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Numerical Simulation of Infantile Skull with Opened Sutures

Mohammed Zahid Saadoon

Mihrabani surgical hospital, Erbil, Kurdistan Region, Iraq
Email: *mzsmaxillofacial[at]gmail.com*

Abstract: ***Growth needs special loading conditions to attend the needed strain for proper tissues stimulation. Configuration of the skull prior to the closure of the sutures provides unparallel weakening needed to accomplish needed growth. We had built a numerical model to represent the idea behind our theory. The model gives promising results that could be more beneficial in other biomechanical researches.***

Keywords: craniofacial growth, opened sutures, biomechanics, numerical model, intramembranous, endochondral

1. Introduction

How our skull grow is a nagging question that occur in the mind in many disciplines' researchers involving craniofacial region such as pediatric surgery, orthodontics, orthognathic surgery…. etc. [1]. No one could deny the increase in the size or change in the shape. No process in the human body, especially growth, is not strictly controlled at the molecular level. [2]

Many conditions associated with growth had been involved in undisputed debate till time of these words writing.[3] Biomechanics of the Craniofacial growth is not an accessory scientific issue, as many futile treatments that had been tried is based upon faulty assumptions. [4]

The understanding of craniofacial growth will be reflected upon our knowledge and management of many conditions.

- Cranial syndromic and non-syndromic synostosis and associated conditions
- Cleft conditions
- Trauma in growing age group
- Effect of each element on the other
- Hard tissues management, especially the TMJ management in case of surgical interventions
- Orthodontic and orthognathic basis, management, and relapses
- Interventions especially surgical should be based upon robust basis [5]

misunderstanding of the growth mechanism would result in loss of the compass and could result in faulty assumption with odd treatments based upon these faulty assumptions [6]. The establishment of a sound theory is a challenge and at the same time important because many futile treatments previously done to the patient have been built upon faulty assumptions.

Shape, size and proportioning in the skull anatomy will result in either malfunction, unaesthetic appearance or both that will affect the patient's life [7]. Targeting the needed changes will limit many additional treatments and provide the best possible results.

Many schemes had been postulated to tracking the growth, but all had missed the most important part of the process. [8]. There is a huge effort to analyze the tracked changes and produce a formula that comprehends them [9]. These steps had many obstacles, and it seems impossible to accomplish such a job. The growth of the craniofacial domain is so difficult that needs to be considered into stages.

- The 1st stage is prior to the closure of the calvarial sutures. In this stage the opened sutures provide unparallel mechanism of weakening. In this paper we had built the model that clearly represent our idea. [10]
- 2nd stage where the viscerocranium begin to develop the weakening features, such as teeth and paranasal sinuses. The Region of weakening should be discussed based on the embryological findings and in collaboration with the anatomy researchers. [11]. In our unpublished work about maxillofacial trauma, we had demonstrated the effect of these structures on the stiffness. The weakeners are fascinating in their arrangement.

Even in the craniofacial region, Endochondral ossification route is the prime bone formation method while Intramembranous ossification provides base to orient skull growth. [12]

2. Craniofacial growth jobs in summary from biomechanical point of view

Craniofacial growth is the process that results in unique soft and hard tissues arrangements that serve many functions. Understanding this process enables us to understand better the normal function as well as understanding the real process that lead to pathological conditions.

This will enable us to address the exact defect that reduce patient suffering and results in best functional and aesthetic results from early interventions which in most times surgical instead of immersing the patient in unnecessary lengthy procedures.

Building the base for structures that initiate and produce other that will build advanced complex structures. This starts from the organization of the pharyngeal arches, not just ending by closure of sutures but continue to produce changes in both soft and hard tissues even after maturity but in slower pace. Craniofacial growth is aimed at providing the base for geriatric changes. The first criteria of arrangement are the providence of suitable shape and structure to accommodate morphogenesis. For an example Meckel's cartilage provides a significant role for mandibular development, but itself will witness resorption.

Growth is a well-controlled process. We suggest that the stiffness is oriented by genetics. The total mechanical response is driven from all components not just by the extracellular matrix of both hard and soft tissues.

Different embryological origins confer upon the resultant structures a wide range of tissue properties. Ectodermal and mesenchymal and ectomesenchymal and endodermal originated cells involved in reciprocating interaction to form the very complex structures. The biomechanical function of different craniofacial structures clearly shows the importance of these origins. An example is enamel where the need to presence of non-soluble proteins dictates its epithelial origin.

Morphogenesis and growth in many stages are produced by cellular hyperplasia and hypertrophy in regions as well as apoptosis in other regions, but in many critical turns the cellular activity itself is guided by the stiffness. The stiffness will guide cellular populations to change direction or pattern of growth or attain certain phenotype or genotype. Again, stiffness is one of the main controllers of the growth.

In our unpublished paper about growth associated with bone derived from endochondral ossification route, we had demonstrated the need for extrinsic force source and intrinsic deformable tissues with solid non deformable tissues to deliver the force in precise controlled fashion.

Result in different osseous structures with successive stiffeners and weakeners to provide optimum trauma response after maturation. This will be done through different processes and modifications (such as the presence of the paranasal sinuses).

Many what appears defects or meaningless discontinuity in between the craniofacial bones (e.g. inferior orbital fissure) had important roles in trauma response.

Staged damaged pattern is also present in the soft tissues. Tissue planes are a distinctive mechanical feature that enable the surgeon to run surgeries safely and efficiently. These anatomical entities should be present to provide predesigned features and pre- designated function after skeletal maturity (namely staged damaged pattern) through macro anatomy:

- Teeth
- Paranasal sinuses and associated air cells
- Sutures between the different bones
- Different fissures and discontinuities in the craniofacial Region or through microanatomy namely bone orthotropicity.

