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Functional Matrix Hypothesis: A Review of Literature

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ABSTRACT

Craniofacial growth is a complex process. The concept that "forms follow function" was first proposed by Vander Klaaw. Functional matrix hypothesis (F.M.H.) is actually an extension of this concept given by Moss. F.M.H. includes a functional matrix and skeletal units. Capsule is an envelope that contains functional cranial components sandwiched between the covering layers. It acts indirectly and passively and not by resorption or deposition. Functional matrix cranial analysis can be done in the maxilla and mandible. There are some limitations in F.M.H., so F.M.H. revisited is explained later which include 4 theories in it.

Keywords: Craniofacial growth; Functional matrix; Skeletal units; Functional cranial components; Maxilla and Mandible.

INTRODUCTION

Craniofacial growth is a complex process. Most of the treatment approaches have been based on the fundamental biological mechanisms involved in the growth and development of craniofacial bones and teeth. The exact mechanism which controls cranio-facial growth has been a matter of debate and research for years together. (1)

Growth signifies an increase in, expansion of any given tissue (Pinkham). According to Moyers, growth may be defined as the normal changes in the amount of living substance. Moss, defines growth as any change in morphology that is within the measurable parameter. Growth is defined as a series of sequential anatomic and physiologic changes

taking place from the beginning of prenatal life to the close of senility. [(1), (2)]

Site Vs Center

A proper understanding of the terms growth site and growth center will help to clarify the differences between theories of growth. Baume had coined these two terminologies. According to him, "growth centers" are places of endochondral ossify-cation with tissue separating force, contributing to the increase in skeletal mass. Growth site has been defined as a region of periosteal or sutural bone formation and modelling resorption adaptive to environmental influences. *All growth centers are also sited, whereas all growth sites are not centers.* Most of the theories of growth are based on where the growth center is expressed.[1, 2]

CONTROLLING FACTORS IN CRANIOFACIAL GROWTH[1,2]

Von Limborgh's Classification:

- Intrinsic genetic factors
- Local genetic factors
- General epigenetic factors
- Local environmental factors
- General environmental factors

Enlow and Moyers' Classification:
Natural

- Genetic
- Function
- General body growth
- Neurotrophism

Disruptive Factors

- Orthodontic forces
- Surgery
- Malnutrition
- Malfunction
- Gross craniofacial anomalies

Goose and Appleton's Classification:

- Endocrinal factors
- Multifactorial inheritance
- Racial differences
- Nutrition
- Diseases
- Socioeconomic factors
- Secular trends

THEORIES OF BONE GROWTH

The first scientific research on craniofacial growth has been credited to Sir Jhon Hunter in the 18thcentury for his studies on the growth of the jaws and eruption of the dentition. The theories are based on the fact where the intrinsic genetic potential or growth center is expressed. [(3), (4)]

The various theories of growth are:

1. Bone remodelling theory
2. Genetic theory
3. Sutural hypothesis
4. Cartilaginous theory
5. Functional matrix theory
6. Servo system theory
7. Composite hypothesis by von Limborgh
8. Rate limiting ratchet hypothesis
9. Growth relativity hypothesis

Paradigm:

A conceptual scheme that encompasses individual theories and is accepted by a scientific community as a model and foundation for further research.
Normal science – Kuhn

The research findings generally agreed to be basic to a scientific field.
Scientific revolution :

Changes in the normal science over the period of time by the introduction of a new paradigm (Fig. 1).

