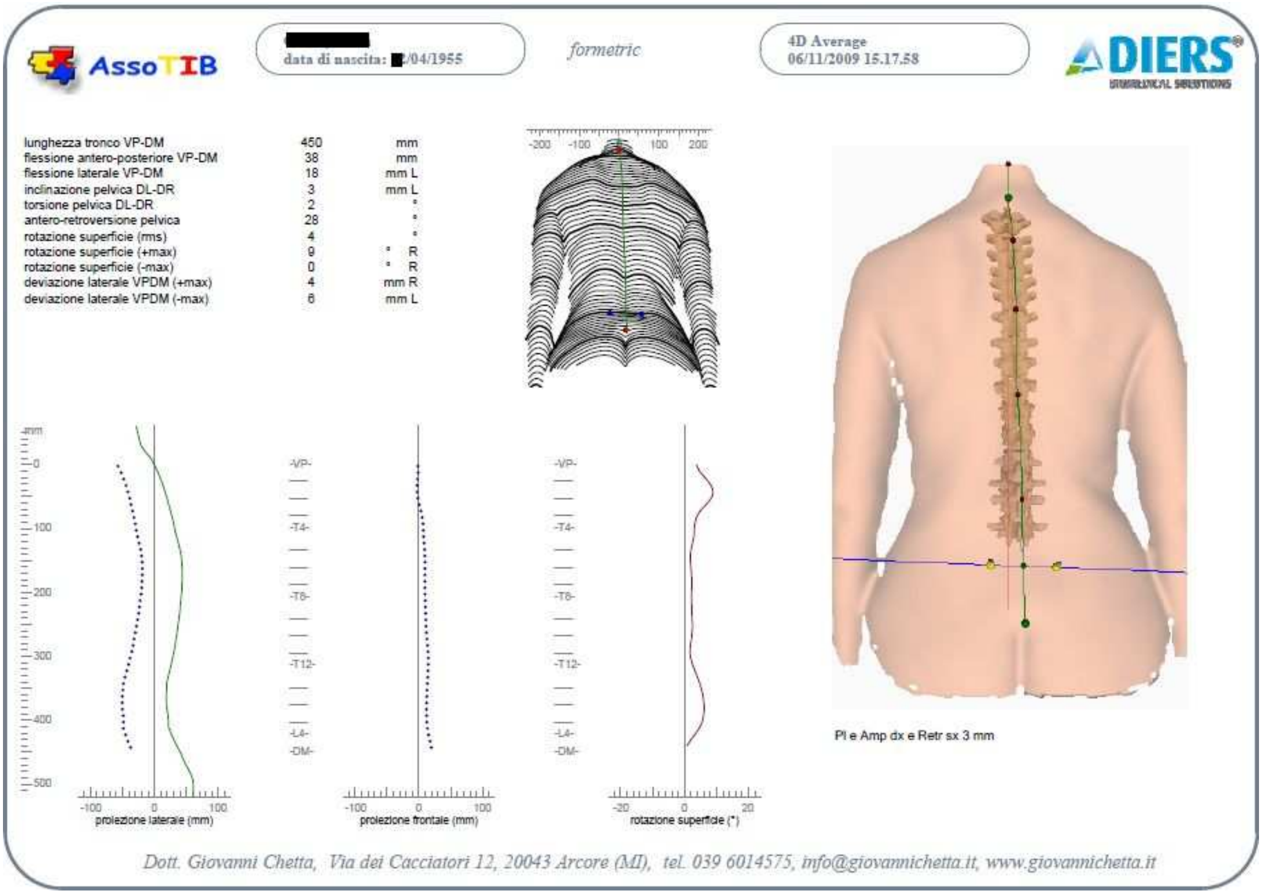
Case study: Lumbago (low back pain)

