



T.C.

YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF ORAL AND MAXILLOFACIAL SURGERY

**EVALUATION OF LATERAL AND AXIAL
FORCES IN ATROPHIC MAXILLA WITH ANGLED
PTERYGOID IMPLANT USING THREE-
DIMENSIONAL FINITE ELEMENT ANALYSIS**

DOCTOR OF PHILOSOPHY THESIS

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ISTANBUL - 2024

THESIS APPROVAL FORM

Institute : Yeditepe University Institute of Health Sciences

Programme : Ph.D. In Oral and Maxillofacial Surgery.

Title of the Thesis : Evaluation of lateral and axial forces in atrophic maxilla with angled pterygoid implant using three-dimensional finite element analysis.

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Examination Date : 27.06.2024

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APPROVAL

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DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

THAIR MAHROQ

27.06.2024



DEDICATION

I dedicate this thesis

To my late grandparents for looking after me with affection and love and their dedicated partnership for success in my life.

To my parents

They were constantly a source of motivation for me. I couldn't have done it alone; They consistently encourage me and wish me the best of luck.

To my wife

She constantly brightens me up and supports me through good and bad moments.

To my uncle

Dr. Ibrahim Mahariq , who shares my father's role and has supported and advised me since I was a little child.

ACKNOWLEDGEMENT

My supervisor, Prof. Dr. Ahmet Hamdi ARSLAN, and our department's head, Prof. Dr. Ceyda Özçakir TOMRUK, especially deserve my sincere gratitude for providing me with the invaluable opportunity to benefit from their knowledge and expertise, and the ability to employ outstanding cases in practice.

I would like to express my heartfelt gratitude to Assoc. Prof. Dr. Ediz DENZ, Assoc. Prof. Dr. Fatih CABBAR, and Lecturers Dr. Volkan DAĞAŞAN. for the learning possibilities provided.

I am grateful to Prof. Dr. Ibrahim MUTLU and his student Zakaria AL JOULAJI Kocaeli University, Faculty of Technology, Biomedical Engineering for guiding and assisting me with the Finite element analysis methods (FEA).

I am grateful for the opportunity to express my heartfelt gratitude to Prof. Dr. Imad ABU KISHK president of ALQUDS university in palestine who assisted me during my PhD studies.

Any attempt at any level could not have been performed satisfactorily without the aid and advice of my coworkers, particularly, Orkun UYGUN, Fikri Can AYIK, Adil ESSLLAMI,

I am grateful for the opportunity to express my heartfelt gratitude to the nurses, dental assistants, and other members of our faculty who assisted me during my PhD studies.

I want to thank my incredible parents, Huseyin and Zeynep MAHROQ, who worked tirelessly to support me and who always believed in my decisions and stuck by me.

Last but not least, I'd want to express my gratitude to my dear wife Lana HELO for her unending love and support, and my young children ,Omer and Zeynep

Without them, I would not have been able to complete the task. I am grateful to you from the depths of my heart.

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LIST OF SYMBOLS AND ABBREVIATIONS

ZMC	: Zygomaticomaxillary complex
ARDS	: Acute respiratory distress syndrome
MOF	: Multiple organ failure
COVID-19	: Coronavirus disease 2019
RAS	: Renin angiotensin system
TMJ	: Temporomandibular joint
MRONJ	: Medication-related osteonecrosis of the jaw
ARP	: Alveolar ridge preservation
IADT	: The international association of dental traumatology
WHO	: World health organization
MSP	: Maxillary sinus pneumatization
GBR	: Guided bone regeneration
SFE	: Sinus floor elevation
BOD	: Bone osteogenesis distraction
PSI	: Patient-specific implants
AMSJI	: Additively manufactured subperiosteal jaw implant
C/I	: Crown-to-implant ratio
A-P	: Anterior-posterior
DICOM	: Digital imaging and communication in medicine

CBCT	: Cone beam computerized tomography
STL	: Standard tessellation
IOS	: Intraoral scanner
SCAI	: Static computer-aided implantology
DCAI	: Dynamic computer-aided implantology
GPS	: Global positioning system
FEA	: Finite element analysis
3D	: 3 Dimensional
CAD	: Computer aided design
DICOM	: Digital imaging and communications in medicine
DOF	: Degree of freedom
°	: Degree
E	: Modulus of elasticity of the body
F	: Force
Kgf	: Kilogram force
m	: Mass
mm	: Millimeters
Mpa	: Megapascal
N	: Newton
P	: Paskal
Q	: Stress

Ti : Titanium

PI : Pterygoid implant

V : Poisson ratio



ABSTRACT

Mahroq T. (2023). Evaluation of lateral and axial forces in atrophic maxilla with angled pterygoid implant using three-dimensional finite element analysis . Yeditepe University, Institute of Health Sciences, Department of Oral and Maxillofacial Surgery, PhD Thesis. Istanbul.

The purpose of this research is to identify the optimal surgical angle for the pterygoid implant, which will be placed at a variety of angles, and to evaluate it using finite element analysis based on the Frankfort Horizontal Plane. A three-dimensional maxilla model was reconstructed from a CT scan of a toothless patient. This model includes the cancellous and cortical bone. The facial region of a 58-year-old male patient with an atrophic maxilla and an angled pterygoid implant was imaged with CT in DICOM format. The raw DICOM data had a 0.3-millimeter section thickness. The MIMICS program created a three-dimensional model of the sections bone tissue. A dental implant with a diameter of 3.5 mm, a length of 16 mm, a conical shape, and a private thread design was placed in the pterygoid bone using SOLIDWORKS. This study investigated at how to place a pterygoid dental implant using both monocortical (at the end of the crest and cancellous bone) and bicortical (between the crest and basal bone) methods at 45, 55, 65, 75, and 85 degrees relative to the Frankfort Horizontal Plane. Ten models were used for this study. CAD models were sent to ANSYS for loading . Boundaries of maxilla before force application are fixed from the zygomatic region. Human mastication was simulated using three load situations with the following characteristics, 150-N axial loading and 50-N lateral loading separately and 50-N lateral loading and 150-N axial loading simultaneously. Based on our studies and according to the Frankfort Horizontal Plane, placing the pterygoid implant at an 85 degree angle is the best in terms of bone stress. In terms of bone strain, it was found that placing the implant at 75 and 85 degree angles monocortically and bicortically respectively has the best outcome. This research concluded that an angle of 85 degree exhibits the most favorable positive attributes in terms of minimizing injury to the adjacent bone tissue and the implant's structural integrity.

Keywords: Jaw Bones, Atrophic Maxilla, Angled Implants, Pterygoid Implant, Finite Element Analysis

ÖZET

Mahroq T. (2023). Üç boyutlu sonlu elemanlar analizi kullanılarak açılı pterigoid implant ile atrofik maksilla'da lateral ve aksiyal kuvvetlerin değerlendirilmesi. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Oral ve Maksillofacial Cerrahi Bölümü, Doktora Çalışması. İstanbul.

Bu araştırmanın amacı, pterigoid implant için optimum cerrahi açığı belirlemektir, bu da çeşitli açılarda yerleştirilecek ve Frankfurt yatay düzlemine dayalı sonlu elemanlar analizi kullanılarak değerlendirilecektir. Kancellöz ve kortikal kemik içerir üç boyutlu maksilla modeli dişsiz bir hastanın CT taramalarından elde edildi. Atrofik maksilla ve açılı pterigoid implantı olan 58 yaşındaki erkek hastanın yüz bölgesi DICOM formatında CT ile görüntülendi. Oluşturulan tek tedavi modeli pterigoid implant uygulaması olarak planlandı. DICOM verileri 0.3 milimetre kalınlığındaydı. Mimics programı bölümlerin kemik kesitlerinin üç boyutlu bir modelini oluşturdu. SOLIDWORKS kullanılarak 3.5 mm çapında, 16 mm uzunluğunda, konik şekilli ve özel yiv tasarımı olan dental implantlar pterigoid kemiğe yerleştirildi. Pterigoid dental implantların yerleştirilmesi monokortikal (kret ve kancellöz kemiklerin terminal sınırında) ve bikortikal teknik kullanılarak 45, 55, 65, 75 ve 85 derecede Frankfurt yatay düzlemine göre incelenmiştir. Bu çalışmada on model kullanıldı. CAD modellerini yükleme için ANSYS'e gönderildi. Kuvvet uygulamadan önce maksilla sınırları zigoma bölgesinden sabitlendi. Kuvvetler, 50N yan yükleme, 150N aksiyal yük ve her ikisinin kombinasyonu olacak şekilde, toplam 3 yük duruma kullanılarak simüle edildi. Araştırmamızın bulgularına dayanarak, pterigoid bir implantın yerleştirilmesi için, çevresel kemik basıncı üzerindeki etkisiyle ilgili olarak, Frankfurt Horizontal Planı göz önünde bulundurulduğunda ve bikortikal yerleştirme sağlandığında en uygun açının 85 derece olduğu sonucuna varıldı. Araştırmamızın bulgularına dayanarak, pterigoid implantın çevresindeki kemik üzerindeki deformasyon oranı açısından optimum yerleştirme açısı belirlenebilir. Özellikle, önerilen açılar monokortikal yerleştirme için 75 derece ve bikortikal yerleşme için 85 derecedir. Bu araştırma, 85 derecelik açının, komşu kemik dokusuna ve implantı yapısal bütünlüğüne zarar vermeme açısından en olumlu özellikleri gösterdiğini saptamıştır.

Anahtar Kelimeler: Çene kemikleri, Atrofik maksilla, Açılı implantlar, Pterigoid implant, Sonlu elemanlar analizi

1. INTRODUCTION AND PURPOSE

Edentulism is a significant issue within the field of dentistry, with the prevalence of total edentulism reported to range from 7% to 69% worldwide. The prevalence of total edentulism in India is around 19%, whereas in the United States it is almost 26%, and in the United Kingdom it reaches 46% (1). The occurrence of significant maxillary resorption might impede the feasibility of using traditional dental implant therapy. Numerous other treatment options exist, including various bone grafting methods of surgical procedures commonly performed in the posterior part of the maxilla, such as the iliac crest block bone graft, Le Fort I osteotomy, onlay-type bone grafting methods, and maxillary sinus lift surgeries (2). The process of resorption of edentulous ridges and the subsequent restoration with complete dentures poses a substantial challenge for clinicians (3).

According to the original idea of the Branemark System, it is recommended to position implants in a rather vertical orientation (4). Therefore, in cases where the maxilla is fully edentulous and atrophic, the inclusion of long distal cantilevers becomes imperative in order to ensure that the patient achieves satisfactory masticatory function in the molar regions. However, it is worth noting that the use of cantilevers beyond a length of 15 mm has been linked to higher rates of implant failure. The user's text does not provide any information to rewrite (5).

Various treatment options have been suggested to address this particular scenario. These options encompass bone grafting techniques, namely bone block grafts and sinus lifting through either crestal or lateral approaches. Additionally, non-grafting techniques have been proposed as alternatives to the traditional implant procedure. These techniques involve implant placement in the zygomatic bone, the pterygoid process, or the maxillary tuberosity, as well as the utilization of short or tilted implants (6). The pterygomaxillary region was accessed via the bone corridor to place virtual pterygoid implants. These implants had lengths of 13, 15, or 18 mm and a width of 4 mm. During the insertion operation, a precautionary measure was taken to maintain a minimum safety distance of 2 mm between the artery and palatine nerve and the implant (7).

Tulasne et al first introduced the concept of pterygoid implants, which was later adopted and used by several researchers (257). The anchorage of these structures is often seen in the pterygoid region. Nevertheless, several investigations have positioned them in a more anterior location, namely in the pterigomaxillary region, aligned with the posterior sinus wall. These implants provide some benefits in comparison to other procedures (8). The establishment of anchorage in the posterior atrophied maxilla is facilitated, hence promoting stability and achieving high rates of long-term success, without necessitating sinus lifts or bone transplants. Furthermore, the elimination of posterior cantilevers and the improvement of axial loading may be seen (8).

The bone and dental implant osseointegration are important for long-term clinical success . Avoiding bone resorption around a loaded dental implant is essential for long-term stability . The analysis of stress and strain distribution in the bone around the implant , together with biological parameters such as oral hygiene, are crucial aspects to consider in the failure process (234).

Finite element study (FEA) is a three-dimensional numerical simulation approach often used in engineering study (9). The finite element method has been used to predict the stress and strain distributions in the bone surrounding a dental implant (3).

The objective of this research is to ascertain the optimal surgical angle for pterygoid implants, which will be positioned at different degree angles. These angles will be assessed using finite element analysis in accordance with the Frankfort Horizontal Plane. It is a craniometric plane, defined as the horizontal plane that is established by identifying, the apex of the upper border of each external auditory canal and the inferior margin of the orbit. This plane serves as a reference for the orientation of a human skull or head (10).

A total of ten pterygoid implants monocortically and bicortically were inserted at varying angles in respect to the Frankfort Horizontal Plane. The study aimed to assess the maximum equivalent stress and maximum equivalent strain in 10 models using the finite element analysis (FEA) technique. Three distinct load scenarios were investigated: 150-N axial loading, 50-N lateral loading, and simultaneous 150-N axial loading with 50-N lateral loading, each applied for a duration of 1 second.

2. LITERATURE REVIEW

2.1. Bone

Bone, a complex tissue, stores phosphate, iron, and calcium for skeletal muscles and marrow. To maintain bone integrity, osteoclasts demineralize and enzymatically digest the collagen matrix to create space for osteoblasts to add extracellular matrix to cortical and trabecular bones. This process helps the skeleton withstand external stresses and stay mechanically competent. Any remodeling imbalance causes bone abnormalities and mechanical incompetence (11).