Eigenfrequency. In order to provide controlled damping effect. The mode of the skeleton is considered very carefully in the design of the skeleton. Soft tissue is also finely tuned to fit well in the total design. Many what seem unnecessary anatomical structures are developed, inarticulate para nasal sinuses. YOU NEED to show the STUDY FOR TRAUMA ALSO FOR NON-HOLLOWED SINUS

In our unpublished work about maxillofacial trauma, we had clearly demonstrated the importance of paranasal sinuses on growth and trauma response. Paranasal sinuses presence had an active role on growth such as maxillary, sphenoid and ethmoid while frontal had more passive effect as we suggest.

a) The stable functional base of the soft tissues coordinates these tissues growth. The Craniofacial region had many houses for soft tissues (orbit, lacrimation system, part of the upper aerodigestive tract .... etc.). These Structures should be accompanied by stable coordinated bone growth.
b) Changing the bone shape according to the final need. Tracking of the craniofacial complex gained attention of the early researchers and got special attention due to its significance. There is a great debate about the method that should be used. Tomographic methods mostly include radiation and its rationale of usage in control growing age could not be justified due to the radiation exposure sequelae.
c) According to the author's opinion, the key point to start from is the needed agreement about referencing. We think that the craniofacial growth had multiple centers at different chronological and physiological growing stages with different paces. An agreement about the main event that leads to an increase in bone volume should be reached before we can resolve these controversies. We think our explanation of growth in both intramembranous and endochondral model is the best presented theory according to our knowledge.
d) We had many aesthetic, functional and mechanical requirements that needed special design for each stage of growth. Growth has multiple stages, and each stage will follow the other. In many times it is reciprocal by which the first element initiates the growth of other element that in return.
e) Provide dental foundation. In the dental development aspect, we had these notes.
    - Intra alveolar dental follicles had a great impact on the stiffness and one of the reasons for the presence of two sets of teeth is to allow more room for jaws deformation. In addition to their importance in function, deciduous teeth bring a volume for the developing of the permanent teeth and provide an invaluable reciprocation in the deformation to the jaw necessary for developing of the permanent teeth.
    - The presence of enamel lamina provides a molecular and mechanical based stiffness reducer that ensures eruption pathway patterned over the developing tooth. Epithelium had one of the most important chemical controlling potencies over other tissues, especially mesenchymal tissues. The odontogenic tumor with epithelial origin had a significant effect upon the jaw's architecture. In addition to the need for special dissolution-proof proteins for the enamel formation, their epithelial origin signifies the need of this tissue's potent molecular signaling capacity. The presence of these tissues and their events indicate different pathological conditions that are peculiar to the jaws (cherubism, giant cell lesion variants, etc.). The difference between a primary and secondary teeth set`

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number is another biomechanical story to be told. Any condition that affects the dentition will have an effect upon the growth and vice versa. The stiffness should be well understood by biologists.

f) Protection and keeping up of the neural structures.
g) Reduce the effect of any possible pathological intervention that would face the process. In the case of defects of any region the body is designed in a manner that enables it to afford the receipt of these limitations of the growth. Craniosynostosis is a wide range of different conditions, but the ability of the body to compensate any defects in the growth due to any sort of restrictions is fascinating. This also includes the growth pattern in the case of hydrocephalus.

Pathological conditions could have a genetic basis and could be idiopathic or even iatrogenic as in the case of post-surgery scarring. In both cases, the body had a fascinating capacity for compensation. Skeletal and dental discrepancies could be mitigated by optimizing a more normal one to camouflage the defective one. The body had wide margins to modify itself, an example is the orbital cavity that is much greater in terms of volume than the net volume of the essential components like these structures:

- Lacrimal gland
- Globe
- Nerves and ganglions
- Muscle and ligaments.

So that in the case of any defect happened to the bony socket, these structures continue to function properly.

Fat affects the total volume of the intraorbital content volume. Intraorbital volume changes could be tolerated to a certain degree. Accordingly, different degrees of exophthalmos or exorbitism could be seen in clinical presentations ranging from severe to mild, due to the ability of the body for compensation. The degree of severity would determine the needed management. The compensation is both functional and aesthetic.

h) Provide cellular and molecular basis to stabilize the given role (This needs more explanation.). This is beyond the scope of this paper.

3. Aim of this study

We suggest that the load is responsible for large amount of growth and composite structure of the bone alignment. How is the growth occurring? We suggest this through mechanisms that need explanation.
In this paper series we want to establish 2 goals

- Presenting an explanation
- Building a numerical model that translates this explanation into digital model that simulates the physical reality with fidelity as high as possible.
- This Building need preliminary intensive knowledge in engineering sciences especially mechanical discipline.

in our paper about endochondral ossification the growth we had produced a model the yielded growth in similar fashion to the actual growth happens in the long bones

4. Methods

The craniofacial structures could be represented into multiple quadrants with very complex anchorage points (sphenoid occiput maxilla…etc.) where these bones connect the other bones.

The effect of the tissue gapping the separated bones had not modeled as well as the intracranial pressure which play a very important aspect. In his model we want to demonstrate the effect of the muscles on the craniofacial structures which is the most important part of the simulation (active phase of muscle contraction)

Bone formation had 2 routes.

- Intramembranous
- Endochondral

Each had unique features that entitled with including genetics arms and functional aspects.

The main reason that is standing behind the presence of these 2 models are

- Need for early mechanical protection for the brain and other structures.
- Provide rigid parts to act as lever arm for stimulation of the synchondrosis regions.
- No loading counterpart for the mechanical muscular action

Growth in pediatric group is staged according to stiffness. MECHANICAL STIFNESS IS THE PRIME EFFECTOR OF THE GROWTH.

The Model Was Derived From CT scan of normal child. The model was then divided into parts that represent the bones of the skull. A sheet of uniform thickness assigned later with soft material to represent the bones.

5. Results and discussion

In order to establish a model of craniofacial growth, 2 important aspects should be respected.

- No midline tension that returns each segment to its original perforce application
- Intracranial pressure had not been considered.

We had suggested different scenarios that represent our best arrangement that demonstrate the effect of the muscles on the whole anatomical domain.

