

AIFIMM Formation

Provider CPD 21418 (UK)

CE Broker ID 50-54885 (Florida USA)

Provider ECM 1701 (IT)

www.mskbiomechanics.com

Mauro Lastrico, PT – Laura Manni, PT

Musculoskeletal Equilibrium: Biomechanical Principles and Clinical Assessment Criteria

Understanding musculoskeletal organization is a fundamental prerequisite for effective physiotherapeutic intervention. This article aims to integrate the theoretical foundations of biomechanics with an operational model of clinical assessment within the conceptual framework developed by Françoise Mézières and further elaborated by the Italian Association of Physiotherapists of the Mézières Method, AIFiMM.

The approach presented here differs from traditional conceptions through adoption of an engineering-based reference model founded not on statistical parameters of normality, but on the definition of ideal conditions of biomechanical efficiency. This perspective makes it possible to quantify the gap between the current state of the system and its optimal configuration, thereby distinguishing between functional equilibria and pathological equilibria.

PART I – THEORETICAL FOUNDATIONS

1. Biomechanical definition of bodily spatial configuration

In everyday clinical language, the term “posture” is often used in a morphological sense, designating a form to be corrected or a position to be modified. This use generates conceptual ambiguity and leads to interventions focused on the external appearance of bodily configuration, while neglecting analysis of the mechanical determinants that sustain it.

From a biomechanical point of view, however, it is necessary to define posture precisely as the expression of the physiological articular sequence, both at district and systemic level, resulting from the vector equilibrium of the muscular forces acting on the skeletal system.

This operational definition makes it possible to move beyond a purely descriptive interpretation: the spatial configuration of the body at a given moment does not represent an independent variable to be judged in aesthetic or normative terms, but rather the observable resultant of a system of forces in dynamic equilibrium.

Consequently, classifying a configuration as “correct” or “incorrect” on the basis of visible form or symmetry constitutes a methodological error. Assessment must instead focus on the quality of the articular sequence: what determines system function is not the position assumed, but the preservation of physiological relationships between bony segments, both within individual kinetic chains and in the overall organization of the body.

On the basis of this conceptual premise, in the remainder of this discussion the term “posture” will be replaced by the expression **musculoskeletal equilibrium**, in order to highlight the dynamic and

mechanical nature of the phenomenon under analysis and avoid the morphological and prescriptive connotations associated with everyday language.

2. Musculoskeletal equilibrium as the resultant of forces

If musculoskeletal equilibrium is the result of a system of forces, its understanding necessarily requires analysis of the vectors that determine it. In biomechanical terms, this means considering muscles not as simple motor effectors, but as vectors of force which, through their tension state and shortening, directly influence segmental alignment and articular sequence.

The mechanical action of muscle is expressed through two components:

a) Basal tone: this represents the level of muscular tension present even in conditions of apparent rest, necessary to guarantee articular stability and positional control of the segment. It constitutes the neuromotor component of equilibrium.

b) Effective muscle length: this determines the distance between bony insertions and, consequently, the angular relationships between articular segments. It constitutes the structural component of equilibrium.

From this perspective, muscular shortening is not interpreted as the direct effect of maintained positions or incorrect habits, but as the consequence of an increase in basal tone that the neuromuscular system uses to guarantee stability and control.

The muscle thus represents the final effector of adaptations that may arise from different domains: biomechanical, altered articular sequence requiring compensations; neurophysiological, modifications in motor control; or regulation linked to emotional states, somatic expression of alertness or defence. These adaptations, although differing in etiology, all find in muscle tone a common pathway of expression.

3. From the neuromotor component to structural modification

When increased basal tone persists over time, the process does not remain confined to the contractile component of the muscle alone. Constant tension progressively induces changes also in the connective tissue component, the supporting and force-transmitting tissue composed of fascia, tendons, and endomysium.

This evolution from the functional to the structural level represents a critical point in the natural history of adaptation: when the connective tissue component adapts to sustained tension through tissue remodeling processes, shortening tends to stabilize. At this stage, the reduction in distance between bony insertions becomes biomechanically relevant: the traction exerted on skeletal structures modifies articular relationships and contributes, over time, to the progressive alteration of the physiological articular sequence.