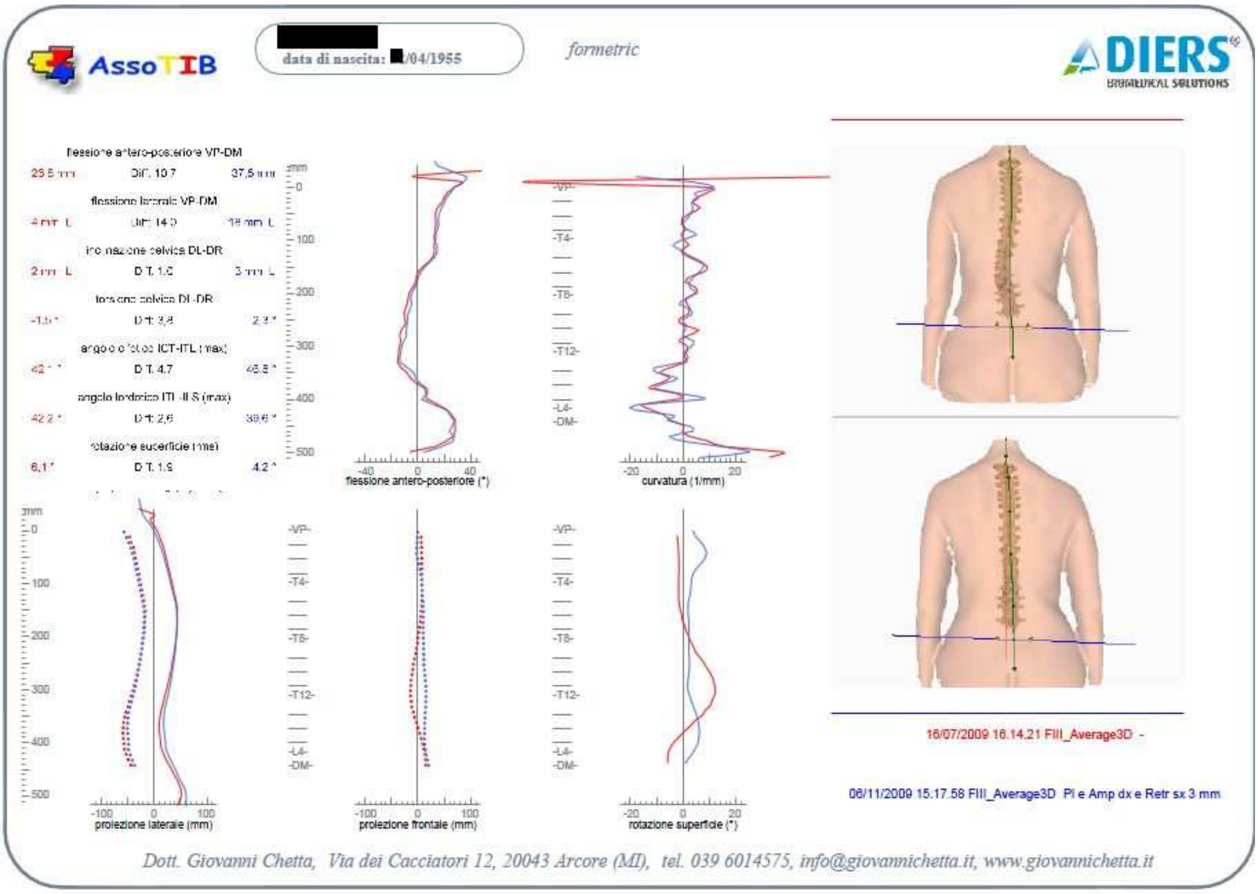
Female born in 1955, with “chronic” and disabling lower back pain and inferior limbs pain and weakness (significant lumbar scoliosis).

TIBodywork program: customized ergonomic insoles, manual techniques (bodywork), and postural exercises.

Results: symptoms disappeared, clear functional and structural improvement.