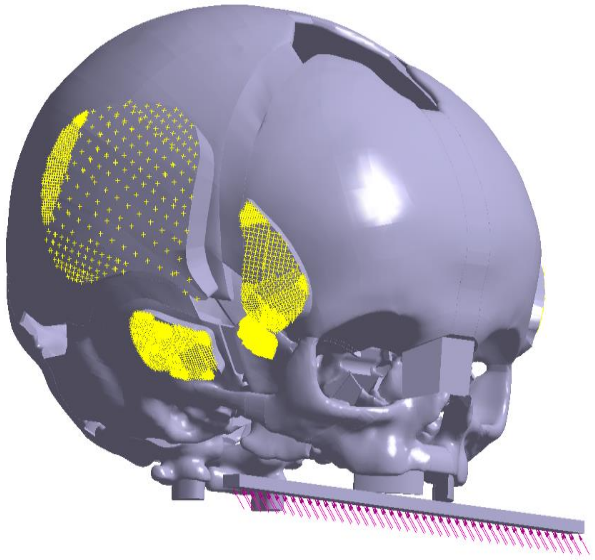


Figure 1: Yellow regions are fixed and red arrows represent the force applied

The previous figure represents a boundary condition where the force had been applied to an elastic rod rectangular in cross section. The yellow regions represent part of the mastication muscles inserted into multiple different bones. These boundary conditions should be reviewed and finely tuned by researchers in the anatomy sciences.

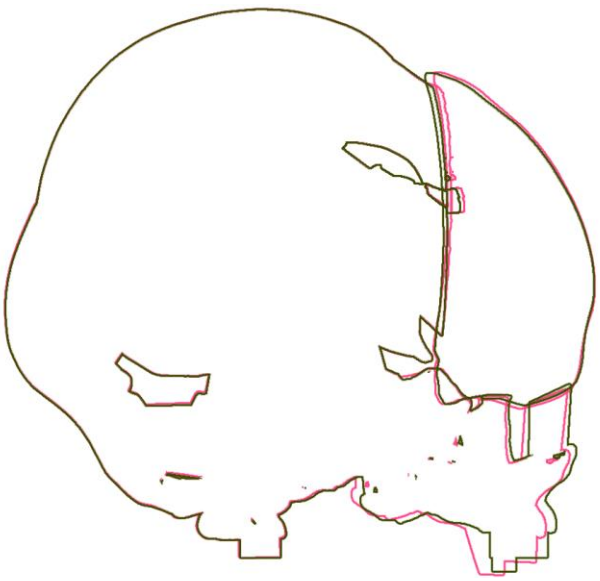


Figure 2: In order to understand the relative movement, we had drawn the outline of the skull prior and after of force exposure

This is the outline of the skull of the infant. The physical model could assume the digital model, but this should be verified. Verification of the bone movement is still in its infancy and many times including radiation exposure or placement of tracking hardware directly on the bone which represent a challenging job especially when we want to compare normal individuals with those with abnormal skulls like in the case of craniosynostosis.

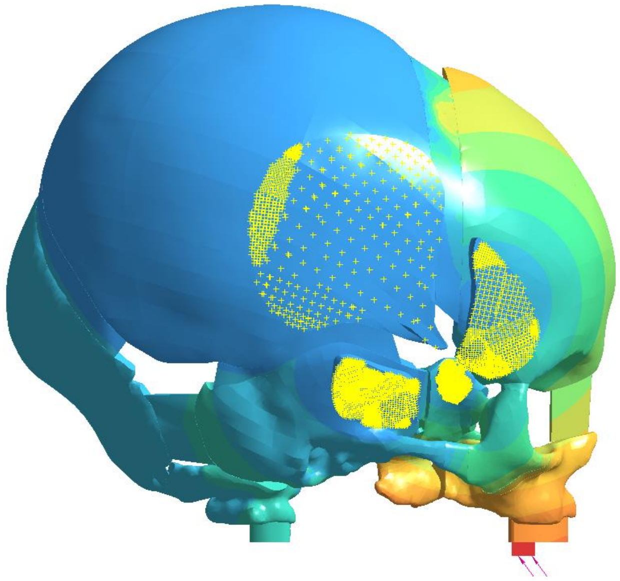


Figure 3: Displacement of the previous model with the selected boundary conditions.

The direction of the force application is clear from the lateral view. The response of the craniofacial assembly is very complex and governed by:

- Muscles
- Bones
- Ligaments that hold the bones in their place and connecting each to other
- The intracranial pressure

In the current study we want to establish the model needed to reveal the effect of the muscles as well as present model that could be used to demonstrate more complex conditions such as craniosynostosis where disturbed mechanical stimulation leading to marked deformity. Parametric approach is the ultimate goal we are paving the road toward

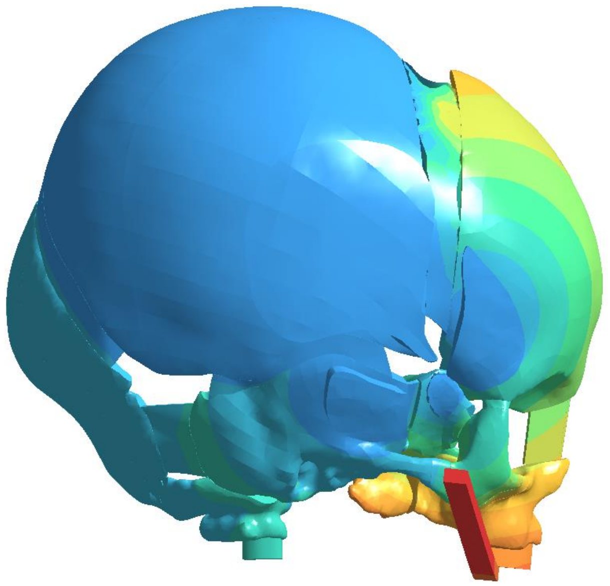
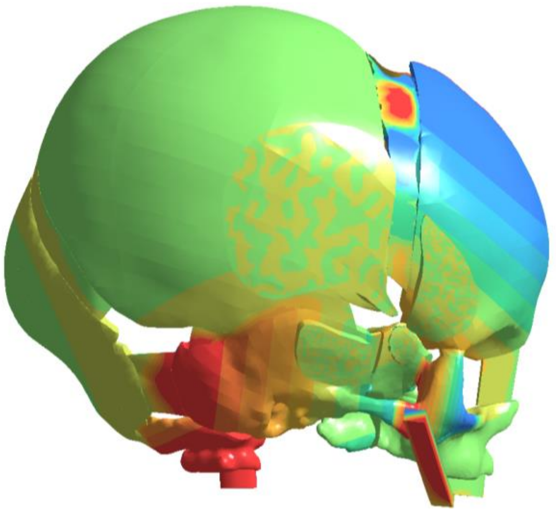


Figure 4: Total displacement could mislead the researcher when do the analysis.

