Physical Factors

First of all, we must consider the physical factors.

The physical factors that operate within us are often dismissed as trivial, but they cannot be ignored. The permanent, powerful endogenous force exerted by blood pressure is a good example. When we observe the edges of the skin draw away from an incision, or the separation of the incised edges of an aponeurosis, the permanent tension within the prestressed tissues is obvious. Less visible forces include osmotic pressure, Van Der Waals forces and Ph gradients. They all determinine a set of specifications necessary for biological life. These basic, essential forces were identified by D'Arcy Thomson, an 19th century Scottish biologist and mathematician, but his work was submerged by the wave of evolutionary thinking. We can't neglect them or ignore them, and any concept must integrate and respect them, otherwise it will end in failure, as were attempts to understand living matter solely through cybernetics or even genomics.

But what can we really gain by looking at anatomy from a different perspective? What does the observation of living matter and the study of our microanatomy have to offer that is uniquely different from traditional anatomical research?

Continuity; global form; No layers or separate organs; Connective or constitutive tissue? Paradigm shift

The first major observation is the continuity of structures. The fibrillar architecture forms a continuous framework that *structures* the entire body from the surface of the skin to the cell interior, from macroscopic to microscopic down to the molecular level and atomic structures. Form, in the Kantian or Spinozist sense - physical spatial relationships - can now be described. Simple, contiguous physical spatial relationships can be defined within living matter. They determine a structured, continuous form that can be represented, drawn and schematized. This ties in with the concept of a bodywide matrix.There is total physical continuity within living tissue, and this renders the concepts of virtual spaces, separate planes and other artificial divisions within living tissue definitively obsolete.

This continuous mesh of interwoven fibers traditionally called connective tissue can no longer be neglected. Simple logic points towards to an essential conclusion: this irregular fibrillar network is found in all types of tissue, including muscle, periosteum, tendon, fat, and is continuous with the cytoskeleton, as demonstrated by the American biologist Donald Ingber.

This raises the following question: is the role of connective tissue simply to connect and separate organs and specific anatomical structures, or is it *constitutive*, providing a global, three dimensional architecture in which different types of cells can perform their specific roles?

This would represent **a fundamental paradigm shift**. From now on, anatomy can be perceived only in terms of globality and continuity. There can be no more layers, strata, separate planes, but instead, a single, common fibrillar network inhabited by cells with different densities. Our anatomy manuals still describe highly stratified layers of tissue, a model first described by Vesalius in the sixteenth century. The anatomy described by Vesalius and our elders must now be reconsidered in the light of current scientific thinking that integrates life sciences with modern physics and new mathematics.

But once we have addressed the question of continuity, there still remains an equally fundamental question: why does this fibrillar architecture, which appears to be optimally coherent, at first appear to be a a confusing entanglement of continuous fibrillar chaos? This would explain the apparent lack of interest shown by our forebears.

What is really disturbing is that this framework of *constitutive* fibers with its wide variety of shapes and forms displays no symmetry or regularity. We cannot find any known Euclidean forms. There are no vertical, horizontal or parallel fibers, no lozenges or circles. Instead, we find a tangled mesh of fibers, a mishmash of complete chaos. There is no discernible beginning or end to this irregular, global network.

This irregular continuity is disturbing because it is not what we were taught. Traditional anatomical teaching prepares us to discover a well oiled, organized, rational human machine governed by the principles of classical Newtonian physics. To accept that the architecture of the sliding systems, to which we owe the harmonious movement of the body, is completely irregular and apparently chaotic questions the basic principles of linear causality.

Movement; Mobile form; Economical movement; No loss of energy; Zero entropy; Infinite movement with no beginning or end

The fibrillar movements within the multifibrillar network clearly have a functional finality, which is mobility. Form can also be mobile, and we can describe this mobility. We see fibers that stretch, slide and divide, and behave coherently in 3 dimensions. We have already discussed this fibrillar behaviour in previous films.

But if we look more closely, we realize that the fibrillar mechanism is full of surprises on a purely mechanical level. We've seen that the fibrillar system is able to absorb an applied force by diffusing it across the network, thus permitting both interdependence of separate anatomical structures, and optimal transmission of the force.

But when we take a closer look at the set of movements, we observe a mechanical system in constant search of equilibrium.