Bone consists of calcified tissues with approximately 5-10% water, 50-70% hydroxyapatite, and 20-40% organic constituents. These organic components mostly include type I collagen and approximately 10% noncollagenous proteins, which play a crucial role in the process of mineralization. Bone may be classified into two categories based on its porosity and unit microstructure. The bone marrow is enveloped by compact bone, which is sometimes known as cortical bone or dense bone. The bone marrow consists of cancellous bone, which is sometimes referred to as trabecular bone or spongy bone. The adult human skeleton is highly vascularized and made of 80% compact and 20% cancellous bone (12).

The maintenance of bone structure is precisely controlled by the coordination of mechanical and hormonal inputs. Osteoporosis, a bone density disorder, results from imbalance. The development and metabolism of bones are influenced by trace minerals such as iron, zinc, copper, calcium, phosphorus, and magnesium (Mg). Both trace element deficiency and excess may increase the risk of bone diseases like osteoporosis (12).

Human skeleton bones attach muscles, tendons, and ligaments for locomotion. Adult hematopoiesis microenvironments are in bones. The body's unique ability to regenerate bone to its preinjury state emphasizes bone's importance in mammalian physiology (13).

Bone remodels throughout life, supporting structure and locomotion and protecting vital organs like bone marrow and the brain. Calcium and phosphate are stored in bone. To prevent bone damage and maintain bone mechanical strength and calcium homeostasis, continuous remodeling is needed (14).

2.1.1. Bone biology, structure, histology

The last few decades have changed our understanding of bone biology. Osteoclasts, multifunctional bone cells encased in calcified bone matrix were thought to be inactive for years. Today, osteocytes are essential for skeleton function because they play crucial roles in many physiological processes inside and outside the bone microenvironment (15).

Bone is an exceptional and intricate biomaterial. Its strength and toughness surpass all other biomaterials. Moreover it exhibits a high degree of adaptability, dynamic structural characteristics, and significant metabolic activity. The physiological and mechanical demands exerted on an organism play a crucial role in determining and influencing bone form, size, and strength (16).

2.1.2. The osteocyte

Osteocytes make up 90–95% of adult bone cells and are multifunctional. The mean half-life of osteoblasts is 150 days, but they can live up to 25 years in bone. Osteocytes descend from osteoblasts. They come from bone marrow mesenchymal stem cells. When the osteoblast stops forming matrix, it can become an osteocyte or apoptose. Flat-shaped bone lining cells cover bone surfaces and do not resorb or form bone (15).

Bone fluid surrounds the osteocyte body in the mineral lacuna. This special liquid oxygenates and nourishes bone cells (15).

2.1.3. Bone biology and COVID-19 infection

Coronaviruses cause respiratory and digestive system damage due to their diverse RNA virus. A comprehensive analysis of recently identified COVID-19 has revealed significant and widespread physiological harm to the human body. Interstitial pneumonia progresses to the development of severe acute respiratory distress syndrome (ARDS) and subsequent multiple organ failure (MOF) (17).

Similar to the SARS-CoV virus, which infiltrates the human body, the spike protein of the SARS-CoV2 virus has the ability to attach itself to its functional receptor known as ACE2 and releases peptides for membrane fusion. ACE2 expression is a key entry point for SARS-CoV-2 and promotes virus republication (18).

The renin angiotensin system (RAS) exerts regulatory control over several systemic activities through its protective axis including ACE2. A carboxypeptidase that is highly expressed in the kidney, cardiovascular system, and gastrointestinal tract, with a somewhat lower expression in alveolar epithelial type II (ATII) cells, contributes to the exacerbation of lung injury by enhancing pulmonary vascular permeability (19).

The insufficiency of pulmonary angiotensin-converting enzyme 2 (ACE2) resulting from infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) diminishes the synthesis of angiotensin (Ang)-converting enzyme and exacerbates hypertension and fibrosis (17). Despite the limited understanding of COVID-19 and its potential immune responses in the host, there has been a notable focus on bone metabolism based on pathophysiological findings. The bone-forming ability is enhanced as a result of the exacerbation of pre-existing conditions due to SARS-CoV-2 infection. The invasion of viruses leading to ACE2 deficiency has been seen to potentially result in the loss of bone matrix and the development of early muscular disorders (17).

2.1.4. Bone types

Mammals are supported by their musculoskeletal systems. Human skeleton bones attach muscles, tendons, and ligaments for locomotion. Adult haematopoiesis microenvironments are in bones (13).

According to research, the repair ability of bone is attributed to the regulatory interaction between osteoblasts, which are responsible for bone formation, and osteoclasts, which are responsible for bone resorption. These two cellular elements play a crucial role in maintaining bone health. Prior studies conducted on osteoblasts have demonstrated the significance of morphogen gradients, such as BMP and SHH, in the process of bone regeneration (20).

The presence of these morphogen gradients, along with others, plays a critical role in the process of bone formation, also known as osteogenesis. Medicine is interested in the osteoblast lineage because of its role in bone development and disease. Although some bone repair capacity is maintained throughout adulthood, it decreases significantly with age, potentially causing osteoporosis (13).

2.1.5. Cell types involved in osteogenesis

During both homeostasis and damage, the skeletal lineage comprises several cells that are responsible for bone maintenance and repair (21). The osteoblasts, osteocytes, and chondrocytes are all members of this cell lineage. The skeletal cell types responsible for bone and cartilage formation are osteoblasts, whereas osteoclasts break down bone (22).

Osteoblast and osteoclast activity maintain equilibrium in order to regulate appropriate bone homeostasis. However, this balance tends to shift as individuals get older, when osteoclast activity is greater than osteoblast activity, as it is in postmenopausal women in particular, the outcome is increased bone resorption and weaker bones (22).

2.1.5.1.Osteoblasts

The main cells that form bones are osteoblasts. By secreting proteins into the extracellular matrix, many osteoblasts come together to create an osteon, these proteins include type I collagen, osteopontin, osteocalcin, and alkaline phosphatase. The skeleton is supported by type I collagen and calcium hydroxyapatite (23).

2.1.5.2.Osteoclasts

Large multinucleated osteoclasts resorb bone. These haematopoietic cells differentiate into osteoclasts via M-CSF and RANKL (Figure 2.1) (13).

Bone homeostasis is achieved by osteoblast and osteoclast cells. Osteoblast lineage cells like osteoids are responsible for the mineralization of bone and the formation of osteocytes. They do this by secreting hydroxyapatite and calcium. Cells called osteoclasts break down bone. Bone homeostasis is achieved by balancing the two cell lineages (Figure 2.2) (13).

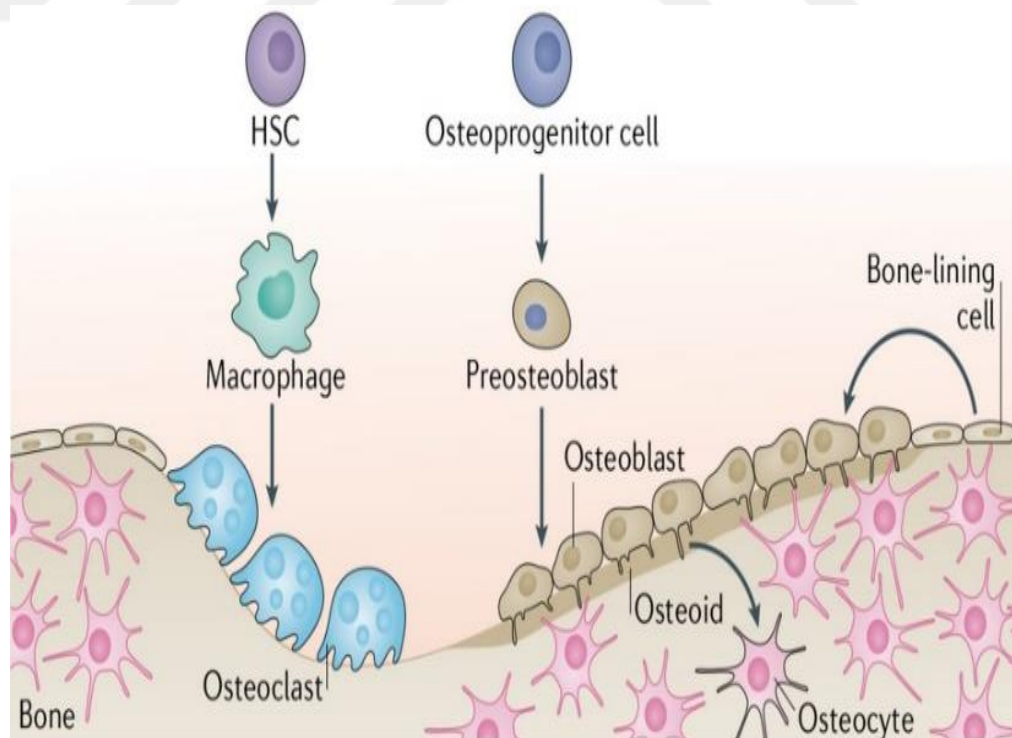


Figure 2. 1. Bone homeostasis (13).

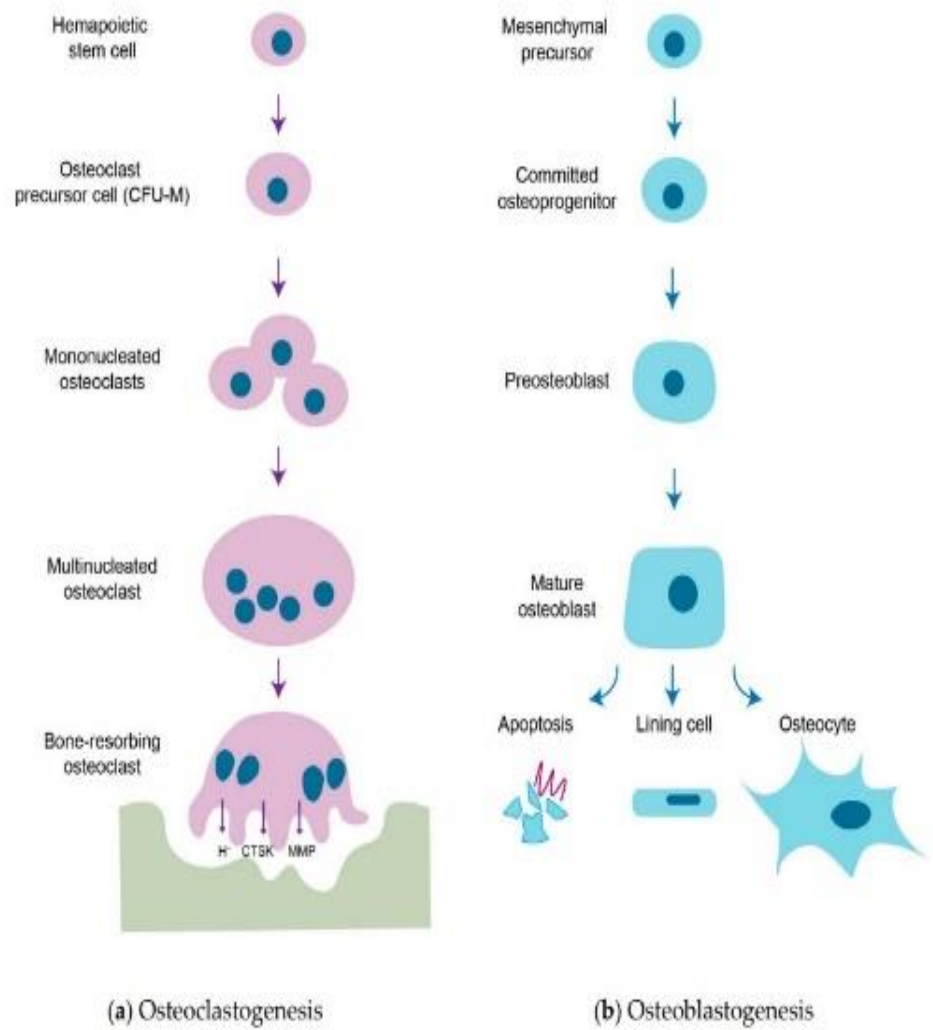


Figure 2.2. Strategies of osteoclastogenesis and osteoblastogenesis (13).

2.2. Facial bones

Facial bones framework for the head and face, the cranial bones protect the organs inside. Temporomandibular joints allow the cranium to move and perform many oral functions (24). The majority of cranial bones develop from ectodermal neural crest cells, also known as NCCs. These cells begin their development near the dorsal borders of the closed neural tube (25).

The formation of the pharyngeal arches (PA) must occur simultaneously with facial development. In mammals, the PAs develop in pairs by the fourth week of pregnancy. These outgrowths are located on both sides of the pharynx (26).

The brain and other organs are protected by 14 types of 22 small bones in the cranium. The atlantooccipital and temporomandibular joints give it mobility (TMJ). The TMJ allows complex mandibular movement, making it essential for oral functions. Teeth are important for oral functions. The periodontal ligament (PDL) anchors the teeth to the alveolar bone, and they penetrate the gingiva (Figure 2.3) (24).

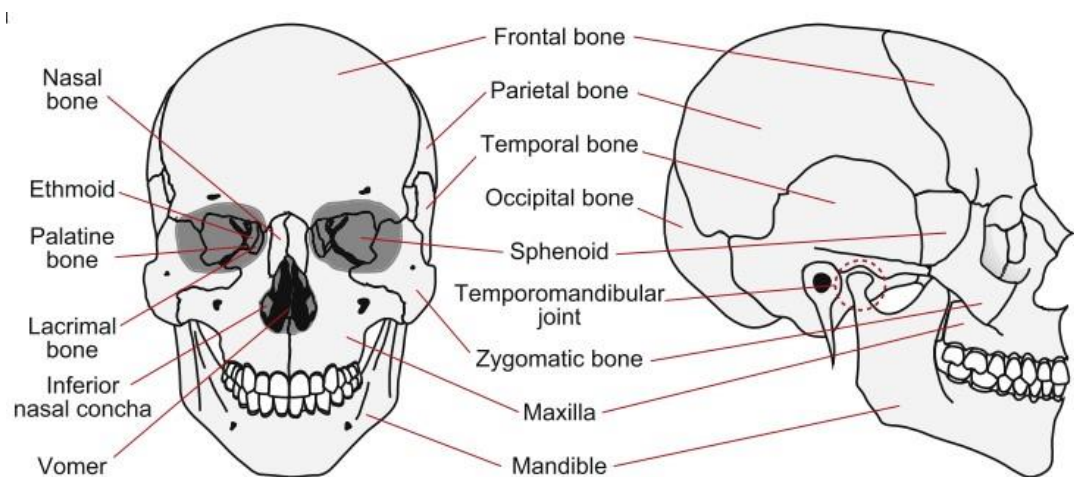


Figure 2. 2. Cranial bone anatomy (24).

