The Fundamentals for Craniofacial Morphogenesis - A review with emphasis on the decisive dynamics

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Abstract
A rekindled need to understand details of craniofacial morphogenesis stems from the clinicians requirement to distinguish normal variation from the effect of abnormal or pathologic processes. The understanding of the developmental blueprint is core to diagnosis, timing, planning of treatment and predicting post treatment outcomes. The morphogenesis works constantly towards a state of composite, architectonic balance among all of the separate growing parts. The various parts, developmentally merge into a functional whole with each part complementing the others as they all grow and function together. The present overview takes into account the principal fundamentals of the morphogenesis and the decisive dynamics involved therein. There is a cephalo-caudal gradient in the craniofacial growth pattern. In accordance with functional matrix theory, the major determinant of growth of maxilla and mandible is enlargement of nasal and oral cavities, which grow in response to functional needs. The craniofacial complex can be divided into four areas that grow rather differently. These are cranial vault, cranial base, nasomaxillary complex and mandible. The craniofacial morphogenesis leads to an aggregate state of structural and functional equilibrium. A thorough understanding of the process and patterns is the 'vital key' for successful therapies in this region.

Keywords: Craniofacial, morphogenesis, dynamics.

Introduction
The developmental process for craniofacial morphogenesis has a blueprint which is core to clinical diagnosis and treatment. The morphogenesis aims to achieve a composite architectonic balance amongst the separately growing parts which merge to form a functional whole. The present overview takes into account the fundamentals of craniofacial morphogenesis and the decisive dynamics involved therein.

Cephalo-caudal gradient
There exists a cephalo-caudal gradient in our normal growth patterns. There is a progressive reduction in relative size of head as growth takes place. The head accounts for 30% of the total length at birth and the percentage contribution reduces to 12% for adults [Fig. 1]. In contrast there is faster growth of trunk and lower limbs. At birth the lower limb forms is proportionately longer while in adults the lower limb is ½ of the total length. The reason for this is that the different tissues of the body grow at different rates and their concentration is different in different parts of the body.

Fig. 1: Change in overall body proportions during normal growth and development from birth to adult age.

The growth of brain and neural tissue is complete by age seven. The general body tissues, including muscle, bone, & viscera, exhibit an S-shaped curve, characterized by slow growth in childhood and adulthood and growth spurt during puberty [Fig. 2]. The lymphoid tissues are known to proliferate in late childhood to counteract infection. At the same time the genitals show an increased growth.

This cephalo-caudal gradient can be appreciated in relation to craniofacial growth and development. In infants, the cranium is larger with a smaller face and in
Fig. 2: Curves for growth of four major tissue systems of body. The x axis indicates the age in years while the y axis is a measure of the size attained as percentage of total postnatal growth.

Contrast in adults the face is larger vis-à-vis the cranium. [Figure 3] In terms of facial growth, the mandible which is farther away tends to grow longer and more compared to the maxilla. So, the cephalo-caudal gradient of growth is applicable here also.

Fig. 3: Infants [left] have relatively larger cranium and smaller face

There exists a cephalo-caudal gradient of growth in facial growth pattern also. After 6 yrs, there is little further growth of cranium. The brain has nearly reached its adult size. The facial skeleton grows much longer and forms a much larger proportion of skull in adult than in a child [Fig. 4].

In terms of facial growth, mandible, being farther away from brain, tends to grow more and longer than maxilla, which is closer [Fig. 5].

Figure 4: Cephalo-caudal gradient of growth in facial growth pattern.

Figure 5: Mandible grows more than maxilla

Possibilities at the cellular level

At the cellular level there are three possibilities of growth. These are hypertrophy, hyperplasia and secretion of extracellular material by the cells. The hyperplasia or increase in the number of cells is an important and prominent mechanism. The hypertrophy or increase in size is a mechanism of lesser importance. The third possibility for growth is secretion of extracellular material by cells. This secretion of extracellular material by cells is particularly important for the growth of the skeletal system where the extracellular material secreted subsequently mineralizes.

The functional matrix theory of Moss advocates that growth and development is essentially a response to functional needs and is mediated by soft tissue. The soft tissue grows and bone and cartilage react. As an example we can consider the growth of cranium. The growing brain separates the cranial bones at the sutures. The new bone passively fills in at these sites so that the brain case fits the brain. Thus for a small brain there exists a small cranium while a large brain has a large
brain case or cranium. In cases of hydrocephaly the cranium is necessarily large in size. Similarly when eyes are large the orbital cavity is larger and vice versa. So, the growth irrevocably takes place in response to functional needs. Application of this theory by Moss on growth and development of maxilla and mandible generates an interesting statement. The growth of maxilla and mandible takes place in response to functional needs and is mediated by the enlargement of nasal and oral cavities. It is the nasal and oral cavities which grow while the bone and cartilage react.