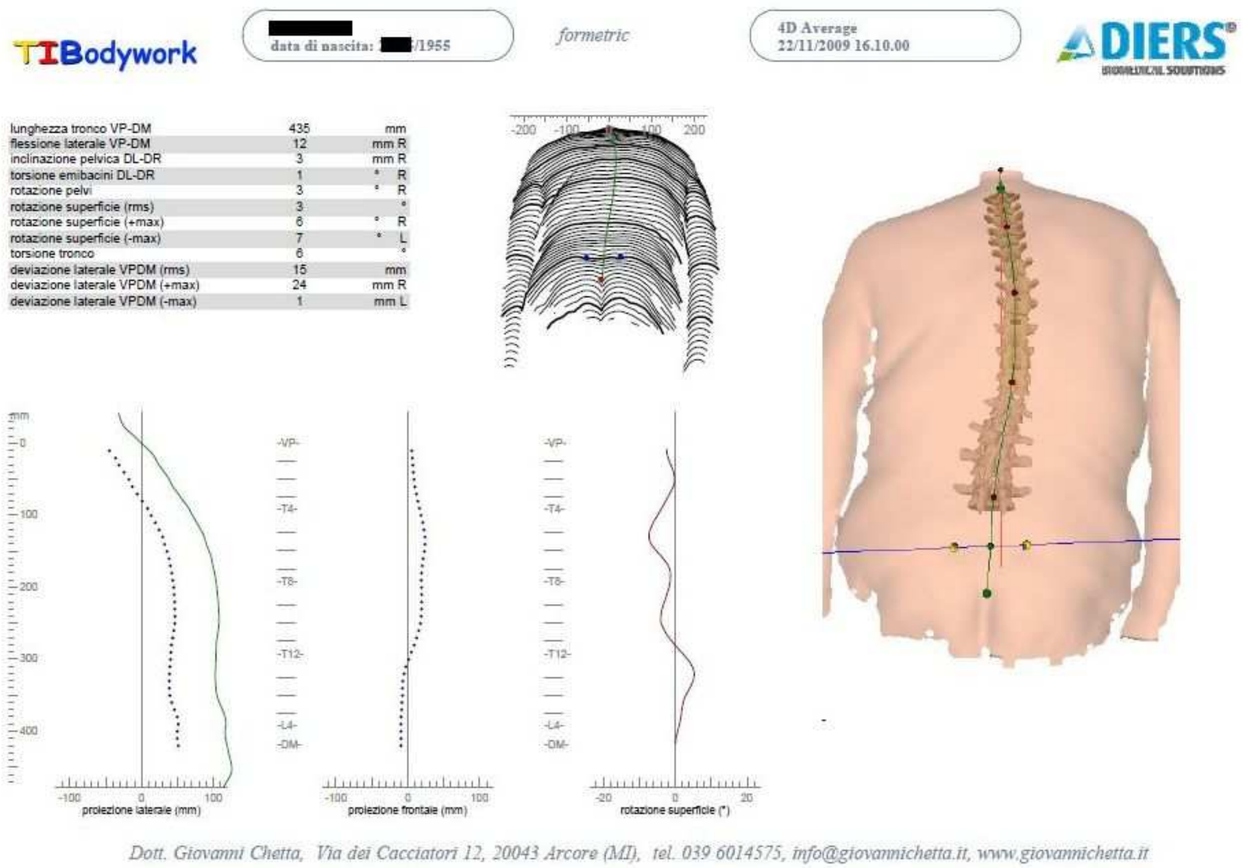



AssoTIB
[redacted]
data di nascita: [redacted]/04/1955
formetric
4D Average
06/11/2009 15.17.58
DIERS
BIOMEDICAL SOLUTIONS
lunghezza tronco VP-DM 450 mm
flessione antero-posteriore VP-DM 38 mm
flessione laterale VP-DM 18 mm L
inclinazione pelvica DL-DR 3 mm L
torsione pelvica DL-DR 2 °
antero-retroversione pelvica 28 °
rotazione superficie (rms) 4 °
rotazione superficie (+max) 9 ° R
rotazione superficie (-max) 0 ° R
deviazione laterale VPDM (+max) 4 mm R
deviazione laterale VPDM (-max) 6 mm L
Pl e Amp dx e Retr sx 3 mm
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