2.2.2. Jaw bones

The maxilla and mandible, the inferior craniofacial bone, play important roles in daily life. The mandible and maxilla support the dentition, making chewing and speech possible (27). The mesodermal germ layer produces the axial and appendicular bones, while neural crest cells from the neuroectoderm form the maxilla and mandible (28).

The jaws are distinct from the rest of the skeleton in a number of important ways, embryologically speaking, they include teeth and are mostly formed from cells migrating along the cranial neural crest (the so-called ectomesenchyme) (29).

The jaw and teeth have long fascinated dentists and oral surgeons. However, with dental implants, dentists sought more precise and technically advanced jaw anatomic and radiographic examinations (30). Recently developed dental implants have increased the need for radiologist involvement in mandible and maxilla imaging (31).

Oral surgeons must know the precise location of the neurovascular bundle in the mandibular canal as well as the maxillary sinuses in order to be successful. Gaining an understanding of the height of the alveolar process, width, and shape is also important (31).

Bisphosphonates (BPs) cause a reduction in the markers of bone resorption and formation. Medication-related osteonecrosis frequently occurs in the jaw, which can also be impacted by the reduction of bone metabolism (MRONJ) (32).

2.3. Maxillary bone

The maxilla , which is situated in the center region of the face, serves as structural connections between the orbits, nasal cavity, and zygomatic arches. Additionally, it provides a relationship with the jaw via the dental arcades (33).

Upon examination of the inferior aspect of the maxilla, it is seen that the hard palate is a complicated structure, consisting of many bones. The palatine process of the maxillary bone is anatomically distinct from the horizontal plate of the palatine bone by the presence of the transverse suture. The pterygoid process of the sphenoid bone is shown posterior to the palatine bone (34).

The anatomy of the incisive canal, highlighting the significance of pre-surgical planning for the administration of local anesthesia, implantation of dental implants, and extraction of impacted teeth in the anterior maxillary region (35). It has been hypothesized that the front portion of the maxilla might serve as a recipient location for bone transplants. Extremely few research have looked at it as a potential donor location (36).

The pterygomaxillary buttress is the buttress that links the maxilla to the sphenoid bone at the most posterior position (37). Major vascular damage has been linked to the pterygomaxillary fossa. Craniofacial surgeons are always looking for new ways to reduce complications from pterygomaxillary dysjunction (38).

The posterior maxilla is created when numerous bones come together to form a single unit. These bones include the maxillary bone, the palatine bone, and the pterygoid plates of the sphenoid bone (39). At the point where the maxillary bone and the palatine bone meet, the descending palatine canal and the sphenopalatine fossa are formed, both of these structures have a great deal of blood and nerve supply going through them (39).

2.3.1. Alveolar process

The alveolar process is an entity that is reliant on teeth and goes through a significant transformation after the loss or removal of a single tooth or many teeth (40). The alveolar process is then changed into an edentulous ridge, which is shorter and thinner than the previous alveolar process (41). Extensive vertical and horizontal tissue resorption has been seen as a consequence of healing in the extraction socket, resulting in dimensional changes that carry related hazards (42).

The methods of alveolar ridge preservation (ARP) have undergone significant development as a protocol with therapeutic relevance. It is assumed that the adoption of these techniques facilitates favorable healing of tissues while minimizing changes in bone and soft tissue dimensions (43).

In the aesthetic area of the maxilla, the alveolar bone condition often permits the use of immediate flapless implants. However, it is crucial that these procedures be conducted by a skilled expert who takes into consideration the quality of both the bone and soft tissue (44). According to the available research, there are substantial connections between the density of the maxillary alveolar process and the density of the mandibular alveolar process, as well as the anteroposterior and lateral lumbar spines, the hip, the radius, and age (45).

The International Association of Dental Traumatology (IADT) recommends a treatment protocol for alveolar bone fractures that includes the repositioning of the fractured fragment followed by a period of splinting lasting for a duration of 4 weeks (46). The achievement of optimal outcomes in alveolar bone transplantation necessitates the implementation of preoperative planning that is well coordinated with orthodontic care (47).

2.4. Extraction and alveolar socket wound healing

In humans, tooth extraction is one of the most common procedures performed in the field of oral surgery (48). The process of tooth extraction triggers a series of biological processes that cause changes in the balance and physical structure of the surrounding periodontal tissues. This ultimately leads to a gradual decline in the size and strength of the alveolar ridge due to lack of usage (49).

In addition, approximately half of the alveolar bone width may be lost due to resorption during the remodeling of the alveolar ridge that occurs after an extraction (48). After a tooth is extracted, the alveolar bone and soft tissues alter significantly, which might compromise esthetics and make functional rehabilitation more difficult (50). Following the removal of a tooth, the vestibular and lingual surfaces of the surrounding alveolar bone are demonstrated to undergo resorption, according to the findings of many research studies (51).

Alveolar ridge preservation (ARP) treatment is often recommended as a preventive measure against significant alveolar ridge degradation subsequent to the extraction of a whole or partial tooth (52). Guided bone regeneration involves enhancing the alveolar ridge or regenerating bone, whereas guided tissue regeneration involves regenerating bone, periodontal ligament, and cementum around natural teeth (53).

The thickness of the buccal alveolar bone is a significant indicator of the degree of bone remodeling that occurs throughout the post-extraction healing phase (52).

2.4.1. Tooth extraction wound healing

The act of extracting a tooth sets in motion a sequence of reparative mechanisms that include both hard tissue, such as the alveolar bone, and soft tissues like the periodontal ligament and gingiva (54). Extraction socket healing has been the subject of research on both animals and people, and the sequence of biological processes has been analyzed (54).

The process of tooth extraction has been characterized as a surgical procedure involving the removal of dental tissue, which might potentially result in various

functional, psychological, postural, and local alterations (56). The process of local alterations that seal wounds and restore tissue homeostasis is known as "socket healing." (57).

Several human investigations have documented dimensional alterations in the alveolar ridge after tooth extraction (58). The socket-healing process ends when the socket entrance is closed by firm epithelialized soft tissue or radiographic bone fill (57).

The socket entry has the potential to undergo restoration within a timeframe of 10 to 20 weeks, while the process of radiographic bone fill may be noticed between 3 and 6 months after the extraction procedure (59). In the setting of tooth extraction wound healing, alendronate (ALN) as a monotherapy antiresorptive drug had no deleterious effects on bone formation and instead enhanced bone development in the ossicle implant model (60). So, it was seen that the socket-healing process can be broken down into three steps that happen in order and often overlap: inflammatory, proliferative, and remodeling (57).

2.4.1.1. Inflammatory phase

The inflammatory phase, which occurs between days 3 and 5 after extraction, is marked by vasoconstriction of the damaged blood vessels. This leads to the aggregation of platelets in the bloodstream, causing them to stick to one another and create a fibrin plug (61).

Swelling, redness, heat, and discomfort are some of the clinical signs that correspond to this condition. During the second phase of cell proliferation, several types of inflammatory cells release cytokines and growth factors that stimulate the development of fibroblasts and vascular endothelial cells (62).

2.4.1.2. Proliferative phase

The proliferative phase, which occurs around 14 days after surgery, is distinguished by the development of pink granulation tissue that consists of inflammatory cells and the release of collagen. The clinical signs that are associated with this condition include the process of re-epithelialization, the presence of pink tissue coloration, and the creation of scars (63).

A problem with the management of the proliferative phase may result in an excess of collagen, which encourages cicatrization and scar contracture during the maturation process of wounds. This can have a significant negative impact on the ultimate function and look of the injured region (62). The use of low-level laser irradiation has been shown to expedite the proliferation phase of the healing process and mitigate the inflammatory response (64).

2.4.1.3. Remodeling phase

During the remodeling phase (which occurs six weeks after surgery), the main goal is to achieve equilibrium between the degradation of matrix, namely the elimination of type II N-collagen, and the synthesis of matrix, particularly the replacement of type I collagen (63,65).

The fibroblasts begin to degrade, and the more robust type I collagen progressively takes the place of the less robust type III collagen that was produced by the fibroblasts (61).

2.5. Edentulism

Edentulism, according to the World Health Organization (WHO), edentulism is an epidemic that threatens global health, and defined by WHO, is the total lack of teeth and is classified as a handicap. The primary etiology of edentulism often arises from the complete loss of all permanent teeth subsequent to their eruption (66).

Changes in population have led to a rise in the number of old people, this is standard in the majority of nations. In 2020, there were 703 million individuals aged 65 and more, and that figure is projected to quadruple in the next 30 years, according to a United Nations report (67). The loss of teeth is associated with several detrimental outcomes. The condition is characterized by the degradation of orofacial structures, including bony ridges, nerves, receptors, and muscle (68).

Tooth loss and edentulism have been identified as factors linked to a diminished quality of life in relation to oral health (69). This is primarily due to the physiological effects on speech and mastication, as well as the social implications related to esthetics and appearance (70). Additionally, the nutritional and psychological repercussions of tooth loss and edentulism further contribute to the overall decline in oral-health related quality of life (OHRQoL) (71,72).

Periodontitis and edentulism are linked to several health issues, including mental health illnesses including depression, anxiety, and personality changes (e.g., emotional stability and awareness) (73). There is an elevated risk of death from all causes and from particular causes in those with periodontitis and its most severe sequela (edentulism) (74).

Multiple systemic concomitant illnesses, including obesity, pneumonia, head and neck cancer, cognitive impairment, and an elevated risk of death, have been shown to be related with tooth loss and total edentulism, as indicated by various reviews (75). It is essential for the public health system to implement measures aimed at preventing and managing oral illnesses, particularly among those with poor overall health, ethnic minorities, and those with little financial resources (76).

2.5.1. Epidemiology of edentulism

Tooth loss is a crucial measure of oral health, particularly for the elderly, and is followed internationally as a population oral health indicator (77).

In Canada, a notable proportion of persons aged 60-79 years, namely 14.2%, have self-reported experiencing suboptimal oral health (78). This finding is of particular significance due to the demographic trend of an aging population. It is projected that the demographic group including those aged 65 and above will have a 70% increase in its share over the course of the next two decades (79).

By 2050, China will have 400 million individuals aged 65 and older due to population aging (80). In the country of Japan, those who are 65 years of age or older now constitute 23% of the total population. It is projected that this proportion will increase to 38% by the year 2050 (81).

In the US, Canada, Australia, and the UK, the prevalence of edentulism ranges from 6% to 8% for adults, increasing to 20% to 26% for those over 65 (66). In India, Brazil, and Turkey, edentulism ranges from 48% to 60% among the elderly in low- and middle-income nations (66).

In the US, 9.7% of older persons became edentulous between 2006 and 2018 (82). From 2013 to 2018, there was a statistically significant rise in the rate of edentulism among Korean people aged 75 and above (83). According to the 2017–2018 Australian national adult oral health study, 8.1% of adults between the ages of 55 and 74 were toothless (84). According to the WHO study on global ageing and adult health wave says , the rates of edentulism in India (16.3%) and Russia (18%) are quite comparable (85).

The prevalence of severe tooth loss, as measured by age standardization, is substantially greater in Iran than it is everywhere else in the world, approximately half of Iran's senior population is toothless (86).

2.6. Jaw resorption and classification of atrophic jaws

Bony changes and abnormalities in the alveolar ridge may result from periodontitis, injury, missing teeth, or agenesis (87). Numerous writers have extensively reported the occurrence of fast and permanent alveolar bone resorption, as well as significant atrophy of the maxillary alveolar ridge, after the loss of teeth (88).

As the jaw loses its ability to hold teeth, the edentulous alveolar ridge loses bone due to a lack of muscular stimulation and the absence of physiological tension strain (88). After teeth are extracted, the alveolar bone always resorbs. The loss of alveolar bone has serious effects on chewing ability, facial appearance, and denture retention (89).

Because of this, atrophy is a continuous and progressive process of bone remodeling and osteolysis. It is also called a progressive and permanent process (90). Several studies determined that the mean annual vertical reduction of the anterior maxilla was 0.1 mm, with a range of 0-0.7 mm. This rate varies from person to person and even within a person at different times (88,91). Indeed, the loss or extraction of teeth initiates a cascade of biological processes that result in the deterioration of the alveolar process, thus leading to a gradual atrophy (92).

Cawood and Howell conducted a classification of edentulous jaws by examining a sample of 300 maxillary and mandibular jaws, which included both dentulous and edentulous specimens, in a randomized manner (93). The anterior and posterior areas of the jaw that the alterations in the morphology of the alveolar process exhibit a consistent pattern subsequent to tooth extraction (93).

According to a study presented at the 4th International Congress on Preprosthetic Surgery in 1991, it was suggested that the research conducted by Cawood and Howell about the stage of the resorption of the alveolar ridge provided the most comprehensive and well acknowledged recognized categorization system available at that time (88).

The complete understanding of atrophy remains elusive owing to the complex interplay of several variables that influence the pace of alterations in both the outward morphology and internal composition of the alveolar ridge (94). The prevailing observation indicates that atrophy tends to escalate as individuals get older, exhibiting a positive correlation with extended periods of tooth loss (94).