The system provides an immediate solution to any constraint. This is a completely new, previously unobserved mechanism. It is never ending, flexible, adaptable and interactive. There is no tearing or sectioning of fibers. The system comes up with unexpected solutions. It is energy efficient and seemingly inexhaustible, and therefore displays minimal entropy.

Could this be an example of an irreversible dissipative structure described by Ilya Prigogine, author of "Order out of Chaos", and who was awarded the Nobel prize for chemistry in 1977? That is to say, a structure that functions contrary to the second principle of thermodynamics, which states that in an isolated system loss of energy is inexorable and increases over time. This is called entropy, and in traditional physics entropy is associated with disorder and the loss of information.

Prigogine suggests that an open system that is not in a state of equilibrium does not necessarily evolve towards maximal entropy and degradation, but on the contrary is capable of transforming lost or "dissipated" energy produced by any disturbance (for example, a rise in temperature in a liquid). This "dissipated" energy is utilised for the creation of a new organised project that is more complex, and enables the structure to adapt to its function. He stated that the particularity of life is to reverse the process of entropy with a subsequent increase in complexity that opens up a world of infinite possibilities. Prigogine concludes that living systems are not subjected to the 2^{nd} principle of thermodynamics, and that the characteristic feature of life is the reversal of this process of entropy.

While I was looking for a coherent explanation by using mechanical principles more suited to the function of a steam engine, the explanation provided by Prigogine's work enabled me to realise that the apparent fibrillar chaos I was seeing could not only be be efficient, but in the most beautiful way. Thus reassured, I could now understand all the spatial movements made by the human body in 3 dimensions, with minimal entropy.

At the same time that Prigogine introduced the notion of the dissipative nature of the system, he also added the notion of irreversibility in time.
This concept of the *dissipative* nature and irreversibility of the system appealed to me because I had noticed that fibers do not all function in the same way. This too was what I had observed.
Some are fixed, stable, and therefore determined to behave in a predictable way. Others seemingly less so, but unidirectional, as in the case of the lengthening of fibers with rings made of elastin and collagen.

In addition, there was a disturbing phenomenon associating an apparent determinism and randomness that recalled certain principles of quantum physics. Look closely at the movement of the fibers in some of the sequences. They move up and down, divide and then come together again. We cannot anticipate any of the movements. Their behavior is unpredictable, and yet prepared to deal instantly with all internal or external mechanical constraint. These are clear examples of the unpredictability of the movement and trajectory of the fibers, but also of non-determinism and non-reversibility within this chaos of fibers. Of course I found these observations puzzling to say the least!

This amazing behaviour at the molecular level is mind boggling! How can all these collagen molecules peel away from each other and then stick back together again in an instant, smoothly and without rupture? If we think about it, each precise combination of fibrillar movements at a specific time and place will never be repeated.

Watching these movements closely makes you ready to understand the non-determinist nature of this fibrillar behaviour. The association of all these individual movements represents incalculable combinations that cannot be resolved mathematically, and ensures that each movement we make is not reproductible in space and time in a creative non-deterministic universe that allows for the possibility of multiple solutions. Each movement is therefore unique, but how is this possible when we know that tissue memory is absolute?

A patient never returns the day after a massage session with their skin deformed. The irreversibility in time proposed by Prigogine nevertheless accompanies an immediate return to the determinism of the form.
This complicates matters, but Prigogine had an answer.He wrote that if the constraints increase, the dissipative phenomena increase, and so the thermodynamic system then deviates from its equilibrium and reaches a threshold of marginal instability which evolves towards the appearance of multiple solutions, an increase in complexity, fluctuations and amplifications that generate a new operating regime within an unpredictable complex structure.

"There must be innovation, and a non-deterministic universe allows for innovation."

The observation of all this uncertainty inevitably led me to quantum physics, especially since we are talking about microscopic scales of about a micron that can be influenced either by Newtonian or quantum physics, or both. I was confronted with the observation of apparent disorder resulting in efficiency, and the mixture of quantum and Newtonian physics with a dose of thermodynamic physics thrown in for good measure. It was obvious that I needed to change my way of thinking.

