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From the Concept of Muscle Chains to Complex Systems

1. A historical and scientific evolution

The concept of “muscle chains” has historical roots that precede its modern clinical systematization by many decades.

In 1875, Reuleaux introduced the concept of the “kinematic chain” as a mechanical system in which the movement of one segment has defined relationships with every other segment in the system.

Later, in 1924, Baeyer defined the “kinematic articular system,” shifting the idea of simple anatomical segments toward components of a more complex system.

From the 1940s and 1950s onward, several researchers in physiotherapy began to observe clinically that groups of polyarticular muscles appeared to behave as integrated functional systems.

Among these pioneers, Françoise Mézières, in France, proposed in the late 1940s the idea of muscles that “overlap like the tiles of a roof,” forming myofascial chains.

In the following decades, several schools developed different classifications:

- Souchard developed Global Postural Reeducation
- Busquet proposed muscular and articular chains
- Myers introduced the concept of “myofascial meridians” in *Anatomy Trains*

Each of these approaches shared the empirical observation that muscles operate in interconnected systems, although through different applied models.

1.1 From empiricism to science

The evolution of the concept of muscle chains shows the gradual transition from empirical intuitions to scientific explanations.

The clinical observations of the pioneers, although initially lacking rigorous mathematical models, highlighted real phenomena that the physics of complex systems can now explain formally.

This evolutionary process reflects the way science progresses: from empirical observation to theoretical understanding, and from theory to experimental validation.

1.2 The conceptual leap: from linear systems to complex systems

This chapter addresses the transition from the concept of muscle chains toward a broader understanding of complex systems.

While the early theories of muscle chains were based on linear interpretative models, modern

complex systems science offers mathematical and physical tools for understanding the behaviour of the musculoskeletal system.

Nonlinear mathematics and complex systems theory explain phenomena that the traditional view could not interpret: how small dysfunctions can generate widespread symptoms, why compensations are often unpredictable, and how the body is able to develop adaptive strategies. These concepts represent the application of advanced physical principles to the musculoskeletal system.

1.3 Complex systems: definition and scale of observation

A complex system can be defined as any “thing” composed of more than one element. This definition contains an essential characteristic: the scalar and infinitely divisible nature of complexity.

The concept of a complex system functions like an open hourglass, expanding both toward the micro and toward the macro.

Each individual represents a complex system in relation to their own subsystems—visceral, neurological, musculoskeletal, and so forth.

Each of these subsystems can in turn be broken down into further subsystems: the musculoskeletal system can be divided into regions, each region into joints, each joint into specific components, and so on toward the infinitely small.

The same logic applies in the opposite direction: the individual becomes a subsystem when one wishes to study the behaviour of a population, which in turn becomes a subsystem in the analysis of continental or planetary phenomena, proceeding toward the infinitely large until the whole universe is included.

Only in quantum physics do elements exist that are not further divisible.

For general physics, any system can be decomposed into smaller elements: it is simply a matter of having the appropriate tools to do so.

This characteristic of infinite divisibility and recombination represents one of the defining properties of complex systems.

2. The four characteristics of complex systems

What is commonly called a “muscle chain” actually represents an example of a complex system governed by precise and predictable physical laws.

The aim is not to replace classical concepts, but to provide them with a scientific basis that explains how they work and expands their possible applications.

3. First characteristic: interdependence and interaction of elements

In a complex system, all the elements that compose it are interdependent and interacting.

The classic example is the spider’s web: if one portion is acted upon, the entire web must adapt to the change.

Applying this principle to the musculoskeletal system, any segmental action localized to one body region will determine adaptations in adjacent regions.

These adaptations may be corrective or negligible, but they may also be aggravating.

If the regional action is corrective with respect to skeletal axes but produces an increase in the energy of the system—in the sense of increased muscle tone—systemic aggravations greater than the correction obtained will occur.