This model represents the deformation in its exaggerated status. Such models should be viewed in animation derived from the FEA environment.



Displacement in the X direction clearly shows the center of different regions of rotation in relation to each other. Although we have no in vivo data that give us a clue about any measurable vector of deformity due to limited facilities.

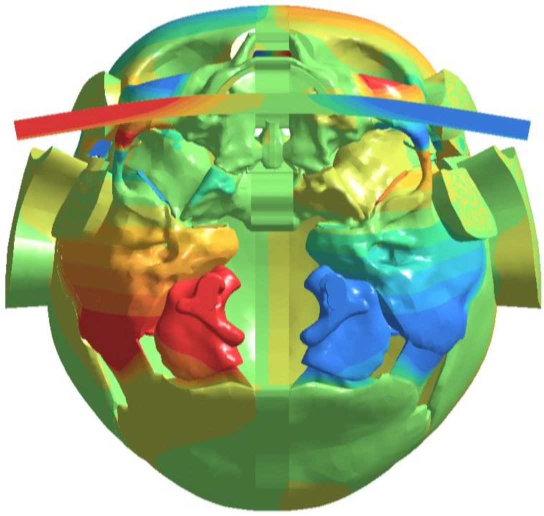


Figure 5: The differential rotation is clearly shown. The pivoting is designed very well especially in the base of the skull.

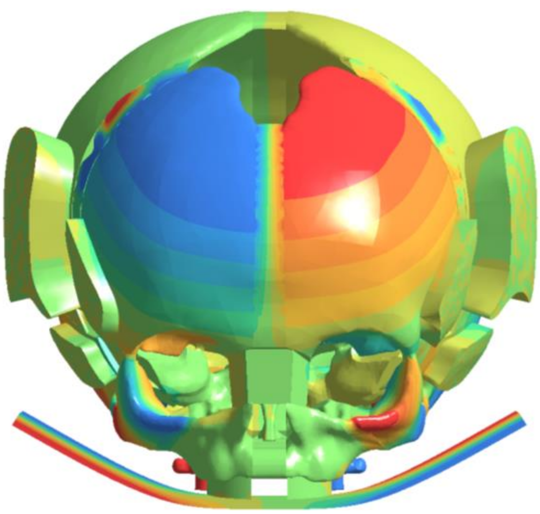


Figure 6: X field displacement.

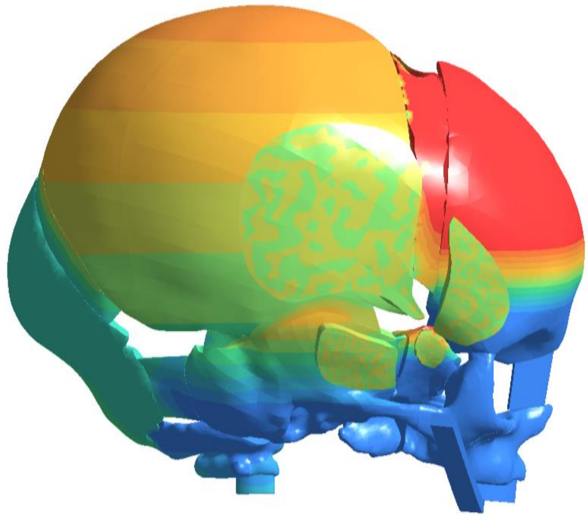


Figure 7: In the case of Y field displacement, different view of rotation is achieved.

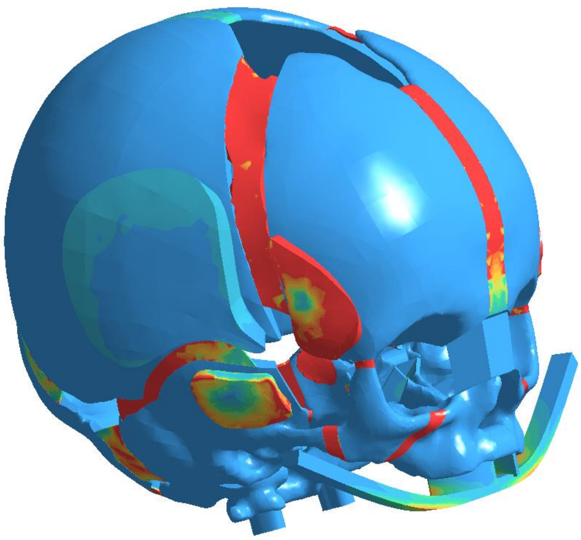


Figure 8: With every change, strain should be sought and sought.

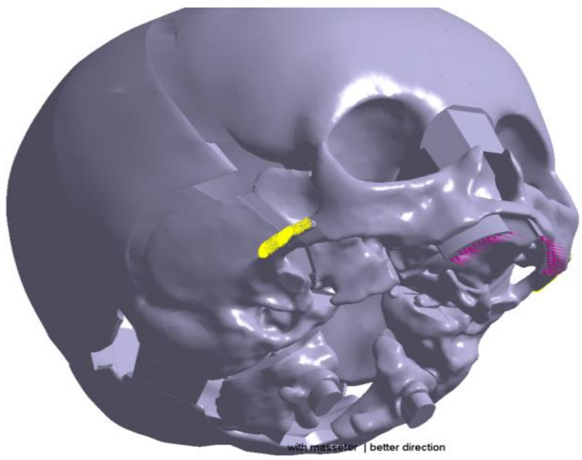


Figure 9: Each muscle had a specific vector that will provide the needed part of the stimulation for certain part of the complex 3D growth. The dentition development is one of the prime effectors of the growth.

Another boundary condition should be considered where the zygomatic arch had been fixed and the force had been applied to the maxilla. Growth is an intricate process where muscle contraction is the prime stimulator. The dentition development accompanied with the development of the child's ability to perform his daily activities will shape the newly formed bones.