I had to leave the comfort of my traditional academic world and begin to study the science of complex, chaotic and non-linear systems. This is what we call Chaos Theory, which refers to chaos as described by modern physics. The study of complex non-linear systems such as ecosystems allows us to address complex natural phenomena that are unstable and cannot be accounted for by classical mathematics and physics. Ecosystems do not express themselves with the forms of classical geometry such as straight lines, planes, circles, spheres, triangles and cones.

Euclidian measurements such as length, width and height cannot account for irregular forms like clouds, waves, turbulence in a torrent of water or the distribution of the branches in a tree. These are the forms and patterns of life. Clouds are not spheres, mountains are not cone shaped, and lightning doesn't move in straight lines. Natural geometry is interlaced, entangled and twisted.

The classical linear model of Platonic harmony turns out to be inadequate, and it cannot help us to understand complexity because it favours order and stability. In 1795, Laplace, the master of determinism declared in his book "A Philosophical Essay on Probability" that order is the result of random events.

Natural systems are said to be chaotic and complex because of the explosion of the number of possibilities of interacting, non linear, chaotic events and because they create disturbance, *turbulence* and thus disorder. This in turn leads to unpredictability and instability. Henri Poincarré, a French mathematician, physicist and philosopher of the late 19th century was the precursor of the Chaos theory. He asserted that the laws of nature do not deal with certainties, but possibilities. The future is not given, it is in the making

The Meteorologist and mathematician Edward Lorenz, who won the Crafoord Prize in 1983, established the legitimacy of The Chaos theory through the discovery of strange attractors. The Chaos theory shows that the apparent disorder is governed by an underlying dynamic order. This provides an explanation for previously incomprehensible natural phenomena and the behaviour of ecosytems. To his great surprise he discovered that two meteorological models calculated from almost identical initial conditions give rise to two divergent curves as time passes. Lorenz thus highlights the chaotic nature of meteorology. It was he who famously declared that a butterfly flapping its wings in the Amazon forest could cause a hurricane in Washington. In other words, the effect is not proportional to the cause. This is non-linearity.

The observed chaos would therefore be an *orderly, deterministic and structured disorder* that concentrates information into manifest forms. The fibrillar network that I had observed so many times presented a mode of operation that no classical linear model could account for.

For me, a rational thinking surgeon, this was a period of neuronal turmoil and an upheaval of my way of thinking. At the time I felt that everything that I had learned was perhaps not wrong, but certainly incomplete. Everything needed to be reconsidered from this new perspective of nonlinear chaotic systems.

Form as volume; Concept of the Microvacuole or microvolumes that permit adaptabilty; Fluid dynamics

I studied the fibers first because I was looking for a rational explanation for the sliding of tendons, and the fibers seemed to be central to this mechanism. They were also easy to observe. But it was also necessary to explore fluids and volumes in the body. Fluids such as blood, bile, urine, cerebrospinal fluid and intra – articular fluid are omnipresent during surgery. All tissues are humidified at all times. But when a surgeon makes an incision in the skin, fluid doesn't flow freely from the incision. We notice a little liquid known as lymph along the edges of the incision, but that is all. So the fluids that represent 85% of our body weight do not escape through the incision. Their distribution appears to be organised, but how?

Intratissular endoscopy reveals the existence of microvolumes, irregular polyhedral forms that are all different – the same forms we find a the surface of the skin. Their seemingly chaotic disposition, their variable forms, and their non-systematized contiguity nevertheless reveal an underlying order. This irreguarity is not the result of chance or accident. They are irregular for a reason, because a degree of irregularity enables them to occupy space more efficiently compared with Euclidian forms.

I named these microvolumes *microvacuoles*. The subdivision of living matter into microvolumes allows us to tackle the thorny problem of the distribution of fluids within living matter, and the adaptability of this living matter to external physical forces and pressures. When I compress the skin, the internal pressure of the microvolumes varies simply because the fibres, consisting mainly of collagen, move and then return to their original spatial configuration once the constraint is removed, due to the pre-existing tension of the fibres. This is also posible because the microvacuoles are not hermetic, thanks to the tensioactive properties of their membranes. However, the overall volume of the microvacuoles remains constant. Their form is maintained by the Glycoaminoglycans they contain and which are water attracting.

Inside the constantly changing polyhedral framework of the microvacuoles are fluids, but there are no rivers or underground lakes. Living matter is soaked in fluid, rather like the juice inside the pulp of an orange. These are colloidal fluids consisting of various proteins, mineral salts, water and various other contents. Their presence is permanent, but in varying concentrations.

