The Architecture of the Collagenous Connective Tissue in the Musculoskeletal System – An often overlooked Functional Parameter as to Proprioception in the Locomotor System [1].

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This article partly consists of a partial rewriting of the doctor thesis performed by the author at the University Maastricht in 1988 with the title The Organization of the Substrate of Proprioception in the Elbow Region of the Rat.

Philosophical and methodological introduction

How to define fasciae anatomically, in general and in the musculoskeletal system in particular?

In my first training as anatomist, some forty years ago, my methodological attention was not drawn in the first place to connective tissue or fasciae and their anatomy. In Gray's Anatomy *fasciae* are defined as "masses of connective tissue large enough to be visible with the unaided eye" (Gray's Anatomy 39th ed., 2005). I was trained to consider fasciae for example as connective layers that had to be removed, they 'covered' something. The classical anatomical method was and still is dissection. Dissection is the method of analyzing in a literal procedural way. One had to separate, to dis-sect and the revealed structures ('organs') had to be 'cleaned' en 'cleared' from connective tissue. Connective tissue was, roughly spoken, something like a covering or sleeve over en in between the dissected structures, it had to be removed during the dissection procedure. When connective tissue was met as a layer, a membrane, a fascia, covering a body structure, organ or region it was given a name and the nomenclature for those layers was derived from the anatomical substrate that the layer (membrane, sheath, fascia) was covering. *Fascia cruris, fascia colli media, fascia renalis*, for example: connective tissue anatomy was defined as suborganisation in the hierarchy of anatomical structures like muscles, organs and so on. Even nowadays anatomy textbooks and atlases represent for example in their figures most of the time muscles as discrete anatomical structures with the surrounding and enveloping connective tissue layers removed ('cleaned').

Most of what is called *fascia* traditionally is considered in the above mentioned way. Fascia is defined in leading textbooks of anatomy as "masses of connective tissue large enough to be visible with the unaided eye" (Gray's Anatomy 39th Edition, 2005) and they are often classified as (discrete) anatomical entities or structures related to organs (in broader sense). But are the fasciae, the membranes, the sheaths in the body in fact distinct and discrete anatomical structures or are we dealing with a continuity? Is the anatomical view ('eye') that contributed parts of this continuity to anatomical structures and entities like body walls or regions (e.g. *fascia endothoracica* or *fascia colli media*), like organs (e.g. *fascia renalis*) or like body parts (*fascia cruris*) missing something? Schleip mentions the fascia "as the dense irregular connective tissue that surrounds and connects every muscle, even the tiniest myofibril, and every single organ of the body forming continuity throughout the body" (Schleip, 2003). In the latter way fascia is considered to be an important integrative element

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in our posture and movement organization and is often referred to as our *organ of form* (Varela, 1987).

Yet usually the notion which every anatomist in fact is able to observe, is denied that in removing or dissecting the connective tissue in the form of “layers’ one may notice various degrees of attachment. Sometimes a layer or fascia is nearly loose or only loosely connected with the underlying structure or tissue, on the other hand very often the interwoven anatomy between a fascia and an underlying structure is very tight and really has to be cut, e.g. in the case of the *fascia cruris*. But in essential the methodological issue always tended to be that connective tissue layers or structures when they were not clearly organized in a mechanical *in series* relationship with muscular tissue or muscular structures - like approved structures as tendons and aponeuroses - were ‘removed’, be it ‘dissected’.

It is this methodological mentality that lead to the fact that traditional anatomy dissected (and in that way analyzed) the musculoskeletal system *s.s.* in discrete anatomical structures. In most textbooks and atlases the anatomy of the musculoskeletal system *s.s.* is represented by the anatomical ‘trinity’ Bones, Joints (articulations with or without ligaments or similar regular dense connective tissue structures) and Muscles (yes or no with auxiliary structures like tendons and aponeuroses). It is this view that is nowadays widely spread in the minds of people[1]. Later on in this essay it will be discussed that this view in fact is a methodological error: architectural and mechanical spatial relationships between the various tissue components of the musculoskeletal system *s.s.* reveal functional units that go across the traditional anatomical entities of e.g. bones, joints and muscles. The notion that the afore mentioned ‘trinity’ is an unwanted reduction of functional relationships and coherence is nowadays also supported by the fact that in the central nervous system the traditional anatomical organization of the musculoskeletal system *s.s.* is not or only partly represented topologically. With this is meant that in the central nervous system the functional components of position and motion that are coordinated by the central nervous system are not the muscles (and joints), but movements and actions. In fact “the brain knows nothing about the muscles" as already commented by Jacobson in the nineteen-seventies. This correlates with modern task-dependent models as initiated by Loeb et al. (Loeb, 1984) (Loeb, 1982) i.e. that motor units are not necessarily organized in the central nervous system with respect to individual motor nuclei but are organized according to behavioral tasks. In fact considerations like this form the background for the option to talk in this essay about the musculoskeletal system *s.s.* This is meant to conceptualize a locomotion system in a broader sense (*s.l.* or *sensu lato*) which includes the coordinating and regulating nervous system (central as well as peripheral) that has to be discriminated from the locomotion system in the narrower sense (*s.s.* or *sensu stricto*) which is represented by the actual musculoskeletal system.

