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The Ten Golden Factors that Determine Bone Fractures, Fracture Determinants

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Abstract: ***Fracture management is present comprehensively in the texts of many specialties, especially maxillofacial surgery and orthopedics. Absence of inclusive definition make these managements speculative in many times. Engineering oriented definition of the bone fractures should be clear to the physicians to get better inclusive definition that will be the basis for better management. This dictates brief discussion about the fracture itself, as an event, then more discussion related to the bone as an engineering material. Although bone will never be a static material.***

Keywords: bone fracture, biomechanics, craniofacial trauma, maxillofacial, surgery, orthopedics

1. Introduction

Fracture is an event witnessed in the emergency on daily basis [1]. As a policy, the anatomical location of the fracture dictates the specialty that deals with. Main surgical specialties that deal with fractures [2].

- Maxillofacial for the facial fractures
- ENT for nasal fractures
- Neurosurgery for the cranial fractures
- Orthopedics for extremities fractures
- Poly trauma would dictate x multidisciplinary approach

Due to the diversity of the specialties, different protocols had been done. Many greed protocols in a specialty is considered unacceptable in others. Even in the orthopedic surgery with all the advances in that science the speech about the fracture itself is limited [3].

2. Fracture biomechanical definition

Fracture, engineeringly, is defined as separation or fragmentation of a solid resulting from loads or stresses with creation of at least two new surfaces [4]. To make a good design we should anticipate fracture and plan to reduce its deleterious effect [5].

Many criteria had been supposed to determine materials` behavior after loading [6]. These criteria are applied to engineering materials and although bone are ever changing material, it could be applied to some extent for bone. Engineering yields a criterion that had been agreed about bone is the Von mises stress [7]. Other criteria had been supposed, but this criterion had most fitted due to its more comprehensive and precise definition. It is dependent upon exceeding a certain critical value by the maximum shear stress [8]. We are highly in agreement about its mathematical assumption. In mechanical engineering, the terms stress concentration had been replaced by the author as weakeners due to intentionally done anatomical features by the great Creator [9]. This definition needs many modifications to fit better in the case of maxillofacial trauma field.

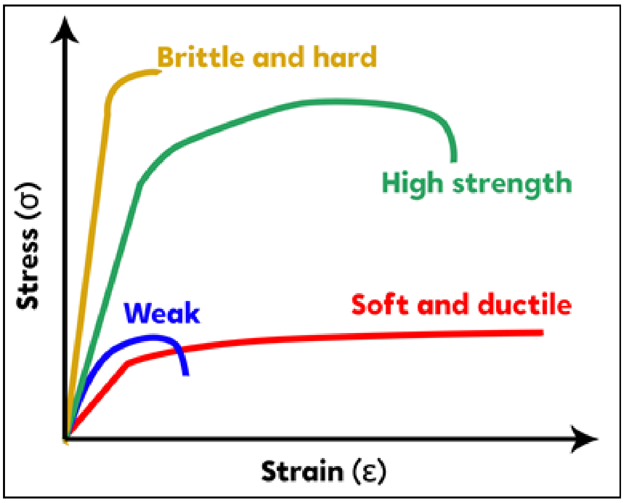

Figure 1: SS curve for most of the engineering materials

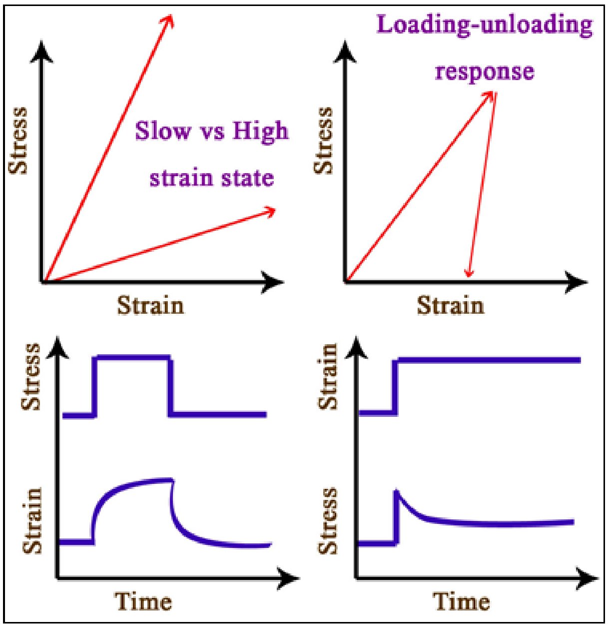

Figure 2: Different materials had different responses

These figures show strain-dependent material response which is the feature of the vast majority of living materials.

Modern mechanical engineering discipline analysis, namely FEA, deals with homogeneous materials in most cases, while bone is composite inside composite inside composite and we should always emphasize this fact. Bone is a material with its built-in sensors and mechanism that guarantees repair in case of any damage [10]. Human service life is the fact that all of us will face and should prepare ourselves for, ***but no bone will fail due to simple loading specifically in the maxillofacial region***. The only possible failures that could be seen are from pathological conditions or trauma. Stress fracture should be regarded as a ***biomechanical trauma*** rather than a simple repetitive event.

Fracture is a non-linear event that makes separation of a bone partial or complete into at least two segments. It mostly involves a bone where one part has restrained mobility and another part where mobility permits its separation from the other part. This separation will not follow a linear curve. Some material like PEEK had notch sensitivity and application of this concept to the bone is highly erroneous. The complex design of cranial facial regions could permit an analogue of this feature which we had called (anatomical weakeners). The strain rate-controlled behavior will permit very complex responses of the bone. Bone geometrical response by is self is highly non-linear [11].

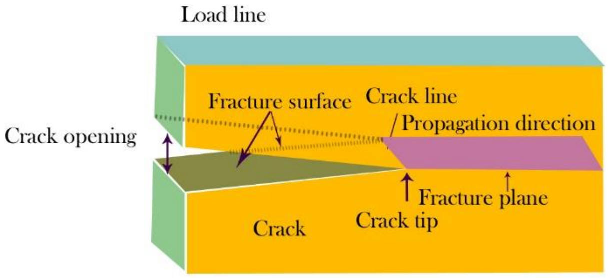

Figure 3: How crack element should be discussed

How bone fracture should be understood

Current description of bones` fractures is mechanically deficient. Our management is linear from a mechanical point of view which is used to treat a highly non-linear event. This will result in poor management in many cases. The soft tissues had a good ability to hold fractures and attain healing even without any intervention. Accordingly, closed reduction is highly advisable in many cases.