Fluids are certainly not lakes or rivers, but soaking living matter like the juice in the pulp of an orange. These are colloidal fluids consisting of various proteins, mineral salts, water and other variables permanently present at varying concentrations.

Biological water, the study of which is still in its infancy, could exist in two states, dense and not dense, and seems to play a role in the phenomenon of transmembrane transport across interfaces. Macromolecules influence the behavior of viscosity. They can connect two points within a flow, transmit forces and alter the viscosity of fluids by their cohesion and their ability to assemble.

Colloidal states are an "ultra-divided" state of matter and have a capacity to disperse that generates an excellent exchange surface which increases considerably at the interface. For example, the surface of foam is much greater than the surface of a bubble. Their ultra-light masses are animated by Brownian movement, and so they seem to escape the force of gravity, as well as the Van Der Waals forces. Michael Feigenhaum, Albert Lichaber and Leo Kadanoff were awarded the Wolf Prize for physics for pointing out that minute modifications in these systems can lead to significant changes in their overall behaviour, at all scales. This is called *turbulence*.

The relationships between the viscosity, plasticity and elasticity of living matter and its behaviour under pressure are studied by a branch of mechanical science called Rheology. But how are these fluids distributed, and how are they slowed down in different types of pathology such as oedema? What forces are involved?
This ability of a dynamic state capable of switching from one direction to another at high speed is called phase transition in the language of the physics of chaotic complex systems.

An increase in temperature causes the molecules to vibrate, then matter expands, and then it becomes discontinuous and the molecules move away from each other, obeying the laws of fluids.

This is the physics of soft materials that won a Nobel Prize for Pierre-Gilles De Gennes in 1991. The study of organic soft matter is still in its infancy. As special frontiers between two forms of existence, these interpenetrating phase transitions at all scales obey nonlinear mathematics. Forecasts of future states are difficult to predict and are said to be random.

These changes of state can be observed in the living human body. Local pathologies such as oedema or inflammation can be considered as turbulence. In tendinitis, old hematomas, and olecranon bursitis, we first observe an oedematous reaction, with enlarged microvacuoles and fibres.The microvolumes are drawn or pushed apart, and the fibres separate, forming a space that is not pathological, but is rather an *adaptive response* that modifies the local physiological behavior of the fibrillar network. The multifibrillar, microvacuolar system is progressively transformed into a *Megavacuole.*

What we can see is the formation of larger spaces, filled with glycoaminoglycans, and free of fibres. For example, the carpal tunnel in the wrist is the primary area of mechanical constraint during flexion. The flexor tendons are subjected to this constraint as they pass below the annular ligament. We see the same mechanical constraints acting on the pulleys of the fingers. The multifibrillar sliding system adapts to repetitive mechanical pressure during flexion of the wrist and fingers by forming what appear to be carpal and digital canals, but are actually what we call *megavacuolar morphological variations*.

This conclusion is very important because it also provides an explanation for certain anatomical spaces in the body such as the spaces surrounding the heart ,the pericardium, around the lungs ,the pleura, and even the peritoneum. These spaces all have one thing in common. Inside them, there is permanent, repetitive movement.

We could hypothesise that during phylogenisis, a more effective formula has been developed to meet the specific mechanical requirements in these areas. This remains structurally coherent with the multifibrillar architectural organisation of the entire human body.

And it is this structural coherence that is fundamental, because it is then possible for us to describe a body that is structured by the same architectural framework, with two essential components:

- firstly, *mobile components* either with or without functional adaptations brought about by phase transition. These are the sliding areas, composed essentially of fibers and fluids and containing few cells. These areas play a *shock absorbing role*. They deal with endogenous or external constraint by absorbing and spreading the load. This permits the interdependence of separate, distinct anatomical structures during movement. A good example is the sliding system around tendons that absorbs constraint, thus permitting optimal gliding without disturbing the surrounding structures. There is no rupture in the movement. This allows for harmonious, synchronised movement of specific anatomical structures throughout the body without disturbing or interfering with the movement of surrounding structures.