In a preliminary investigation involving the examination of 60 mandibular edentulous ridges, three primary classifications were suggested: cylindrical, referring to ridges without any undercut and possessing adequate height exceeding 13 mm; undercut, indicating ridges with undercut either on the buccal, lingual, or both sides; and atrophic, characterizing ridges lacking undercut and exhibiting excessive resorption with a height less than 13 mm (95).

It is important to note the prominent patterns of atrophy phases that are assumed by the categorization. Specifically, they noticed a high prevalence of edentulous cross-sections falling under classes III and V, while classes IV and VI were detected less often(88).

The Cawood and Howell categorization system and anatomic dental chartings are used to categorize and depict the cross-sectional sections of the mouth, namely m (molar), p (premolar), ca (canine), and i (incisor). The figure's upper panel exhibits the levels of atrophy, which are classified as classes I-VI, in the anterior maxilla (particularly the central area i) and the posterior maxilla (represented by cross-sections of anatomical areas m and p). The present illustration has been sourced from the scholarly study conducted by Cawood and Howell in the year 1988 (Figure 2.4) (88).

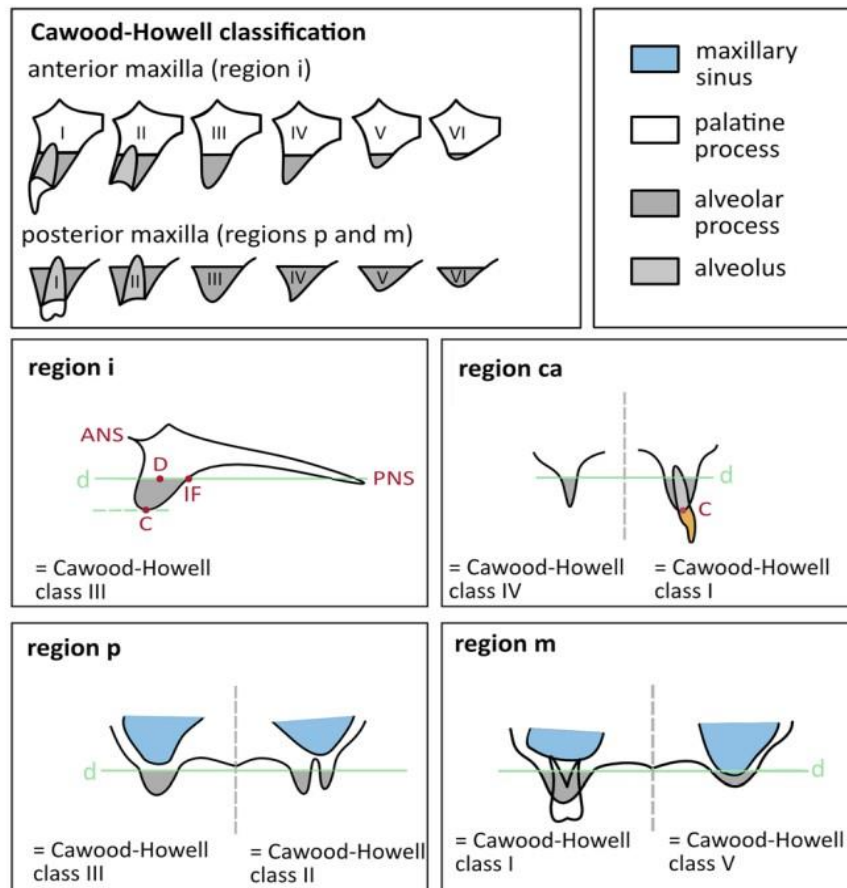


Figure 2. 3. The Cawood and Howell categorization system (88).

2.6.1. Edentulous maxilla

The maxilla is a bony structure situated in the central area of the craniofacial complex. It primarily consists of two maxillary bones that are bilaterally positioned and joined together at the sagittal midline by the intermaxillary suture (96). Each maxillary bone has a hollow, curved alveolar process that serves to house the maxillary teeth and support the top dental arch (97).

The overall volume of the maxillary sinus cavity tends to diminish as an individual ages. However, it is worth noting that the alveolar process and the floor of the maxillary sinus generally do not suffer significant morphological alterations (98).

Research conducted on tooth loss caused by periodontitis has shown that maxillary molars are the tooth category that is most often affected (96,99). During the first six-month period subsequent to the excision of an anterior tooth, the maxilla undergoes a major volumetric alteration. The observed horizontal changes exhibit a range of 29% to 63%, while the vertical changes demonstrate a range of 11% to 22% (100).

The phases of maxilla atrophy described by Cawood and Howell are related with a weakening of the circumoral muscles, which in turn causes a shrinking of the mouth, involves a loss of lip support, ultimately resulting in a reversal of the lip position (101). This last point is especially crucial in the front part of the maxilla (102).

Physiological bone remodeling may be linked to genetically determined low maxillary bone density and is reported to occur at a more accelerated and pronounced pace compared to the mandible (103). Traumatic occurrences like long-term denture wear may accelerate anterior and posterior bone resorption. This loss in bone volume may prevent dental implant implantation without further augmentation (103).

2.6.2. Maxillary changes evaluation

Oral and maxillofacial surgery is a pioneering specialty that has used digital technology. Digital design and manufacturing (CAD/CAM) technologies have made significant improvements in oral and maxillofacial surgery (104).

Maxilla that have lost all of their teeth often have a substantial degree of pneumatization of the sinuses and atrophy of the alveolar bone (Figure 2.5) (105).

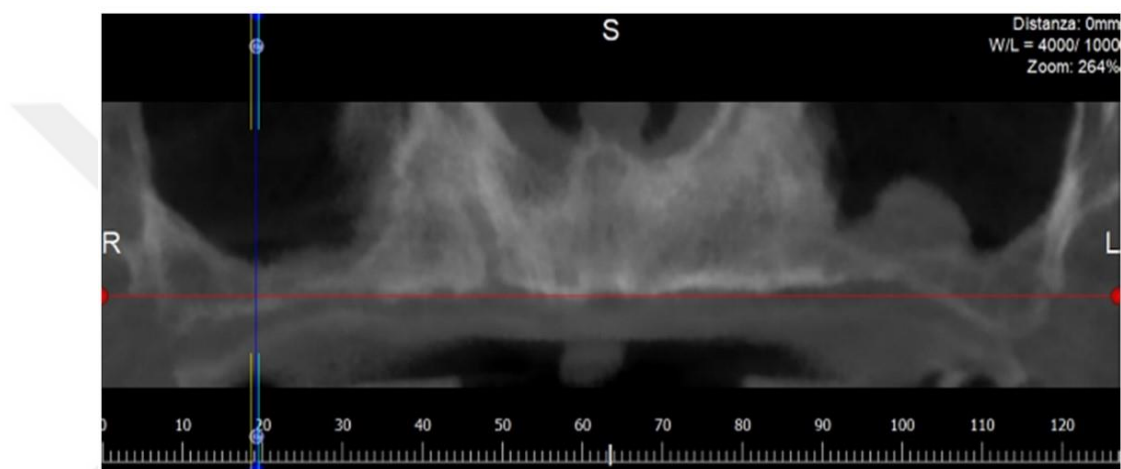


Figure 2. 4. Atrophied maxilla cone beam computed tomography (105).

Misch suggested a classification of bone density for implant treatment using CT image composition and density readings (106). D3-D4 bone, with a thin layer of cortical bone and fine trabecular bone, is found in the posterior maxilla, whereas D1-D2 bone is denser and found in the anterior and posterior mandibular ridges (106).

Loss of posterior molar roots on the maxillary sinus floor leads to increased osteoclastic activity and bone resorption, leading to additional development of the inferior side of the sinus (107). Resorption of alveolar bone and sinus cavity pneumatization might cause insufficient bone height for dental implant surgery (107).

2.6.3. Sinus pneumatization

The maxillary sinus, referred to as the "antrum of highmore," is the most sizable among the paranasal sinuses and undergoes embryological development during 16 weeks of gestation. The sinus exhibits a pyramidal morphology and comprises four distinct walls. These walls consist of a base, which is constituted by the lateral wall of the nose, and an apex that extends towards the zygomatic process (108).

The loss of teeth leads to both horizontal and vertical resorption of the remaining bone, which can subsequently result in the development of maxillary sinus pneumatization following tooth extraction in the maxillary molar area (109,110).

The maxillary sinus, which is the biggest of the paranasal sinuses, undergoes initial development during 10 weeks of gestation. Following the process of birth, the sinus undergoes pneumatization, extending into the growing alveolar ridge as the permanent teeth emerge (110). Prior research has shown evidence of physiological and post-physiological alterations in the maxillary sinus. From a physiological standpoint, it can be observed that the maxillary sinus undergoes a constant process of pneumatization following birth (111).

From a physiological standpoint, it can be observed that the maxillary sinus undergoes a constant process of pneumatization following birth. A study has shown that the duration of this process extends till the second decade in females and until the third decade in males (112). In a separate investigation, the most significant pneumatization was seen during the age range of 19 to 30 years. The etiology and degree of sinus pneumatization remain unclear, however, the following factors that contribute to the variation in human craniofacial morphology include inheritance, craniofacial configuration, bone density, growth hormones, and air pressure within the sinus cavity (113).

On average, the pneumatization of the maxillary sinus was measured to be 1.56 ± 3.93 mm. The process of extracting second molars has been found to result in the most significant degree of pneumatization. This finding should be taken into account while formulating treatment strategies for this specific tooth location (111).

From a post-physiological perspective, the extraction of posterior teeth in the maxilla has the potential to stimulate remodeling of the alveolar ridge, leading to an enlargement of the maxillary sinus. From a clinical perspective, it has been shown that maxillary sinus pneumatization (MSP) might result in a reduction in bone height, which may provide challenges for the placement of dental implants in the future. This phenomenon is often accompanied with ridge resorption in the uppermost part of the socket following tooth extraction (114).

In general, there was a significant correlation between the quantity of MSP and the age of patients. The prevalence of MSP decreased as age increased, with a higher occurrence observed in the 18-34 age range. However, there was no significant correlation between MSP and gender or the sides affected by multiple sclerosis. Hence, in light of the potential ramifications associated with the extension of maxillary sinus pneumatization (MSP) into the alveolar process, it becomes crucial to ascertain the extent and magnitude of MSP prior to initiating therapy in the posterior area of the maxilla. This has particular significance for those at a higher risk, namely those within the age range of 18 to 34 years (115).

CT scans are useful for assessing sinus disease, septa, and arteries before maxillary sinus surgery (107).

2.6.4. Atrophic maxilla

A severely atrophic maxilla would be defined as an arch or quadrant that has undergone significant osseous resorption, often combined with enlargement of the maxillary sinus that yields insufficient ridge height and/or width to allow implant placement without osseous grafting to create volume (116).

However, the problem becomes more complicated in patients exhibiting extensive maxillary resorption. The placement of dental implants in the upper jaw can be complicated by various factors. These include centripetal resorption of the alveolar process, pneumatization of the maxillary sinuses, the presence of the nasal fossa and the nasopalatal duct, as well as the quality of the bone, which is classified as type 3 or 4 according to the Lekholm and Zarb classification (117).

The Bedrossian categorization provides a framework for determining the appropriate surgical method to be employed. The evaluation of the patient's panoramic radiograph allows for the completion of this task. The maxilla may be anatomically divided into distinct zones: Zone I, which spans from the canine tooth on one side to the canine tooth on the other side; Zone II, which encompasses the premolars; Zone III, which includes the molars; and Zone IV, which pertains to the zygomatic region (Figure 2.6) (116).

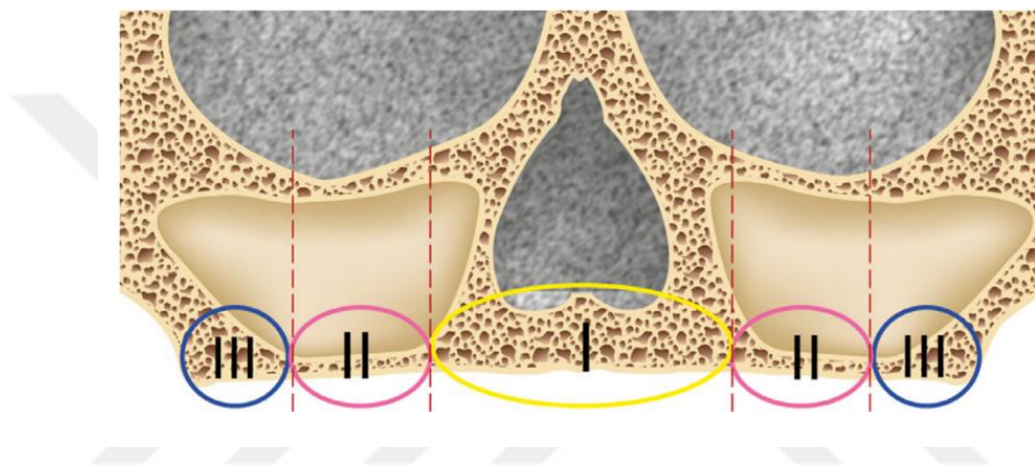


Figure 2. 5. The Bedrossian classification (116).

The quality and quantity of maxillary bone are often less than that of the mandible. This is mainly because of the type of bone present in the posterior maxilla. Lekholm and Zarb (1985) provided a comprehensive description of the four primary bone types found in the maxilla and mandible. Type 1 bone is mostly composed of homogeneous cortical bone. Type 2 bones refer to skeletal structures characterized by a central region composed of tightly compacted cancellous bone, encased by a cortical bone layer measuring a minimum of 2 mm in thickness. Type 3 bones refer to skeletal structures characterized by a central core composed of tightly packed cancellous bone, encased by a relatively thin covering of cortical bone. Type 4 bone is mostly composed of non-dense cancellous bone, which is bordered by a thin layer of cortical bone (118).