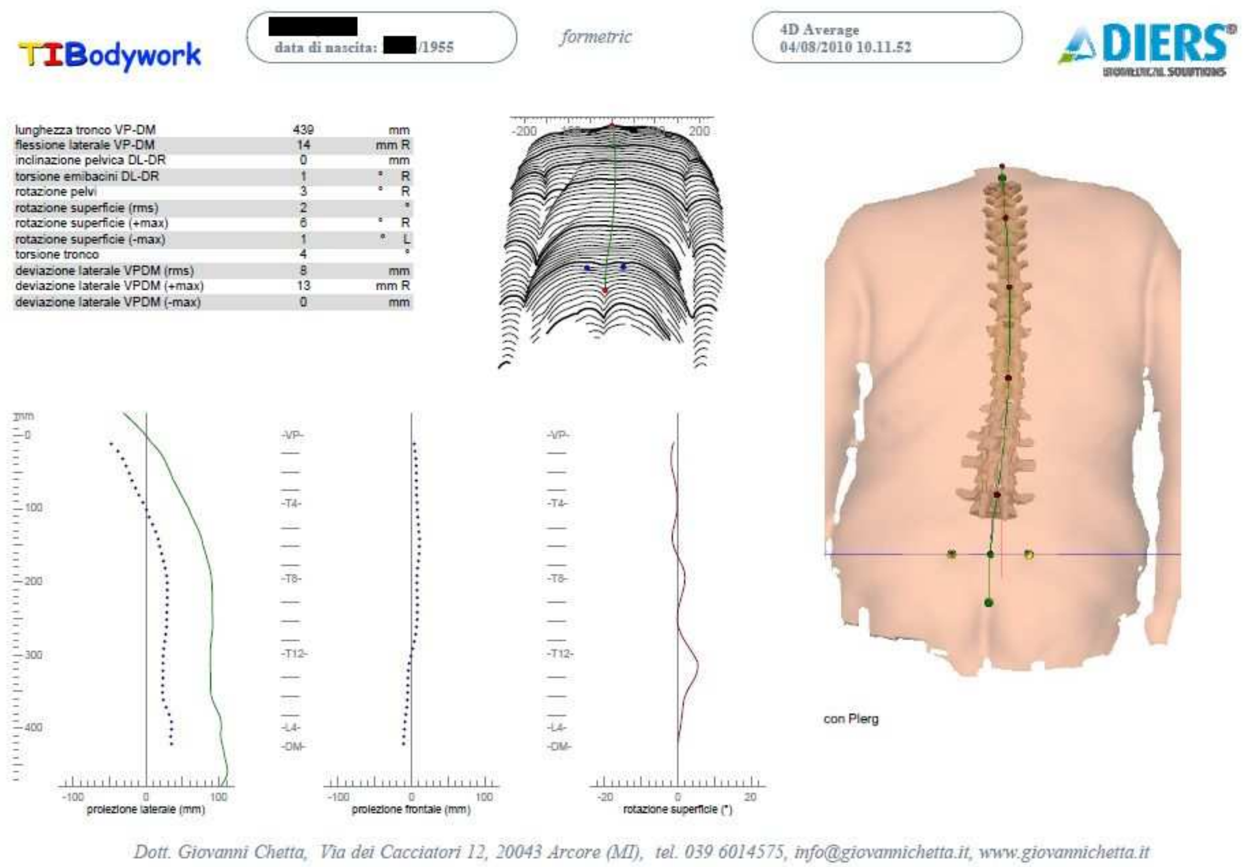

AssoTIB
[redacted]
data di nascita: [redacted]/04/1955
formetric
DIERS
BIOMEDICAL SOLUTIONS
flessione antero-posteriore VP-DM
Diff. 10,7
37,5 mm
flessione laterale VP-DM
D.T. 1,0
D.T. 4,7
D.T. 1,9
6,1°
4,2°
flessione antero-posteriore (°)
curvatura (1/mm)
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
16/07/2009 16.14.21 FIII_Average3D -
06/11/2009 15.17.58 FIII_Average3D Pl e Amp dx e Retr sx 3 mm
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

Case study: Lumbosciatica

Female, born in 1955 suffering for years from significant left side lumbosciatica (arthrosic discopathy and osteoarthritis L1-L2 and L4-L5, scoliosis) and cervicalgia.
TIBodywork program: manual techniques (bodywork), postural exercises, and customized ergonomic insoles.
Results: significant improvement of symptoms, function and structure.



lunghezza tronco VP-DM	435	mm
flessione laterale VP-DM	12	mm R
inclinazione pelvica DL-DR	3	mm R
torsione emibacini DL-DR	1	° R
rotazione pelvi	3	° R
rotazione superficie (rms)	3	°
rotazione superficie (+max)	6	° R
rotazione superficie (-max)	7	° L
torsione tronco	6	°
deviazione laterale VPDM (rms)	15	mm
deviazione laterale VPDM (+max)	24	mm R
deviazione laterale VPDM (-max)	1	mm L