- secondly *an operative component* of the same multifibrillar system with the same fibrillar framework, and part of the continuous bodywide fibrillar network, but essentially filled with cells and fewer fluids. Examples are fatty lobules, the thyroid gland, the kidneys and the adrenal glands, each with specific functional roles, and in which the relationship between the fibers and the cells is surprisingly fusional.

Within these more homogenous concentrations of cells, endoscopic observation has revealed rather unexpected relationships between the fibres and the cells. Firstly, one cannot dissociate the cell from the fibrillar mesh. The cells are embedded in the fibrillar network, and they are in total continuity with this network. The fibrillar network and the cytoskeleton together form a structural continuum.

Another observation is that some cells appear to migrate along certain fibers

Yet another important conclusion is that cells do not occupy all the space in the body. Some areas of the body contain very few cells, particularly those areas subject to mechanical stress.
Cells alone are therefore not responsible for the form and volume of the body.

This simple perception of the biomechanics of living matter enables us to explain mobility, adaptability, the arrangement of cells and the distribution of fluids in the body. But it raises the following question: How is this volume of colloidal living matter, containing at least 75% of water, able to overcome gravity, the strongest fundamental force in our universe?

The answer to this question has already been explored with the concept of tensegrity. This concept was developed by Buckminster Fuller, an American Architect, and demonstrated by the sculptor Kenneth Snelson. Stephen Levin coined the term biotensegrity when he applied this concept to living organisms. It represents a major advance in our understanding of the organization of anatomical structures, and helps us to understand how the multifibrillar network is able to grow, and withstand the force of gravity. The concept of prestressed internal tissues with fibers that represent cables organized within a global network is in total agreement with the model of the organization of living matter that I propose.

It is the only concept capable of explaining the perfect balance between the constituent structures of the body. Except for a few nuances and minor details, it matches our observations exactly.

One of these details is the observation of fractalization. We now know that some fibres in the multifibrillar network are able to divide into sub-fibrils. In this way, force is dispersed throughout the structure right down to the molecular level. The force of gravity is also diminished in this way, at all scales, from macroscopic to microscopic.

From the outset we observed this phenomenon of fractalization at the surface of the skin. But we now know that it also occurs in the fibers and subfibrils and at the molecular level. Fractalization, or scale invariance, was first described by Benoit Mandelbrot, a mathematician who coined the word 'fractal', and is recognised for his contribution to the field of fractal geometry. A fractal structure looks similar no matter what distance we view it from. Whatever the scale under which it is examined, each part posesses the same structural pattern as the whole. This property is called self-similarity. Fractal structures display regularity within their irregularity, and this adds another dimension to the chaotic aspect of living matter.

Some authors, with reference to Mandelbrot's work, have suggested that fractal structures represent the underlying geometry of nature and a basic, universal feature of morphogenesis.

This is a widespread phenomenon in anatomy. Their fractal organization enables anatomical structures to increase the surface area that separates two different environments. In this way, a large surface can be contained within a small volume, thus providing a larger surface area for exchange. This is the case with the alveoli in the lungs but also the intestinal villi. Each villus is divided into smaller, comparable formations. We find similar arrangements in tendons. Fascicles contain fibers, fibrils and microfibrils and collagen molecules. This solution has been retained by nature because it increases metabolic efficiency and maximises the exploitation of space.

This organizational model is comparable to that of a tree, which is a perfect example of the fractalisation of life. Fractalisation occurs across all scales from the trunk to the main and secondary branches, stems and then the framework of the leaf and down to the plant cells themselves.

But we must be careful. Unlike Mandelbrot's drawings, nature offers us *irregular* fractalisation. There are no Euclidian forms in the human being. There are no regular, repetitive forms. Why is everything irregular, asymmetrical and fractal? Irregularity is the rule. Why is this tangled mesh of fibres and complex movements so difficult to replicate by even the most powerful computers? Why do we never see perfect symmetry? Why does the unidirectional force of gravity create such superb physical irregularity?

This brings us to the notion of *rupture of symmetry* developed by Nobel Prize winners Kobayashi and Maskawa in 2008. They explained that at the moment of the Big Bang, the universe was symmetrical and without structure. As it cools, the universe ruptures one symmetry after another, thus allowing the appearance of an increasingly differentiated structure. This allows for the appearance of matter and light in the quantum vacuum, producing the germ of the wide variety of structures currently present in the universe.