2.7. Rehabilitation of atrophic maxilla

Individuals who have severe maxillary atrophies serve as evident illustrations of the modifications in their skills to chew, swallow, and speak, which therefore have psychological consequences. As a result, this group of patients becomes significant candidates for reconstructive interventions (119).

The rehabilitation of edentulous subjects with extreme bone resorption with fixed dentures can be a challenge due to inadequate bone volume to anchor standard implants (120). Due to the significant resorption of the maxilla, the utilization of detachable prosthesis poses a potential risk to the individual's masticatory function, speaking abilities, and overall quality of life (121).

Anterior alveolar bone resorption, pneumatization of the sinuses and limited bone volume in the posterior region reduce the possibility of inserting standard implants (121). The bone loss, particularly in the maxilla, combined with age, muscle hypotonia, and inversion of the lips, results in facial changes in shape and appearance (122).

The process of alveolar bone resorption, classified by Cawood and Howell, can result in adverse effects, such as the loss of prosthetic support and retention and loss of soft tissue support of the upper lip, as well as having an impact on vertical facial dimensions (123).

Ridge atrophy and maxillary sinus pneumatization result in several issues with regard to the rehabilitation of posterior maxilla areas by means of functional and aesthetic implant-supported prostheses (124).

Various treatment options have been suggested to address this particular scenario. These options encompass bone grafting techniques, specifically block bone grafts and sinus lifting through crestal or lateral approaches. Additionally, there are non-grafting techniques available, which involve modifications of the traditional implant procedure. These modifications include implant placement in the zygomatic bone, the pterygoid process, or the maxillary tuberosity, as well as the utilization of short or tilted implants (4).

A variety of alternative therapies are currently accessible, including bone grafting methods such as the iliac crest block bone graft, Le Fort I osteotomy, onlay type bone grafting techniques, and maxillary sinus lift operations in the posterior sectors of the maxilla. There are several drawbacks associated with these approaches. Firstly, they sometimes require repeated operations. Additionally, they entail the utilization of extraoral donor sites, such as the iliac crest or skull, which can result in additional morbidity. Furthermore, patients undergoing these procedures must endure a prolonged period without oral rehabilitation while they wait for graft consolidation and healing to occur. An alternate approach involves the placement of implants into the pterygoid process and the zygomatic bone (2).

In the existing body of research, several methodologies have been documented as potential solutions for addressing these issues. These methodologies encompass bone grafts, sinus lifts, as well as tilted, zygomatic, and pterygoid implants (8).

2.7.1. Grafting techniques

Presently, there exist several methodologies for the restoration of atrophic maxillary ridges as documented in scholarly literature. Many studies regard the use of autogenous bone in the grafting method to be optimum (125).

Bone grafts followed by osseointegrated implants may restore both the form and function of atrophic maxillae (125).

When considering a sinus lift treatment, surgeons might utilize several substances to graft the sinus floor and elevate the membrane to obtain desired bone height. There are many graft material used to enhance the maxillary sinus (61).

Xenograft refers to the transplantation of tissue or organs from one species to another, an allograft refers to a transplant obtained from a donor of the same species as the recipient. An autograft refers to a graft that is obtained from the same patient, an alloplast refers to a graft material that is obtained from a non-animal source and is either produced or designed (61,126).

Researchers recommend autogenous bone transplants because to their osteogenic potential, lack of antigenic reactivity, and reduced danger of cross-contamination. However, this bone transplant has disadvantages such as limited donor locations and surgical intervention-related morbidity (127).

Allogeneic grafts are biocompatible, less postoperative pain, and have no morbidity to the donor site. They are also accessible in infinite numbers (125).

The protocol for grafting Misch states that successful integration of bone graft relies on many factors: surgical asepsis, soft-tissue covering, graft space maintenance, immobilization, regional acceleratory phenomena, host bone blood vascular optimization, and growth factor optimization (55,128).

The therapy include augmentation grafting to restore bone mass and support an implant-supported prosthesis (129). Augmentation methods like crestal onlay, inlay, Le Fort I osteotomy, and distraction osteogenesis are used to reconstruct atrophic edentulous maxillas before implant placement for implant-supported restorations (130).

2.7.1.1. Sinus lifting

The most commonly used augmentation technique to obtain sufficient bone volume is sinus floor augmentation (131).

The most appropriate therapeutic intervention for addressing inadequate bone volume in the posterior region of the maxilla involves performing a maxillary sinus lift procedure. This procedure entails placing bone grafts beneath the sinus membrane (also known as the Schneiderian membrane) and on the floor of the sinus. By doing so, the height of the maxillary ridge is increased, thereby enabling the successful placement of dental implants in this specific region (132).

The procedure known as transalveolar osteotome sinus floor elevation, also referred to as the osteotome technique, is capable of enhancing the density of the maxillary bone and raising the sinus membrane by the use of replacement materials for grafting purposes (133).

Historically, two methodologies have been employed for the management of a vertically deficient, edentulous posterior maxillary ridge characterized by poor bone density: direct and indirect approaches. The lateral maxillary sinus window technique is often employed when the remaining bone height measures 5 mm or less, whereas the indirect transcrestal approach is utilized when the residual bone height is equal to or greater than 5 mm (134). Both augmentation procedures demonstrate clinical effectiveness and exhibit high rates of implant survival, despite the presence of distinct problems and limits associated with each method (135).

There are several difficulties that might arise both during and after the sinus elevation surgery utilizing the lateral technique. Indeed, the occurrence of Schneiderian membrane perforations, epistaxis, postoperative discomfort, and edema might be regarded as significant disadvantages associated with this therapeutic option (136).

When it comes to maxillary sinus surgery for operations linked to dental implants, there are four primary ways that are performed. Sinus lift and bone graft, bone graft and insertion of implants with sinus lift, sinus elevation and implant placement without the use of bone graft, endoscopic surgery of the sinuses (137).

It is advisable to utilize various bone grafting materials, such as autogenous bone, autogenous tooth bone graft, allograft, xenograft bone, and alloplast bone, for the purpose of augmenting alveolar bone. However, optimal outcomes are achieved when the graft material predominantly consists of autogenous bone (138).

Sinus lifting is a commonly employed technique for the placement of dental implants in cases of alveolar bone shortage within the posterior maxilla. The direct (lateral) and indirect (crestal) protocols have been discussed in relation to sinus raising procedures due to the presence of residual alveolar bone height (139).

Various surgical techniques have been employed to conduct open sinus lifting via the lateral wall, enabling the elevation of the schneiderian membrane within the sinus cavity. The prevailing method frequently employed in clinical settings involves the utilization of a surgical diamond bur in conjunction with a revolving handpiece. Piezosurgery is an innovative osteotomy technique that employs ultrasonic piezoelectric vibrations. This method enables the selective cutting of hard tissues by utilizing different frequencies (140,141).

The clinical results of piezosurgery were shown to be comparable to those of conventional diamond bur in the context of open sinus lift surgery. As such, piezosurgery may serve as a viable alternative to the use of traditional diamond bur (142).

2.7.1.2. Onlay grafts

Different augmentation techniques have been used to improve the volume of the alveolar crest, such as onlay bone grafting (OG), sinus lift elevation (SL), the interpositional ‘sandwich technique’ bone graft, and distraction osteogenesis (143).

Augmentation studies with autologous bone are mostly heterogeneous with regard to the surgical technique, source of the bone grafts, and duration of follow-up, and therefore provide different recommendations for treatment procedures (144).

Steller et al study concluded there is a significant influence of time and bone grafting technique on the subsequent proportional resorption of the iliac bone graft. This bone height reduction was found to be greater for onlay grafts than in the sinus lifting technique (145).

There are many techniques available for augmenting bone in the atrophic maxilla. The surgical treatments most commonly employed for bone augmentation are bone grafts, guided bone regeneration (GBR), maxillary sinus floor elevation (SFE), and bone osteogenesis distraction (BOD) (146).

The indications for onlay bone grafts involve the augmentation of the existing bone in both the vertical and horizontal dimensions. Vertical bone augmentation with block grafts is recommended in cases when the remaining crest height measures less than 5 mm, namely in Cawood and Howell class IV, V, and VI classifications (147). The utilization of horizontal bone augmentation is advised in cases where the alveolar ridge width measures less than 4 mm or less than 5 mm in regions of aesthetic significance, particularly those next to the labial line (146).

There exist many sources of intraoral and extraoral donors for autogenous bone grafting (ABG). The maxilla and mandible are potential sources for the extraction of intraoral bone, which encompasses several regions such as the mandibular symphysis and parasymphysis (located in the chin area), the mandibular ramus, maxillary tuberosity, and coronoid process. Intraoral bone blocks have decreased rates of resorption, but their availability is not always guaranteed, and at times, they may possess insufficient volume for grafting purposes in situations with substantial bone defect, the use of extraoral donor sites becomes imperative. The sources of extraoral donor bone include the iliac crest, calvarium, and tibia (149).

The grafting procedure for the atrophic maxilla is the bilateral sinus floor elevation for vertical posterior inlay augmentation, combined with an anterior block onlay grafting for horizontal augmentation. Implants have the same success rates in grafted maxilla as those placed in normal maxillary bone (122).

2.7.2. Nongrafting techniques

A significant number of clinicians exhibit a preference for opting for graftless alternatives when it comes to the implantation of dental implants (150). The available choices for implant placement without the use of grafts include zygomatic or pterygoid bone implant insertion, as well as the use of short implants (129).

Branemark et al study reported long-term success with autogenous onlay bone grafting and endosseous implant insertion in 2001. The first endosseous implants had an 80% success rate after 2-15 years of follow-up (151).

Widmark et al study revealed that the success rate of maxillary implants was higher when implanted in native bone compared to implants inserted into grafted bone (152). Implants inserted in grafted maxillas had an 82% success rate, whereas those placed in native bone had a 96% success rate (152).

With digital technology, patient-specific implants (PSI) may be made, disruptive 3D printing has revived subperiosteal implants (153).

2.7.2.1.The additively manufactured subperiosteal jaw implant (AMSJI)

The additively manufactured subperiosteal jaw implant (AMSJI) concept is comprised of two distinct subunits, namely the left and right subunits. The customization of these devices is contingent upon the individual patient's bone structure, which is determined by a provided CBCT data set (153).

The AMSJI technique is a modern approach aimed at addressing the needs of a certain subset of patients who possess insufficient bone volume to support screw-type endosseous implants (Figure 2.7) (154). The tailormade approach not only facilitates attachment onto the bone, but it also provides the patient with an instant functional restoration by a singular surgery (155).



Figure 2. 6. Two additively made sub-periosteal jaw implant (AMSJI) segments positioned on the bone in a computer depiction of the procedure (154).

2.7.2.2. Short implants

To overcome the possible complications in grafting techniques , the use of short dental implants was proposed as an alternative treatment option to rehabilitate posterior areas of the maxilla. The precise characterization of short implants is an area of ongoing investigation and has yet to be definitively established (156).

The use of short dental implants has been studied as an alternative treatment option also in the posterior areas of the maxilla , in recent years 2021 as Carosi et al concluded that the short dental implants less than 6 mm placed in resorbed posterior areas of the maxilla avoiding bone augmentation procedures reported high survival rates during a short to medium follow-up (157).

Regularly, short implants are used to avoid invasive surgeries that could risk important parts of the body. There are different points of view in the literature about the possible problems with using short implants when the crown-to-implant (C/I) ratio is high, such as the possibility of minor bone loss or even implant loss (158).

Furthermore, the definition of short implants remains hazy, with some researches using a threshold of 10 mm and others using a threshold of 8, 7, 6, or 4 mm. The existing data shows that shorter implants may improve patient satisfaction and reduce implant failure, marginal bone loss , and biological problems (159).

Based on the findings of the past studies, it can be concluded that short implants measuring 6 mm or less have shown favorable survival rates throughout the short to medium-term follow-up period in the posterior maxilla. However, it is important to note that the long-term effectiveness of these tiny implants has not yet been adequately shown (157).

As a foreseeable therapy for the posterior jaws, especially in instances requiring supplementary surgical procedures, short implants demonstrated negligible bone loss, prosthesis failure, and complication rates equivalent to normal implants. However, caution should be used when using implants shorter than 8 mm (between 4 and 7 mm) in length due to an increased risk of implant failure (161).

Patients with an atrophic posterior arch may benefit from the implantation of extra-short implants (6 mm) for up to three years. In reality, short implants have not only showed comparable survival rates but significantly decreased bone loss in the first three years after implantation (162).

As compared to lengthy implants (>10 mm) in terms of bone volume, biologic problems, cost, and surgical time. However, extra-short implants increased the risk of prosthetic problems. Long implants had a better 5-year survival rate than extra-short implants (162).

2.7.2.3. Angled implants

Patients with extensive alveolar bone loss need preparatory surgical treatments like bone augmentation and sinus lift before they may have a dental implant placed (163).

For optimal outcomes, patients with significant alveolar bone loss need surgical intervention, such as bone augmentation and sinus lift treatments. These methods can lead to higher patient morbidity, treatment costs, and can have complications. Malo P et al created the all-on-four concept in 2003 to address these limitations (160).

Dental implants are used in denture rehabilitation. A severely atrophic alveolar process requires bone grafting, sinus elevation, and soft tissue care to treat entire edentulism with a typical implant-supported fixed repair. Nevertheless, bone augmentation presents notable risks of consequences, such as infection, loss of soft tissue shapes and/or volume, graft failure, and potential dangers associated with donor materials. Additionally, there are procedural challenges and patient morbidity concerns. Furthermore, reconstructive surgery entails higher expenses and a lengthier recovery period (164).

Tilted implants in the maxilla and mandible save bone grafting and have similar success rates to axially inserted implants (165). Patients also prefer them, angled implants improve implant survival due to distal cantilever extension (166).

