MUSCLE ATTITUDE

Muscles represent strength, and the history of mankind is peppered with full of muscular heroes performing unusual feats. Considered as a sign of virility and strength and frequently exhibited, muscles are visible beneath the skin and easy to palpate.

Whether literally or figuratively, the muscle is central to all human action, swinging between the extremes of violence and tenderness, its contractile role always in keeping with the required gesture.

However, a muscle is never mobilised in isolation as seen in this sequence, for there is a harmony that spreads from one muscle to the next during movement.

One wonders then if this harmony is entirely orchestrated by the central nervous system as is widely accepted, or whether it also proceeds by way of an inherent elasticity that spreads from muscle to muscle.

To find out, we shall explore the muscle in vivo, within it's environment in a living person.

The para-vertebral region surrounding the insertion of the Latissimus Dorsi muscle with the muscle layers of the back and the ribcage is a perfect area to explore surgically.

The muscles are just below the skin, in direct continuity with the hypodermis, and the vertebrae. The Latissimus Dorsi and paravertebral muscles are strong and imposing structures in the thorax, which facilitates their anatomical identification.

These macroscopic observations, however, cannot ignore large areas where sliding occurs, permitting movement between individual muscles, as well as between the muscles, skin and ribcage.

At what is known as the mesospheric level, in other words that of human observation, as the camera slowly approaches the area between distinct muscular groups, the observer will be impressed by a genuine entwining and interweaving of opalescent fibres, which create a link of total continuity between the muscles.

As soon as we separate the muscles, these fibrous images transform into images of sparkling, scintillating, mobile mirrors and ephemeral lights disappearing instantly, only to be replaced by others.

What are these reflections, how and why are they produced, and why do they exist between muscular structures?

So, in order to progress further, and without at first realising it, the student observer will be required to separate, lacerate and destroy this amalgam of structures which do not seem to be part of the organs and which often hinder access to them.

For in fact, as during surgery, in order to expose the structures, the surgeon has to find a way through, create a route of access, and in so doing, one must break through these clusters of dense, heterogenous and continuous fibres, which give the impression of surrounding and wrapping around all the so called noble elements, binding them together.

This veritable continuum of fibres, which is present in all spaces throughout the body, has been named connective tissue by the anatomists. It is present everywhere, from the muscular depths to the surface of the skin, connecting separate elements. But is this tissue solely connective, is this really its only role?

To the naked eye, this tissue at first seems fairly uniform and unimportant, and of little interest to the anatomist. However, the mere introduction of an endoscope during surgery, with the patient's written consent, changes everything.

The endoscope combines a High Definition FullHD camera with a coherent bundle of flexible glass fibres capable of transmitting images, a lens, and a source of cold light. Thanks to this new technology, it is now possible to obtain degrees of definition never before achieved. The diameters of the lenses are either 4mm or 2.5mm with excellent focusing but with limited resolution. Added to this, is the problem of having to constantly refocus as well as the strange apparition of mist, droplets, and fatty deposits that require constant cleaning of the lens with a special liquid.

Endoscopy allows us to enter an arachnoid world of extreme morphological diversity and, without prior knowledge, discover an unexpected biological structural organisation, opening up an abyss of meditation as to the meaning of this discovery.

In fact, this apparent monotony contains a range of diverse colours, and forms that are almost geometric, allowing for precise movements.

Moving the high power lens into the areas surrounding the muscle allows us to discover the blood vessels that supply the energy, clusters of cells in plates curiously spread over the surface of the muscle, or within the sliding fibres. Again we find the spaces filled with scintillating facets, refracting the light like mirrors dumped haphazardly in a heap.

Indeed, the cold light emitted by the endoscope enhances certain contrasts and it is easy to observe that the mirrors themselves consist of interwoven fibres associated with liquids, irregularly interlaced as if disposed randomly throughout the spaces.

Look at these images in which the opalescent veil is woven from small cables and chaotic bundles.

We have seen in the previous films "Strolling Under the Skin" and "The Skin Excursion" that these fibres consist of collagen, especially type 1 collagen, and contain liquids such as glycoaminoglycans with varying chemical compositions.