3.1 Clinical examples of interdependence

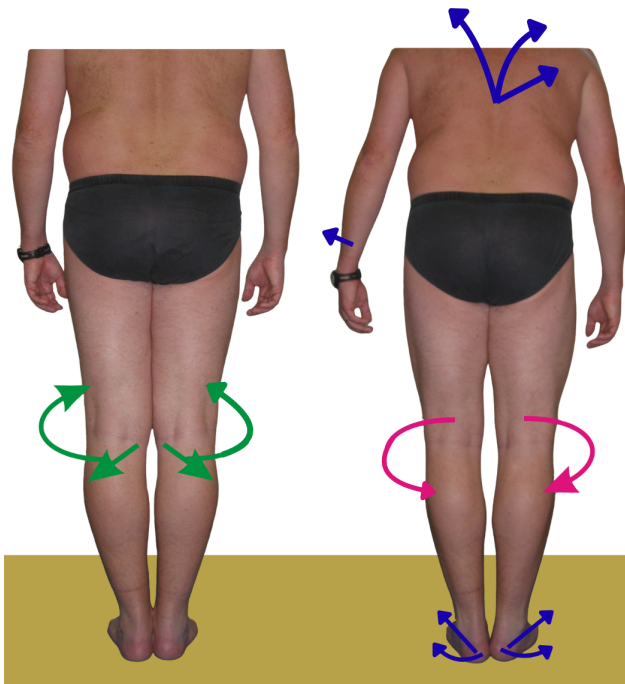


Fig. 01 - In the habitual posture, photograph on the left, the patient shows internal rotation of the lower limbs, highlighted by the posterior projection of the medial femoral condyles (green arrows). When asked to perform active correction, photograph on the right (magenta arrows), and with passive correction as well (not shown), modifications in body alignment become evident (blue arrows):

- anterior flexion of the trunk and lateral displacement;
- abduction of the upper limb;
- widening of the base of support with transfer of load toward the lateral border of the foot;

with consequent greater difficulty in maintaining upright stance and a systemic increase in muscle tone. In this case, the aggravating systemic components derived from the local corrective action are greater than the positive effect of the correction itself.

In the previous example, the local correction required high-intensity activation of some muscle groups. In the following example, by contrast, the corrective request is theoretically low in energy expenditure: derotation of the upper limbs, which should occur simply through activation of the humeral external rotators.

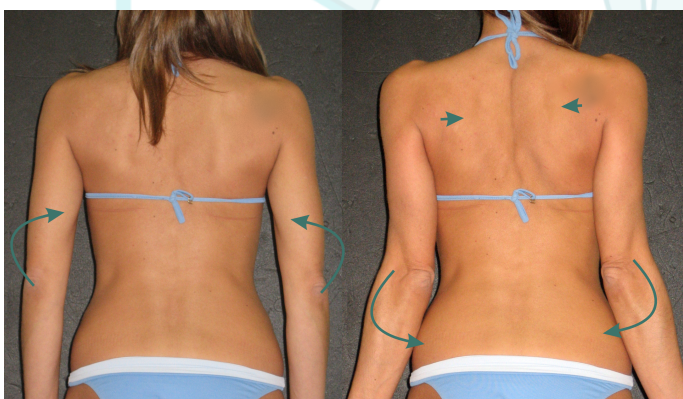


Fig. 02 - Photograph on the left: patient in habitual posture, showing internal rotation of the humeri. Photograph on the right: external rotation of the humeri is requested. Although no shoulder problem is present, the patient co-contracts, together with the external rotators, other muscle groups that produce scapular adduction skeletally, with anterior projection and compression of the thoracic vertebrae and increased tone. Here too, systemic aggravation is greater than the correction obtained.

It is therefore possible that attempts at self-correction—the parent telling a child to “stand up straight,” self-corrections in front of a mirror, or segmental instructions during movement—may conceal the risk of structural aggravation.

Therapeutic interventions must therefore also be modulated in order to avoid the onset of “mathematically certain” problems.

4. Second characteristic: systemic understanding is necessary

Understanding the functioning of a complex system can only occur by considering the system as a whole.