The development is according to steps and in predesigned sequence. The development seems to occur in an incremental anchoring fashion. The development of the deciduous teeth provides a significant effect on the development process.

- It provides the strain enhancer of the jaws that provides the room for development of the permanent dentition.
- Provide a potent base for muscle action that affect the craniofacial growth.

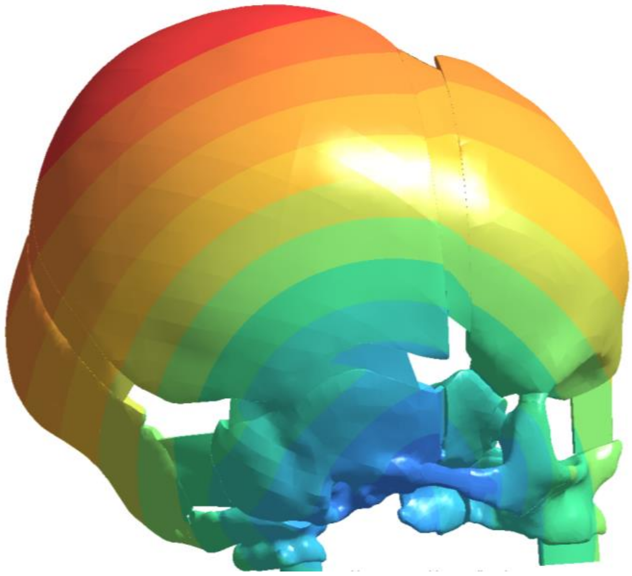


Figure 10: The total displacement could not enable us to characterize the complex growth pattern.

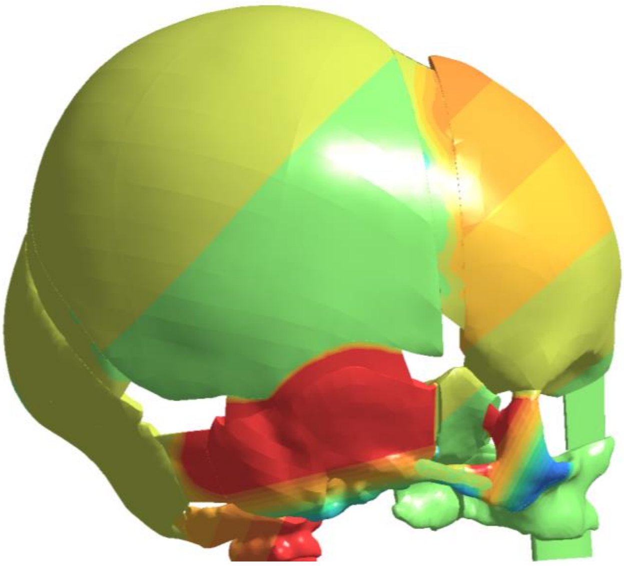


Figure 11: The X displacement had a very interesting pattern. The craniofacial bones had a very complex arrangement that provided very complex yaw roll pitch movement for each individual bone at a very complex multiple coordination system.

No direct straight movement in the body that lead to elongation but rather we had angular movement that lead to elongation at different site by the effect of the reciprocation.

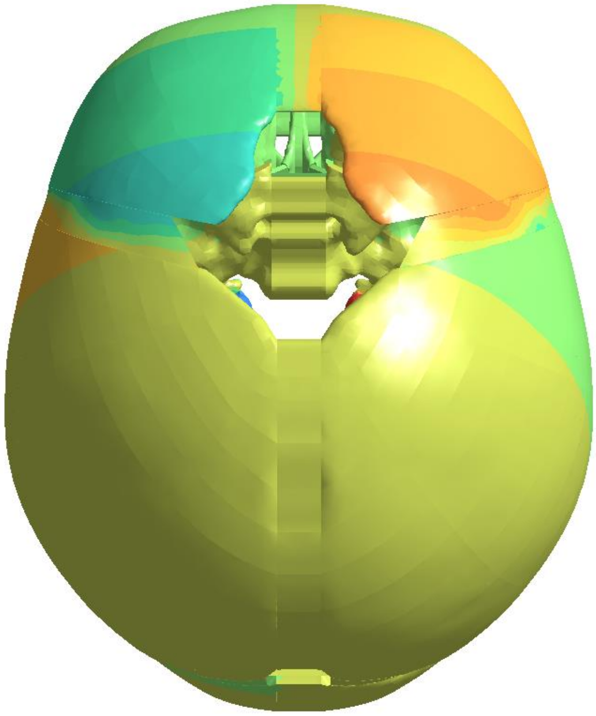


Figure 12: This is another view of the X field of displacement.

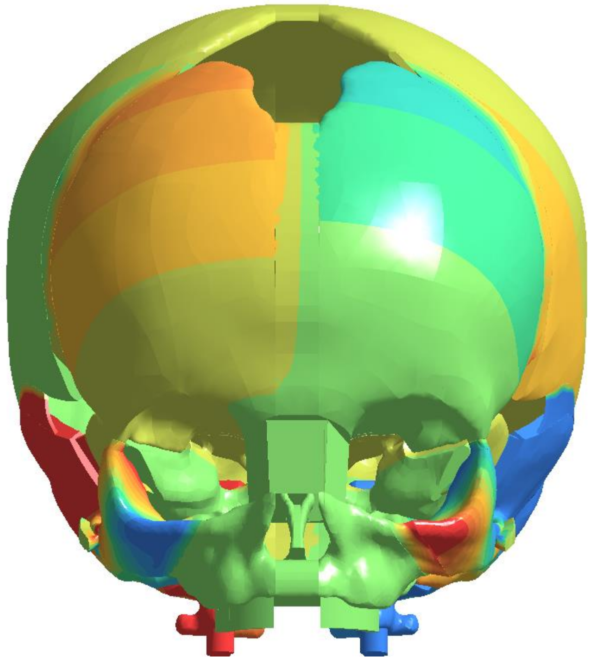


Figure 13: Other scenario had been supposed where the maxillary alveolar process analogue had been fixed and the force had been applied to the bones.