We also know that these fibres are irregularly disposed, apparently fractal, meaning that the large fibres divide into smaller ones which in turn divide into even smaller ones themselves. These fibres and liquids define the spaces that we have named microvacuoles.

The formation by these fibres of a homogenous entity within the heterogenous mass define the connective tissue, and we have already begun to study their disposition and their dynamic behaviour within the sliding systems.

But does this also apply to muscle? Could it be that we also discover a fractal organisation that would, for example, provide a link between the muscle fibres, the epimysium, perimysium and the endomysium? We would then be in the presence of a coherent, global, functional tissue rather than what we usually consider as distinct, separate histological entities.

Once we have cut through the skin, the muscle is not very far. It is distinguished by its Bordeaux, purple colour and stringy texture, striated, and contracts as soon as we use the electric scalpel. The muscle is not, however, an entirely distinct entity from the surrounding anatomical structures because the muscle is surrounded, as we have seen, by this connective tissue, and it is necessary to peel away the epimysium to really get into contact with the muscular structures.

Sometimes, the epimysium of certain muscles is surrounded by a reinforced membrane, which permits sliding during contraction of the muscle. This is the aponeurosis. Sometimes, on the other hand, the sliding system is more tenuous.

Entering a muscle is not easy. There is strong resistance to the passage of the endoscope by what feels like braiding of the fibres. Even though the show is amazing, the scientific harvest is poor, and one is forced to retreat.

The solution is to address the muscle in the same way as surgeons do, in order to bypass the obstacle. The endoscope is oriented towards areas of easier exploration. We let it slide towards these opalescent short or long fibrils and blood vessels of varying forms in the areas surrounding the muscles. This is what we call the Epimysium. Epimysial fibres are in continuity with the surface of the skin, and blend into the hypodermis, as we have already described in our previous films. But they also enter, leave, mix with, combine, separate, and penetrate deep into the perimysium, separating the bundles of muscle fibres. It seems obvious, apart from the sheer beauty, which is not negligible, that everything is connected, everything is in contuinuity There is no break in continuity of living matter. There are no sheets of tissue, layers or sub layers arising from nowhere. The epimysium and perimysium are continuous structures. As for the endomysium, which binds the muscle cells together, it's finesse means that we can only guess at its presence during endoscopy.

The projection of the fibres of the perimysium seems to be much more disorganised and global. Compared to the lengthened, longitudinal, and parallel aspect of the muscle cells, their architecture is neither parallel, symmetrical nor regular.

For these perimysial fibres also surround, penetrate and encircle the bundles of muscle cells. However, what is surprising, is the impression of tissue fusion between the collagen fibres and the cells which compose the bundles, while at the same time preserving an apparent anatomical independence which can be confirmed using a colorimeter, and is most certainly functional.

The muscle cell nestles within this fibrillar architecture, in the same way as the adipocyte nestles within the mesh of the fatty lobule. One might think that the collagen fibres and their finer components mould and shape muscle cells by way of their intimate architecture.

And given that these endless, more or less diffuse networks of collagen fibres and fibrils link the large and thick connective formations such as fascia and tendons, this raises the real question for those who work with living organisms: Is this connective tissue not simply the tissue that is ignored by all manuals of anatomy and histology? Could it play other roles than that of a simple "supporting tissue", which is the accepted term, but whose meaning is still rather vague.

Despite fine focusing and high magnification - sometimes as much as 50 times - providing high definition images, endoscopic exploration during surgery does not enable us to see the ultimate subtlety of detail. The absence of contrast between different living structures does not permit us to go much further, and so the doubt about continuity between all these structures remains, particularly as far as the endomysium is concerned. The limits of current endoscopic exploration have been attained.