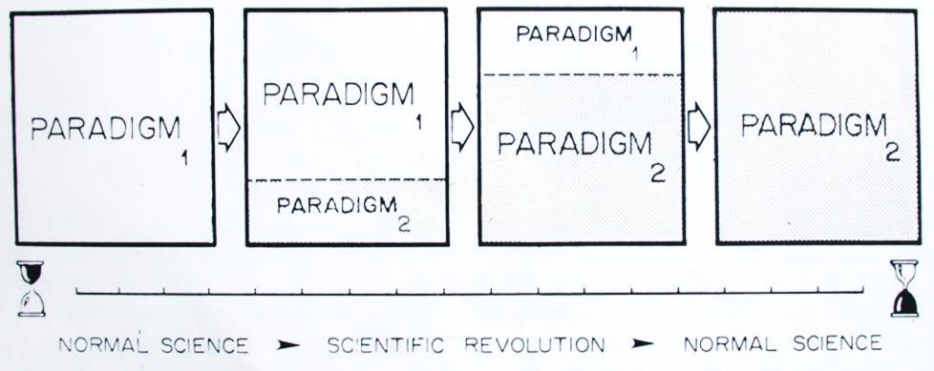

Fig. 1. New Paradigm Shift

FUNCTIONAL MATRIX HYPOTHESIS [1] - [4]

The concept that "forms follow function" was first proposed by Vander Klaaw (1948-52). The functional matrix hypothesis is actually an extension of this concept. Melvin Moss and his co-workers developed the form and function concept into the "functional matrix hypothesis". It was introduced in the 1960s and was reviewed and updated by him in the 1990s.

The essence of the Theory:

The basic principle of the functional matrix hypothesis is simple. The craniofacial skeleton develops initially and later grows in direct response to the extrinsic epigenetic environment (Fig. 2). Moss states that "*bones do not grow- bones are grown"*.

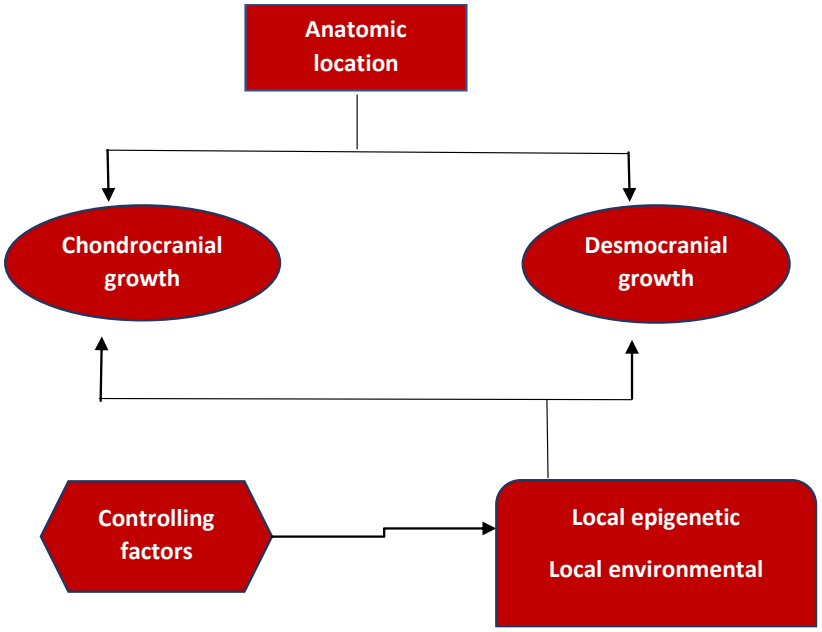

Fig. 2. Controlling influences on growth according to Moss

Proponents of the functional matrix theory state that the expansion of the soft tissue matrix is primary and the bone growth is purely a secondary and compensatory event.

According to Moss: The functional matrix hypothesis claims that the origin, growth and maintenance of all skeletal tissues and organs are always secondary compensatory and obligatory responses to temporally and operationally prior events or processes that occur in specifically related nonskeletal tissue-es, organs or functioning spaces (function-nal matrices) Fig. 3.