This means that, in order to interpret the meaning of the segmental strategies—both static and dynamic—that the system puts into action, it is necessary to observe the links between the altered regional pattern and the overall patterns.

It also means that the symptom may be the expression of a local disorder, a referred disorder, or a systemic disturbance.

To identify the central origin of peripheral symptoms, one must rely on an overall musculoskeletal analysis, on the use of dermatomal charts and peripheral innervation charts; analytical and systemic testing will make it possible to detect the dominant factors interfering with muscular balancing and to distinguish between primary and secondary shortenings.

5. Third characteristic: emergent abilities and substitutive moments

A complex system, in pursuing its goals, is able to generate solutions that cannot be predicted from examination of the individual elements.

In other words, it is able to generate “emergent abilities.”

This third characteristic has very important therapeutic implications.

It essentially means that, when carrying out an action, the muscles anatomically assigned to that action will not necessarily be the only ones used.

These muscles may be replaced or accompanied by muscles that, according to a vector analysis based on linear mathematics, should not or could not come into play.

Substitutive moments are therefore produced.

5.1 The two contexts of substitutive moments

These moments appear mainly in two situations:

5.2 Substitution for energy optimization

From physics we know that force couples, compared with single forces, offer the advantage of performing better work while using less total energy.

Almost all muscles can make use of synergists as force couples, whereas others remain “isolated”

and vectorially subdominant in their agonist or antagonist role.

Some examples include: the rectus abdominis in lowering the thorax during active expiration; the serratus anterior in scapular abduction during anterior projection of the upper limb; the rectus femoris in anterior propulsion of the ipsilateral hemipelvis during gait and in balancing pelvic retroversion while climbing stairs; and the hyoid muscles during mandibular opening.

The cortical centres, that is, the pyramidal system, identify the movement goal, the “what,” whereas the “how” is controlled by the subcortical centres, the extrapyramidal system, through a mapping called the body schema.

The “what” takes priority over the “how.”

If the antagonists to the target movement are excessive in resistant force, that is, shortened, the isolated muscles become vectorially subdominant and unable to perform the action.

Because the action takes precedence over its execution mode, these muscles will be integrated by others through emergent coordinative patterns that allow a goal-directed action through alteration of physiological skeletal movement.

The neuromuscular system develops coordinative strategies that transcend the isolated anatomical function of the individual muscle, creating unexpected vector resultants through the synergistic activation of muscle groups not predicted by segmental analysis.

Examples of substitutive strategies

Case of humeral external rotation: In Figure 2, the “excessive” skeletal reactions to the simple request for humeral derotation were highlighted.

More specifically, palpation and visual observation show involvement not only of the scapular adductors and the upper trapezius fibres, but also activation of the latissimus dorsi and the subscapularis.

The patient used the humeral internal rotators to support the external rotators.

How the humeral internal rotators can contribute to external rotation through unconventional recruitment patterns cannot be explained by isolated vector diagrams: this is an emergent ability that the system uses through complex synergistic coordinations to achieve the “what” in the “here and now.”

Substitutive respiratory strategy: In physiological quiet inspiration, the diaphragm, after descending, should allow its costal insertions to increase the transverse volume of the rib cage.

If, for example, the latissimus dorsi opposes resistance to lateral expansion of the thorax, because respiratory function has priority, the diaphragm, through its vertebral insertions and together with the psoas with which it forms a force couple, will lift the thorax by increasing lordosis.

The increase in lordosis will be confirmed visually by the abdomen appearing to “inflate.”