TIBodywork
[redacted]
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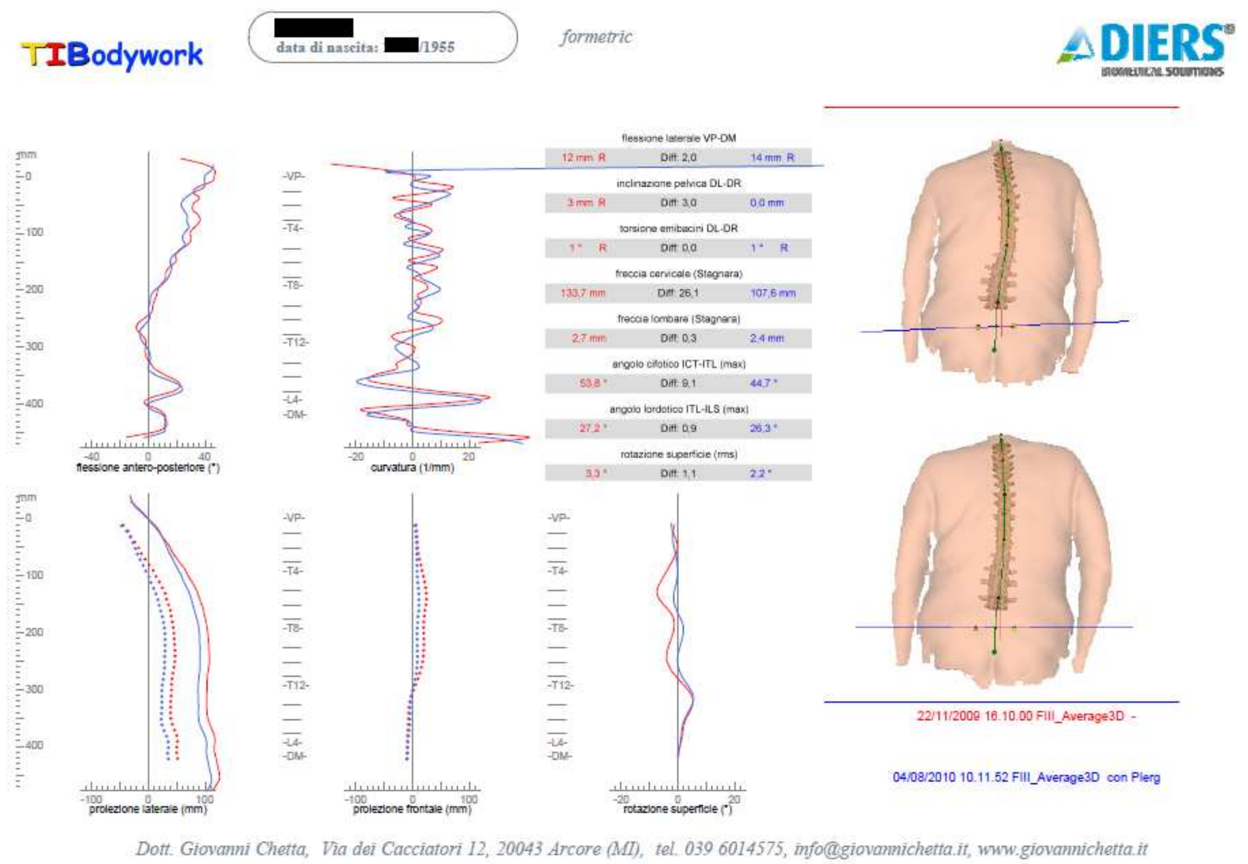
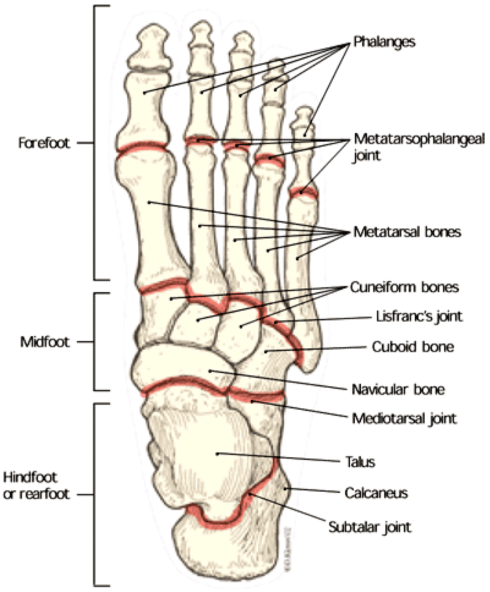
formetric
4D Average
04/08/2010 10.11.52
DIERS
BIOMEDICAL SOLUTIONS
lunghezza tronco VP-DM 439 mm
flessione laterale VP-DM 14 mm R
inclinazione pelvica DL-DR 0 mm
torsione emibacini DL-DR 1 ° R
rotazione pelvi 3 ° R
rotazione superficie (rms) 2 °
rotazione superficie (+max) 6 ° R
rotazione superficie (-max) 1 ° L
torsione tronco 4 °
deviazione laterale VPDM (rms) 8 mm
deviazione laterale VPDM (+max) 13 mm R
deviazione laterale VPDM (-max) 0 mm
con Plerg
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it