The All-on-Four technique enables complete arch rehabilitation without the need for bone augmentation. It involves the use of a fixed prosthesis that is supported by two axial implants in the anterior section and one tilting implant in the front of the mental foramina and anterior lobe of the sinus in each posterior section (167).

The all-on-four approach uses two anterior upright implants and two tilted posterior implants in the second premolar area with a distal inclination parallel to the maxillary sinus wall (168). Periodontal ligaments and other soft tissue structures absorb occlusal stresses, making natural teeth and implanted dentures biomechanically different (168).

Distally inclined posterior implants are another possibility. Implants in preexisting bone improve bone anchoring and prosthesis support. Tilting implants also allows lengthy implants, which enhance bone-to-implant contact area and main stability. It also distances anterior and posterior implants, improving stress distribution and avoiding lengthy cantilevers (169).

Some research suggest that angled implants have higher bending moments at the angled abutment. Nevertheless, the rigidity of the prosthesis and its improved support have the potential to decrease stress on both the implant and the surrounding bone. In the context of full arch and partial restorations, it has been shown that both axial and tilted dental implants exhibit comparable outcomes in terms of implant survival and overall implant success rates over an extended period of more than five years. Therefore, it is important for dental professionals, including dental practitioners, oral surgeons, and prosthodontists, to be aware of and consider the presence of angled dental implants in cases when there is insufficient posterior bone and the patient declines substantial bone augmentation procedures (169).

Regardless of implant number, posterior implant inclination optimizes force distribution. In this prosthesis, inclined implants limit the horizontal extension of cantilevers and/or prevent maxillary sinus grafting, improving implant distribution in unfavorable instances (170).

As an alternative to sinus floor elevation, tilted implants have been proposed. Tilted implants placed in the accessible bone would show less difficulties compared to

sinus elevation using a lateral window approach or an osteotome mediated method. Despite the absence of statistically significant differences, which exhibited comparable outcomes in terms of implant survival and marginal bone loss. Partial rehabilitation over maxillary-tilted implants can be performed immediately with low risk of problems (171).

Since in the late 1990s and early 2000s, the practice of intentionally tilting dental implants to increase anterior-posterior (A-P) implant distribution while avoiding the maxillary sinuses has been frequently described. The use of tilted posterior implants has since been documented in several clinical studies that demonstrate comparable survival of these implants, with no reported increase in bone loss associated with implant angulation (172).

There may be fewer implants total if the number of posterior implants is lowered due to their angulation. Angulated implants are only recommended for specific cases when the A-P implant distribution may be enhanced without compromising the integrity of the maxillary sinus (172).

Implantologists recommend posterior maxilla distal deliberately tilted implants to circumvent bone grafting constraints. Intentionally tilted implants perform similarly to axial implants. Distal purposefully tilted implants can increase posterior maxilla bone volume, reduce bone augmentation, improve implant primary stability when long implants are utilized, and shorten the cantilever. Dynamic navigation for purposefully skewed implants is promising due to its benefits. Few studies have examined dynamic navigation accuracy for purposefully tilted implants (173).

2.7.2.4. Zygomatic implants

Zygomatic implants introduced by Branemark in 1988, in order to facilitate the rehabilitation process, it is imperative to have an adequate amount of bone volume in the anterior maxilla. Specifically, the bone should possess a minimum height of 10 mm and a width of 4 mm to accommodate the insertion of 2-4 conventional implants. This is necessary so that the patient can have zygomatic implants placed (174).

Accepting the limited direct bone availability within the maxilla and relying on the zygomatic bone for support is a unique approach (175).

In cases of severe atrophic maxillary, zygomatic implants have been proposed as an alternative to extensive grafting surgery. The average length of a zygomatic implant is between 35 and 60 mm, and it is located close to several anatomic constraints(176).

Zygomatic implants offer the benefit of engaging stable pre-existing bone, but they also avoid the need for extensive augmentation operations, which are generally performed under general anesthesia and are associated with a higher risk of complications (175). Zygomatic implants and anterior implants cure severe maxillary atrophy. They are also suitable for individuals with maxillary resections and systemic pathologies such cleft palate, or epidermolysis bullosa that cause significant maxillary atrophy (2).

The sinus slot method was created by Stella and Warner in 2000. This method allows for a more buccal placement of the implant head, which facilitates prosthetic repair, and increases visibility of the implant's precise location, minimizing the risk of sinus problems and postoperative discomfort. Success was calculated as a weighted average of 97.8% (2). Extrasinus zygomatic implants are being attached to the lateral sinus wall and zygomatic bone in a unique approach (2).

The factors for a successful zygomatic implant were: clinical stability with no signs of movement, no pain, no infection, or other implant-related pathology, no peri-implant radio transparencies, and a prosthetically good implant position (174).

When compared to significant bone augmentation, the placement of implants in the zygomatic and pterygoid regions is an efficient, less intrusive therapeutic option (176).

The primary indication for zygomatic implants remains constant, which is to provide posterior maxillary support for individuals who are fully edentulous and have substantial sinus pneumatization and severe resorption of the posterior alveolar ridge (177). Acute sinus infection, maxillary or zygoma pathology, and uncontrolled or malignant systemic illness contraindicated to zygomatic implant surgery (177).

2.8. Implant in pterygoid region

The resorption of the posterior maxilla can be intensified by several circumstances, including the expansion of the maxillary sinus, resorbed of the alveolar bone crest, and inadequate bone density (7).

Atrophy can be caused by a number of various factors, including injury, infection, and periodontal disease, which can reduce bone volume and make implants less successful (178). The literature documents many therapies for these problems, including as bone grafts, sinus lifts, and implants placed at different angles, including zygomatic and pterygoid implants (8).

The success rate of dental implants has been demonstrated to increase when enough bone is present to act as an anchor, due to the advancements in implant dentistry facilitated by the concept of osseointegration (179). It is well knowledge that implant placement in the posterior maxilla may be difficult owing to the low quality and quantity of bone that is present in this region, as well as the presence of the maxillary sinus (180).

The definition of pterygoid implant is "implant placement through the maxillary tuberosity and into the pterygoid plate (179), which are designed to be inserted into the dense cortical bone formed by the posterior wall of the maxillary tuberosity, the horizontal process of the palatine bone, and the pterygoid process of the sphenoid bone (181).

It is anticipated that the pterygoid implant would go through the maxillary tuberosity as well as the pyramidal process of the palatine bone before engaging the pterygoid process of the sphenoid bone (180). The attainment of considerable primary stability can be accomplished without the need for sinus lifts or bone grafts by the utilization of anatomical structures such as the maxillary tuberosity, the pyramidal process of the palatine bone, and the pterygoid process of the sphenoid bone (182).

Instead of using zygomatic implants, an alternative approach involves the insertion of implants in the pterygoid or pterygomaxillary area, which is located next to the maxillary tuberosity and behind the maxillary sinus (178). The pterygoid process is usually denser than the maxillary tuberosity, the utilization of this technique is recommended for the purpose of anchoring implants in maxilla with atrophic conditions (183).

2.8.1. Pterygoid processes anatomy

Cancellous bone of type III and type IV are located in the construction of the tuberosity of the maxilla. Thick cortical bone is located mostly in the construction of the pyramidal course of the palatine and the pterygoid process of the sphenoid in the human skull. The inner surface of the pterygoid fossa is lined by the plates of the intermediate and parallel pterygoid. During head and neck imaging, the pterygopalatine fossa is a critical area that must be evaluated with extreme caution because of its significance as a major part of the deep space (184).

The pterygopalatine fossa is a rather elongated, funnel-shaped compartment that is just behind the posterior wall of the maxillary sinus. Its rear boundary is created by the merged anterior mass of the medial and lateral pterygoid plates, and its anterior border is formed by the corpus maxillae. The pterygopalatine fossa may be found just behind the posterior wall of the maxillary sinus. The pterygopalatine canal is formed when the fossa, which is bounded superiorly by the body of the sphenoid bone, becomes more narrow in the posterior region (185).

The pterygopalatine fossa is a space in the shape of an inverted pyramid formed by the junction of the maxilla, palatine, and sphenoid bones (186). The composition of the pterygopalatine fossa includes adipose tissue, the pterygopalatine ganglion, the maxillary division of the trigeminal nerve and its associated branches (namely the zygomatic nerve, posterior superior alveolar nerve, and infraorbital nerve), the vidian (pterygoid) nerve, the peripheral branches of the maxillary artery, and a limited number of emissary veins. Additionally, the maxillary division of the trigeminal nerve is located in this region (186).

The anatomy of the pterygomaxillary region may vary greatly from person to person. Because of this, a specific pre-surgical radiological examination need to be carried out each time a pterygoid implant is intended to be positioned in this location (183).

Patients who need pterygoid implant or another procedures such as Lefort 1 osteotomy absolutely need to have a comprehensive awareness of the anatomy of the pterygomaxillary junction (Figure 2.8) (188).

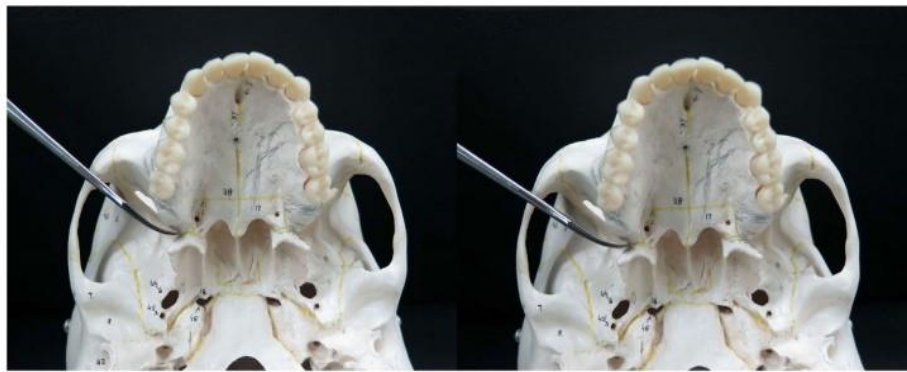


Figure 2. 7. Pterygomaxillary junction (188).

The pterygomaxillary junction is created when three primary bones come together to form a single structure. These bones are the posterior section of the maxillary bone, the pyramidal process of the palatine bone, and the pterygoid process of the medial pterygoid of the sphenoid bone. Together, these bones make up the pterygomaxillary junction. This juncture has exceptionally thick cortical bone, with a density value ranging from 602.9 to 661.2 units, which helps to provide the implants with a great deal of stability and anchoring (189).

The pterygoid fossa is bordered by medial and lateral pterygoid plates, but the pterygopalatine fossa is a critical region that has to get special attention since it is regarded as a vital location in the deep space (190).

The confluence of the maxilla, palatine, and sphenoid bones encloses the pterygopalatine fossa in the skull. The pterygopalatine fossa is filled with adipose tissue, the pterygopalatine ganglion, the maxillary division of the trigeminal nerve and its

branches, the pterygoid nerve, the distal branches of the maxillary artery, and a few emissary veins. Other contents include the distal branches of the maxillary artery. The most successful method for inserting the implant is via the pterygoid process and into the pterygoid fossa (190).

The basis for the support of pterygoid implants is drawn from three components (The tuberosity of the maxillary bone is a bony prominence located in the posterior region of the maxilla, the pyramidal process of the palatine bone is a notable anatomical feature, the pterygoid process of the sphenoid bone) (191).

Based on the anatomic position, Reiser et al study classified the posterior maxillary implant as follows: tuberosity – pyramidal process, tuberosity – pterygoid process, tuberosity – pyramidal process – pterygoid process, pyramidal process – pterygoid process, maxillary tuberosity, pyramidal process – pterygoid process, pyramidal process – tuberosity, pyramidal process – maxillary tuberosity (192).

2.8.2. Surgical techniques

Implants are put in the pterygoid process using a method that needs surgery training and a thorough understanding of the area's anatomy (8). The implant is secured by initially anchoring it within the pterygoid plate of the sphenoid bone. Subsequently, it traverses the maxillary and palatine bones with a distal angulation ranging from 35 to 55 degrees. The specific angulation is contingent upon the tuberosity bone's height and the maxillary sinus floor's location (193).

At the point where it enters the pterygopalatine fossa, the internal maxillary artery makes a crossing that is one centimeter above the pterygopalatine suture, therefore 25 millimeters is the distance that must be traveled from the artery to the lower end of the pterygomaxillary suture, because there are no important structures in the location of the insertion, the surgeon may perform the procedure in a risk-free environment. The veins of the pterygoid muscle are the source of any bleeding that may occur in this location; however, the bleeding may be rapidly stopped upon the introduction of intraosseous fixation, and it will not resume after the implant is set (194).

In the clinic, the starting drill was based on the shape of the tuberosity, the distance from the planned starting point to the end of the tuberosity, and where the sinus was in relation to the tuberosity. When placing pterygoid implants, the operator's training and sense of touch are very important because they can't see where they're going (182).

The pterygoid implant location is planned target location to engage the fixture distal to the tuberosity. This target site is comprised of the maxillary tuberosity, the pyramidal process of the palatine bone, and the pterygoid process of the sphenoid bone (Figure 2.9) (195).

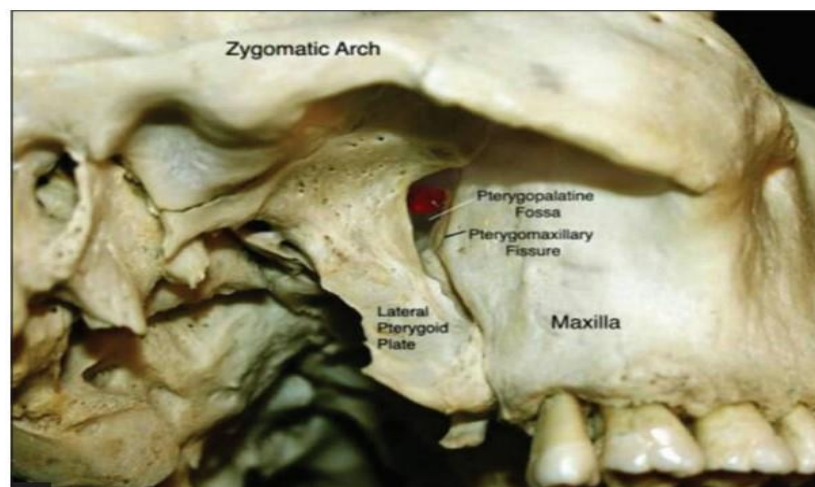


Figure 2. 8. The maxillary tuberosity, the pyramidal process of the palatine bone, and the pterygoid process of the sphenoid bone (195).