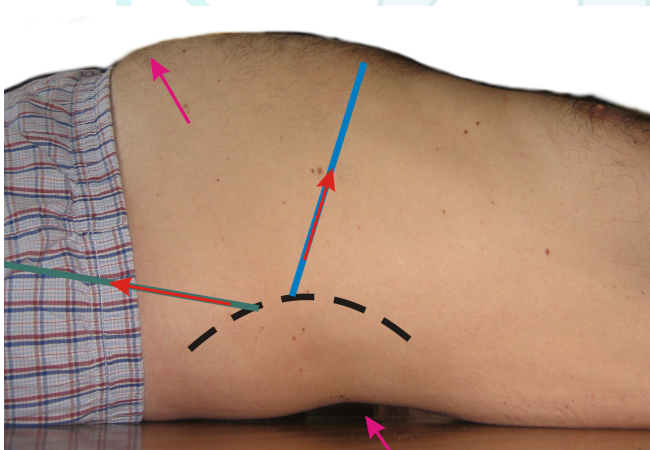


Fig. 03 - Diaphragmatic crura: blue; psoas: green. During inspiration, the patient uses the diaphragm-psoas pair in substitution for the costal dynamics of the diaphragm. The thorax lifts and the hypogastric area expands as a mechanical resultant of the anterior projection of the thoracolumbar spine (magenta arrows).

Frequently substituted muscles

The muscles that tend to be substituted are not random but predictable according to the mathematical logic of force couples:

- infrahyoids
- serratus anterior
- rectus abdominis
- triceps brachii
- quadriceps femoris
- monoarticular muscles in general

These correspond to the muscles that, in the historical literature on muscle chains, were empirically identified as “non-integrated elements,” and now find a mathematical explanation in the theory of force couples.

5.3 Protective strategies and muscular blocks

The second line of investigation into substitutive moments is aimed at identifying articular blocks that are not mechanical but muscular, intended to protect against possible direct or indirect mechanical conflicts.

The absence of pain is not necessarily synonymous with the absence of latent or potential pathology.

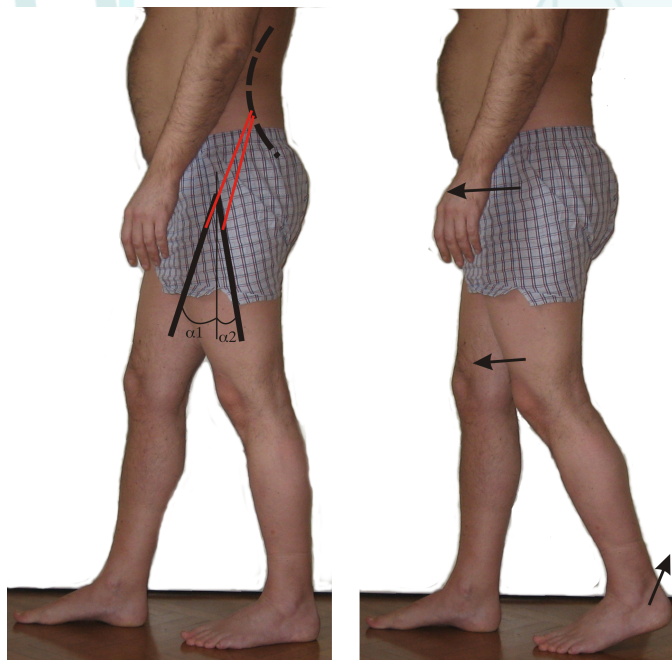


fig 1

fig 2

Fig. 04 - During gait, in the phase in which both feet are on the ground, the patient shows limited hip extension. Relative to the vertical axis, angle alpha 2 is smaller than angle alpha 1 (fig. 1). Once angle alpha 2 is reached, flexion of the lower limb and anterior projection of the pelvis begin (fig. 2). In this case, the limitation of extension could be due to a protective mechanism that limits tensioning of the iliopsoas (red segments), which would in turn increase lumbar lordosis.