TIBodywork
[redacted]
data di nascita: [redacted]/1955
formetric
DIERS
BIOMEDICAL SOLUTIONS
flessione laterale VP-DM
12 mm R Diff 2,0 14 mm R
inclinazione pelvica DL-DR
3 mm R Diff 3,0 0,0 mm
torsione emibacini DL-DR
1° R Diff 0,0 1° R
freccia cervicale (Stagnara)
133,7 mm Diff 26,1 107,6 mm
freccia lombare (Stagnara)
2,7 mm Diff 0,3 2,4 mm
angolo cifotico ICT-ITL (max)
53,8° Diff 9,1 44,7°
angolo lordotico ITL-ILS (max)
27,2° Diff 0,9 26,3°
rotazione superficie (rms)
3,3° Diff 1,1 2,2°
flessione antero-posteriore (°)
curvatura (1/mm)
proiezione laterale (mm)
proiezione frontale (mm)
rotazione superficie (°)
22/11/2009 16.10.00 FIII_Average3D -
04/08/2010 10.11.52 FIII_Average3D con Plerg
Dott. Giovanni Chetta, Via dei Cacciatori 12, 20043 Arcore (MI), tel. 039 6014575, info@giovannichetta.it, www.giovannichetta.it

APPENDIX – Foot and posture

The *foot* is the fixed point on the ground that takes on the burden of the entire weight of the body. The foot is at the base of the anti-gravity control system (tonic postural system) that allows human beings to stand upright and to move in space. It is both a performer and receiver, or in other words, it receives and carries out commands (motor response) through the muscles and at the same time interacts with the rest of the body, providing constant information from the cutaneous exteroceptors present on the sole of the foot and from the proprioceptors in the muscles, fascia, tendons, and joints. The cutaneous exteroceptors of the foot are highly sensitive (0.3g) and provide a constant interface between the environment and the system of balance. The information from the sole of the foot is the only information that comes from a fixed receptor in direct contact with the ground.



During its evolution, due the needs that arose upon taking on an upright position and bipedal ambulation, the foot developed as a diaphragm intended to absorb and sort external (environmental) and internal (muscular) forces, in connection with the infinite planes of space. The structure of the foot is a unique masterpiece of architecture and biomechanics, with its 26 bones, 33 joints, and 20 muscles. Functionally and structurally, it is possible to divide the foot into:

- the *hindfoot* formed by the talus (astragalus) and calcaneus, "the central apparatus" in the biomechanical control of gravity;
- the *forefoot*, made up of the navicular (scaphoid), cuboid, and 3 cuneiform bones (also called the midfoot; the midfoot and the hindfoot together form the tarsus), 5 metatarsal bones (metatarsus) and the phalanges of the five toes; it acts as an" adaptor and reactor".

The foot, in its role as an "antigravitational base", initially comes into contact with the ground, adjusting to it by relaxing, and subsequently stiffens, becoming a lever to push off the surface. Thus the foot must toggle relaxation and stiffening, justifying the analogy with the *variable pitch propeller.* The hindfoot and the forefoot are arranged on planes that intersect in a modifiable way. In ideal conditions, the hindfoot rests vertically and the forefoot horizontally (on a horizontal surface). When the foot bears weight (stance phase), the torsion between the hindfoot and the forefoot fades when relaxing (the foot becomes a moldable platform) and increases when it stiffens (the foot becomes a lever). In reality, the arch structure is only ostensible, as it is an expression of the degree of winding of the foot helix. Therefore, the foot does not make sense as a real arch or vault - but only apparently - rising during winding and lowering during the unwinding of the helix. The winding of the helix, with the resulting accentuation of the arch characteristic, takes place when the foot is stiffening. The unwinding of the foot helix presents a consequential attenuation of the arch and an increase of foot release.

The torsion, or winding of the helix, is connected with the external rotation of the leg. Rotating externally together with the leg bones, the talus rises above the calcaneus, thus locking the mediotarsal joint; the hindfoot moves vertically. The forefoot firmly adheres to the ground, reacting to the forces of torsion applied to the hindfoot; this stiffens the foot. The opposite occurs with the unwinding of the helix, which is associated with the internal rotation of the lower limb.