This is another view of the X field of displacement. The symmetrical distribution bilaterally clearly indicates the unique distribution of the deformity associated with each muscle contraction.

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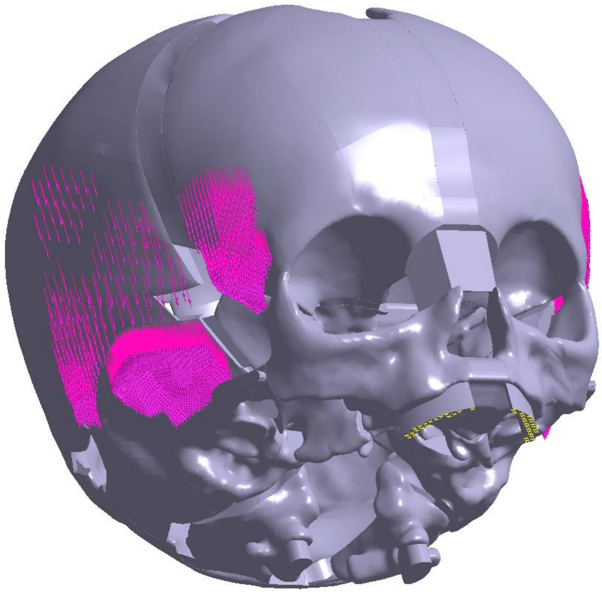

Figure 14: This is another boundary condition.

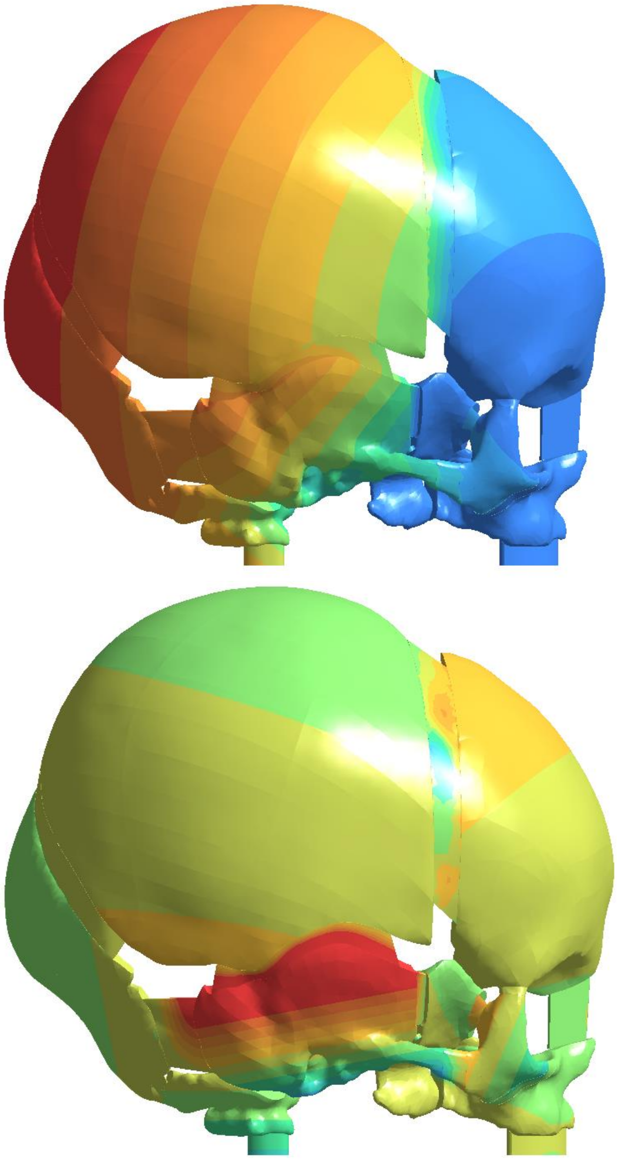

Figure 15: The total displacement should be viewed in the context of other criteria (all displacement fields, strain, strain energy density ... etc. as well as trial for in vivo verification).

The researchers in the neurosurgery and anatomy department are highly in concern with these changes. The body is composite in structure and function. No single function is found in isolation or WITHOUT linking to others. This is seen by all ages. In growing age groups reciprocation between different processes is predominant. After maturity, different functions are fully demonstrated. Pathological conditions show us what will happen at any imbalance.

The muscles are the prime derivative factors for the growth [13]. One of the prime differences between the endochondral and intramembranous routes is that bulk of bone is formed primarily in the later while in the formal bulk of the bone is derived from the compressible extensible growth plate[14].

Osseous tissue growth is derived from compressible tissues in endochondral ossification. Although we don't know the mechanism by which bone is increasing in size, whether it is at compression or release of this compression, which part of the reciprocation. Nevertheless, tension phase at the loading could be the real pathway of growth.

In intramembranous ossification route the growth is complex 3D, while in the case of endochondral it is simpler and almost totally in 2D direction. Cartilage, a hyaline variant, had a great capability to be compressed. Its return to the pre-compression status has some lag [15]. The tuning of the mechanical properties, namely stress strain curve, will be by changing the extracellular matrix driven by the cellular components will give its ability to increase in size vertical to its main axis [16].

We have no agreed numerical model to represent the tissue in charge for growth (elastic, plastic, elastoplastic, viscoelastic, vesicoplastic, vesicoeltoplastic …. etc.) and no agreed failure mode. We suggest that the epiphyseal plate have graded regions with graded histological gradient [17]. We suggest that this lag plays a significant role in osteogenesis and laying down the newly formed bone material [18].

This is also suggested to have the same in the case of fracture healing. In the previous event the intramembranous ossification is happening at the same time. This reciprocal movement (compression-Decompression and tension-detension) is the perfect event that stands behind the organization of the newly formed collagen fibers of the bone. While in intramembranous ossification the tension may be the prime affecter that makes new tissues from yield of other tissues. The only hard tissue that is formed with its final arrangement from the beginning is the teeth [19].

Nevertheless, dentine has ever changed structure according to need. One of the important structures that need special investigation is the ossification of the middle ear ossicles [20]. Its stereotypes movement needs correlation with the formation and the physiological environment [21].