Continuity and connectivity – functional appearance of connective tissue

There are good arguments to state that under the procedural and mental scalpel of the anatomist a continuity has gone lost that has to do with the connective tissue as central matrix of the body. In principle the primary connective tissue of the body, in case the embryonic mesoderm, represents the matrix and environment within which the organs and structures of the body have been differentiated and therefore are embedded. This in between remaining connective tissue matrix however exhibits two principles of ‘connection’. The German embryologist Blechschmidt discriminated the mesoderm as germinal layer as different from (opposed to) the two others. He stated the mesoderm as an so-called ‘inner tissue’ against the ectoderm en endoderm as ‘limiting tissues’. In histology, ‘limiting tissue’ is commonly called epithelium and is almost solely constituted by cells with relatively few intercellular space. Most derivatives of the so-called ‘inner tissue’ are identified in histology as connective tissue. ‘Inner tissue’ could therefore be described as undifferentiated connective tissue, in principle organized in three components: cells, intercellular space (interstitial substances) and fibers (Blechschmidt, 2004).

During the development of the mesenchyme one could describe **functionally** two principles or patterns. On the one hand 1) there is the building out of the component 'intercellular space' which for example happens in the formation of coelom and body cavities and joint 'cavities', where spatial separation is ensured and therefore motion is enabled. This is the functional tendency and differentiation of 'creating space'. In such cavity formation processes the primary enlarged intercellular space is lined up and delimited by a limiting epithelium (in case of the body cavities a so-called mesothelium). As to their functional maintenance such epithelia are more or less dependent from the presence of continuous motion. This is demonstrated by the tendency of fascial layers like peritoneum and pleural membrane to adhere as soon as motion of the related structures and organs is absent. The so-called body cavities like the peritoneal cavity therefore also function as a kind of 'joint cavity'. Actually the often applied notion 'cavity' is not completely correct. The peritoneal space, just like the 'real' synovial joint 'cavity', rather represents a fissure functioning as a sliding and slipping space or fissure. On the other hand 2) there is the tendency of differentiation in the direction of a strict connection or connective tendency, i.e. the formation of a binding medium, either fibers (such as regular dense connective tissue structures like membranes and ligaments) or interstitial substrate and matrix (like for example is configured in cartilage).

Respected in this way one could figure a whole spectrum of connection in the body. On the one extreme tight connecting structures like the desmal suturae in the skull where dense connective tissue membranes indeed construct a nearly immobile joint (sometimes such sutures might completely ossify). The other extreme are the completely non-joining joints (or 'dis-joints'), which are the synovial articulations where the uttermost mobility is exerted. Cartilaginous joints (symphyses) more or less represent an intermediate scale of connecting: in humans nearly all the classical symphyses (like the ones between the vertebrae or the two pubic bones) tend to the formation of an articulating fissure. But the mentioned 'dis-connecting' extreme might also be configured to be represented by the fissures of the body cavities where organs and body walls and organs among themselves are (dis-)connected in a relationship of mobility.
Here it should be emphasized that such considerations are only true in a phenomenological and functional approach and do not tell anything about the conditions in which and by which those tissues and structures differentiate. In phenomenological terminology however it may be stated that the primary connective tissue can 'connect' ('bind') and can 'dis-connect' ('create room'). In a way this is recognized by Gray's Anatomy when they state that "joints in principle are connections between bones (*arthroses*)" but that the "specialized connective tissues of the constituted joints can be either solid or develop a cavity" (Gray's Anatomy 39th ed., 2005) The synovial joints are called *diarthroses* and in principle connect two enchondral bones (with the mandibular and sternoclavicular joint as exception). The solid joints are in that view the non-synovial joints and are called *synarthroses*. Depending on what is called the 'intervening' connective tissue, these are *fibrous joints* or *cartilaginous joints*. Fibrous joints are most of the time composed of regular dense connective tissue, sometimes somewhat more fibro-elastic (sutures, gomphoses and the syndesmoses).

Later on in this essay it will be discussed that also intermuscular spaces might appear in two ways of connectivity. On the one hand as a kind of 'mobile joint' in the form of sliding and slipping spaces with loose areolar, bursa-like connective tissue as 'dis-connecting' medium. On the other hand as mechanical intermuscular septa constituted by regular dense connective tissue, appearing as tough connecting membranes offering an insertion area to the neighboring muscle fascicles (*vide infra*). This also includes the view that in general fasciae might exhibit two appearances with different mechanical and functional consequences. It will be explained that by means of an alternative dissection procedure by which not organs or discrete anatomical structures but different types of tissue elements are dissected from each other, two types of fasciae may be recognized in the musculoskeletal system in the context of the architecture of the collagenous connective tissue. 1) There exist muscular fasciae adjacent to spaces filled with loose areolar connective tissue ('sliding tissue') and sometimes adipose tissue that are situated intermuscularly. They enable the sliding and gliding of tendons and muscles against each other. 2) There also are intermuscular and epimysial fasciae that serve as areas of insertion for neighboring muscle fibers which in this way can reach mechanically a skeletal element over and via those fasciae (Van Mameren, 1984).