Fracture could involve one or all of the next elements.

- Crack propagation
- Exceeding the bending strength
- Shear fracture or buckling of the structure.

Some of the bone is flat where it could be bent or flexed toward a direction and attaining cracking in another situation or could have buckling response in third situations. We think that this is why the skull is composed mostly from flat bones.

The fracture could

- damage the same bone.
- transmitted to distant sites according to the permissible range of movement.

The concept of gradient of stiffness is not just suited to linear daily activity, but also to traumatic non-linear events. The most astonishing fact is that the bones are suited and designed to behave under all conditions and give the same planned response every time.

The engineering calculations depend upon well knowledge of material itself and boundary conditions [12]. In the facial skeleton we had not confirmed the description of the bone in many aspects, especially orthotropicity. This gap should be understood and filled, otherwise, we will stay in the area of assumptions especially for the theoretical part of the engineering analysis.

In the case of bone, Griffith and Champy concepts are far away from being applied in our field due to the nature of the bone itself, namely orthotropicity as well as geometrical nonlinearity of the facial skeleton. Bone is an ever-changing material. So that any analysis about fracture resistors is facing the bone remodeling capacity. This should be understood clearly by any engineering researcher involved in biomechanics of the bone. Accordingly, there will be no fatigue damage until accumulation of stresses at high rate that exceed remodeling capacity in normal individuals, like in marathon fracture, or at normal rate but defective remodeling capacity, like in the cases of antiresorptive drug receivers. In certain conditions, orthopedic surgeons may face stress fracture, but this specific type of fracture present in the maxillofacial region is highly doubtful.

The only condition to be seen as frank fatigue followed by failure in the maxillofacial region is the fracture of the endodontically treated teeth due to the absence of dentine repair [13].

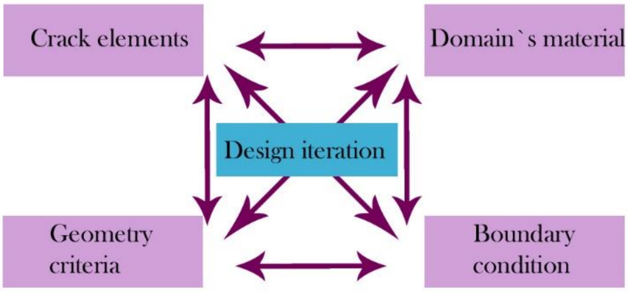

Figure 4: Design process had many elements to be considered

In engineering sciences, any failed material should be discarded, and we should learn a single lesson or many lessons regarding surgical tools. But in the case of bone, it will change design by itself in a process beyond the scope of this paper.

One of the most important matters to be considered is whether fracture due to the impaction of the object will displace the facial skeleton for small displacement such as hitting fist in case of interpersonal violence or like basketball hitting. In such a case the momentum is low and could result in short displacement due to the deflection of the hitting object. The uniqueness of the facial skeleton produces deflection or moving away of the hitting object from the body. In other conditions the impaction object will engage the facial skeleton and continue to displace the facial skeleton such as hitting by

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car. Accompanying soft tissue injuries could be different, ranging from abrasion to avulsion. The engineering analysis of the soft tissue injury is another story that needs a huge amount of work which is beyond the scope of this paper.

It is important to know that some fractures of the midface involving multiple bones could occur due to single site impaction. In the panfacial fractures, there could be multiple impact sites. Impaction of a bone adjacent to the already fractured site could lead to more devastating injury or an odd pattern of fracturing, due to the absence of optimum biomechanics required to resist that damage of the second or third trauma [14]. *In Aous theory we had three main components of the facial skeleton that are main trauma receivers*. These osseous regions could be regarded as the cornerstone in any fracture management as well as in etiology of the fracture itself.

- Frontal bone
- Zygoma
- Palate and alveolus of maxilla

Mandible had a totally different role in the trauma and most bones of the midface should be regarded as soft tissue compartmentalizing components rather than a pure osseous structure that resists fracture. This involves the whole face. Regarding mandible as a buttress of the face needs review. Mandibular bone is highly different in terms of its response from other bones of the face that are attached to the neurocranium. Those bones are highly connected, while the mandible is isolated, and each of them could determine the whole net response. The mandible had no direct connections to the facial skeleton. It could be regarded as a highly floating bone. Its behavior, as we will denote, is like long bones. Including this bone in the category of pan facial fracture as integral part should be disagreed from the author point of view, but it's fracture in case of panfacial fracture should be regarded concomitant. Its role in such fracture is to get relocation of the facial bone relative to the occlusion to preserve pre-trauma skeletal configurations.

When you isolate the central mid face from the whole mid face and test the model, you can see the impact of the bone and at least provide visual guidance. This approach is very important and had been used by Le Fort when he had done his research in maxillofacial trauma.

Other parts of the midface had a major role as soft tissue house and to a lesser extent to guide the response of these bones and connect them. This is from a mechanical concepts' perspective. Their configuration is not only respecting mechanical performance only. Many engineering disciplines should be digested very well in addition to biological sciences to understand the magnificent facial anatomy from a functional point of view. One of their roles is also to shape the upper airway to achieve optimum bio-aerodynamics. Other aspects from other engineering disciplines' perspectives should also be respected. Frontal sinuses are weakener and strengthener at the same time. Providing the most prominent part of the bone with a staged damaged structure will absorb the energy of the hitting object and at the same time will reduce the amount of impact injury to the most precious part of the skull, namely the brain. This is provided by the anterior and posterior wall of the frontal sinus. With deficiency in the central part of the frontal bone at the anterior cranial fossa, we will get excellent compliant mechanisms to protect the brain. The connection of the ethmoid with the frontal bone, by itself only, is a fascinating story that needs separate work to tell it.
We had considered the effect of PD ligament as a neglectable element in our analysis. The presence of the PD ligament and teeth in the models should be investigated carefully [15]. Many biomechanics researchers consider the presence of teeth had no effect on their response to the job. Equations of the motion, that describe how different bodies are interacting between each other, should be considered, and should be brought into any discussion about traumatology.

In many instances, a certain amount of facial deformity is already present in the pre-trauma status. In such cases pre-trauma records (the best current modality is the CT scan) is used to compare to the post trauma status. Although we consider our knowledge in biomechanics of trauma is deficient, trauma data (e.g. pre and post trauma CT scan) with careful investigation of the cause, then correlating them to the traumas` results could provide an excellent source of information. Nevertheless, knowing of fracturing objects, which had been already interacted with the facial skeleton, could remain vague in almost all cases. Trauma events that led to fracture almost always happened in an unpredictable way.