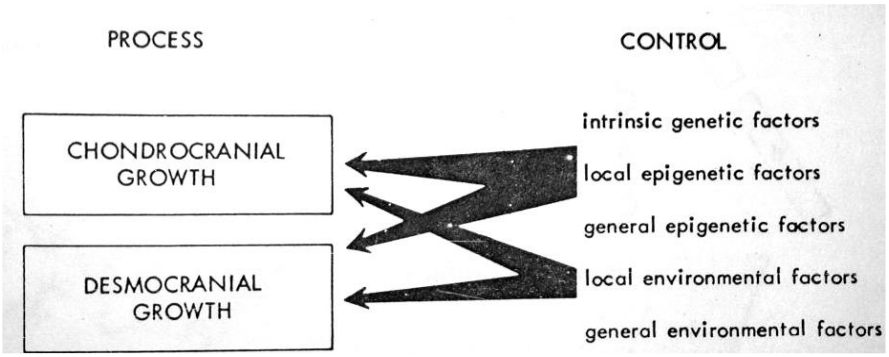

Fig. 3. Moss's view on control of cranial growth

Functional Matrix Hypothesis

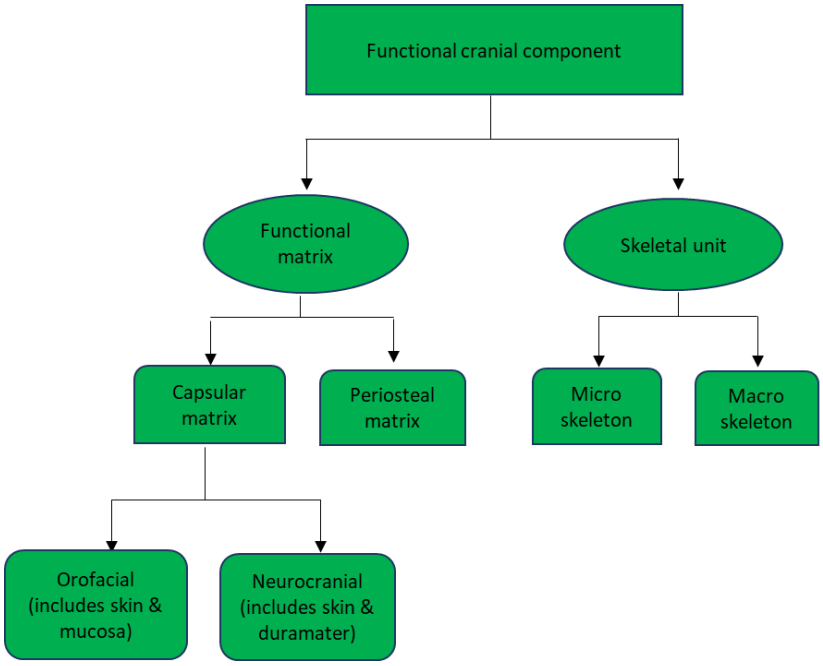

Fig.4. Functional Matrix Hypothesis

SKELETAL UNITS: [5], [6]

Micro skeletal unit -

When bone is composed of several continuous skeletal units, these are termed as micro skeletal units. Its growth is modulated by periosteal matrices. This includes the temporalis-coronoid process, masseter, teeth-alveolar bone.

The change in size and shape of these micro skeletal units occurs independently of the change in spatial position. Moss used two terms for this: Transformation or intraosseous growth (Fig. 5). E.g. mandible