The use of other techniques can therefore be valuable in defining the boundaries and exact nature of this system

To achieve this, we will use the electron-scanning microscope on a rat's paw. The rat's paw has been treated with formalin and prepared using a technique called sodium digestion. This entails soaking the rat's paw in a solution of sodium hydroxide. The paw is then rinsed and freeze dried. What remains is what you can see here: white tissue in which all muscular and cellular components have been eliminated. However, the electron-scanning microscope only shows the surface of objects under investigation. One must then penetrate into the interior of the paw. To be sure of what we are looking at, we then proceed through a binocular magnifying glass. The electron microscope enables observation of a greater depth of field, practically within the space under observation. As a result, one can observe the global structure of the object under observation - in this case, the rat's paw - at low degrees of magnification. This allows for unlimited enlargement of the image, so enabling us to observe the finest details of the finest fibres of connective tissue.

This allows us, as shown in this image at low magnification, to see the remains of the Gastrocnemius Lateralis muscle, and to see that the collagen fibres present between the Gastrocnemius Lateralis and the Extensor Digitorum link up with the epimysium of the Gastrocnemius Lateralis.

Then, if we move into the muscle at higher magnification, one can see that the collagen network that constitutes the epimysium continues into the muscle via a network of parallel and oblique partitions. From these partitions, collagen fibres ramify into the space formed between one partition and the next down to a scale equivalent to the size of a cell, which is about 50 microns. All these collagen structures within the muscle link up with the other part of the muscle, which happens to be the tendon, easily recognisable by it's tightly packed, parallel bundles of collagen fibres.

The collagen fibres of the tendon branch out in turn to form the paratenon, branching out again into a very fine network of fibres, which interweave with the sliding aponeuroses, and further afield with the hypodermis.

What are the implications of these microsopic and endoscopic observations? The essential observation is of fibrillar continuity. There is no break in the tissue continuity, be it within muscle, tendons, or around the arterial and venous structures and the structures surrounding the adipocytes. All these structures are formed in the same manner and are continuous.

We have already encountered these problems when we discussed the sub-cutaneous tissue in "Strolling Under the Skin", and the epidermis and dermis in "The Skin Passage". Now we have discovered the same continuity of tissue within in the muscles. The concept of the organisation of living matter into stratified layers, hierarchical layers of sheaths, lamellae and strata cannot satisfy an anatomist who studies precise, endoscopic, functional anatomy. It is certainly useful in order to learn simplified, descriptive anatomy, but it is the essential concept of the global nature and continuity of tissue that one must now accept.

Even though are of different colours, textures and shapes, they are all linked to each other. This is a global tissue concept.

We have already demonstrated and highlighted these fibrillar structures with irregular three-dimensional organisation that can be considered as chaotic.

Perhaps at the muscular level, we can now envisage the same concept, and consider that muscle is an assemblage of interwoven collagen fibres oriented in the direction of constraint and cellularised by muscle fibres, which are the contractile components. Within which, of course, everything is interlinked. This view inevitably leads to conceptual consequences.

(raises conceptual issues?) The first of these concerns the creation and transmission of force, which is of course the principle role of muscular function.

Indeed, if these elements are linked, all mechanical stress will act on all the muscular structures, whether they are epi-, peri-, or endomysial. But how and where does this transmission take place? We can clearly see in this sequence that traction on a muscle spindle induces a transmission of the force to the neighbouring spindle, and that the collagen tissue participates. Seen from afar, there is nothing mysterious about this, but if we look closer, the behaviour of the fibres is surprising, and far from being strictly linear or behaving simply, like ropes.

During careful endoscopic observation, we have found that these perimysial fibres move over each other. But this is not a regular or direct deployment of the fibres. Instead, we can identify a series of simultaneous, unpredictable movements, such as division, lengthening, and sliding of fibres.

Watch this sequence between collagen fibres with a diameter of 20 microns in the perimysium. Within the space of two seconds, we can see mobility, division, and distension.

This is surprising, but reinforces our hypothesis of global behaviour, because all these movements have already been described beneath the skin, around the tendons, and now we find them around and within muscle.

These collagen fibrils therefore possess their own non-linear dynamic relationships, but how are they attached to the contractile element: the muscle cell?

In vivo endoscopic observation does not identify the exact nature of these musculo-connective tissue links.