The only way to validate trauma analysis is to conduct studies on real living people, but this is a totally unscientific, unethical and illegal way. The alternative is to choose.

- cadavers, with consideration of post-mortem changes in both soft and hard tissues
- Animals with close anatomy to human species
- Physical and phantom models
- Virtual models

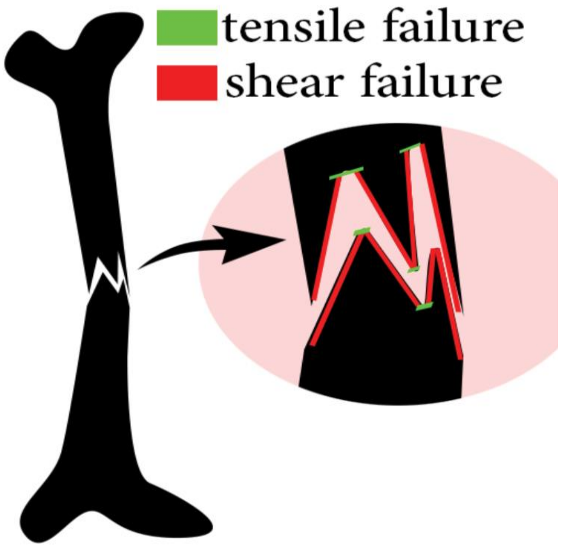
The facial struts [16], that are considered by many maxillofacial surgeons and highly emphasized upon in many maxillofacial trauma texts or chapters, represents an imaginary concept rather than robust mechanical description based upon sound biomechanical description. These struts need to be redefined. We had many objections about these concepts, but in this publication, we want to settle a base to understand more important concepts. We prefer to discuss reformatted formulas in the light of what we are regarding more important concepts.

The living tissues have a variable and sometimes significant amount of stored mechanical and chemical energy [17]. Fracture healing is derived by chemical stored energy of the bone. It will be guided as well by the mechanical transduction provided by physiological stimulation that causes orientation of the newly formed osseous tissues in order to form regional-like bone. The most important aspect is to restore the original fibrous structure of the bone, or in another word its orthotropicity.

Our histological model of bone includes a small amount of highly strained areas that could be damaged or yielded in certain directions more readily than other directions to guide the fracture itself at where to continue in more predictable fashion and at the same time to guide the repair process exactly any possible micro damage that had been occurred. At the same time, the vast majority of bone material could afford extended time of repeated stresses. In other mechanical engineering description, ***high endurance level***. Any damage or any pathological condition to any arms of the repair process (either congenital like in osteopetrosis or acquired like in anti-osteoclast during receiving) will lead to accommodation of these damages that could possibly resulting in catastrophic failure of bone structure, as in idiopathic fracture of bone after long term bisphosphonate administration. We should clarify that bone resorption is not guided by osteoclast. Both processes, resorption and deposition are guided by osteocytes and the osteoclast just had a significant role, but for a short term of the whole process at the same time.

The fracture of the bone should be regarded as composite structure response rather than solid homogeneous. In case of transverse fracture, what is happening is a mixture of shear failure to a great extent in a plane different from the plane of the separating fracture, while tensile failures to a lesser extent. The predominant pattern in bone is the shear. The difference between different fracture types (like transverse and spiral) is that in the case of spiral there is a relative weakness in the bone locally that leads to presence of well-defined propagation of the fracture line and extension of it into adjacent regions to the trauma site. Bone crack propagation should be reviewed as composite material damage. Extension of the crack due to

- Relative weakness of that area
- Vectors of the force make the impact site stronger than the adjacent area, although the mass of the impact site is much less, but the orthotropicity of the bone could favor mechanical response in a certain direction for a given region. So, emphasizing the bone orthotropicity is of paramount importance. This involves the soft tissues damage as well as hard tissues.



Pure total tensile failure is not occurring in all regions of the fracture site, but possibly to a limited extent in some regions. This had been marked as green regions of the previous figure. Both occlusal force and trauma force will strain the bone but bending that occurred due to the occlusal load is totally different from the buckling event at trauma time. During daily activities, any stress that could cause harm by exceeding its capability to resist this load to the organ will give an alarm via neurosensory nociceptive feedback.

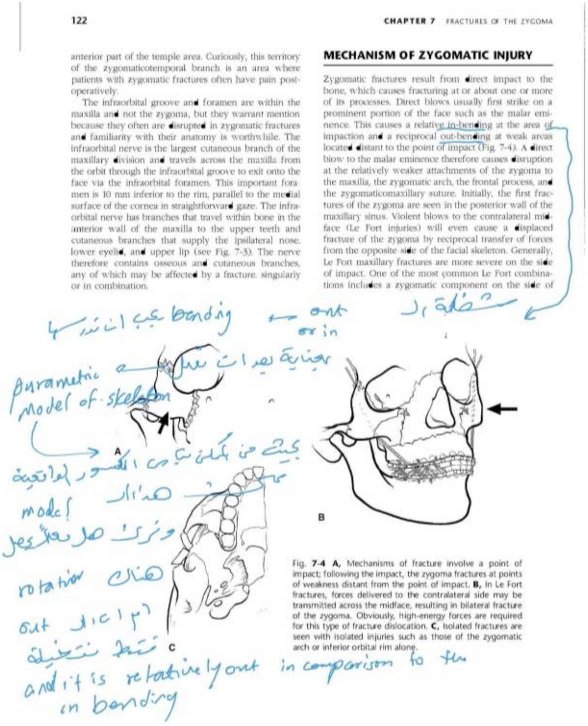
Dental apparatus had excellent mechanical biofeedback and the tissues had unique arrangements that exaggerate the movement of the dentition in response to the loads. In addition to this, the organization of teeth and periodontal structure provide excellent gradient of stiffness making the normal daily activity possible without damaging these structures and enhance this feedback. This had been demonstrated well in the ***(Mohammed bodies analysis)***. Enamel is the hardest tissue in the body followed by dentin, which is hard, but slightly softer than enamel while cementum has a more softness. PD ligaments are very soft with viscosity components. The stiffness gradient is reversed again from the lamina dura, where calcification of bone is enhanced that is embedded in the relatively soft medullary bone which is invested inside the harder cortical part [18].