Often the continuum and continuity of the 'connective tissue apparatus' in the human is emphasized, in particular in osteopathic circles. Such a view is completely in harmony with the view described here, in particular if one considers the formation of cracks and fissures ('articulating spaces') as a way of 'connecting', enabling mobility. The manifold appearance of the functional quality 'connecting' and 'intermediating' however sometimes obscures the principle function of connective tissue. This problem is reflected in the wavering and divergent classifications that are given in anatomical and histological textbooks as to connective tissue. Gray's Anatomy categorizes as follows (Gray's Anatomy 39th ed., 2005). First category is the *connective tissue proper*. They are called "proper" because they are the types usually meant when the phrase "connective tissue" is being applied. *Areolar* (or 'loose') *connective tissue* "holds" organs and epithelia "in place", and has a variety of fibers, including collagen and elastin. *Dense connective tissue* forms ligaments and tendons. (Some classification systems include fibrous connective tissue instead. It is roughly equivalent to regular dense connective tissue.) To the *connective tissue proper* also is counted: elastic tissue, reticular connective tissue (the latter forming a soft skeleton to support the lymphoid organs like lymph nodes, bone marrow, and spleen) and adipose tissue containing adipocytes and used for cushioning, thermal insulation, lubrication (primarily in the pericardium) and energy storage. After the second category of *embryonic connective tissues* Gray's Anatomy discriminates *specialized connective tissue* as third category which consists of bone, cartilage and blood. Although classified as connective tissues, the latter three are often considered separately. The last two in this category are classified as "supportive connective tissue": bone (osseous tissue) makes up virtually the entire skeleton in adult vertebrates and "cartilage in most other vertebrates it is found primarily in joints, where it provides cushioning". Blood functions in transport which in the categorization attempted in this article also is a way of 'connecting' and 'mediation'. It is obvious that such a classification is not very consistent in its categories and not based upon functional criteria.

As to fascia again the usual classifications tend to inconsistency. After that Gray's anatomy first gives a definition of fascia as "masses of connective tissue large enough to be visible with the unaided eye" (Gray's Anatomy 39th ed., 2005) they mention various examples of fasciae. There are fasciae as sheaths around nerves and vessels, fasciae "**on the surface**" of muscles and organs and in between movable muscles, meant as "mechanical isolation", whatever they mean by that. Special reference is made by Gray's Anatomy to the *superficial fascia* and to the *deep fascia*, the latter in particular developed in limbs where it condenses to thicker non-elastic sheaths and cases around the muscles. Again it is obvious that the anatomical discrete structure (for instance muscle) here is considered as reference and that the fascia is defined as a kind of secondary auxiliary envelop. Take a scalpel and dissect it away or dissect two neighboring muscles, 'clean' them from the fascial layers and one disrupts a continuity where it *in vivo* exists.

Connective tissue in the musculoskeletal system – two faces of the fascia

In the kinesiology science usually **two** components are assumed to exist in the musculoskeletal system in order to convey mechanical forces and stresses over (along) the synovial joints. In the first place there exist regular dense connective tissue structures (likes ligaments) that convey (transmit) those forces ‘passively’. Secondly, there are the muscles as the ‘actively’ forces conducting components which are organized *in parallel* to the former structures. In this view ligaments can only perform their force conveying and stresses transmitting function in a very particular position of the joint (or: of the articulating bones) i.e. when they are stretched and loaded in a certain joint position (‘passively’). On the other hand muscles are capable of this function in varying positions of the joint because they are able of a continuous adaption in length (‘actively’). This is presented in Figure 1. In this schedule it is also obvious that if the peri-articular connective tissue (like capsules and ligaments) is considered to play a role in providing mechanoreceptive input for the quality of stathesthesis and kinesthesis (proprioception) in the CNS, it can only be triggered in a particular joint position i.e. when the connective tissue at stake is stretched.

In the late eighties of the twentieth century anatomists of the University Maastricht, The Netherlands started to challenge this concept by studying the architecture of regular dense connective tissue complexes in the musculoskeletal system *s.s* and in the cubital region in particular. This work was mainly performed by Van Mameren, Drukker and Van der Wal and lead to several publications (Mameren & Drukker, 1984) (Drukker, Mameren, & Wal, 1983). Primary impulse for the ‘alternative’ way of dissection that was developed here, was the notion that in experimental conditions it was challenged that a synovial joint like the human elbow joint was stabilized by so-called ligamentous structures. In a dissected model of the human elbow joint in which ligaments were cut, stability was maintained adequately (Mameren H. v., 1983). Such and other findings challenged our ideas about the mechanical architecture of the peri-articular structures in that region and their role in the transmitting of forces and stresses along the elbow joint. In the next passages it has to be realized that with ‘connective tissue’ is meant *regular dense connective tissue (rdct)* unless mentioned otherwise.