Here again, electron microscope observation after freeze drying tissue specimens – that is after setting all the components of the muscle, and not just the collagen - will enable us to reveal the existence of physical links. We can then remove the long muscle cells, which have hardened. The spaces created by this procedure reveal a multitude of details as the dissections proceed.

When we observe the surface of a muscle cell at high magnification, we can see collagen fibres spreading out from a strand of perimysium like ivy branches, and then coming into contact with the surface of the cell and the endomysium.

And, even more amazing, in this picture we can clearly see that the collagen fibres are continuous with the structures contained within the membrane of the muscle cell, and that they are even continuous with the cytoskeleton.

So, in this way, the contractile forces produced within the myofibril can be transferred both morphologically and mechanically to the tendons, especially since we find these links at regular intervals of about 300 microns along the muscle cells, in all three dimensions.

A muscle is therefore not merely a group of longitudinal muscle cells arranged in the form of a barrel that transmits a force to the tendon.

In reality, each muscle cell is closely associated with the collagen network via crosslinks within an endomysial framework composed mainly of type 4 collagen fibres, which connect the muscle cells to each other over long distances. TROTTER and PURSLOW have thus been able to say that the force produced by a contracting muscle cell can be transmitted laterally through the network to its neighbours.

So, what happens during muscle contraction triggered by a nervous impulse.

The contraction causes the intermingling of the actin and myosin fibrils located in the sarcomere. This contraction then spreads through the cell towards the tendon, but it also

spreads laterally to the endomysium and especially to the collagen fibre bundles within the perimysium.

The movement is subsequently transmitted to the large collagen bundles that merge with the tendon.

However, the collagen bundles don't all attach to the tendon. They also constitute the epimysium which represents a link between muscles, and which could transmit some of the force to neighbouring muscles, as demonstrated by Hoeling et al.

Finally, the muscular contraction is transmitted by a dissemination of forces via this three dimensional network which links together all parts of a muscle. If we consider a limb, this network not only links together all parts of a single muscle, but also all the other muscles, and all parts of the limb itself.

This transmission and modulation of force throughout the entire structure is of great interest because it helps to explain why blood vessels don't rupture during muscle contraction when the energy demand is greatest, thus preventing bleeding and bruising.

One also wonders whether the connections between the perimysium and the muscle cell are formed randomly along the cell surface or at specific locations?

In order to find out more, we needed to go back to the laboratory, and here the transmission electron microscope provided the answer.

This time, we used a transmission electron microscope. We took a small piece of muscle, which was prepared using special techniques. It was then impregnated with, and set in an epoxy resin, which is very hard, and allowed us to cut very thin sections of the prepared tissue. Subsequently, the electron microsope allowed us to observe and learn what was contained in the prepared section of tissue.

This longitudinal section of a contracted muscle cell from a rat will provide us with the initial indications. Indeed, at all points of contact with the perimysium, clearly visible here at the top of the picture, and by applying mechanical traction sufficient to alter their shape (pulling on them hard enough to deform their shapes,) we always find one or more nuclei, as well as impressive clusters of mitonchondria in contact with the connective tissue.

The same observation can be made in a cross-section of two muscle cells from a bull, showing that the type 1 collagen fibres of the perimysium - identified by their striation – establish contact at places where there is a nucleus and abundant mitochondria at the periphery of the contact point.

Such coincidences cannot be due to chance alone, since we know that the nuclei control the production and maintenance of proteins and that the mitochondria are responsible for the metabolism of energy, and partly responsible for calcium metabolism. A phenomenon of mechano -transduction can therefore be suggested.

This global conception of muscle as a zone of contractile cellularisation of collagen tissue, which provides architecture and form, with links to all other tissues throughout the body, is reinforced by this last sequence filmed beneath the skin. Here we see that manipulation of the surface of the skin triggers multidirectional movement of the fibres of the muscular epimysium beneath the skin, demonstrating a direct physical interaction. Perhaps research into Myopathy will make use of these new avenues of exploration. However, it is certain that the benefits provided by massage, manual therapy, post – operative re – education, or simply regular physical exercise can now be explained in a rational physiological and non controversial manner by considering their effect on the flexibility of these contractile and connective structures that are so intimately linked.