Although buckling and bending are two totally different mechanical terms [19], they are used interchangeably erroneously. This bending claimed to be the cause behind the jaw’s tori. The jaws bending could provide a nidus of concentrated changes at the outer cortical surface leading to highly cortical structures. On the other side, and in many cases, the midline suture of the palate could be patented until the last third decade of the life which should be correlated to the growth pattern and odd patterns of fracture resulting from different anatomical variation. Although we had studied a single parametric model to simulate the normal anatomy, these anatomical conditions should be regarded as a separate entity rather than making a conclusion on the whole trauma management from already odd anatomical architecture.

Bone material is designed to withstand force generated by gradient of stiffness where joints and other damping components are highly integrated

- PD ligaments
- Cartilage to bone
- Ligaments
- …...etc.

In the case of an implant manufactured from titanium, this will be highly deranged. Osseointegration will cause severe disruption of stress distribution and the resultant gradient of stiffness is totally different in the case of dental implants [20]. This will change the whole osseous structure of the skull.



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CHAPTER 7 FRACTURES OF THE ZYGOMA

anterior part of the temple area. Curiously, this territory of the zygomaticotemporal branch is an area where patients with zygomatic fractures often have pain postoperatively.

The infraorbital groove and foramen are within the maxilla and not the zygoma, but they warrant mention because they often are disrupted in zygomatic fractures and familiarity with their anatomy is worthwhile. The infraorbital nerve is the largest cutaneous branch of the maxillary division and travels across the maxilla from the orbit through the infraorbital groove to exit onto the face via the infraorbital foramen. This important foramen is 10 mm inferior to the rim, parallel to the medial surface of the cornea in straightforward gaze. The infraorbital nerve has branches that travel within bone in the anterior wall of the maxilla to the upper teeth and cutaneous branches that supply the ipsilateral nose, lower eyelid, and upper lip (see Fig. 7-3). The nerve therefore contains osseous and cutaneous branches, any of which may be affected by a fracture, singularly or in combination.

MECHANISM OF ZYGOMATIC INJURY

Zygomatic fractures result from direct impact to the bone, which causes fracturing at or about one or more of its processes. Direct blows usually first strike on a prominent portion of the face such as the malar eminence. This causes a relative in-bending at the area of impaction and a reciprocal out-bending at weak areas located distant to the point of impact (Fig. 7-4). A direct blow to the malar eminence therefore causes disruption at the relatively weaker attachments of the zygoma to the maxilla, the zygomatic arch, the frontal process, and the zygomaticomaxillary suture. Initially, the first fractures of the zygoma are seen in the posterior wall of the maxillary sinus. Violent blows to the contralateral midface (Le Fort injuries) will even cause a displaced fracture of the zygoma by reciprocal transfer of forces from the opposite side of the facial skeleton. Generally, Le Fort maxillary fractures are more severe on the side of impact. One of the most common Le Fort combinations includes a zygomatic component on the side of

عيب انتشارها bending ← out or in

مشكلة ال

parametric model of skeleton

عجائبية تصورات تعمل

بحيث من الممكن تحديد الكسور المتوقعة

model هذا ال

وترك مجال لل

rotation هناك

out أم ال

شغلة نتخيله

and it is relatively out in comparison to the in bending

Fig. **7-4** **A,** Mechanisms of fracture involve a point of impact; following the impact, the zygoma fractures at points of weakness distant from the point of impact. **B,** In Le Fort fractures, forces delivered to the contralateral side may be transmitted across the midface, resulting in bilateral fracture of the zygoma. Obviously, high-energy forces are required for this type of fracture dislocation. **C,** Isolated fractures are seen with isolated injuries such as those of the zygomatic arch or inferior orbital rim alone.

Figure 5: This is one of the notes I had written during the maxillofacial fellowship examination's preparation. I had put it here for a reference to show how one should include the notes.

3. Golden 10 point, Fractures Determinants

In order to understand the trauma mechanism of the fracture we should review the nature of the bone composite structure. The next factors will determine the fracture that possibly resulted from any trauma.

1) Bone is the composite inside the composite.

Bone composite orthotropicity and fracture toughness should be included in any theory. Bone is composite on different levels. Bone is like wood in terms of ease in splitting in the direction of fibers but resist fracture in other directions.