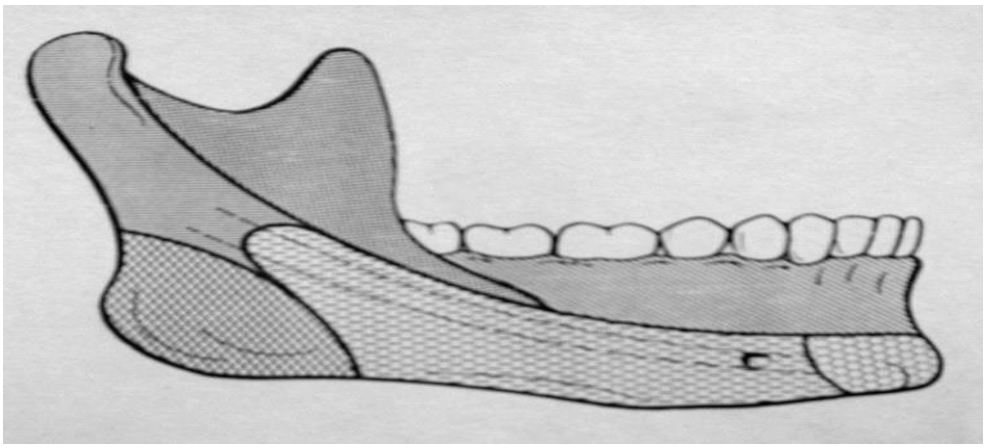

Fig.5: Mandible as a micro skeletal unit

Macro-skeletal unit -

When the adjoining portions of a number of neighbouring bone are united to function as a single cranial component. The capsular matrix expansion causes the macro-skeletal unit to changethe position. This process is called translational growth. E.g. Inner-surface of the calvarium.[6]

FUNCTIONAL MATRIX:

Periosteal matrix-

Consists of muscles, blood vessels, nerves, glands they bring about changes in their related skeletal units. Acts directly and actively. process of osseous deposition and resorption. The resultant effect transformative growth i.e. change in size and shape (Fig. 7).

In this A – Resorption

B- Deposition

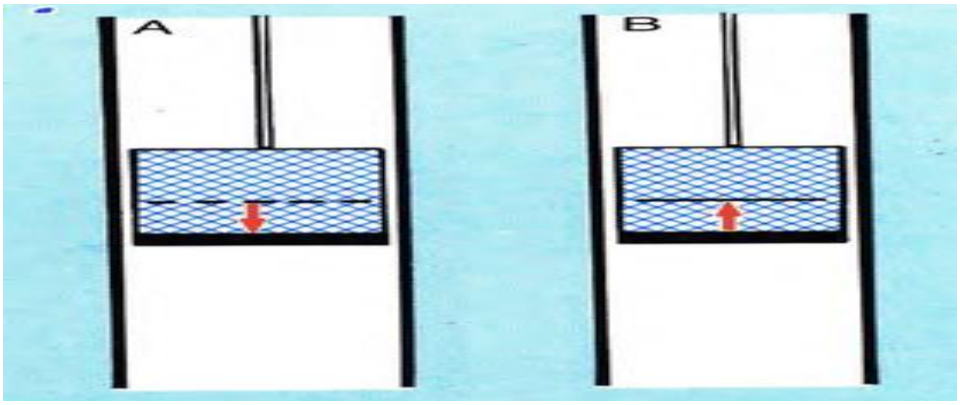

Fig.6: Diagrammatic representation of resorption and deposition

Capsular matrix:

A capsule is an envelope that contains functional cranial components sandwiched between the covering layers. It acts indirectly and passively and not by resorption or deposition. These do not alter the size and shape of skeletal units instead they change their location in space. This type of growth process is called "Translation" (Fig.7).

Facial skeletal units are passively & secondarily moved in space as the capsular expands.[7]

Example:
Neurocranial capsule – skin & dura mater.
Orofacial capsule – skin and mucous membrane.
Moss termed change in spatial position "Translation"
No osseous deposition and resorption