The transition from a reversible increase in tone to a stabilized structural modification therefore marks the boundary between an adaptation that can still be managed through neuromuscular modulation and a condition that requires intervention aimed at restoring tissue length. It is at this stage that muscular shortening becomes a primary determinant of alteration in musculoskeletal equilibrium, rather than a merely reversible consequence of transient factors.

4. Articular sequence and mechanical organization of the system

The concept of physiological articular sequence constitutes the fundamental reference parameter for assessing musculoskeletal equilibrium. By articular sequence is meant the spatial and functional relationship between adjacent bony segments, defined by:

- the reciprocal alignment of bony segments in the frontal, sagittal, and transverse planes
- the congruence of articular surfaces at rest and during movement
- the physiological distribution of loads across the articular structures

This principle becomes particularly evident in the presence of scoliosis: even when the patient voluntarily assumes an apparently “correct” position, deviation of the articular sequence remains unchanged, and with it the alterations in force relationships persist. The same principle applies to less evident clinical situations, in which small articular misalignments alter the mechanical organization of the body in the absence of macroscopic deformities.

Articular sequence is not a local property of a single joint, but a systemic organization: alteration of one articular relationship in one district necessarily implies compensatory adaptations in other districts, in order to maintain the functions of the system, gravitational equilibrium of the G and R pair, gaze orientation, and movement capacity.

5. Adaptation, compensation, and reduction of functional margin

When one or more joints lose the ability to move according to a physiological sequence, the musculoskeletal system does not “freeze,” but reorganizes itself. Other structures are progressively recruited to maintain function, guarantee stability, and allow movement despite the limitation present.

This process, defined as compensation, does not in itself represent dysfunction, but rather the expression of the intrinsic adaptive capacity of the biological system. Compensation makes it possible to preserve essential functions, walking, reaching, manipulation, by redistributing loads and modifying motor strategies.

Over time, however, these compensatory strategies tend to stabilize through the neuromuscular and connective tissue remodeling mechanisms previously described. What initially allows continued movement without pain, or with contained symptoms, ultimately further modifies the mechanical organization of the system by distributing loads and tensions in a non-physiological way.

It is in this evolutionary phase that compensation, while still ensuring function, may become an indirect source of overload and remote symptomatology. The fundamental distinction is not qualitative, presence or absence of compensation, but quantitative: all biological systems operate through mechanisms of adaptation and compensation; what discriminates a functional equilibrium from a pathological one is the extent of deviation from the physiological sequence and the mechanical price the system is forced to pay to maintain it.

6. Relationship between symptom and mechanical alteration

In the model presented here, pain does not necessarily coincide with the primary cause of the alteration, but neither is it necessarily separate from it.

In many clinical situations, the symptom is local and directly correlated with the mechanical alteration present: for example, increased tone in the scalenes or levator scapulae may determine segmental cervical rotation or compression, generating pain at the cervical spine itself. In these cases, the anatomical correspondence between the site of the symptom and the site of the mechanical dysfunction is immediate.

In other cases, however, pain represents the point at which the system, after having compensated for

a long time, exhausts its adaptive margin. The symptom then emerges where loads and tensions can no longer be redistributed effectively, while the primary mechanical alteration that triggered the compensatory chain may be located at a considerable distance.

This distinction does not serve to deny the diagnostic value of the symptom, but to clarify why musculoskeletal equilibrium cannot be assessed exclusively on the basis of pain location.

Understanding the systemic configuration and the compensatory chains is a prerequisite for identifying the mechanical determinants of symptomatology, whether local or remote.

7. The engineering reference model

In the assessment of musculoskeletal equilibrium, an engineering reference model is adopted rather than a statistical one.

This approach differs radically from models based on the statistical distribution of parameters within the general population. As in engineering, one works with respect to an ideal condition of maximum biomechanical efficiency, while knowing that this condition can never be fully achieved, because only through a theoretical reference model is it possible to quantify deviations, guide interventions, and progressively evaluate improvement of the system.

It is the same principle applied to the study of engine performance: the engineer reasons in terms of 100% efficiency, while knowing that it can never actually be reached. If one were limited to describing what happens on average, without a theoretical reference model, technical progress would stop. It would not be possible to identify margins for improvement or quantify how far the real system deviates from the optimal configuration.

In the same way, in biomechanics, reference to an ideal physiological articular sequence does not represent an unattainable goal to be imposed on the patient, but an indispensable conceptual tool for interpreting, quantifying, and improving the mechanical organization of the body.