The central prerequisite in the ‘alternative’ dissection procedure that was applied here was to maintain continuity of the connective tissue (if present) by a connective tissue sparing dissection procedure. In the lateral elbow region that served as the primary experimental target region, the antebrachial fascia (*fascia antebrachii*) was not removed but opened by longitudinal section parallel to the length axis of the muscles underneath. Thereafter the fascia was released from the muscle fibers of the underlying muscles that were immediately attached to it. For the superficial extensor muscles that were involved, this was not a problem in the distal third of the so-called muscle belly where they change to the peripheral tendons. Here underneath the fascia a ‘gliding and sliding’ layer of loose areolar tissue was found, nearly like the tissue to be expected in areas of tendinous bursae. At this level the various muscles of the dorsal antebrachial region were presented as the anatomical separated structures and entities as they are conceptualized in the anatomical dissections and textbooks.

Figure 1 Opening of the antebrachial fascia in the distal region. Intermuscular loose areolar connective tissue

In the proximal half of the forearm the situation appeared to be totally different. Here the antebrachial fascia served as an area where muscle fibers of the underlying muscles where attached to (inserting). So only a sharp cutting procedure could ‘remove’ the fascia from the underlying muscles. Actually this was not done but after separation of the two types of tissue the fascia was left in situ. Moreover it appeared that the proximal muscle belly fibers also were tightly connected with and originating from strong connective tissue layers that were situated intermuscularly and that were immediately continuous with the superficial layer of connective tissue i.e. the fascia. It came out that in the whole proximal lateral cubital region a complex apparatus existed constituted by regular dense connective tissue layers that mainly consist of muscle compartment walls. Those layers were situated on top and deep to muscles (epimysial layers) but also intermuscularly. From all those layers, that are in fact part of ‘ muscle cases’, muscle fibers originate. The layers themselves converge towards the lateral humeral epicondyle. In fact there were hardly **no** muscle fibers inserting to the epicondyle directly. Only of the most superficial part of the *extensor carpi radialis* muscle a part of the muscle fibers was originating from (inserting to) the supracondylar humeral periost. Also there could in the superficial lateral cubital region not be described collagenous fibers running form bone to bone like the *collateral radial ligament* is always described. The majority of the collagenous fibers in the proximal lateral cubital region is interposed between skeletal tissue and muscle fascicles. No **separate** entity like a *collateral radial ligament* could be demonstrated and described.

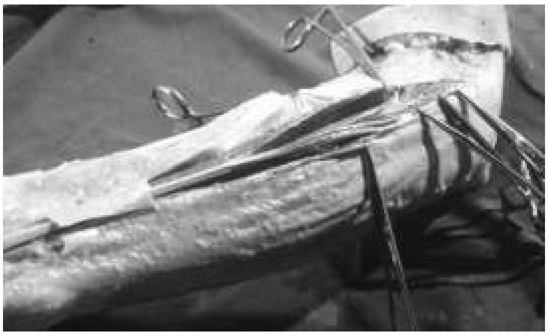


Figure 2 The compartment walls of the proximal muscle compartment of the third extensor digitorum muscle opened and dissected from the muscle fibers

Figure 3 Proximal lateral elbow region. Muscle are dissected away from the epicondylar connective tissue apparatus and reflected (to the left). The convergence of the remaining muscle walls towards the lateral humeral epicondyle is clearly presented.

Figure 4. Lateral proximal forearm region. Muscles and muscular tissue have been removed. The most proximal extensions of the muscle compartment walls (the epicondylar connective tissue apparatus or LCFTS, see text) are left in situ

Next we more or less recapitulated the dissection as it is usually performed in the dissection room. In this procedure **muscles** are dissected and taken out. If one does so, the knife (scalpel) has to cut sharply away the proximal muscle bellies of the extensor muscles, in this way '**leaving in situ**' strong bands of collagenous connective tissue that could be identified as *collateral radial ligament*. But that structure was therefore dissected our as an artifact! The same is true for the usually described *annular radial ligament*. In the alternative connective tissue sparing method the proximal portion of the *supinator* muscle appears as a broad and long aponeurotic structure. This aponeurosis is an integrate part of the afore mentioned and revealed *epicondylar connective tissue apparatus*. It merges with the other layers and in this way becomes an integrate part of it also converging to the lateral humeral epicondyle. **Not any** muscle fiber of the *supinator* muscle has a boney insertion on the humeral epicondyle. Again, when one however ' dissects' the supinator muscle 'out' , only then a strand of collagenous connective tissue remains that could be identified as *annular ligament*. However the constituting collagenous fibers run in proximodistal direction (and **not** in a more or less circular ('circumradial') direction as it is nearly always represented in anatomy books. And they exhibit cut edges, indicating that again a mechanical continuity has been distorted in the effort to dissect ligaments and muscle as parallel structures. On the contrary most muscle fascicles in the proximal joint region are organized **in series** with the connective tissue of this apparatus.