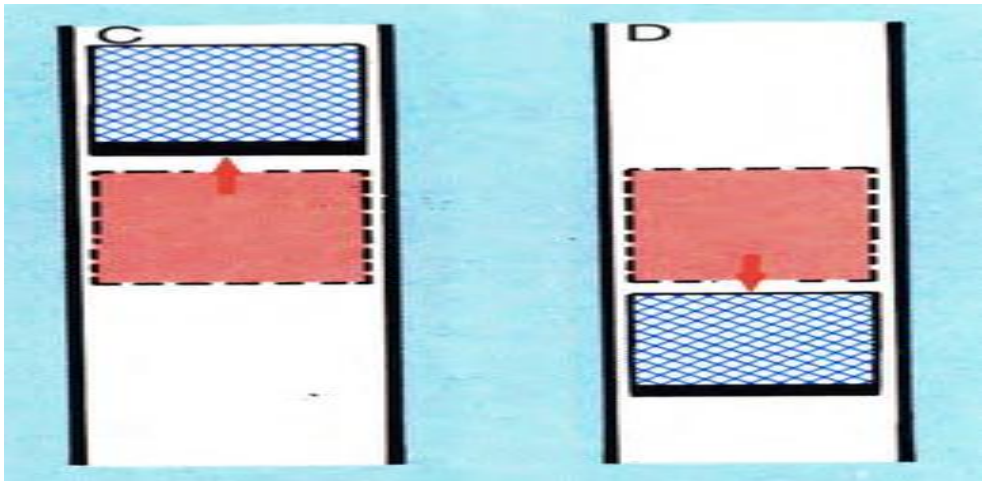

Fig.7: Diagrammatic representation of transformation and translation

Functional cranial analysis of Maxilla

Moss and Greenberg point out that the basic functional matrix for the basic skeletal unit is the infraorbital neurovascular triad.

In this: maxillary division of trigeminal nerve that plays the major role in maintaining the spatial constancy of the infraorbital canal to the anterior cranial base. The area of the infraorbital foramen is the site of the first ossification of the human maxillary bone.

Bone formation begins at about the end of the 6th week in form of radiating trabeculae. The orbital mass functional matrix virtually ceases its volumetric growth by the end of 1st decade.(7)

The definitive height of the nasal cavity is attained at the same time. Mostly all the functional matrices that might affect the position of the maxillary basal skeletal unit come to rest at this time and do not participate in further growth of the maxillary complex. The non-basal maxillary matrices related to oral and dental function continue to grow after 10 years of age. The maxillary base is passively carried downward, forward and laterally as a result of the expansion of its capsule.

Moss and Greenberg state that three types of bone growth are seen in the maxilla:

Firstly, primary expansion of the orofacial capsule. (These changes help to maintain anatomical and functional continuity between maxilla and adjacent bones). Secondary, there are changes in bone morphology associated with alteration in absolute volume, size, shape or spatial position of any or all of the several relatively independent maxillary functional matrix-like orbital mass. Finally, there are bone changes associated with the maintenance of the form of the bone itself. Example: Posterior repositioning of the zygomatic arch which has a forward movement of arch. (7), (8)

Functional cranial analysis in the mandible:

The mandibular matrix consists of:
- All muscles with mandibular attachments.
- Neurovascular triads
- Associated salivary glands
- The teeth
- Fat, skin and connective tissue
- The tongue
- The oral and pharyngeal spaces
- The basal tubular portion serves as a protection for the mandibular canal and it follows a logarithmic spiral in its downward and forward movement from beneath the cranium. This is called the "Unloaded nerve concept".

The most constant portion of mandible is the arc from foramen ovale to mandibular foramen and mental foramen.

According to moss, three important phenomenon occurs during the growth of mandible:

1. Constancy of relative position of mental foramen in the mandibular corpus (Fig. 8)

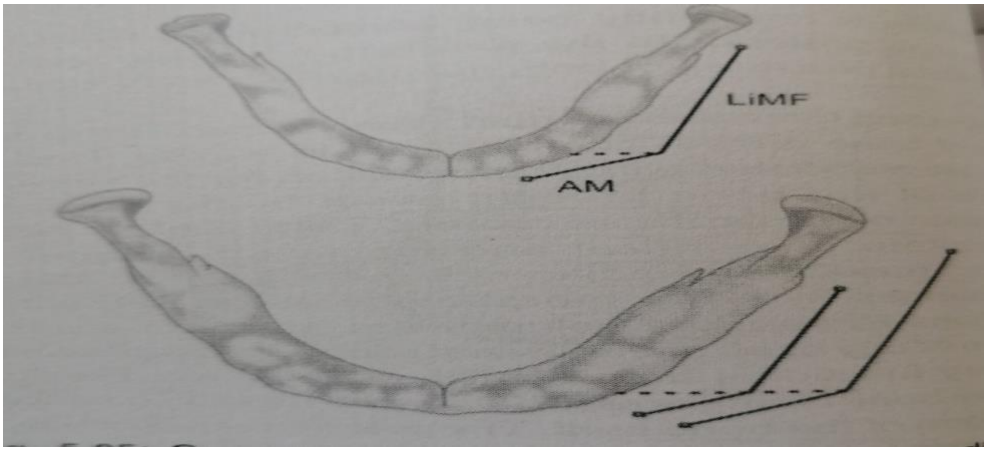

Fig.8: Comparison of fetal and newborn mandibles

2. Absolute migration of the dentition through the alveolar bone:

This movement happens during the 1st two decades.

3. Change in the direction of mental foramen:

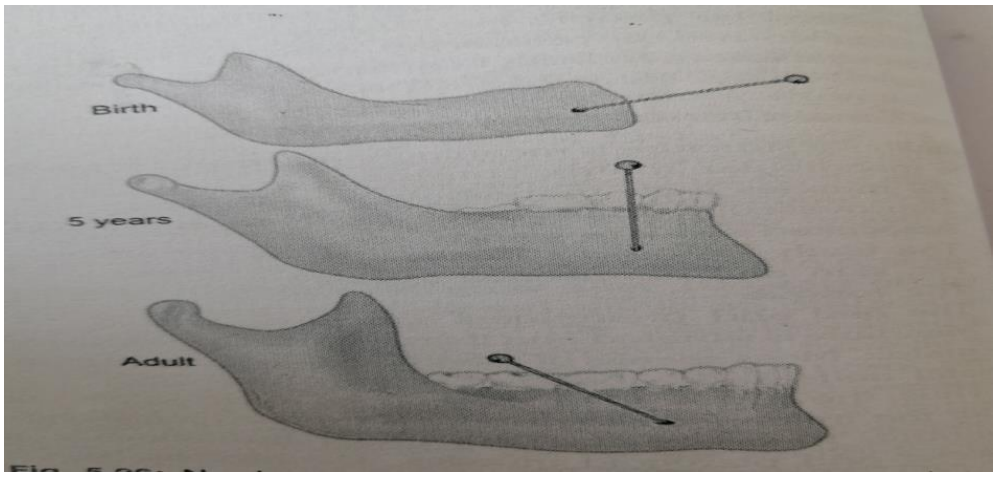

Fig. 9 Newborn 5 years old and adult mandible

LIMITATIONS OF F. M. H:

Methodological constraint
Hierarchical constraint

1. Methodological constraint:

Macroscopic measurements permitted only method-specific description that cannot be structurally detailed.

Experimental bases of FMH were cephalometric follow up of individuals.

This method added quantitative aspects of localized cephalic growth kinematics to the earlier qualitative description of growth dynamics. [8]

2. Hierarchical constraint:

F.M.H does not explain how the extrinsic, epigenetic functional matrix stimuli are transduced into regulatory signals at the cellular, multicellular or molecular levels.

It couldn't describe the downward (i.e. cellular, subcellular) or upward processes (i.e., multicellular) taking place during growth.

The new version of F.M.H. tries to bridge the gap between hierarchical constraints and explains the operation from genome to organ level by two concepts:

1. Mechanotransduction occurring in single cells.
2. That bone cells function multicellularly as a connected cellular network.

Functional matrix hypothesis revisited:

Advances in biomechanical, bioengineering and computer sciences allow the creation of a more comprehensive revision of the functional matrix hypothesis.

In F.M.H. revisited inclusion of two topics:

1. Mechanism of cellular mechanotransduction.
2. Biological network theory.

F.M.H. Revisited:

1. F.M.H. Revisited 1:The role of mechanotransduction.
2. F.M.H. Revisited 2: The role of an osseus connected cellular network.
3. F.M.H. Revisited 3: The genomic thesis
4. F.M.H. Revisited 4: The epigenetic antithesis and the resolving synthesis.