Muscles inevitably tend to shorten over time, and it is not realistic to think that this process can be eliminated. The human body cannot attain, nor maintain, theoretical biomechanical perfection.

Nevertheless, the difference between a functional equilibrium and a pathological one is not qualitative, but quantitative.

In other words, the body always uses the same principles of organization and compensation. What changes is the extent of deviation from the ideal configuration and the mechanical price the system is forced to pay to maintain it. The engineering model provides the reference parameter for quantifying this gap and directing therapeutic intervention toward progressive reduction of the distance between the real and the ideal.

PART II – OPERATIONAL ASSESSMENT MODEL

8. The ideal biotype as an assessment tool

In assessing alterations of musculoskeletal equilibrium, both in static and dynamic conditions, reference is made to an ideal biotype. This biotype is extrapolated through the engineering-type model described above: a reference model that points to the best biomechanical solution possible with respect to physiological articular sequences.

It is essential to reiterate that this model does not represent a statistical norm or an aesthetic ideal of symmetry. By definition, we are all moderately asymmetrical. The ideal biotype instead constitutes a conceptual tool that makes it possible to measure the gap between the patient's actual musculoskeletal configuration and the theoretical configuration of maximum efficiency.

It is precisely this gap, the gap between what one is and what one ideally should be, that determines whether a system is in functional equilibrium or pathological equilibrium. The farther the real configuration deviates from the ideal model, the greater the mechanical load the system must

sustain in order to maintain essential functions, and the greater the probability of developing overload, progressive compensation, and eventually symptomatology.

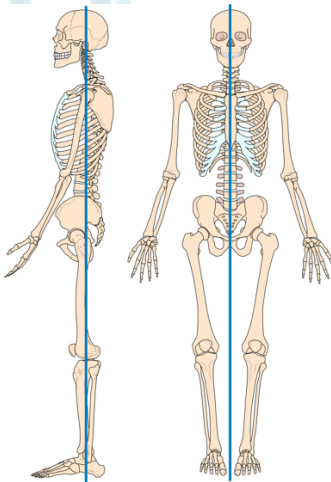
9. Characteristics of ideal musculoskeletal equilibrium

Each part of the body has its own centre of gravity. The overall centre of gravity of the body is the vector resultant of the sum of each of them. The projection on the ground of the centre of gravity of the human body in upright stance corresponds to the ideal vertical line falling at the centre of the area delimited by the supporting surface of the feet.

From a biomechanical point of view, in ideal symmetrical musculoskeletal equilibrium observed in the sagittal plane, the vertical projection of the centre of gravity, or resultant barycentre, passes through the following reference points:

- anterior to the lateral malleolus
- anterior to the knee joint
- posterior to the hip joint
- through the greater part of the lumbar vertebrae
- through the acromioclavicular joint
- through the cervical vertebrae
- through the external acoustic meatus

On anterior or posterior observation, the ideal body appears divided into two perfectly symmetrical hemibodies, and the vertical projection of the centre of gravity passes through the malleolar centre. These parameters define the theoretical condition in which the musculoskeletal system operates with maximum mechanical efficiency, minimizing energy expenditure for maintenance of upright stance and reducing non-physiological loads on articular structures.



10. Static assessment parameters

In static observation, the patient is assessed frontally, posteriorly, laterally, and in the supine position on the floor. The constant reference is the position of the feet: whenever possible, heel and first metatarsal should be in contact, and the gaze directed forward. This standardization allows reproducibility of observation and clear identification of adaptations.

10.1 Frontal observation

Below is a list of the principal parameters. Any other observable element may prove useful in functional assessment.

Foot and toes

- The halluces should be in contact along their whole length and free from rotation
- The toes should be relaxed, free from flexion, rotation, or lateral deviation, and should not actively participate in maintaining upright stance

Lower limbs

The lower limbs should show four contact points:

- malleoli
- upper third of the calves
- medial femoral condyles
- upper third of the thighs

Knees

- Frontal observation concerns the position of the patellae

Pelvis

Three parameters are assessed:

- lateral translation
- elevation, difference in level between the iliac crests
- rotation in the transverse plane

Waist triangles

- The triangles formed by a base described by the profile of the upper limb until contact with the hip joint, and by two sides described by the lateral thoracic border and that of the quadratus lumborum, are observed. The two sides should not show acute angles.