During amelogenesis and dentinogenesis, the arrangement of the organic matrix will take its final arrangement from the beginning. Enamel had many features that required a stable mold that necessitated dual deposition phases. Final deposition of enamel preceded by gradual resorption of the primary formed enamel. This quiescence and stable milieu are required. Also, this is seen as a process at fracture site healing. It is important to emphasize the presence of intramembranous and endochondral ossification route side by side at the fracture sites that needed biochemical and biomechanical correlations [22].

In the intramembranous route, we have different settings that are till now not fully exposed by the scientists. The craniofacial region had complex bony arrangements that lacked many mechanical features resulting from functions associated with long bones. It has many elements, other than mesenchymal elements, namely epithelial components that are closely related to the bone (teeth and paranasal sinuses).

We think that meninges of the craniofacial region play a significant role in the development which needed to be studied especially from biomechanical as well as biochemical point of views.

No region in all of the body had such epithelial-mesenchymal interactions like in the craniofacial region [23]. Accordingly, these structures need a special mechanism different from any region elsewhere. Many bones in this region had both ossification routes. Accordingly. These structures need special mechanisms. Many of the bones and regions had both ossification routes. These combined ossification routes should be understood in the context of need. Endochondral ossification is highly load driven, while this is not the issue in intramembranous route [24].

The question is whether load plays an initiator role and at the same time maintaining transduction activity? Or do they act separately? And what about which is the first and which is the second? These questions need to be answered for both routes.

Prestrain related to the composite structure of the bone should be addressed in both those driven from the intramemberanous and endochondral routes

The epiphyseal plate will have both mechanical stimulations (compression followed by expansion) as part of normal exposure to loading on the associated bone. Tension will occur at one site and at the same time compression will occur at the opposite site. The position of these mechanical events is related mainly to the vector of the force applied. In case of intramembranous ossification many mechanisms could be recalled fulfilling the needed physical stimulation. These should be applied in the digital model.

- Intracranial pressure that is transmitted via dura.
- Occipitofrontalis muscle.
- The mechanical properties of the fontanel and tissues in between the calvarial bones.
- The fascial tissues that are connected from the left to the right side over the top of the head.
- The growth in the endochondral part of the skull is suggested to have the mentioned reciprocal mechanical effect upon the intramembranous part.

We have central defect-like discontinuities that are branching from the center of the developing skull. The mechanical force that caused the calvarial hemispheres to be separated will affect both ossification routes via the exerted stress on all parts centrally as well as those located on the sides of this central defect.

We could say that we have anterior and posterior hemisphere and at the same time 2 lateral hemispheres. The open sutures provide unparalleled mechanical stiffness reduction (they are stiffness reducers) that stand behind a great part of the growth. The already established calvarial bone with still in growing phase base of the skull represent the perfect matching of needed element for growth via force reciprocation.

As the defect is still opened till a certain stage of the development, we suggest that in the endochondral and intramembranous has the highest chance of performing horizontal field of the growth, but later on when sutures become closed and with development of the teeth, vertical growth will get more acceleration.

Although this assumption, according to our point of view, is the best and highly mechanical valid, we should follow the growth based on real data such as tomographic investigations. The best modality is MRI. Developing special protocols and hardware enhancements could make MRI more suitable and compatible for this purpose as it is suboptimal in comparison to CT in bony structures evaluations. CBCT needs special consideration due to their inherited limitations. The simplest limitation is that larger volume examined regions will result in more degraded image quality. *Always we should remember that the growth is an incremental process that need constant stimulation.*

Bone growth would be followed by soft tissues growth. At the same time, bone growth is derived by this soft tissue. Any deviation from the normal orchestrated steps will result in a pathological condition accordingly. Any soft tissues trauma in the growing patient like post-surgery fibrosis and scarring will affect bone growth followed by deficient soft tissue growth.

Growth restriction also had reciprocal effect start by soft tissues then bone finally bone in the last will limit soft tissues growth as a response to the deficient stimulation. In all growing process boundary conditions should be understood well. The presence of deforming loaders is essential. We had 2 groups of muscles.

Central paravertebral muscles that have direct connection to the skull provide the prime effect on the endochondral part of the growth. These could be regarded as extrinsic muscles of the skull.

- Paravertebral muscles
- SCM
- trapezius.

The foramen and fissures in the skull base reduce stiffness as well as other structures. Their arrangement is orchestrated within the muscle traction vectors.

Muscles of mastication in aid with the inframandibular muscles affect the intramembranous growth directly and endochondral ossification to less extent. This arrangement is from mandible to skull which could be regarded as the intrinsic muscle of the skull.

Other muscles' sets including
- Facial muscles
- Parapharyngeal muscles
- Lingual muscles …, etc.
- We think they have a less significant role. In our current model we want to introduce this concept as a numerical simulation for better demonstration.

In many papers written about craniofacial growth, the fundamental concept of the current idea which needs further development and refinement that provide concept of enlargement are missing.

This is clear in resorting to theories that explain craniofacial growth by meaningless explanation such as the nasal septum is responsible for facial elongation. We had not done a model with combination of endochondral and intramembranous at the same time in the craniofacial model due to the limited resources, like what we had done in the long bone model due to:
1) We didn't develop a mechanical model or numerical model for intramembranous growth which comprises great portion of the calvaria and base of skull (viscerocranium)
2) Need to define the extent of synchondrosis which necessitates at least an anatomist collaboration.
3) Need to choose a suitable bone model with an initial agreement about the used materials properties.
4) Correct formulation of the boundary conditions

What we had not done was a combined analysis of the endochondral route like a long bone for the skull model. In the first place we need to define many biological entities from a mechanical point of view and need an anatomist to guide us. Finally, more refinement of the current model is highly advisable and needed.

References

[1] R. G. V. S. Manlove AE, "Craniofacial Growth: Current Theories and Influence on Management.," *Oral Maxillofac Surg Clin North Am.* , 2020;32(2):167-175. doi:10.1016/j.coms.2020.01.007.

[2] Christopher L.B. Lavelle, "Growth and development of the craniofacial skeleton, Editor(s): Christopher L.B. Lavelle,," *Applied Oral Physiology (Second Edition), Butterworth-Heinemann,* , 1988,.