The functional matrix hypothesis revisited.

1 (Fig 10) The role of mechanotransduction:

Mechanotransduction is a process by which a mechanical stimulus is converted into a biological signal to affect cellular response. All vitals cells respond to alternations in their external environment, by a process called:

a. Mechanoreception :
"Transmit an extracellularly physical stimulus into a "receptor cells".
b. Mechanotransduction :
Transform the stimulus "informational content" into an intracellular signal.

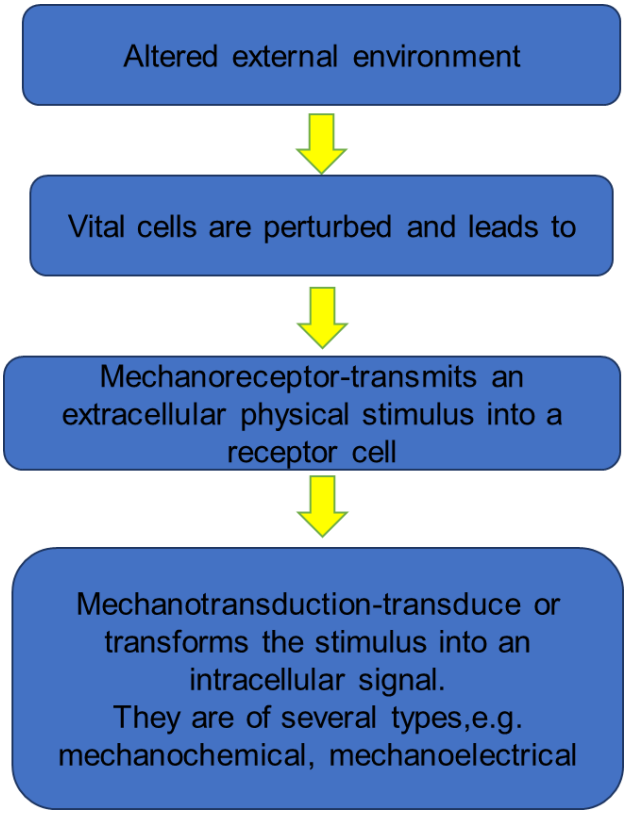

Fig 10. The functional matrix hypothesis revisited

The function (l matrix hypothesis revisited

2: The role of an osseus connected cellular network):

Bone is subjected to constant loading, both static and dynamic. This is essential for the normal homeostasis of bone.

When the threshold value of the force is exceeded, the loaded issue responds to the stimulus by the triad of bone cell adaptation. The triad includes:

1. Bone deposition
2. Maintenance
3. Boneresorption

The osseous mechanotransduction has four unique properties:

1. Bone cells are not cytologically specialized like other mechanosensory cells.
2. Single bone loading stimulus evokes three adaptional responses, whereas non-osseous process generally evokes one.
3. Osseous signal transmission is aneural, it doesn't involve a neural pathway, unlike other mechanosensory signals.
4. The adaptational response is confirmed within the individual bone.

Osseous mechanotransduction translates the periosteal functional stimulus into a skeletal unit cell signal by two skeletal cellular mechanotransductive processes:

- Ionic
- Mechanical

1. The ionic or electrical processes involve some form of ionic transport through the bone cell plasma membrane. There is a subsequent intercellular transmission of created ionic signal, in turn, are computed by the osseous connected cellular network.

The functional matrix hypothesis revisited.

3: The genomic thesis:

-The whole plan of growth, the whole series of operations to be carried out, the order and site of synthesis and their co-ordination are all written down in nucleic acid message".

-Within the fertilized egg lies the information necessary to generate a diversity of cell types in a precise pattern of tissues and organs that comprises the vertebrate body.[(9),(10)]

The genomic thesis:

-The genomic thesis holds the genome, from and moment of fertilization, contains all the information necessary to regulate (cause, control and direct)

1. The intranuclear formation and transcription of mRNA
2. To regulate also all the internuclear and intercellular process of subsequent and structurally more complex, cell tissue, organ and organismal morphogenesis. Succinctly all features are ultimately determined by the DNA sequence of the genome.