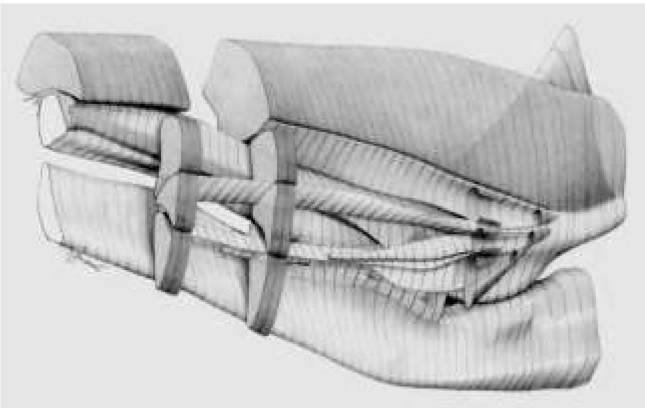


Figure 5 Reconstruction of the epicondylar connective tissue system in the rat. With exception of the ECR muscle the muscle tissue is mainly not represented. Left elbow, lateral view

It was concluded that in the proximal lateral cubital region there exists a complex apparatus of collagenous connective tissue layers which mainly consist of muscle compartments walls. These converge towards the lateral humeral epicondyle and the ulnar olecranon. The majority of the collagenous fibers in the proximal lateral cubital region is interposed between skeletal tissue and muscle fascicles. Only a small portion of them runs from bone to bone and in this respect may be classified as ligamentous fibers. No **separate** entities like collateral and/or anular ligaments can be demonstrated and described. Therefor most muscle fascicles in the proximal joint region are organized ***in series*** with the connective tissue of this apparatus. So in that region **muscle/connective tissue units** are to be distinguished which form the functional units that transmit tensile stresses over the elbow joint. In these units muscular and collagenous connective tissue are organized *in series.* They do not coincide with the usual anatomical classification into muscles and ligaments. In the distal extent of the foreleg, such functional units indeed coincide with muscles and their distal tendons (as functional ánd morphological entities).

This quite different architecture that was revealed has consequences for the way in which one interprets the conveying of tensile forces and stresses over a synovial joint. In principle two types of forces have to be handled and conducted in a musculoskeletal system with synovial joints, the way in which the main part of the human locomotion system is organized. Compressive loads are conveyed through the skeletal elements and their surfaces (joint surfaces). The other category of forces are the tensile forces (stresses) which may considerably vary in direction (torque, shear, extension and everything in between). Usually it is assumed that there exist **two** components in the musculoskeletal system in order to convey those mechanical stresses over (along) the synovial joints. In the first place there exist regular dense connective tissue structures (likes ligaments) that convey (transmit) those forces ‘passively’. Secondly, there are the muscles that serve as the ‘actively’ forces conducting components which are organized in parallel to the former structures. In this view ligaments can only perform their force conveying function in a very particular position of the joint (or: of the articulating bones) i.e. when they are stretched and loaded in a certain joint position (‘passively’). On the other hand muscles are capable of this function in varying positions of the joint because they are able of a continuous adaption in length (‘actively’). This is called here the *in parallel* view and it demonstrated in Figure 1.

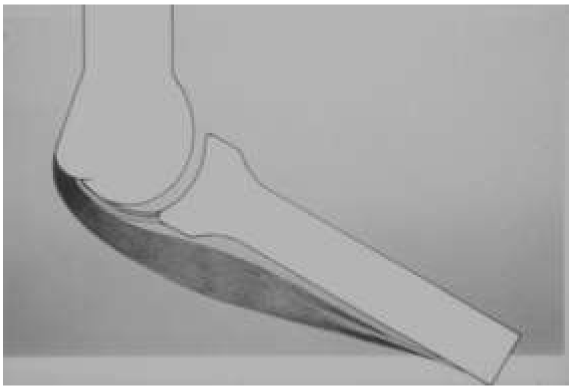


Figure 6a The ‘classical’ *in parallel* organization. From inside to outside: articular capsule, next reinforcing iuxta-articular regular dense connective tissue structures (ligaments) and on the outer side peri-articular muscle

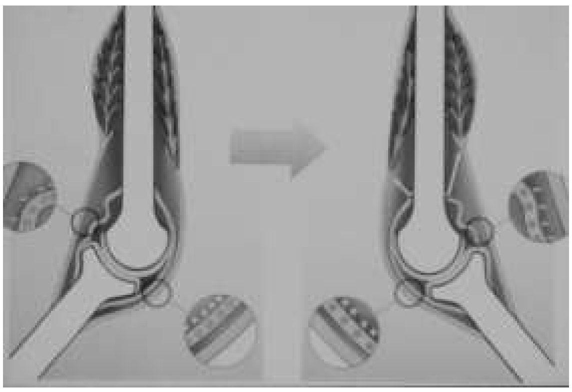


Figure 6b The ‘classical’ organization principle of iuxta-articular connective tissue running form bone to bone, organized *in parallel* to the muscular component. Only in a particular position of the joint the connective tissue can transmit forces or signal in the sense of mechanoreceptor triggering (++++ versus -----)