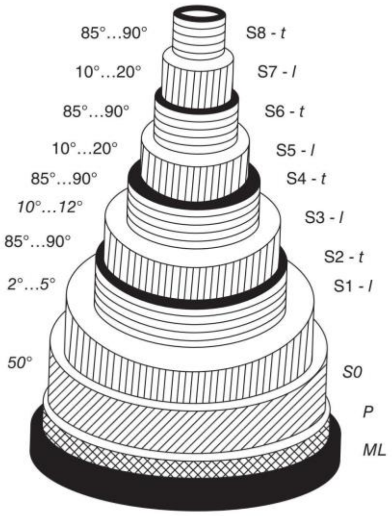


Figure 6: Composite structure of the thick-walled bamboo

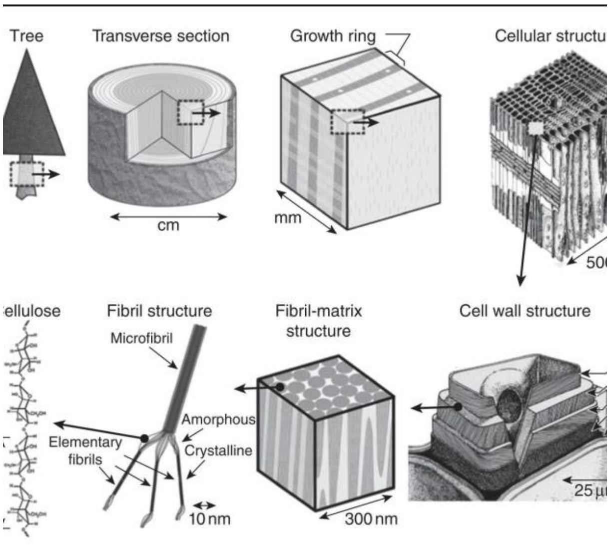


Figure 7: Composite inside composite inside composite

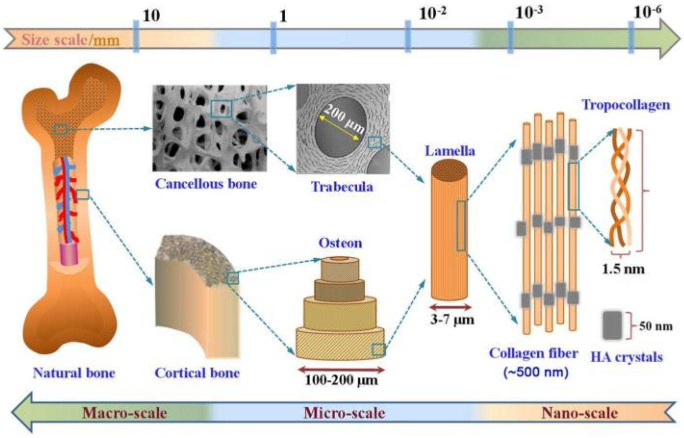


Figure 8: The high similarities of the wood structure and the bone is evident

Before discussing any mechanical concept, we emphasize that the bones are capable of their weight bearing due to the orientation of their fibers and their capability to resist tension and shear converting these 2 resistances into compression resistance. The bone strength is a result of the interaction of the fibrous and matrix portion of the bone. The total mechanical response of the bone is derived from the summation of the responses of all elements on all the levels (Nano, Micro and Maro) [21]. The bone weight-bearing capacity is derived from the matrix that is held by its fibrous structure. This is an axiom of composite engineering discipline. The bone capability to resist compression and bear weight is derived from the arrangement of its fibers as we stated previously.

The maintenance and maturation phases of bone is a cellular-controlled process. The amazing compartmentalized structure of the bone on all levels enables precise control and modification. Mechanotransduction provided by osteocytes had been agreed as the controller of bone physiological changes [22]. During the forever ongoing process, osteocytes are calling osteoclasts to clean any micro-damage resulting from daily activity. Thereupon, osteoblasts repair the defect created by osteoclasts.

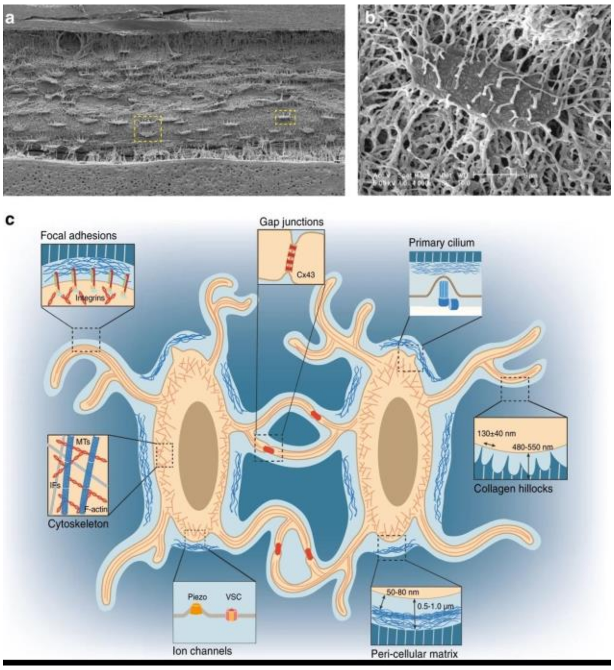


Figure 9: Osteoblast network structure

2) Bony macro anatomy.

It is imperative to the researchers in the biomechanics (from any scientific discipline whether anatomy, maxillofacial, orthopedics, …. etc.) to define the border of the nano micro and macro level of the bone structure. It will cause geometrical nonlinearity. Fracture is highly affected by the design of the domain, not only the mechanical properties of the material of the tested domain. Bone stiffness is not simply determined by its outer shape. Bones could be classified according to their stiffness into different categories. There are not only differences across large and small bones, but among regions of the same single bone

a) **Had mechanical balancing effect** as it will favor displacement in one direction and resist other directions. In many times anatomical regions are composed from multiple structures intimately associated with each other behaving as a single anatomical unit, different bones and ligaments, like in wrist or ankle joints. Carpals and tarsals, in their honeycomb structure, will behave better than cortical or even cancellous structures and could behave like compliant or auxetic material. The cancellous part simply is the honeycomb structure of the cortical part rather than a different entity.

b) **Rigid, formed from highly cortical percent,** mandible in the facial region or diathesis of long bones are the best examples that fit in this category.

c) **Slender, small cross section** in relatively long bone, where it provides a secondary strut and also provides a base for soft tissues attachments. Zygomatic arch is the best example.

- **Mass composed mainly of cancellous**, like head of femur or maxillary tuberosity. The cancellous part of the bone provides unparalleled mechanical performance as well as cellular reservoir. ***Stiffness of the connection between multiple bones play a great in modifying the total response of the limb***

Generally, we have 3 degrees of stiffness in different anatomical connections between connected bones according to the entitled mechanical functions.

- **Least stiffness** in hand and foot where the total stiffness is affected by the soft tissues' component of the specific anatomical region
- **Intermediate** as in tibiofibular or radioulnar connection and ankle joint
- **High stiffness** in suture of the skull
- The Ultimate stiffness in seen the case of bone itself

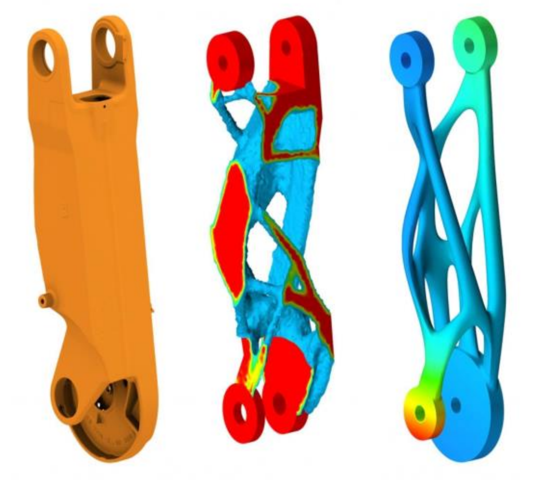


Figure 10: You can get the best by the least

Topological optimization is used to reduce manufacturing costs and achieve the best performance by the least material. Bone is a very economic material that regulates itself by itself. We had these keynotes that should be present in any discussion.

- Endochondral bone is load driven in both formation and maintenance phases.
- The design is driven by the osteocyte network.
- Strain energy density is an agreed criteria that we could use to anticipate bone response.

3) Eigenfrequency of the anatomical domain

Mode of any object dictates its response in the high impact events [23].