-In this, morphogenesis is the predetermines reading out of an intrinsic and inherited genomic organismal blueprint where in addition to molecular synthesis the genome also regulates the geometric attributes of cells, tissues, organs, organismal shape, size and location.[10],[11]

- The genomic thesis originated with classical Mendelian genetics.
- Recently, molecular genetics extended the claim of the thesis to the regulation of all aspects of ontogeny.

Drawbacks of genomic thesis:

-Genomic thesis is denied because it is both reductionist and molecular that is descriptions of the causation (control, regulation) of all hierarchically higher and structurally more complex morphogenetic processes are reduced to explanations of mechanisms at the molecular (DNA) level.[12]

-Example: the genomic thesis of craniofacial ontogenesis passes directly from molecules to morphogenesis: directly from DNA molecules to adult gross morphology, ignoring the role of the many epigenetic processes and mechanisms competent to control a large number of intervening, and increasingly more structurally complex, developmental stages.

-The epigenetic antithesis, detailing both processes and mechanisms, is integrative, seeking to clarify the causal chain between genome and phenotype.

Its goal is to identify and describe comprehensively the series of initiating biological processes and their related underlying (biochemical, biophysical) responsive mechanisms that are effective at each hierarchical level of increasing structural and operational complexity. [7],[8],[9]

The functional matrix hypothesis revisited.
4. The epigenetic antithesis and the resolving synthesis:

-It is a fallacy that the genome, the totality of DNA molecules, is the main repository for developmental information; i.e. that there exists a genetic program, or blueprint, theoretically capable of creating an entire organism.

Biological mechanisms and processes :

The dialectic process concludes here with an epigenetic antithesis and a resolving synthesis, following two additional definitions:

1. A process is a series of actions or operations that lead toward a particular result.
2. A mechanism is the fundamental physical or chemical process involved in, or responsible for, an action, reaction, or other natural phenomena. That is, mechanisms underlie processes.

Epigenetic processes and mechanisms:

-In craniofacial morphogenesis more is about the process than mechanisms.
-Example: undescribed epigenetic processes of "intrauterine environment" can regulate fetal mandibular growth, The future aim must be to elucidate the molecular, genomic, mechanisms whose activation underlies the adaptive growth processes of the mandibular functional cranial components (that is, of the mandibular skeletal units and their related functional matrices).

Epigenetic regulation of higher structural levels:

-Epigenetic process of extrinsic loading play a major role in the regulation of bone tissue and bone organ growth, development, and morphology.
-At the tissue level: there are several strain-specific differences in bone tissue microstructure. Closely similar epigenetic mechanisms and processes are observed in the adaptational responses of all connective tissues, including cartilage, to loading.
-At the organ level: physical activity processes regulate organismal skeletal adapational responses. Other epigenetic processes affecting bone tissue include local vascular factors.

A resolving synthesis:

-A resolving synthesis will clarify the bases for continued discourse.
-According to this morphogenesis is regulated by both genomic and epigenetic processes and mechanism.
Both are necessary causes, only their integrated activities provide the necessary and sufficient causes of growth and development.[13], [14]

CONCLUSION:

In the F.M.H. there are limitations earlier like they did not explain the growth at molecular end subcellular level. Then 1997 Moss revised this hypothesis and explains growth at the microscopic level. Moss explained that signal transmits through mechanoreceptor and osseoreceptor.Genomic and epigenetic processes are examples of totally different types of causation-

Genomic- formal cause

Epigenetic- efficient cause.

Individually both are necessary causes, but neither are sufficient causes alone. Together they provide both the necessary and sufficient causes for the control of morphogenesis. Nevertheless, epigenetic processes and events are the immediately proximate causes of development, and as such, they are the primary agencies.

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