A similar type architecture and organization was also revealed in the rat, the experimental animal in which we studied the organization of the morphological substrate of proprioception (Mameren & Wal, 1983). Again the majority of regular dense connective tissue structures in the proximal lateral cubital region however appears to be interposed between skeletal periosteum and muscular tissue. Most deep as well as superficial regular dense connective tissue structures are organized in series with muscle fascicles. Collagenous fibers running from bone to bone - thought to be stressed passively by displacement of the articulating bones - hardly occur.In both situations there occur broad aponeurotic layers of regular dense connective tissue to which relatively short muscle fascicles insert that - on the opposite side - are directly attached to skeletal elements. Such configurations of muscle fascicles attached to the periosteum of one articulating bone and via a layer of regular dense connective tissue indirectly attached to another articulating bone, could be considered to be "dynamic ligaments". Such "dynamic ligaments" apparently are not necessarily situated directly beside the joint cavity or in the deep part of the joint region.

In an *in series* configuration, as in nearly all the proximal collagenous connective tissue structures in the region, the role of the collagenous fibers in the conveying of tensile stresses also depends on what muscle fascicles are active. *In vivo* not only displacement of bones influences the state of stress and strain of connective tissue structures (passively), also muscular action may do so. In an architecture as described here no adequate basis exists for the distinction between passively and actively joint-stabilizing structures - organized *in parallel* to each other - i.e. muscles and ligaments. The exclusive role of the joint capsule and its reinforcements in the passive conveying of tensile stresses - already questioned by Van Marneren (1983) and Drukker et al. (1983a) on the basis of experiments - can no longer be accepted. The functional units involved in the transmission of forces do not consist of topographically defined and separate entities of muscular ór collagenous connective tissue. Collagenous connective tissue structures are not either ligamentous structures or auxilliary muscle structures. For instance, a structure like the supinator aponeurosis (or: supinator septum in the rat) may be classified as epimysial fascia but also as aponeurose or tendon and even as a ligament (with adjustable length and tension). The usually implicitly assumed topographical orientation of constituents of the locomotor apparatus, passively or actively involved in the maintenance of joint stability and integrity - i.e. deep (ligaments) respectively superficial components (muscles) - is also challenged by the *in series* architecture described here.

So ligaments cannot be distinguished as separate entities in the lateral cubital region of man and the rat. For instance, an anular ligament cannot be discerned. The proximal extension of the compartment wall of the supinator muscle or so-called supinator septum could be mistaken for it. If the supinator muscle would be dissected as an entity by sharp cutting, a structure like the anular ligament would remain. The functional continuity of the supinator muscle and the regular dense connective tissue lining with its proximal continuation (the supinator aponeurosis or septum) would be artificially interrupted by this procedure. In the studied proximal lateral cubital region there exists **one** joint stability system in which muscular tissue and regular dense connective tissue mainly function in an *in series* situation and is schematically presented in Figure 2. *In vivo* the peri-articular connective tissue (which is not necessarily identical with iuxta-articular) is being loaded and stretched by the movement of related skeletal parts , guided by the tension (and changes in that) of the muscle tissue inserting to this connective tissue (Van Mameren).

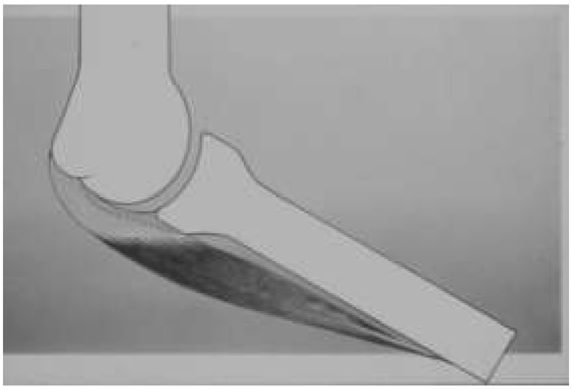


Figure 7a The ‘alternative’ *in series* organization. From inside to outside: articular capsule, next peri-articular regular dense connective tissue *in series* with peri-articular muscle

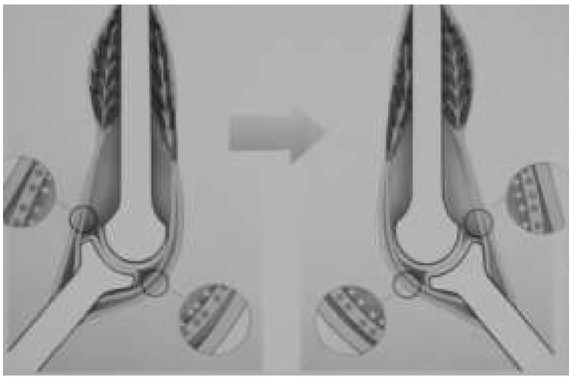


Figure 7b The ‘alternative’ organization principle of iuxta-articular connective tissue organized *in series* to the muscular component. In all joint positions of the joint the connective tissue is brought to tension, is capable of transmitting forces and signalling in the sense of mechanoreceptor triggering (++++ and ++++)

Van Mameren et al. propose to value the existence this connective tissue architecture by defining a *lateral cubital force transmission system (LCFTS)*. In other publications they showed that this system can also be made visible in MRI-section of the region. It is obvious that this approach reveals a principle that can be recognize in many other areas and regions of the body. A similar connective tissue architecture could be described for the opposite region: a *medial cubital force transmission system (MCFTS)* has been revealed.