**Area wise dynamics pertaining to craniofacial growth**

The craniofacial complex can essentially be divided into four areas which grow rather differently. These are the cranial vault, the cranial base, the nasomaxillary complex and the mandible.

At birth, flat bones of skull are widely separated by connective tissues. These open spaces, the fontanelles, allow a considerable amount of deformation of the skull at birth. After birth, apposition of bone eliminates these open spaces fairly quickly, but the bones remain separated by a thin, periosteum-lined suture. These sutures are the growth sites for the cranial vault. Apposition of new bone at these sutures is a major mechanism for growth of cranial vault. Also remodeling of inner and outer surfaces takes place, the bone is removed from inner surface of cranial vault, at the same time, new bone is formed on the exterior surface.

For the cranial base the important growth sites are the synchondrosis'[Spheno-occipital, Intersphenoid and Sphenethmoidal]. The growth at synchondrosis lengthens this area of cranial base and the bone remodeling on surfaces is also important.

![Fig. 7: Maturing cartilage cells extending in both directions which will be replaced by bone.](image1)

The synchondrosis has an area of cellular hyperplasia in the center with bands of maturing cartilage cells extending in both directions, which will be replaced by bone.

For the nasomaxillary complex the growth sites are the sutures that connect the maxilla to cranium and base. Bone remodelling also takes place. The bone is added at maxillary tuberosity and lateral surface of zygomatic process with resorption on opposing surfaces.

![Fig. 8: Resorption and deposition dynamics on opposing surfaces](image2)
Fig. 9: Left-Anterior profile of nasomaxillary region, Right + indicates areas where deposition is predominant whereas – indicates areas with resorption pattern.

The bone is removed from most of the anterior surface. Only a small area around anterior nasal spine is an exception.

The bone is also removed on the nasal side and added on the oral side of the palate creating an additional downward and forward movement of the palate.  

At birth, the nasal cavity lies between the orbits. The nasal septal cartilage grows until the age of six to lower and bring the nasal cavity below the level of orbits.

For the mandible, the growth site is the cartilage covering the condyle. Also, remodeling takes place. The main areas of bone deposition are on the posterior surface of the ramii while resorption occurs on the anterior surface of the ramii and angle of mandible. This results in growth in the posterior and superior direction.

The bone growth and remodeling of maxilla and mandible cause these to grow individually in the posterior and superior direction. When these events are placed in context of growing craniofacial complex both these activities displace the middle face downwards and backwards.

Fig. 10: Developmental dynamics making mandible grow in posterior and superior direction.

Fig. 11: Middle face grows down and forwards [direction of arrow] as a result of upward and backward growth individually of maxilla and mandible.

Fig. 12: Mandible growth dynamics; resultant growth of middle face is down and forward even though the deposition and resorption dynamics creates upwards and backwards movement of mandible.
This is a remarkable pattern in growth and remodeling wherein the resultant effect is opposite to the individual growth. The figure 13 again illustrates this interesting dynamics on the mandible. There is displacement downwards and forwards with upward and backward remodeling.

**Rotational dynamic**

Another feature of craniofacial growth and development is rotation of both maxilla and mandible. The direction of rotation is same but degree of rotation is more for mandible on which typical features are more marked as compared to maxilla. The type of rotation has decisive influence on dental development, as extreme rotations influence the space conditions and vertical relations within the dentition. [Deep bite or open bite]

Fig. 13: Arrow in clockwise direction illustrates backward rotation of mandible, arrow in anticlockwise direction indicative of forward rotation as viewed from the right side.

When viewed from the right side the clockwise movement of mandible is backward rotation.

The backward rotation is characterized by a large gonial angle and an increased anterior facial height with decreased posterior facial height. The symphysis menti in this case is tilted forwards. When backward rotation is excessive it leads to open bite. In this condition, the teeth of upper and lower jaw do not touch each other even when the jaw is closed.

When viewed from the right side the anticlockwise movement of mandible is forward rotation.

This is characterized by a small gonial angle and decreased anterior facial height. The symphysis menti in this case is tilted backwards. When forward rotation is excessive it leads to deep bite. In this condition, there is increased overlapping of lower teeth by the upper teeth.

**Conclusion**

In the end the author would like to reiterate that craniofacial morphogenesis is a composite change of all components and not an isolated event. The various parts, developmentally merge into a functional whole with each part complementing the others as they all grow and function together. A delicate balance exists between growth and remodeling and the male and female differences are accounted for by a more intense growth phase in males. These growth and development patterns help us in understanding variation. A rekindled need to understand the details and dynamics of craniofacial morphogenesis stems from the clinicians requirement to distinguish 'normal variation' from the effect of 'abnormal or pathologic processes'.

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