The incision is designed to fully expose the tuberosity, including its posterior aspect, for the purpose of thorough inspection and instrumentation (192). To position the implant apex into the pterygoid plate, the surgeon needs to tilt the handpiece medially. The central region of the pterygoid process, located between the plates, exhibits the highest degree of bone thickness, providing significant support. The location of this is approximately three to four millimeters towards the center from the alveolar crest (192).

The insertion of a pterygoid implant is comparatively less invasive as compared to the placement of a zygomatic implant. Pterygoid implants exhibit greater length compared to conventional dental implants, since they necessitate traversing the maxillary tuberosity and the pyramidal process of the palatine bone in order to establish connection with the pterygoid process of the sphenoid bone (196).

Bahat et al think it essential to open the patient's mouth a minimum of roughly 35 mm in order to obtain adequate implant angulation (8).

The surgical approach for placing a tuberopterygoid implant adheres to the same fundamental concepts that underlie conventional implant surgery (197). It is possible to consider the pterygoid implant technique a more straightforward kind of surgical treatment since it does not include a bone grafting process. This method is linked to a reduced risk of morbidity across the board, as well as reduced treatment expenses and accelerated recovery durations (197).

The use of pterygoid implants is a potentially feasible alternative for healthcare professionals involved in the restoration of individuals who have undergone bilateral maxillectomy (198).

The surgical approach of pterygoid implant placement has been linked to an extremely low risk of problems. One of the most frequent complications that was recorded was bleeding that occurred during the operation, it is likely that the pterygoid muscles were injured during the implantation process, or that the pterygoid bone plate was drilled through, both of which may lead to intraoperative bleeding (197). One primary challenges associated with this surgery is to the sensitivity of the approach and the challenges it poses for both doctors and patients in terms of access (198).

The need for careful consideration and clarification about the misclassification of pterygoid implants as either pterygomaxillary or tuberosity implants should be emphasized. Since the last comprehensive examination of the scholarly works as documented by Bidra et al, Jamdade et al studies (180,199).

One of the primary surgical complications that may arise during the surgical procedure is hemorrhaging, mostly due to the close proximity to the internal maxillary artery (8). which is located around One centimeter superior to the pterigomaxillary suture. It is worth noting that this particular complication is seldom (8).

Valeron et al study reported mild venous hemorrhage occurred due to the placement of the drill a few millimeters into the retropterygoid region. The issue was resolved with the use of local hemostatic techniques (201).

Krekmanov et al study documented difficulties encountered during the procedure of implant anchorage into the pterygoid process. During the insertion procedure, a loss of an implant occurred as a result of drilling that extended beyond the pterygoid process (202).

It is possible that the greater palatine foramen poses a significant threat of bleeding within the mouth. Other typical problems include trismus and discomfort, both of which are simple to treat (180,182).

Several problems associated with surgical installation have been documented in the literature. These include instances of moderate venous hemorrhage, minor trismus, misplacement of the implant, and a singular case with a persistent episode of pain and discomfort (203). One of the most frequent complications that was documented was bleeding that occurred during surgery, It is likely that the pterygoid muscles were injured during implantation, or that drilling through the pterygoid bone plate caused the bleeding that occurred during the operation (204).

Contraindications for this treatment include a smaller mouth opening, the lack of tuberosity, and third molars that are impacted (8,182). A full-thickness flap was utilized to expose both the whole maxilla and the tuberosity areas (Figure 2.10) (205).

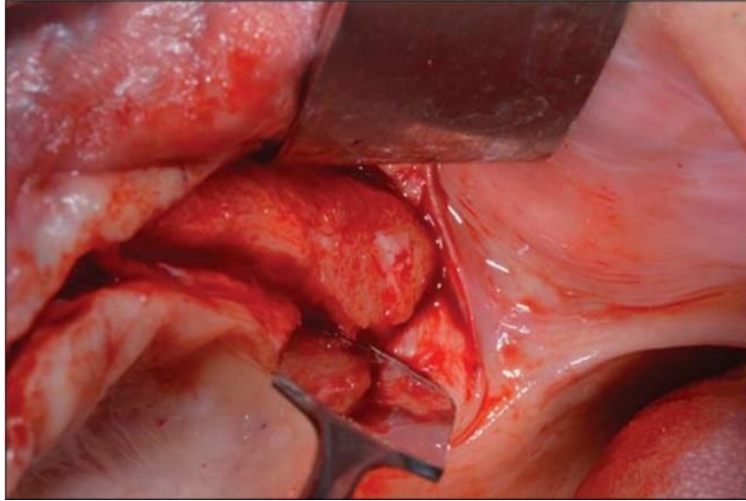


Figure 2. 9. A complete flap of full thickness originating from a single pterygomaxillary area (205).

2.8.3. Indication of pterygoid implants

Severely atrophic maxilla represent a significant indication for three-dimensional maxillary reconstruction. Various bone-augmentation techniques have been proposed in this regard (205). Several retrospective studies have been reported about the placement of pterygoid implants as an alternative to sinus augmentation in the posterior maxilla (210).

The utilization of short implants in the premaxillary areas, in conjunction with pterygoid implants in the pterygomaxillary regions, gives an alternative approach for expediting treatment duration, reducing the probability of surgical complications, and diminishing patient suffering and financial burdens (205).

In 1989, Tulasne introduced the concept of pterygoid implants as a viable alternative to traditional dental implants, aiming to bypass the need for sinus lift procedures or bone grafts (257).

The utilization of pterygoid implants offers significant benefits and justifications, primarily in terms of obviating the necessity for sinus lift operations or bone graft procedures. Consequently, this approach effectively reduces patient morbidity and expedites the overall duration of treatment (183).

The pterygoid implant has predominantly been employed for the purpose of rehabilitating patients with atrophic maxilla or as a means to avoid the need for maxillary sinus augmentation treatments (207).

The utilization of pterygoid implants in patients presents a potential hazard of sinus membrane perforation, alongside the possibility of graft resorption surrounding the implant. Moreover, the management of chronic maxillary sinusitis poses a considerable challenge in patients. The absence of minimum bone height in patients and the uncertainty surrounding the vascularity of the transplant are notable factors (208). Treatments such as sinus lifts frequently include double site interventions and the incorporation of bone grafts, which extends the duration of the healing process. These treatments also carry the potential danger of sinus membrane rupture and the subsequent susceptibility to infection (209).

2.8.4. Biomechanical load on pterygoid Implant

From a biomechanical perspective, it is advisable to refrain from restoring pterygoid implants with distal cantilevers in order to reduce the inherent risks associated with cantilevers (210).

To minimize the risk of occlusal pressures that may cause injury, it is advisable to refrain from inclining the implants (210).

Wilkirson et al study presented findings about the biomechanical characteristics of pterygoid implants in individuals with total edentulism (178). No articles studies were discovered that provide a comprehensive examination of the biomechanical characteristics, despite the existence of clinical case evaluations (178).

By doing a biomechanical analysis on pterygoid implants, enhanced treatment strategies and prospective investigations can be facilitated (178).

Wilkirson et al. found that the utilization of pterygoid implants resulted in a notable reduction in both stress and strain levels within the adjacent bone. This observation held true throughout all cases examined, in contrast to the usual scenario in which just conventional implant placement was employed. The crestal bone of the

premolar area and the implant-abutment connections of the pterygoid implants exhibited the greatest values (178).

Several research evaluated the phenomenon of bone loss. The present research have evaluated the extent of bone loss in panoramic radiographs one year following the application of load, revealing an average marginal bone loss of 0.71 mm (210).

Curi et al conducted an assessment of marginal bone loss following one year of loading. They detected a mean bone loss of 1.3 mm in the mesial direction and 1.1 mm in the distal direction, utilizing panoramic radiography (210). In their investigation, Curi et al examined the average bone loss surrounding pterygoid implants at the 36-month mark following the initiation of loading. The findings revealed a mean bone loss of 1.21 mm, with 1.31 mm seen mesially and 1.01 mm distally) (210).

In another study about pterygoid implants conducted by Curi et al. , the permanent prosthesis put over pterygoid implants were shown to generate a significant level of patient satisfaction. Furthermore, patients did not encounter any difficulties pertaining to their speaking abilities or the maintenance of oral hygiene (210).

In another study about pterygoid implants conducted by Cucchi et al. , during the one-year examination, it was seen that the soft-tissue shapes and crestal bone levels were steady, with no discernible clinical or radiographic alterations of significance. The patient expressed contentment with regard to both the functional and cosmetic aspects of the rehabilitation process. (Figure 2.11) (205).

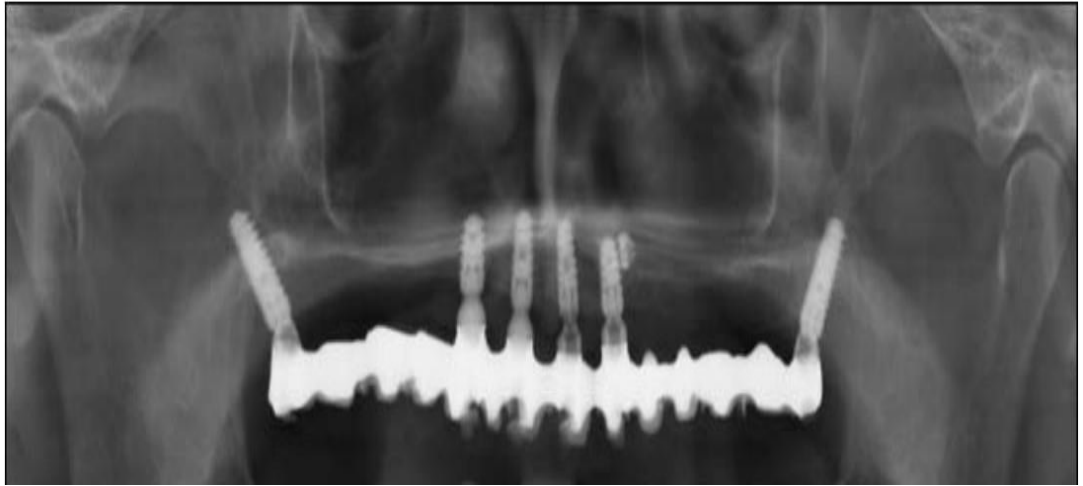


Figure 2. 10. Panoramic radiographs were utilized to assess the implant-prosthetic relationships (205).

2.8.5. Radiological approach to pterygoid implants

The requirement for invasive procedures like sinus lift operations or bone grafts is reduced or eliminated when pterygoid implants are used. This reduces patient risk and speeds up the healing process (211).

The researchs revealed that the pterygomaxillary area averaged 21.16mm in length. According to Tulasne et al study implants in the pterygoid area need to be at least 13 mm in length for satisfactory primary stability (7, 257).

Patturaja et al study shows average antero-posterior and buccopalatal angulation of pterygomaxillary region as 81.26 degree and 73.58 degree respectively (211). Similar finding Rodriguez et al, reported The average mesiodistal angulation of the pterygoid implants was found to be 70.4 degrees with a standard deviation of 7.2 to decrease non-axial load and improve long term success of the implant (Figure 2.12) (Figure 2.13) (7).

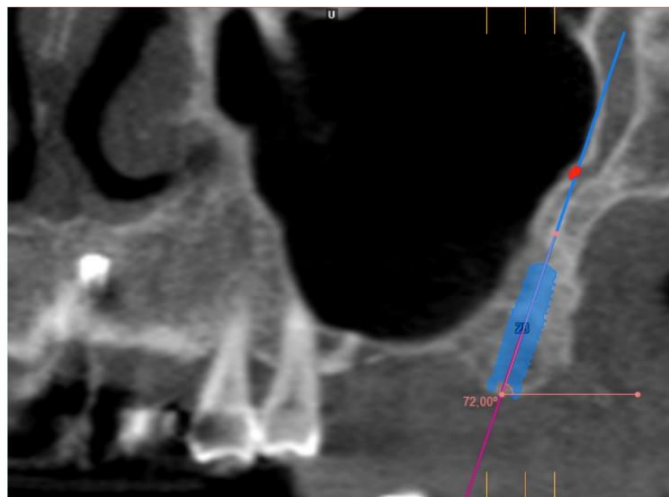


Figure 2. 11. The mesiodistal inclination (panoramic view) is shown as the virtual implant is placed along the pterygoid bone corridor (7).

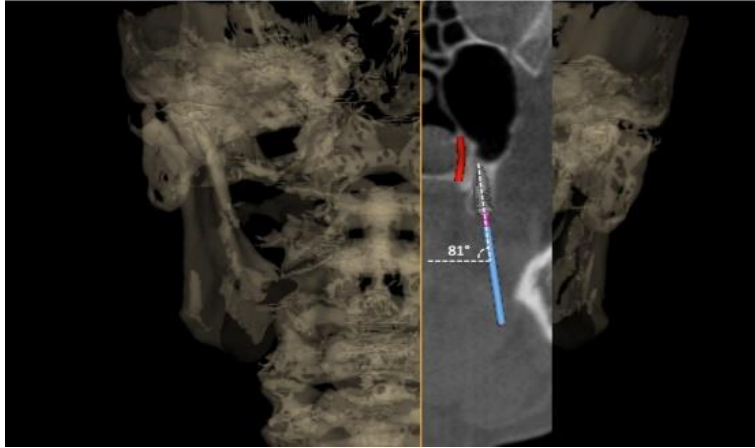


Figure 2. 12. Virtual buccopalatal angulation implant insertion in coronal view. The implant body should be at least 2 mm from the palatine artery (7).