Shoulder girdle

Two parameters:

- lateral thoracic convexity
- rotation in the transverse plane

Shoulders

Two parameters:

- elevation, level difference
- anterior displacement

Clavicles

Two parameters:

- course relative to the horizontal, ascending or descending
- apparent difference in length

Upper limbs

Four parameters:

- humeral rotation, the intercondylar line should be perpendicular to the bodily midline
- elbow position
- forearm position
- hand position

Cranium

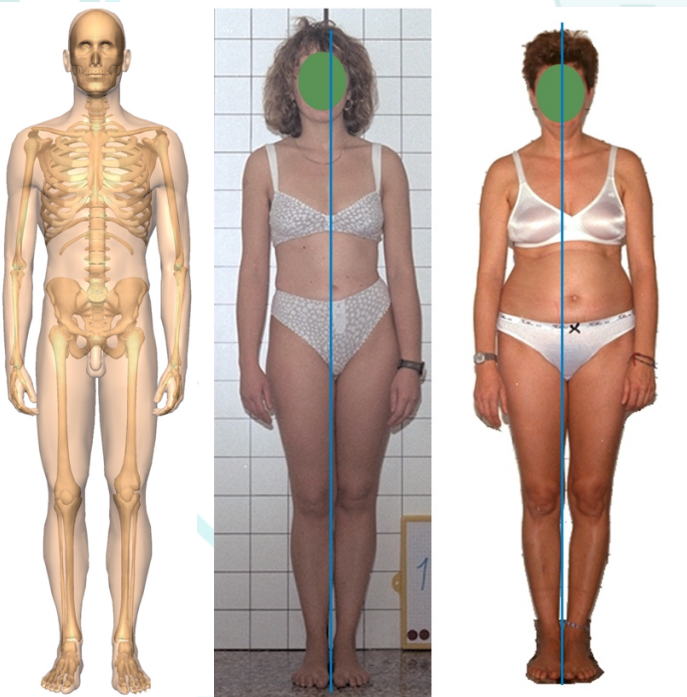
Two parameters:

- lateral inclination
- rotation in the transverse plane

Accessory elements

- palpebral fissure, horizontal orientation
- any lateral deviation of the mandible

In addition to differences between the two hemibodies, it is necessary to assess whether the individual segmental barycentres are aligned with the vertical line passing through the malleoli. When this alignment is absent, muscular tone must necessarily increase in order to permit maintenance of upright stance.



10.2 Posterior observation

In addition to verification of the data observed frontally, posterior observation includes further specific assessments:

Achilles tendons

- They should be parallel and vertical

Knees

Assessment includes:

- femoral rotation, the four femoral condyles should lie on the same line perpendicular to the midline
- presence of flexion or recurvatum

Gluteal region

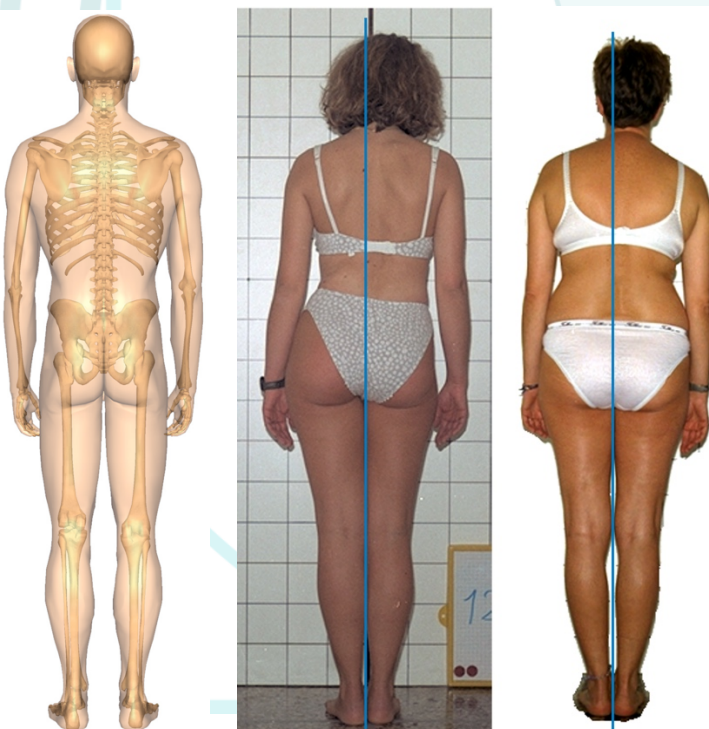
- The course of the gluteal lines, which should be present, deep, and long