We had done many modal analyses as part of the non-linear responses' evaluation. Sharing these works needs separate space and this job is beyond the scope of the current edition. We will share *tables contain the natural frequencies of all model's modal analysis*

At time of impact, the whole structure would deviate with direction of the force vector. The greatest magnitude of the displacement direction of the osseous structure could not be in match with the force vector, but it could be close to one of the force vector components. The other parts would retain their position. If the mode of the bone matches the impact frequency, more devastating fracture could be resulted. Any domain, when vibrating, will have regions with high displacement. Accordingly, the position *of the impaction weather at the top or bottom of bone will yield different results [24].*

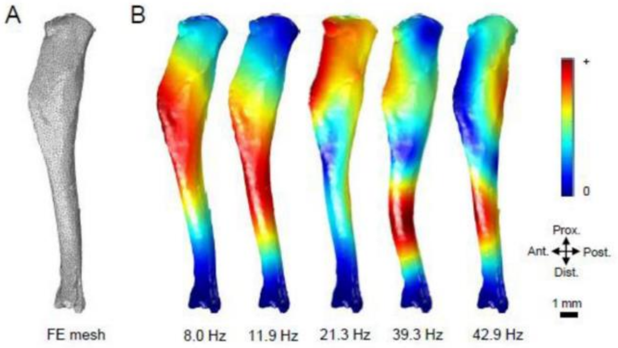


Figure 11: Modal Analysis showed how it affects bone metabolism.

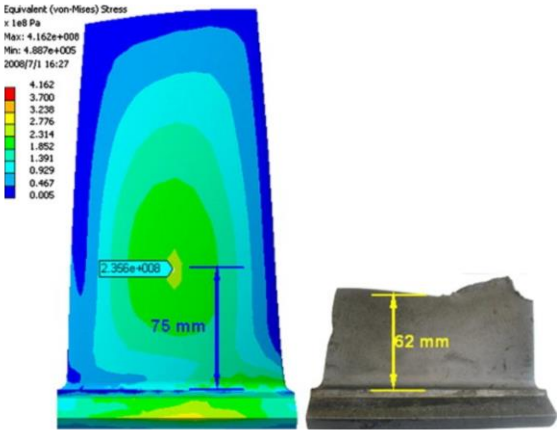


Figure 12: It is well known in mechanical engineering that modal analysis could predict the fracture pattern.

This is applied in the case of a new hardware design process.

4) Inertia of the bone itself.

This criterion is what keeps bones in their place when trauma occurs. Status of the muscles at time of trauma will be the variable player that highly affects trauma response. Passive inertia imparted by ligaments and soft tissue itself had a great effect, but this factor is mostly constant. They are position dependent. Muscle affects inertia actively, but ligaments passively. Although they are consistent, their response is highly nonlinear and strain rate dependent. We have 2 sets of the muscles that affect craniofacial region:

- Paravertebral muscles, SCM and trapezius, we had called them as the extrinsic muscles of the skull
- Muscles of mastication in case of the mandible, we had called them as the intrinsic muscles of the skull

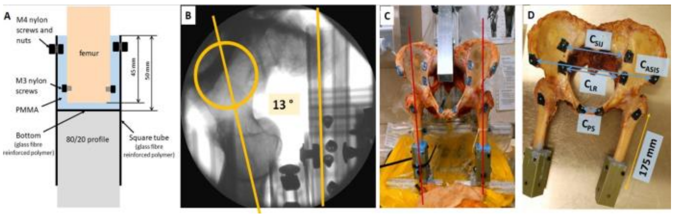
Possible effect of these muscles upon other anatomical regions would be anticipated, but this needs further evaluation. The muscular twitch response is much slower than the speed of the impaction in the most trauma case when fracture is occurring. Unless the muscle is already contracted at time of trauma, their active effect could be neglected. Any fracture when occurs, if the structures at the impact level or below it holds up itself, fracture will extend to involve the more superior regions. This is quite true in the case of maxillary trauma, as the attachment is superior and lateral and more posterior in the case of the mandible.

This is defined as the concept of graded damage, and in most cases the body is pre-designed to behave like this. Many talented surgeons had developed very good experience to manage different fractures and to recognize the different patterns of fractures clinically and correlate these patterns to the anatomy of the osseous structures and plan excellent treatments. They are capable of choosing the best suitable needed management for certain trauma but recognizing the cause and correlated to the result remain a dilemma in many aspects of the maxillofacial trauma.

The concept of staging is neither new nor we had not invented it, but we are trying to put a formula for understanding many important aspects of trauma. The staged damage is not only on the macroscale, but also on the micro and nano scale of bone histology.

Jaws fracture is due to the inertia of the jaws which is due to ligaments in the case of multiple interconnecting bones (such as the mandible where it is connected to the skull and those connecting jaws to the skull and neck) as well as the bones itself. These mechanical systems are not just simple connections. Mandibular fractures depend upon soft tissue rather than bone itself and its attachment to the skull, namely TMJ can have a role equivalent to the muscle effect due to this point (inertia) specifically. In the case of maxillary fractures, we are depending upon bones rather than soft tissues. This means less stiffness of the maxillary bone attachment at the base, but at the same time it had high inertia at this base.

In contrast to this, inertia and stiffness of the mandible itself coupled with viscoelasticity of the soft tissue envelope that invest the mandible is higher. We should put in our mind that the connection to the skull permits high ROM. Therefore, we will gain a higher range of motion of the mandible in addition to a thicker jawbone which would control the stiffness. In another word, the mandible is thicker, but it is still a floating jaw while the maxilla is fixed with a weak base and nearly null soft tissue attachment apart from the palatal tissues which had relatively higher thickness. ***The inertial effect had been studied in other bones in detail.***



Inertia should be kept in mind [25]

5) Prestress of the bone [26]

This criterion [27], by itself, which especially dictates the crack propagation is a very important factor that imparts highly customized toughness of the anatomical structures for both soft and hard tissues. We suggest that the bone itself had different prestress in different directions and different regions that keep this structure ready for any trauma. This is especially clear in the mandible. The mandible could be regarded as a long-curved bone. This feature could be easily manifested experimentally. Less prestress is seen in the growing age group, that will be converted to be settled into higher levels after skeletal maturity.

This will make the pediatric injury to be green stick in nature. Nevertheless, in adults this might also occur. We claim that the fracture in the pediatric age group had different crack propagation control. The prestrain is not peculiar to the bone material only, but also involves the whole anatomical domain which is multi-source from bone and ligaments. ***All living tissues are prestrained in thier status.*** Prestrain is an approach to control domain response to loadings.

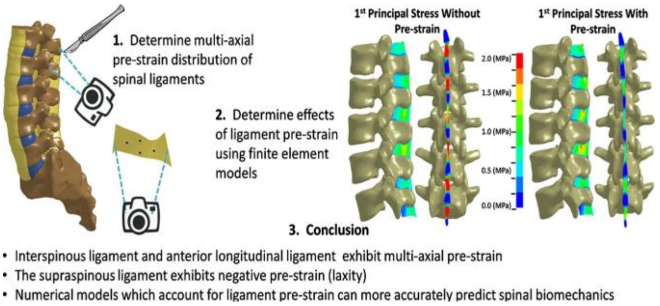


Figure 13: Pre-strain could be multidirectionnal and with differnt value [28]

6) Site of the trauma collision and vector of the force in relation to the bone.