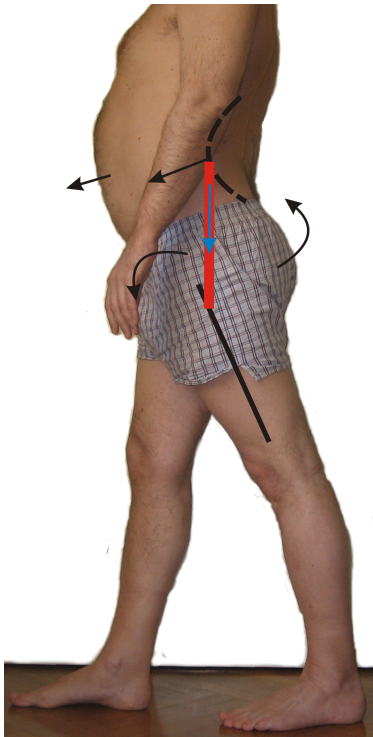


Fig. 05 - The patient was asked to perform greater hip extension while maintaining the foot on the ground; the articular test did not reveal any coxo-femoral problem. As a consequence of the action, the patient reported the appearance of pain in the lumbar region, which had not been perceived during spontaneous gait.

Visually, the following become evident (black arrows):

- *anterior tilt of the pelvis*
- *anterior projection of the lumbar spine*
- *anterior projection of the hypogastric region*

The hypothesis is that hip extension places the psoas under tension (red). The limitation of coxo-femoral range therefore appears to be functional to the protection of potential latent conflicts in the lumbar region.

5.4 Therapeutic implications

From a therapeutic perspective, it is important to detect the substitutive strategies in action and create the conditions for isolated muscles to recover their anatomical function.

This can be achieved through recovery of length in the “braking” muscles, those in excess resistant force, so that the subdominant muscles are freed and automatically reintegrated into systemic function.

The goal is not to strengthen the subdominant muscles, but to free them from interference by the dominant muscles.

6. Fourth characteristic: equilibrium at the edge of chaos

The concept of Equilibrium at the Edge of Chaos is derived from nonlinear dynamics theory and deterministic chaos theory, where it represents the condition in which a complex system operates with maximum efficiency and adaptability.

Biomechanically, this state is identified by the dominance of Working Force over Resistant Force. In this region, the system responds optimally to small signals, or perturbations, modifying its state with minimal energy expenditure.

A complex system therefore uses its energy most effectively when it operates at the “edge of chaos,” that is, when the elements of stability and dynamism are in a balance that allows small

signals to modify the state of the system.

Applied to the muscular system, this occurs when Working Force is dominant over Resistant Force, when dynamic elements prevail over static ones, which are calibrated at the minimum necessary to guarantee articular stability: **WF >> RF**.

One of the prerogatives of complex systems is adaptability: the “edge of chaos” is the place where there is enough innovation to produce a dynamic system, and enough stability to prevent it from falling into anarchy.

If a living system approaches the dynamic margin too closely, it risks falling into incoherence; if it withdraws too far from it, it becomes rigid.

6.1 Optimal conditions

The physiological vertebral sinusoid and the physiological systemic articular sequence are possible only if there are no specific structural alterations and if all muscles work under ideal length conditions.

Under these conditions, the musculoskeletal system finds itself at the “edge of chaos,” because small signals can guide different behaviours while saving energy.

For example, it may pass from the static phase to the dynamic phase with only a small displacement of one body segment.

6.2 The self-reinforcing circuit of rigidity

If the muscular system is in a state of increased Resistant Force due to excess basal tone of the contractile component, and if this persists over time, the connective portion of the fibre becomes involved, leading to shortening of the muscles themselves, that is, primary muscular shortenings. An analogous mechanism may occur as a consequence of dysfunction in another system, producing secondary muscular shortenings.

In both cases, the consequence will be misalignment of the individual skeletal centres of gravity and loss of dynamic muscular capacity.

The system then enters a self-reinforcing circuit: misalignment of the individual skeletal centres of gravity requires greater basal contraction to maintain upright stance and dynamic function; increased basal tone produces muscular shortening, with consequent further misalignment of the centres of gravity and changes in the sinusoidal course of the spine and in the axial alignment of all the other joints.

The system moves away from the “edge of chaos” and becomes rigid.

7. Conclusions: the conceptual transformation

This conceptual transformation—from empirical muscle chains to physically demonstrable complex systems—represents the natural development of brilliant intuitions toward a complete scientific understanding of the human musculoskeletal system.