Spinal column

- The vertebral sinusoid is controlled manually and visually, identifying abnormal courses in both the sagittal and frontal planes

Scapulae

- The relationship between the medial borders of the scapulae and T5, which should lie on the same line
- The reciprocal relationship between the scapulae, elevation and adduction or abduction



10.3 Lateral observation

The lateral observational plane makes it possible both to verify some of the preceding data and to assess new ones.

Ankle and foot

- The tendon of insertion of the peroneals should pass posterior to the lateral malleolus

Vertical alignment

Relative to an ideal line passing through the Achilles tendons and perpendicular to the ground, four contact points should be found above:

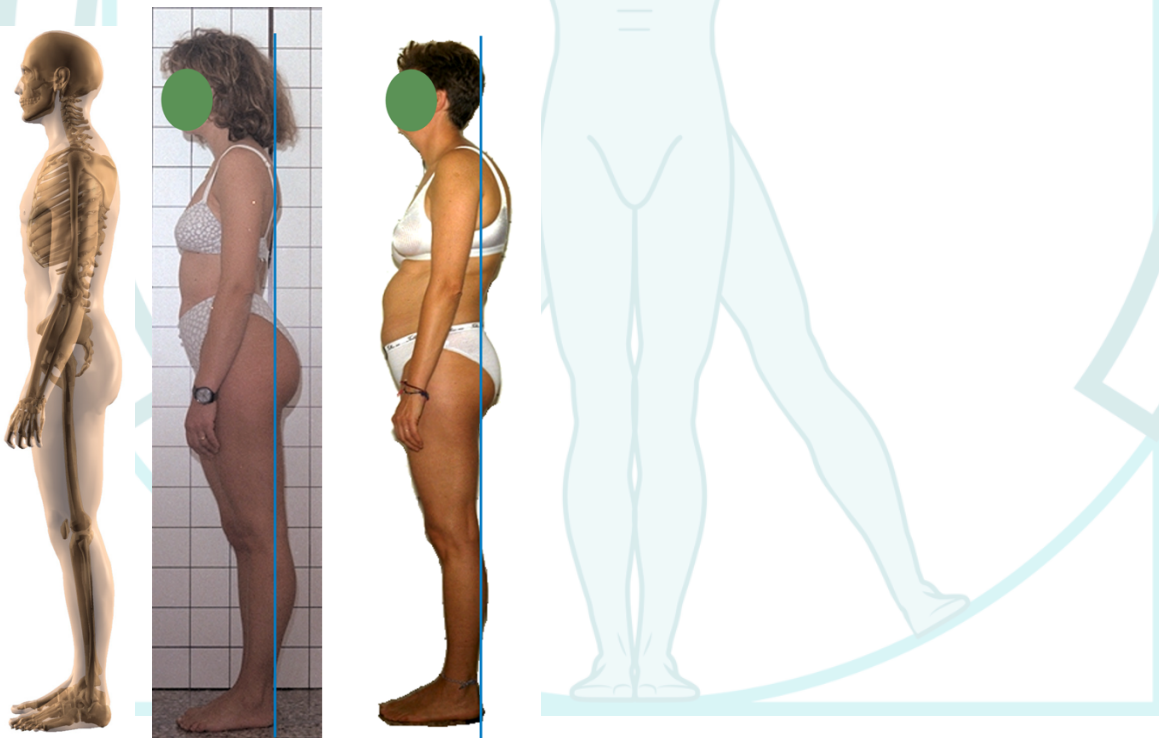
- upper third of the calves
- buttocks
- T5, fifth thoracic vertebra
- occiput

Thorax

- The sternal line should form, relative to the vertical passing through the manubrium sterni, an inclination of approximately 30 degrees

Abdomen and pelvis

- The imaginary line extending between the xiphoid process and the pubis should be straight and vertical
- The pelvis should be neither anteverted nor retroverted



10.4 Observation in the supine position on the floor

Observation in the supine position takes place in two stages:

1. the patient is initially asked to position themselves as they feel straight. This provides information about their body schema, by verifying whether there is correspondence between the subjective sense of “straight” and objective reality;
2. they are then passively aligned, taking into consideration the malleolar centre, pubic symphysis, jugular notch of the manubrium sterni, and cranium.