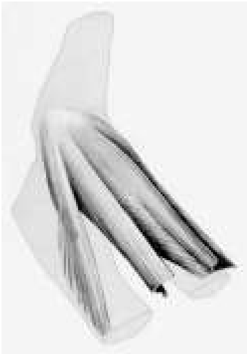


Figure 8a The LCFTS. Only the connective tissue components are represented

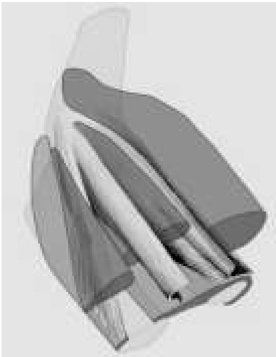


Figure 8b The LCFTS. Compared to figure 8a also the muscles are represented

Only such an architectural approach brings to light that fasciae exhibit a variety as to their mechanical relationships with neighboring tissue and therefore may play quite different functional roles, for example sometimes rather should be understood as aponeuroses. The nomenclature 'Fascia' should therefore be considered and reevaluated critically in every region. The 'classic' fasciae of the organs (also of muscles) usually represent the first type of fasciae mentioned here ('gliding fasciae') with in that case the coelom as 'joint space'. Also many epimysial muscle fasciae function in this way. A fascia like the *fascia cruris* however rather functions as an epimuscular aponeurosis

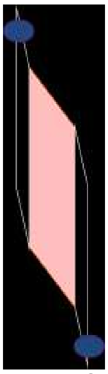


Figure 9 Schematic diagram of the 'dynament' as architectural unit. Proximal a rdct layer (membraan, aponeurosis, septum, etc.) with muscle fascicles attached to it, mostly extra-muscular. Distal a rdct layer (tendon, aponeurosis, etc.) with muscle fascicles attached to it, mostly intra-muscular. In this basic situation the muscle component is organized as intermediate between two rdct structures. *Rdct = regular dense connective tissues*

Usuualy we tend to think in units of muscle and ligamenst (caouslar reinforvement_ as twe the compneetn that may cooevcet two skeletal elemsnast and that serev as the firce trasmmsisosb sybstarte. Pheneoenlogicaal one coudkl consider huypotheist the exstsien of dynamsmst as the architectural unet o th emusculatskelet syeten. Wuith this is menet a unit of regular dens coemnecte tissue coneected to a perisost or skete elemen with atatache (instead) to it mascle fascicle. Distaly ther is the tedeno as susbrare of regular dense conecetie tsise also with muscle facsile inserting to it. So an funadmenetal dyanmenet would look like this:

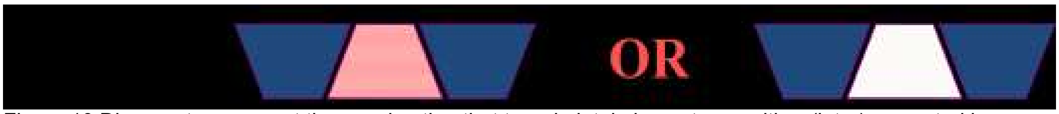


Figure 10 Diagram to represent the usual notion that two skeletal elements are either (inter)connected by connective tissue (ligaments) or with muscular tissue (muscles with auxiliary structures)

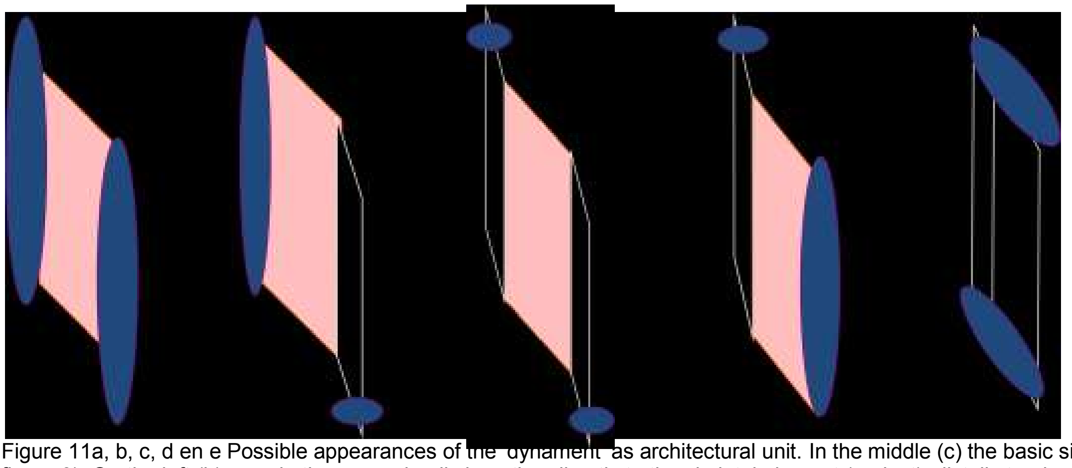


Figure 11a, b, c, d en e Possible appearances of [redacted] as architectural unit. In the middle (c) the basic situation (see figure 9). On the left (b) muscle tissue proximally inserting directly to the skeletal element (periost), distally tendons. On the right (d) muscle tissue distally inserting directly to the skeletal element (periost), proximally septa en aponeursoses. On the extreme right (a): only muscular fascicles, no intermediating rdct structure, a ‘typical muscle’. On the extreme left (e): no muscle tssue intermediating, only rdct, a ‘typical ligament’. *Rdct = regular dense connective tissues*

The architecture of connective tissue instrumental in Proprioception.