Anatomy of the facial skeleton is well suited and customized to receive vast majority of the traumatizing objects. This is a highly variable factor that is part of fracture pattern diversity.

7) Intervening tissues between bone and colliding object.

The viscosity of the tissues is strain -rate dependent. Soft tissues, especially fat, had a great impact upon the trauma through absorption of a great portion of the energy and breaking the site of impaction with bone to reduce the trauma. Facial soft tissues distribution is designed to respect this point. This point is beyond our biomechanical knowledge.

In many instances the trauma may cause avulsion of the soft tissue resulting in compromised aesthetic. Careful evaluation of the defect should be attempted before embarking on any treatment. Deflection of the traumatic object is also aided by the soft tissues.

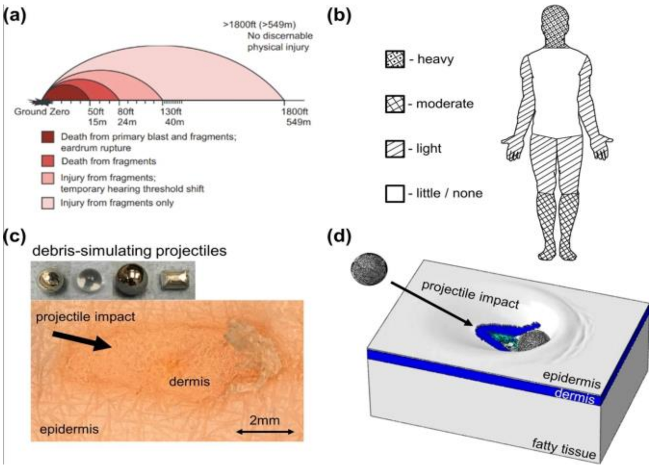


Figure 14: Soft tissue response is another field that need separate work [29]

Soft tissue affects the osseous injury via

- By playing cushing effect where it intervenes the traumatizing object and the bone
- Muscle will stabilize the bone, which tremendously affects the response linearity.
- Ligaments could be the prime passive stabilizers of the bone when impaction occurs. The best example is the TMJ role in mandibular fractures.
- Provide a bed to stabilize the fractured segment and initiate the healing process. This is in the post-trauma healing phase. The design of the human skeleton is suited not just for reducing the trauma extent, but also to allow a base of repair.

8) Status of the bone attachment to its base.

Maxilla could be regarded as floating in comparison to the axial skeleton but fixed to the skull. Mandible is highly floating with higher DOF in robotic language. It has a weak connection to the skull via TMJ, while maxilla is rigidly fixed to its base as we said.

9) Momentum of the impaction object.

The amount of delivered energy to the bone is directly proportional to these criteria. These criteria could be seen in many texts.

10) deformability of the traumatizing object.

Fist versus hammer and stone are clear examples. This is dictated by whether all energy is delivered or part of it will be dissipated by the hitting object itself as well as the amount of soft tissue injury elsewhere.

Additional notes:

Who are working in orthognathic surgery know and appreciate how the bone is weak and fragile. As an example, in Le Fort I maxillary osteotomy, cutting of lateral maxillary sinus' walls will reveal how they are so thin that it could be even perforated easily by a simple sharp instrument.

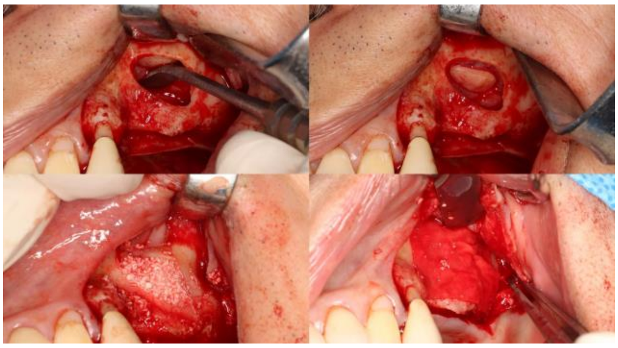


Figure 15: This picture shows clearly the thinning of the maxillary sinus lateral wall.

In mandibular sagittal split osteotomy, the separating of ramus cortices results in a sound that in many times gives the surgeon an indicator about splitting achievement. This is clear evidence about the orthotropicity of the bony structure of the mandibular ramus that is found everywhere in other bones of the body, but in different orientations. Nevertheless, the architecture of bones is fascinating, resulting in quite strong structures and in other instances very susceptible to fracture. Also, this is apparent in the central part of the viscerocranium, namely the nasoethmoid complex. During FESS, paranasal sinuses walls are very thin, their removal by rotary instrument reveals their weakness. Nevertheless, their arrangement with the surrounding soft tissues resulted in unparalleled geometric nonlinearity.

The presence of a thin bony plate should not deceive us to consider it as a strut. One of the author's ***objections about the concept of buttresses*** is that it had no well-defined mechanical description in most instances. The surgeons imagined them as strong pieces of connections. In addition to this, perception of bone as a plastic material is highly erroneous imagination. In reality we have very thin walls with some thicker regions. In the case of the lateral side of the midface, the walls of the maxillary sinus are too thin. This will make the effect of the zygoma as the prime stabilizing element of the palate questionable. We consider the zygomatic connection to the palate to have gradient of stiffness through the lateral part of the maxilla. The thin-walled midface is concealed and protected providing total response by all of these walls.
The axial cross section of the maxillary sinus is not a haphazard design, although we had no direct explanation to this design, but it needs to be well studied as well as other designs. In the next publications, we will investigate the effect of anatomical structure on the aerodynamic properties. In the current work, we want to settle many important biomechanical concepts. Other engineering perspectives of complete biological functions of the structure designed in such a way, should be considered in any structural biomechanical performance analysis, such as aerodynamic function.