In the supine position, no muscle is required to activate in order to maintain posture. Consequently, this type of examination is the most relevant, as it provides information about which muscles are actually more shortened and about the consequences of any skeletal alterations.

In upright stance, by contrast, all asymmetries provide information about the muscular strategies enacted for maintenance of antigravity equilibrium.

The observations concern both the sagittal and frontal planes and include all the elements listed above, noting that many findings from orthostatic projection often change in the supine position.

Specific palpatory assessments

- Palpation of the cervical and thoracic vertebrae up to T3, to verify any vertebral rotation or translation. Beyond T3, the thoracic vertebrae are interdependent with the thorax and require different assessment approaches.
- Palpation of the temporomandibular joint in order to evaluate any ascent of the mandibular condyle into the temporal bone fossa or condylar subluxation.
- Palpation of the lumbar vertebrae in order to identify alterations in segmental sequence.

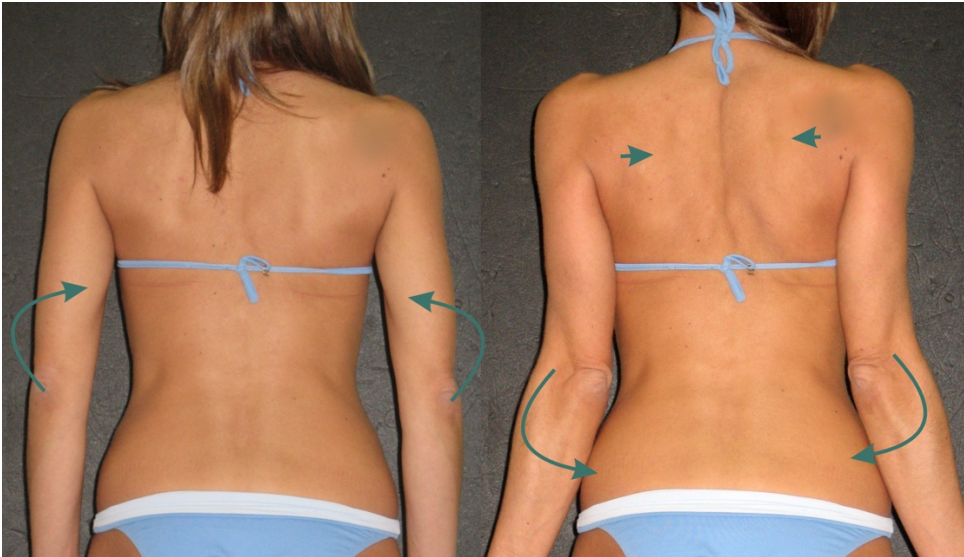
11. Dynamic observations

Dynamic observations concern both active movements performed by the patient and passive movements performed by the operator. In both cases, the reference is the theoretical anatomical model derived from the ideal biotype.

11.1 Active dynamic observations

Active dynamic observations aim to detect whether the actions performed by the patient are carried out by the muscles anatomically assigned to them, or whether substitutive moments are present, emergent motor abilities that compensate for the inability to use the muscles physiologically assigned to the requested movement.

This assessment makes it possible to identify which districts present alterations of the articular sequence such as to prevent movement from being performed according to physiological patterns, forcing the system to resort to compensatory strategies.



On posterior observation, in spontaneous stance, internal humeral rotation can be identified. When asked to correct this internal rotation actively, the patient, although presenting no mechanical limitation at the scapulohumeral joint, uses the scapular adductors in substitution for the humeral external rotators. In other words, the patient uses an altered movement pattern composed of a substitutive muscular action and an aphysiological reaction, scapular adduction. If this strategy is the one habitually used in everyday life, in time infra-scapular radicular compression may occur.