[3] H. A. A. B. Vargo JD, "Identification and Management of Cranial Anomalies in Perinatology.," *Clin Perinatol.*, 2018.

[4] H. A. M. K. M. K. O. H. V. M. D. D. S. R. Knigge RP, "Craniofacial growth and morphology among intersecting clinical categories.," *Anat Rec (Hoboken).* , 2022 Sep.

[5] B. R. Mulliken JB, "Surgical correction of the craniofacial anomalies in Apert syndrome.," *Clin Plast Surg.* , 1991.

[6] T. B., "Basic mechanisms in craniofacial growth.," *Acta Odontol Scand.* , 1995.

[7] A.-A. B. A. A. J. A. Farhan TM, "Craniofacial Anomaly Association with the Internal Malformations in the Pediatric Age Group in Al-Fallujah City-Iraq.," *Biomed Res Int.* , 2020 Aug .

[8] K. &. C. K. &. F. D. &. S. S. Archer, " Software Tools for Craniofacial Growth and Reconstruction.," (2000)..

[9] S. A. V. (. Rengasamy Venugopalan, "Craniofacial Growth and Development.," in *Peterson's Principles of Oral and Maxillofacial Surgery.* , Springer, Cham, In: Miloro, M., Ghali, G.E., Larsen, P.E., Waite, P. (eds) .

[10] T. S. Herring SW, "Strain in the braincase and its sutures during function.," *Am J Phys Anthropol.* , 2000 Aug.

[11] Z. B. W. C. W. N. Song X, "Dynamic Response of the Skull with Sinuses under Blunt Frontal Impact: A Three-Dimensional Computational Study.," *Comput Math Methods Med.* , 2015.

[12] S. K. K. S. Jin SW, "Development and Growth of the Normal Cranial Vault : An Embryologic Review.," *J Korean Neurosurg Soc.* , 2016 .

[13] K. S., "Masticatory muscle influence on craniofacial growth.," *Acta Odontol Scand.* , 1995.

[14] S. M. M. R. Breeland G, "Embryology, Bone Ossification. [Updated 2023 May 1]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan," [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK539718/.

[15] W. T. C. X. E. B. Alizadeh Sardroud H, " Cartilage Tissue Engineering Approaches Need to Assess Fibrocartilage When Hydrogel Constructs Are Mechanically Loaded.," *Front Bioeng Biotechnol.* , 2022.

[16] O. &. D. K. &. M.-K. V. &. G. M. &. B. T. &. S. H. &. H. F. &. G. K. Franke, "Mechanical properties of hyaline and repair cartilage studied by nanoindentation.," *Acta biomaterialia.* , (2007). .

[17] T. S. S. A. N. C. H.-M. N. P. K. F. V. Eckstein KN, "The heterogeneous mechanical properties of adolescent growth plate cartilage: A study in rabbit.," *J Mech Behav Biomed Mater.* , 2022.

[18] S. K. A. L. U. Saito, "Biomechanics of the Growth Plate. In: Poitout, D.G. (eds)," *Biomechanics and Biomaterials in Orthopedics.* , (2004). .

[19] R. J. Hyuk-Jae Edward Kwon, "Development of Teeth," in *Reference Module in Biomedical Sciences,* , Elsevier, , 2018,.

[20] C. G. L. N. P. J. V. L. M. L. Richard C, "Inner ear ossification and mineralization kinetics in human embryonic development - microtomographic and histomorphological study.," *Sci Rep.* , 2017.

[21] C. &. C. F. &. S. P. &. B. M. &. F. M. (. Palumbo, "Osteocyte Apoptosis and Absence of Bone Remodeling in Human Auditory Ossicles and Scleral Ossicles of Lower Vertebrates: A Mere Coincidence or Linked Processes".

[22] M. S. E. G. R. R. X. J. E. P. Z. L. Ghimire S, "The investigation of bone fracture healing under intramembranous and endochondral ossification.," *Bone Rep.* , 2020 .

[23] B. J. E. A. A. A. S. L. O. P. Landi F, "The role of the nasal region in craniofacial growth: An investigation using path analysis.," *Anat Rec (Hoboken).* , 2022.

[24] Z. M. A. S. F.-W. P. Galea GL, "Making and shaping endochondral and intramembranous bones.," *Dev Dyn.*, 2021
[25] A. Bonnaccorsi, “On the Relationship between Firm Size and Export Intensity,” Journal of International Business Studies, XXIII (4), pp. 605-635, 1992. (journal style)
[26] R. Caves, Multinational Enterprise and Economic Analysis, Cambridge University Press, Cambridge, 1982. (book style)
[27] M. Clerc, “The Swarm and the Queen: Towards a Deterministic and Adaptive Particle Swarm Optimization,” In Proceedings of the IEEE Congress on Evolutionary Computation (CEC), pp. 1951-1957, 1999. (conference style)
[28] H.H. Crokell, “Specialization and International Competitiveness,” in Managing the Multinational Subsidiary, H. Etemad and L. S, Sulude (eds.), Croom-Helm, London, 1986. (book chapter style)
[29] K. Deb, S. Agrawal, A. Pratab, T. Meyarivan, “A Fast Elitist Non-dominated Sorting Genetic Algorithms for Multiobjective Optimization: NSGA II,” KanGAL report 200001, Indian Institute of Technology, Kanpur, India, 2000. (technical report style)
[30] J. Geralds, "Sega Ends Production of Dreamcast," vnunet.com, para. 2, Jan. 31, 2001. [Online]. Available: http://nl1.vnunet.com/news/1116995. [Accessed: Sept. 12, 2004]. (General Internet site)

Author Profile

Mohammed Zahid Saadoon BDS– FKHCMS (Maxillofacial Surgery). During 2014-2024 he was involved in may researches in biomechanics and biomechatronic. He developed many theories in maxillofacial traumatology, craniofacial growth and dental implantology. He developed a unique dental implant system. He has a special interest in mechanical engineering applications in the medical and dental specialties as well as in forensic medicine. He is now working as maxillofacial surgeon in Ashty teaching hospital, largest secondary referral centers in Soran discrete at Kurdistan region / Iraq.