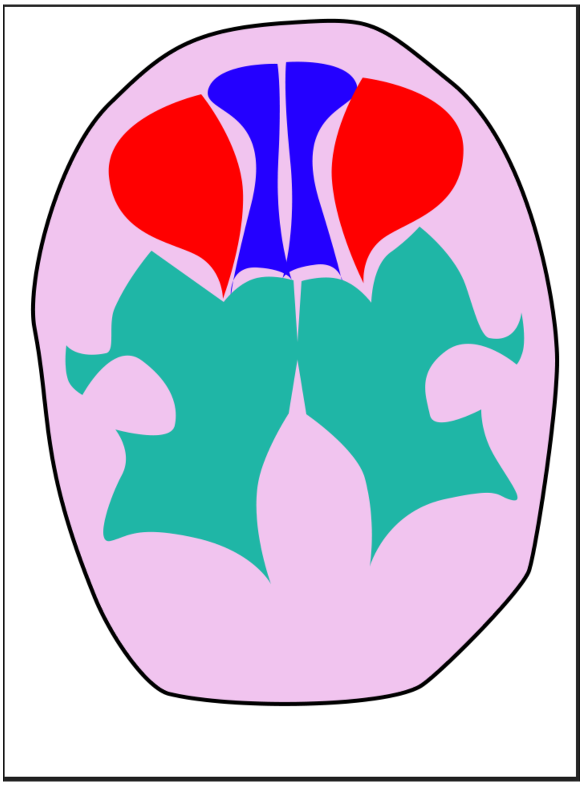


Figure 16: Vectorization of the anatomy in the numerical simulations is very important

The vectorized axial section reveals the shape of the maxilla at this level, as well as the nose cross section. We are suggesting that the first design had mechanical effect and the other had aerodynamic effect. Both had reciprocal relationships and interconnecting effects via chemical messaging which affected growth and physiology. Gradients of stiffness are also present in the aerodynamic function. Olfactory function is also affected by this design which had been weakened significantly in comparison to the canines as an example. Vectorization of the anatomy in the numerical simulations (whether mechanical, aerodynamics, auditory…. etc.) is one of our goals for long term research plans. This goal could be reached via collaboration with anatomy discipline researchers and specialists. This vectorization also could be applied upon the architecture of the medullary space.

In order to make a classification of trauma according to the anatomical regions, we had subdivided facial skeleton into these main regions that had similar responses to the stresses. The anatomical regions of trauma, in order to make a more comprehensible classification, we had subdivided facial regions into groups that include a similar response to trauma.
1) Orbital lateral part, namely the zygomatic bone. It is thick and involves part of the orbital floor.
2) The roof of orbit belongs to the frontal bone.
3) Central Midface region which includes:
    - Orbital medial side and part of the floor, where we have a crumpling response.
    - Nose where it had a neglectable effect upon the trauma response.
4) Maxillary Hard palate and maxillary alveolus. They represent the inferior part of the midface. Both
5) Mandible will be discussed on another site in a more detailed approach, but separately in another publication.
6) The dental part of the jaws plays a significant weakening effect on the jaws.
7) Pediatric and growing patient groups had totally different responses to the trauma due to uniqueness of their anatomy as well as the materials properties.

In the previous last two groups, we had specific biomechanical features that govern their responses.

The attachment of facial bones of the viscerocranium to the neurocranium is also governed by the gradient of stiffness. Midface can be summarized further into 3 main bones that are cornerstone in any trauma. *These bones, with parts of other bones, behave solidly, while other bones could be considered as weakeners for these bones.* Fracture of the body of zygoma or palate is far less common than other fractures. This is due to the ability of the mid-face to be collapsed or disassembled in a predetermined fashion away from these 2 regions. These main bones are
- Right zygoma
- Left zygoma
- Palate and maxillary alveolus

They are connected between them by thin fragile connections relative to other connections. These connections are not located on a single horizontal plane, but rather in a well-calculated design. The joining of the midface to the skull is mainly via the zygoma where this joint is also weakened by its thin attachment to the sphenoid bone. The bony nasal septum by itself is thicker than the lateral maxillary sinus wall. This organization is not haphazard but in a very precise pre-configuration. This should be correlated to the trauma response. The superior maxillary nasal process with other flat surfaces governs the maxillary response to the trauma.

What is called Le Fort fracture (Ⅰ Ⅱ Ⅲ) is resultant of complex mechanical response that determine the level of fracture according to the golden 10 points we have enumerated previously. Nasal septum and pterygoid plates could be regarded as secondary stabilizers or struts. The inferior orbital fissure and pterygopalatine fissure play a significant role in the response of the midface to trauma.

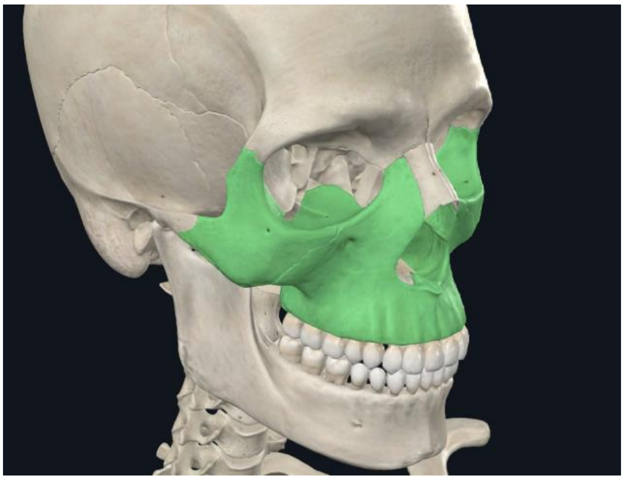


Figure 17: Midface could deceive many author taha it is a bulk of bones

Figure 18: No significant bone structure will remain after removal of the zygoma and maxilla from the midface.

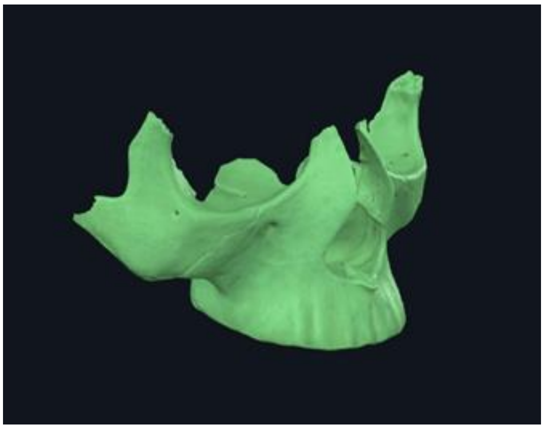


Figure 19: Most of the analysis should be directed toward these bones.

We have two types of struts.

- Primary that will take most of the energy that their fixation is mandatory due to high possibility of instability that could result in aesthetic functional morbidity.
- Secondary that will have less significant rules on resistance.

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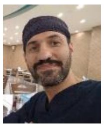
Author Profile



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