11.2 Passive dynamic observations

Passive dynamic observations aim to detect abnormal musculoskeletal relationships, distinguished into two categories:

a) Aphysiological reactions

These are skeletal reactions that occur in ways not congruent with the movement induced. For example, in passive abduction of an upper limb, the physiological reaction is homolateral lateral expansion of the thorax. The aphysiological reaction is absence of homolateral lateral thoracic expansion associated with any other compensatory skeletal movement.



tratto da: dott. Mauro Lastrico
Biomeccanica Muscolo Scheletrica
e Metodica Mézières
Ed. Marrapese

Passive abduction of the upper limbs to approximately 110 degrees.

Instead of expanding laterally, the thorax moves cranially and, above all, in the anteroposterior direction, significantly increasing lordosis.

In this case, because the thoracic skeletal reaction occurs in a different plane, it is defined as aphysiological.

Such a reaction may be induced by the latissimus dorsi, which, placed at maximum length by abduction of the upper limbs, elicits its shortening through increased thoracolumbar lordosis and anterior pelvic tilt.

b) Mobility restrictions

These are limitations of articular range of motion consequent to muscular shortening or structural modifications of the capsuloligamentous components. These restrictions reveal the districts in which loss of muscular length has reached a degree sufficient to mechanically limit articular excursion.

The overall set of passive dynamic observations makes it possible to map the chains of shortening and identify the critical districts in which therapeutic intervention will need to be concentrated in order to restore an articular sequence closer to the physiological model.

CONCLUSIONS

The model presented here integrates the theoretical foundations of biomechanics with an operational system of clinical assessment, providing the physiotherapist with conceptual and practical tools for analysing musculoskeletal equilibrium.

The definition of musculoskeletal equilibrium as the expression of the physiological articular sequence, the interpretation of muscles as force vectors, and the adoption of an engineering reference model constitute the theoretical pillars of this approach.

The ideal biotype does not represent an achievable therapeutic goal, but rather a measuring tool: it is the gap between the real configuration and the ideal one that discriminates between functional equilibria and pathological equilibria. The greater this gap, the greater the mechanical load sustained by the system and the greater the probability of developing overload and symptomatology.

The static and dynamic assessment parameters described in the second part make it possible to quantify this gap operationally, identifying the critical districts in which the articular sequence diverges from the physiological model and in which muscular shortenings have acquired biomechanical relevance.

From this perspective, physiotherapeutic intervention does not aim to “correct posture” understood as external form, but to progressively reduce the gap between the real and the ideal by restoring more physiological muscle lengths and articular sequences that minimize energy expenditure and structural overload.

Only through a precise theoretical reference model is it possible to guide clinical intervention, evaluate its effectiveness over time, and progress toward increasingly efficient configurations of the musculoskeletal system, while remaining fully aware that absolute biomechanical perfection remains, by definition, unattainable.

References

- [1] Sahrman SA. *Diagnosis and Treatment of Movement Impairment Syndromes*. St. Louis: Mosby; 2002. [2] Neumann DA. *Kinesiology of the Musculoskeletal System*. 3rd ed. St. Louis: Elsevier; 2017. [3] Winter DA. *Biomechanics and Motor Control of Human Movement*. 4th ed. Hoboken: Wiley; 2009. [4] Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research into Clinical Practice*. 5th ed. Philadelphia: Wolters Kluwer; 2017. [5] Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *J Spinal Disord*. 1992;5(4):383-389. [6] Fung YC. *Biomechanics: Mechanical Properties of Living Tissues*. 2nd ed. New York: Springer; 1993. [7] Lieber RL. *Skeletal Muscle Structure, Function, and Plasticity*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2010. [8] Page P, Frank CC, Lardner R. *Assessment and Treatment of Muscle Imbalance: The Janda Approach*. Champaign: Human Kinetics; 2010. [9] Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: Testing and Function with Posture and Pain*. 5th ed. Baltimore: Lippincott Williams & Wilkins; 2005. [10] Kibler WB, Sciascia A, Wilkes T. Scapular dyskinesis and its relation to shoulder injury. *J Am Acad Orthop Surg*. 2012;20(6):364-372. [11] Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. *Pain*. 2011;152(3 Suppl):S90-S98. [12] Bar-Yam Y. *Dynamics of Complex Systems*. Reading: Addison-Wesley; 1997. [13] Hall JE, Hall ME. *Guyton and Hall Textbook of Medical Physiology*. 14th ed. Philadelphia: Elsevier; 2021. [14] White AA, Panjabi MM. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia: Lippincott; 1990.