The four characteristics of complex systems offer an interpretative key to phenomena that were previously observed in reality but could not be explained, opening new diagnostic and therapeutic possibilities based on the principles of physics.

Application of complex systems theory to the musculoskeletal system transforms empirical observations into quantifiable analyses.

These four characteristics provide interpretative tools based on verifiable physical principles, making it possible to predict and understand behaviours that the linear approach could not explain.

8. Chapter summary

Historical evolution: from muscle chains to complex systems

From Reuleaux to Mézières and onward to modern complex systems theory. The transition from empirical intuitions to scientific explanations based on demonstrable physical principles.

First characteristic: interdependence and interaction

In a complex system, all elements are interdependent. Every local action produces systemic adaptations that may be corrective or aggravating, like in the example of the spider's web.

Second characteristic: understanding is only systemic

Function can be understood only by considering the system as a whole. The symptom may be a local expression, a referred expression, or the expression of systemic distress.

Third characteristic: emergent abilities and substitutive moments

The system generates solutions that cannot be predicted from examination of the individual elements. Muscles not anatomically assigned to a task may substitute in order to reach the goal, with the "what" taking priority over the "how."

Fourth characteristic: equilibrium at the edge of chaos

The system is optimal when Working Force dominates over Resistant Force. Small signals modify the state while saving energy. Rigidity means movement away from the edge of chaos.

Frequently substituted muscles

Infrahyoids, serratus anterior, rectus abdominis, triceps brachii, quadriceps femoris, and monoarticular muscles in general. These are the same muscles that Mézières empirically described as being "outside the chain."

Local corrections with systemic aggravations

If regional correction increases the energy of the system, in the sense of increased muscle tone, systemic aggravations exceed the local benefits obtained.

Protective strategies through functional limitations

Muscular, rather than mechanical, articular blocks may appear in order to prevent the expression of latent conflicts. The absence of pain does not imply the absence of potential pathology.

Scalar nature of complexity

A complex system can be expanded both toward the micro level, from joints to components to molecules, and toward the macro level, from the individual to the population to the universe. Infinite divisibility and recomposition are intrinsic properties of complexity.

References

- [1] Bar-Yam Y. *Dynamics of Complex Systems*. Reading: Addison-Wesley; 1997. [2] Kelso JAS. *Dynamic Patterns: The Self-Organization of Brain and Behavior*. Cambridge: MIT Press; 1995. [3] Strogatz SH. *Nonlinear Dynamics and Chaos*. Boulder: Westview Press; 1994. [4] Bernstein NA. *The Co-ordination and Regulation of Movements*. Oxford: Pergamon Press; 1967. [5] Latash ML. *Synergy*. New York: Oxford University Press; 2008. [6] Latash ML, Scholz JP, Schöner G. Toward a new theory of motor synergies. *Motor Control*. 2007;11(3):276-308. [7] Scholz JP, Schöner G. The uncontrolled manifold concept: identifying control variables for a functional task. *Exp Brain Res*. 1999;126(3):289-306. [8] Hodges PW, Tucker K. Moving differently in pain: a new theory to

explain the adaptation to pain. *Pain*. 2011;152(3 Suppl):S90-S98. [9] Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research into Clinical Practice*. 5th ed. Philadelphia: Wolters Kluwer; 2017. [10] Schmidt RA, Lee TD. *Motor Control and Learning*. 5th ed. Champaign: Human Kinetics; 2011. [11] Sahrmann SA. *Diagnosis and Treatment of Movement Impairment Syndromes*. St. Louis: Mosby; 2002. [12] Page P, Frank CC, Lardner R. *Assessment and Treatment of Muscle Imbalance: The Janda Approach*. Champaign: Human Kinetics; 2010. [13] Reuleaux F. *The Kinematics of Machinery*. London: Macmillan; 1876. [14] Nicolis G, Prigogine I. *Exploring Complexity: An Introduction*. New York: Freeman; 1989.