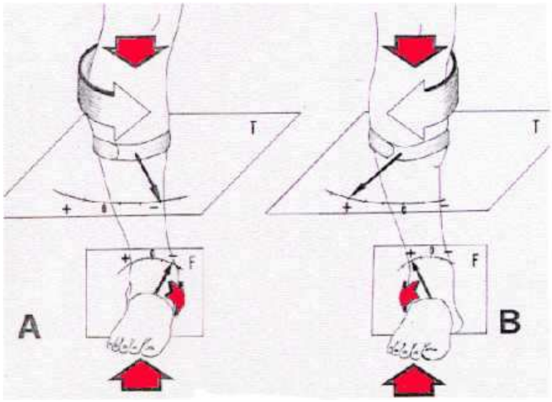
The **talus (astragalus)** is a bone with no direct connection with any muscle (no muscular attachments), and moves following the forces transmitted by the adjacent bones. The talus is a bone of the foot, as it is associated with the calcaneus and the navicular bone during rotations on the sagittal plane (flexion-extension), and is a bone of the leg since it is connected to the tibia and fibula, through the lateral and medial malleolus, during the rotations of the structures above the feet on the transverse plane (rotations internally and externally).

These rotations on the frontal plane (in the feet) and on the transverse plane (in the lower limbs and trunk) take place constantly while stationary (which in reality is a specific case of ambulation), and even more so during ambulation in the strict sense.

The **gait cycle** starts when one heel touches the ground and ends when the same heel touches the ground again. It is made up of a *swing phase*, i.e. the foot is not supporting the body's weight, which occurs between the toe off and the next heel strike of the same foot (ca. 40% of the entire cycle), and the stance phase (ca. 60% of the gait cycle). The *stance phase* can be divided into:

a) *Initial contact* (h*eel strike)*
Upon contact with the ground (reception), the helix unwinds to allow the foot to loosen in order to absorb the weight of the body and to adjust to the surface. In order for this to occur, the lower limb rotates internally, and the talus rotates internally together with it (supinating), the calcaneus pronates, rotating externally. The foot gradually bears the weight of the body and maximum loading occurs when the line of gravity falls in the center of the surface of the foot.

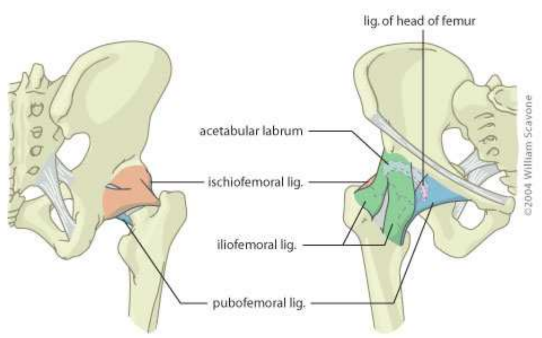
B) Midstance



When the entire sole of the foot is in contact with the ground, the internal rotation of the leg abruptly transforms into external rotation. This initiates a mechanism located in the subtalar joint (talocalcaneal articulation). Following the rotation of the leg, the talus rotates on the transverse plane externally (about 12° on average) pronating and rising above the calcaneus (moving away from the plantar calcaneonavicular – spring - ligament). The calcaneus rotates internally, supinating along the compromise axis ("momentary" axis around which the process of pronation-supination of subtalar joint occurs): the hindfoot verticalizes through the reciprocal screwing of the talus and calcaneus. The cuboid bone, which is firmly connected to the calcaneus, moves downwards and takes the cuneiform bones "on its back". The forefoot rotates in contrast with the hindfoot through its reaction to the ground. Thus the helix winds and the foot "arches" as a consequence: the mediotarsal joint locks and at the same time the weight is transferred onto the IV and V metatarsus through the eversion of the forefoot, which has not yet stiffened at this point. The peroneus longus muscle draws back the first metatarsal head to the ground for stabilization, distributing the weight on all of the metatarsal heads; the foot transforms from a helix into a rigid lever.