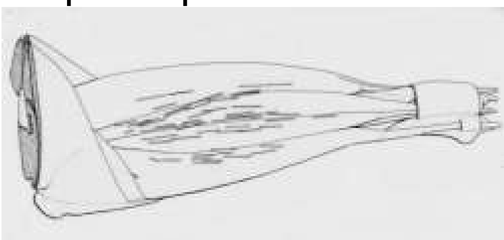
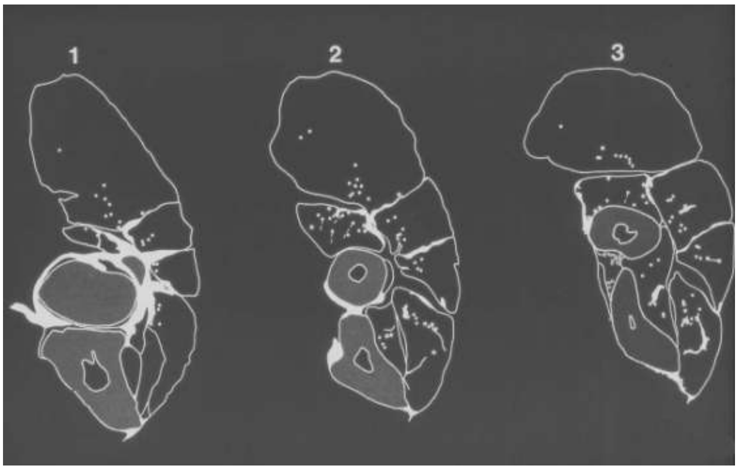


Figure 12a The spatial distribution of muscle spindles in the superficial lateral forearm muscle in the rat. The distribution is clearly more related to the architecture of the proximal epicondylar connective tissue apparatus than to the topography of the muscles



The architecture of the connective and muscle tissue is more important for understanding the mechanical and functional circumstances as to the conveying of forces and stresses over a given joint than is the classical anatomical order of muscles and ligaments.
This also concerns the spatial organization of **mechanoreceptors** (proprioreceptors) in such regions. The spatial organization of such receptors can better be understood and interpreted functionally by means of the architectural relationships than from a stance in which muscles and ligaments are considered to be separate entities organized *in parallel* to each other as to the conduction of tensile stresses. The discrimination between so-called joint receptors and muscle receptors therefore may be considered as an artifact in a functional respect (Van Mameren, Van der Wal). Mechanoreceptors, also the so-called muscle receptors, are arranged in the context of force circumstances i.e. of the architecture of muscle and connective tissue rather than of the ‘classical anatomical structures’ like muscle, capsules and ligaments.

A spectrum of mechanosensitive substrate occurs at the transitional areas between the regular dense connective tissue layers and the muscle fascicles organized in series with them. This substrate exhibits features of type and location of the mechanosensitive nerve terminals that usually are considered to be characteristic for "joint receptors" as well as for "muscle receptors".

Based on architecture and spatial distribution of the substrate of proprioception, it may be assumed that the "joint receptors" in the studied region are also influenced by the state of activity of the muscle organized in series with the collagenous connective tissue in or near which those receptors occur. Therefore, they may function as "muscle receptors".

The muscle spindles and Golgi tendon organs in the lateral cubital region of the rat are concentrated in those areas where - in view of the description of the architecture of the muscular and tissue - the conveying of tensile stresses over the elbow joint is expected to take place.

The usual distinction between joint receptors and muscle receptors is not valid in the concept in which muscular and collagenous connective tissue (structures) function in series while maintaining joint integrity and stability. In vivo those connective tissue structures are strained during movements of the skeletal parts induced and led by tension (alterations) in muscular tissue.

The spatial organization of muscle spindles and GTO's in the region is such as to enable the monitoring of stresses conveyed over the elbow joint as well as of movements of the articulating bones. This allows to classify those receptors in this situation also as "joint receptors".

The morphological substrate of proprioception in the lateral cubital region of the rat is concentrated in those areas where -based on the description of the architecture of the muscular and connective tissue -the conveying of tensile stresses over the elbow joint is expected to take place.

A mutual relation exists between structure (and function) of the mechanoreceptors and the architecture of the muscular and regular dense connective tissue. Both are instrumental in the coding of proprioceptive information to the CNS.

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[1] For example in Wikipaedia 2009 the Musculoskeletal System is defined as “that part of the body that is essential for the capacity of motion and movement, such as the skeleton, the muscle and the joints”.