Life, like all biological processes, is a rupture of symmetry. Symmetry reigns only in an immobile, non evolutive world with no past and no future.

But this irregular fractalization is not fixed. It is dynamic, in order to prevent rupture of the collagen molecules, to preserve the integrity of the microvacuoles and to help resist the force of gravity. But above all, dynamic fractalization enables the development of a form, and growth of the form.
Fractalisation permits self-assembly and growth. It allows the transition from one stable form to another when sufficient energy is available. Fractalization is thus the natural mode, it represents the perfect dynamic relationships of complex nonlinear chaotic systems and it is no longer surprising to discover this process during intra-tissular exploration.

We are now beginning to come up with serious answers to our questions about the fibrillar entanglement observed at the beginning of our intratissular endoscopic exploration.

But this fractalization has other advantages. It sheds light morphogenesis and organogenesis from a new perspective.

Growth and Organogenesis.

The polyhedral structure is not a simple juxtaposition of adjacent structures or mere spatial contiguity. It is the result of all the physical forces mentioned at the beginning of this text.
These generating forces have imposed basic forms that will persist in the chain of evolution and influence organogenesis.
Of course the discoveries concerning Hox genes provide essential answers as to the location of the blueprint. But as far as manufacture and spatial contiguity are concerned, they provide none.

The ability of the fibrils to reproduce the basic polyhedral forms, combined with the phenomenon of dynamic fractalisation, helps us to better undestand how all the forms we observe in the human body can be created. Standard 3D design software is a very efficient tool to illustrate this. For example, if we take a set of lines with irregular intersections as previously described, all we need to do is impose a longitudinal force to obtain cylindrical structures.Tendons are examples of longitudinal structures. The intermuscular septa and some articular ligaments are also longitudinal structures, but the spatial arrangement of their fibres is different. The formation of hollow tubular structures like blood vessels, the bronchial tree, the intestines and excretory ducts occurs spontaneously. The formation of a canal is simply the continuation of an imposed constraint in the same structure.

This is also the case with more complex forms such as the spiral that is seen in vessels, the renal glomeruli and the middle ear. Bone is simply a reinforcement of the fibrillar system with hydroxyapatite. The respiratory system can be considered to be the result of the penetration of air into the fibrillar system. The thyroid is the result of that area of the fibrillar system being inhabited by cells that group together to perform specific physiological functions.

There is global coherence at all levels of organisation within the fibrillar network. The vascular, nervous, lymphatic and muscular systems are completely integrated into this network.
As we approach the conclusion, two avenues of reflexion can be considered. One is of a more general nature. Confronted with this polyhedral human architectural framework, it is difficult to ignore the fact that it is found in all other living species, animal or vegetable. This encourages us to think, or even affirm that all biological systems employ the same universal mechanisms for evolution and complexification.

The second touches on our work as therapists. It is now possible to explain and define pathologies such as oedema – swelling of the microvacuoles without lasting alterations to the multifibrillar, microvacuolar system. Inflammation is a dilatation of the microvacuoles and the vessels, and an alteration of fluids. We now better understand why a scar can have multiple consequences because of the loss of fibrillar harmony that is replaced by stiffness. We have clear mental images of obesity, an overloading of the microvacuoles by adipocytes. The microvacuoles become so heavy that they can no longer resist gravity. Finally, we understand the programmed aging of all the components that is the revenge of gravity, and leads inexorably to the sagging of our contours. There is so much more left to discover about the human body.

Conclusion

We have now arrived at the end of this journey. New techological advances have allowed us to lift a corner of Nature's veil, and we have been able to observe the ocean of disorder that generates the order of life. Life can no longer be defined solely from the perspective of the cell, as it was at the end of the 20th century. It is now necessary to take into account the cell's external environment, namely the fibrillar architecture that forms a symbiotic relationship with the cytoskeleton. The tendency towards reductionism in science, by simplifying complexity, does not correspond to the way in which nature is organized, especially in the field of anatomy.

From now on, it will be difficult to ignore this extracellular "interior architecture", which could be identified using the term "Fascia". Its organization is continuous, irregular, mobile, adaptive, fractal, chaotic and nonlinear, from the surface of the skin to the smallest constituents of our structure, and the vector of that most beautiful of optimal efficiencies - life.