C) Propulsion (heel off)
The heel is lifted from the ground. After tenaciously adjusting to the ground, the toes flex dorsally so that the plantar aponeurosis shortens, contracting by about 1cm (the five rays of the plantar fascia radiate towards the corresponding basal phalanges, connecting to the periosteum in the segments adjacent to the joints) initiating the windlass mechanism that completes the foot cohesion. The center of gravity of the body migrates ventrally and the body begins to fall forward. Perfectly timed contact of the opposite foot and muscular control provide a braking effect, with the action of the triceps surae muscle, formed by the gastrocnemius and soleus (in addition to the tibialis anterior, tibialis posterior, peroneus longus, and dorsal flexors).
In the propulsion phase, the intrinsic forces acting on the foot are equal to 3-4 times the weight of the body. Under correct physiological circumstances, the foot acts as a helix in such a way that the projection on the ground of body center of gravity remains mostly centrally i.e. passing along its axis, which very nearly corresponds to the midline axis of the foot, which passes centrally through the hindfoot and at the center between the second and third toe. (Paparella Treccia 1978, Pacini 2000).

When the *knee* is in flexion it is possible for the leg to move laterally (1-2 cm to the ankle) and in axial rotation (external rotation of 5°). This is necessary to allow for the foot to come into contact with the ground in an optimal way in relation to the irregularity of the surface. During complete extension, since the knee is subject to considerable force due to weight support, in physiological conditions it is highly stable through a locking mechanism that makes the tibia and femur a single articular unit (Kapandji 2002). Therefore, when in flexion, the knee is capable of "filtering" the rotations of the foot and the leg, while when it is completely extended, these rotations are transferred fully to the femur, thus influencing the *pelvic girdle* (in particular coxofemoral and talonavicular joints have a similar structure and arrangement). The rotation of the femur on the transverse plane results in a mechanical push by the femoral head on the acetabulum (hip socket), the tautening of the hip ligaments, and the movement of the centers of gravity of the associated half of the body (centers of pressure). Thus, for example, intra-rotation of the femur can result in an initial anterior tilt of the corresponding hemipelvis and, after the tautening of the posterior ligaments (ischiofemoral ligament) and the movement of the center of gravity of the corresponding half of the body, in a pelvic rotation that follows the rotation of the femur. On the other hand, an extra-rotation can induce a posterior tilt in the homolateral hemipelvis followed by corresponding pelvic rotation though the tautening powerful anterior ligaments (especially the upper band, sometimes named iliotrochanteric, of the iliofemoral ligament and the pubofemoral ligament) and posterior movement of the center of gravity of the associated half of the body.



In the reference position, **the ligaments of the hip** are moderately taut. During external rotation, all of the strong anterior ligaments are taut (tension is at a maximum at the horizontally running bands or the upper of the iliofemoral ligament and the pubofemoral ligament) while the posterior ligaments (ischiofemoral ligament) are relaxed. The opposite happens during internal rotation: the ischiofemoral ligament stretches and the anterior ligaments relax (Kapandji, 2002).

The rotation of the hip is directly reflected in the *lumbar spine.* The ligament and bone structure of the vertebrae as well as the "energy converting" characteristics of the intervertebral discs allow the coupled motion to act on the spine. This corresponds to the primary and primordial need of the lumbar spine to rotate the pelvis during movement (Gracovetsky, 1988). Thus, the lateral flexion of the lumbar spine is always associated with vertebral rotation and vice versa (White & Panjabi, 1978). The modest rotating capacity of the lumbar spine (5°, Kapandji 2002) "forces" us to use part of the *thoracic spine* (capable of rotating about 30°, Kapandji, 2002) during ambulation. A contra-rotation and opposite lateral flexion (with respect to the inferior spine and the pelvis) is necessary in the shoulders and upper thoracic spine (T8 and above) in order to look forward. Scoliotic attitude of the spine helix as well as flat foot/pes planus (helical unwinding foot) and hollow foot/pes cavus (helical winding foot) are transitory physiological phenomena that are interconnected and become pathological only when they occur permanently.

In a biomechanical and pathomechanical context, there is a strong bridge that connects the feet to the overlying body segments, until potentially reaching the cervical-occipital articulations and the temporomandibular joint (TMJ) and vice versa (affecting, via the tensegrity myo-connective network, the entire body).

"In order to understand it is necessary to focus on the smallest element and rise towards the largest"
Richard Feynman (Nobel Prize for Physics, 1965)

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Dr. Giovanni Chetta
Arcore (MI), Italy
www.giovannichetta.it

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