2.8.6. Clinical outcomes of pterygoid implants

There are just a few of studies in the scientific literature that look at pterygoid implant survival rates over short and extended periods of time (204). Several studies have wrongly classified implants implanted into the tuberosity or pterygomaxillary area as pterygoid implants (180).

Implants that are shorter than 13 mm or that are not implanted into the thick cortical pterygoid plate are not considered pterygoid implants, nor are implants that are placed angularly into the tuberosity or pterygomaxillary region (204).

The rate of implant loss was found to differ from study to study. The rates of failure for implants ranged from 2.9% to 10.9%, with 2.9% being the lowest and 10.9% being the highest. It's likely that the varying sample proportions and implant surface treatments used in the research are to blame for this large discrepancy (204). Araujo et al study provides evidence supporting the notion that pterygoid implants exhibit similar rates of implant survival when compared to conventional implants in alternative areas of the maxilla (204).

Pterygoid implants were studied in three different clinical series by Balshi et al. In 1995, they conducted an initial trial in which 51 pterygoid implants with a machined surface were inserted into 41 patients, and the patients were followed for a length of time ranging from one to sixty-three months. The percentage of successful attempts was 86.3% (212).

In 1999, they raised the sample size to 356 implants, and with a follow-up period of 54 months, they found that the success rate was 88.2 percent (213). They performed the procedure in 2005 and implanted 164 pterygoid implants with treated surfaces. After 54 months of follow-up, they found that the success rate was statistically considerably greater than in prior trials (96.3%) (214).

Survival rates reported by Araujo et al ranged from 90% to 98%; however, less than 90% of this data was obtained before functional loading due to poor osseointegration (215).

The recent 1-year follow-up of 15 patients treated with pterygoid implants and anterior standard ones for edentulous maxillae rehabilitation showed great prosthesis stability and no implant loss (215).

Pterygoid implants are able to obtain sufficient bone anchoring length beyond the pterygoid maxillary junction from a prosthetic device driven position with fixed entrance and angulation (216). The implants displayed a different positional connection with the maxillary sinus due to the unique anatomy and volume of the maxillary sinus (216).

The group of implants with a diameter of 4.0 mm and a length of 15 to 18 mm, known as the pterygomaxillary Branemark System, had significantly superior cumulative survival rates compared to the group of implants with a length of 7 to 13 mm (217).

This means that the best biomechanical environment for restoring posterior dentition is achieved when a longer implant completely contacts the cortical plates (217). The studied pterygoid implants demonstrated a high probability of success with low or no complications (218).

2.8.7. Digital approach of pterygoid implants

In a full computerized protocol, the data acquired from a cone beam computerized tomography (CBCT) equipment is in accordance with the digital imaging and communication in medicine (DICOM) standards (219). The characteristics of hard tissue, together with the 3D standard tessellation (STL) data obtained from an intraoral scanner (IOS) detection specialized software is employed to establish a precise match between dental implants and the surfaces of teeth and soft tissues. This enables the dentist to select implant characteristics and locations based on anatomical and prosthetic considerations (219,220).

In order to replicate the virtual blueprint, the operator's hand may be accurately guided by either the static computer-aided implantology (SCAI) systems or the dynamic computer-aided implantology (DCAI) systems (215).

The static system utilizes a tangible surgical guide that is digitally created based on the specific project requirements and then fabricated via a printing process for application inside the patient's oral cavity (221).

Dynamic computer-aided implantology functions similarly to a global positioning system (GPS) (222). with one or two cameras actively identifying the spatial relationships between reference instruments placed on the patient and the surgical handpiece (223). The healthcare practitioner is able to monitor the precise location of the drill in relation to the three-dimensional radiological anatomy displayed on the computer screen (224).

The complete restoration of upper jaws lacking teeth may be achieved by the implementation of two posterior tilting implants and two frontal implants with graft-less treatments (225). which are characterized by their expedited nature and reduced susceptibility to problems (226). May be implemented in patients with urgent systemic health conditions, The use of bilateral pterygoid implants in a comprehensive restoration of the dental arch, together with two to four anterior implants, has been implemented successfully. Stefanelli et al achieved full-arch restorations in thirteen patients by rapid loading and flapless surgical techniques (225,227).

The use of digital technology, including both static and dynamic components, has been shown to facilitate the expedited process of full-arch implant-supported rehabilitation in both maxilla. This approach has been shown in existing research to effectively minimize patient pain (Figure 2.14) (215).

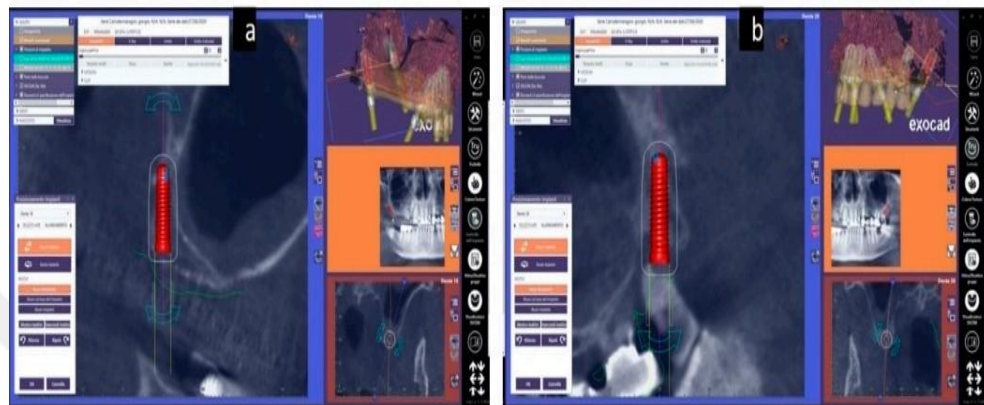


Figure 2. 13. The computerized positioning of implants in the right (a) and left (b) pterygoid regions (215).

2.8.8. Pterygoid implant prosthodontic reconstruction

Osseointegrated implant-supported dental prosthesis rehabilitation is a tried-and-true method with excellent success rates (228). Due to the site of the pterygoid implants, both impression capture and prosthesis insertion at placement might be difficult (229).

Prosthetic procedure for partial or complete arch rehabilitation using posterior pterygoid implants and anterior implants (230). After splinting multiunit impression copings, putty and light body material are utilized for two-step open tray direct impressions, Multiunit implant analogs are connected to the impression copings (230).

In maxillary atrophic patients was decided by the prosthetic priority driving position. This area might take a 16-mm implant (216). Longer posterior cantilevers are one type of prosthetic method that can lead to problems, examples of potential complications include the occurrence of screw and prosthesis breakage, marginal bone loss, and the loss of implant osseointegration, the pterygoid implants avoids these prosthetic limitations (231).

Curi et al study At the time of the abutment connection procedure, the survival of each implant was examined by means of a mobility test (231). Following the implantation of the prosthesis, the survival of each implant was also checked , The research observed a 3-year cumulative survival rate of 99% for the pterygoid implants (231).

The choice of prosthetic rehabilitation method is contingent upon the anatomical circumstances and intermaxillary occlusal profile, two potential approaches include the use of screwed prosthesis or standard fixed prosthesis (232).

2.9. Finite Element Analysis

Finite element analysis predicts how different materials will react to various forces. In orthopedics, this method is mostly used for implant design and testing. As technology advances, clinical applications are being developed, promising surgical planning and implant customization (233).

Element stiffness matrix $[k]$, nodal displacement vector $[u]$, The nodal force vector $[F]$ is denoted as $[F]$. The stiffness matrix element, denoted as k , represents the force exerted in the coordinate direction, as a result of a unit displacement in the coordinate direction. There are four distinct approaches available for the formulation of element characteristics, including direct, variational, weighted residual, and energy balancing techniques. You can assemble element properties using any of these methods. Stiffness matrix and nodal force vector assembly in solid mechanics uses variational approach (constant loads) (234).

Global/structure properties are assembled using element properties to get system equations $[k][u] = [F]$. Then boundary conditions apply. The nodal unknowns are the simultaneous equation solutions. Using nodal values, additional calculations are performed to obtain necessary values, such as stresses, strains, and moments (234).

2.9.1. Finite element analysis method stages

The finite element method solves many engineering analysis problems numerically. It has two main subdivisions. The first calculates structural framework joint displacements and member forces using discrete elements. The second approximates heat transfer, fluid mechanics, and solid mechanics problems using continuum elements. The "matrix analysis of structures" using discrete elements yields results identical to the classical analysis of structural frameworks. True finite elements are the second method. Approximate values of desired parameters are obtained at nodes. A general finite element computer program can solve both types of problems, and "finite element method" is often used to refer to both discrete and continuum element formulations (236).

The finite element method creates linear or nonlinear equations using several mathematical concepts. Usually 20–20,000 equations require the computational power of a digital computer. If no computer is available, the method is useless (236).

The basic concepts of the finite element method have evolved over 150 years, making it impossible to trace its origin. The method we use today evolved from 1950s papers that extended matrix analysis of structures to continuum bodies. The 1960s space exploration funded basic research, which gave the method a solid mathematical foundation and spurred the development of multipurpose computer programs that used it. The design of airplanes, missiles, space capsules, etc. provided applications.

Although the method's origin is unknown, its benefits are obvious. The method works well for irregular-shaped objects with mixed boundary conditions and multiple materials. It works for steady-state, time-dependent, and nonlinear material properties. User-independent general computer programs have been developed. There are programs that generate a grid from a few shape-defining points and analyze and display the results graphically for further study.

Finite element method underpins many computer-aided design programs. The increased use of computer-assisted design requires engineers to understand the finite element method (236).

2.9.2. Applications of finite element analysis in dentistry

FEA is best used in auto crash testing. Its dentistry applications have been highly efficient and accurate in recent years.

2.9.2.1. Applications of FEA method in orthodontics

FEA has helped describe biological structure form changes (morphometrics), especially craniofacial growth and development.

2.9.2.2. Applications in periodontics

FEA helps analyze periodontal ligament stresses under different orthodontic forces and loading conditions and conduct innovative in-vitro and in-vivo natural frequency analysis (237).

2.9.2.3.Applications in prosthodontics

The prosthodontics specialty uses FEA for many purposes, including crown and prosthesis design. In relation to fixed and removable prosthesis designs, FEA studies stress distribution in tooth supporting structures. In various prosthetic rehabilitations, FEA analyzes material behavior, failures, and successes (237).

2.9.2.4 Applications in dental implants

Dental implants allow for highly functional and esthetic restorations and improve treatment predictability. The use of FEA in implant dentistry is crucial. Implant, peri-implant bone (cortical and cancellous bone), and restoration materials are used in FEA studies in implant dentistry. FEA simulates forces at specific points and analyzes stress in the peri-implant region and surrounding structures. The bone tissue's response to a foreign insert implant has been of interest since its popularity in dental clinics. Long-term effects of such stresses are poorly studied. Clear scientific understanding from extensive research can reduce stress on surrounding bony structures. Stress shielding, bone remodeling caused by biological stress changes, is a major cause of implant failure. Finite element method and innovative design reduce stressshielding (238).

In 2019, Reddy and Sundaram systematically reviewed finite element model applications in implant dentistry. Their review confirmed that FEA outcomes can provide detailed structure of the bone around the implant and the implant itself, as well as material, boundary, and loading conditions, bone-implant interface, convergence test, and validation (237).

FEA has been used to study implant component and periimplant bone stress patterns in implantology. Several FEA studies hypothesized that implant number, diameter, length, thread profile, material properties of implant components, and surrounding bone quality and quantity affect peri-implant bone stress. Von Mises stress, maximum principal stress, minimum principal stress, and maximum shear stress are utilized in finite element analysis (FEA) investigations to evaluate the mechanical stress experienced by the periimplant bone. The von Mises stress is often employed as a scalar-valued stress invariant for the purpose of assessing material yielding or failure. The maximum principal stress indicates tensile stress and the minimum compressive stress. Principle stress is good for such studies because bone is ductile and brittle (239).

FEA in trauma/fractures biomechanical responses of defined tissues and organs to specific conditions can be estimated by FEA and biological simulations. FEA of simulated traumatic loads explains fracture biomechanics. Finding a practical, ethical, and reliable facial trauma biomechanics model is difficult. Once used, cadaveric studies are now banned due to ethics. Cadaver death ages and post mortem changes don't match facial trauma patients. Most studies estimate 20–30-year-old maxillofacial trauma patients. FEA creates valid biomechanical analysis models using these facts. Huempfer-Hierl et al studied naso-orbitoethmoid fracture using this method. Finite element analysis showed von Mises stresses above the bone yield criterion that matched clinical fractures. Finite element models can simulate skull injuries and show fracture pathogenesis (239).

2.9.3. Advantages of FEA

Reduces animal and unethical human trials , the method is non-invasive. Make analyzing craniofacial structure material properties and geometries is easier. Force direction and magnitude are precise and stress points can be measured theoretically. FEA method unaltered physical properties of evaluated materials and the test can be repeated. Static and dynamic analyses are possible and saves time (237).

2.9.4. Limitations of FEA

Method is technique-sensitive, the researcher must know material sciences well. Input, statistics, and interpretation errors can cause incorrect output, computer savvy required. Expectations must be met. FEA is time-independent, it is difficult to model biological dynamics of a living component because time and other exposures must be taken into account. Mesh nodal connectivity and other parameters require large data input depending on the problem (237).

Data, information, and interpretation errors will lead to disastrous results. Modeling human structures is difficult due to their complex anatomy and incomplete mechanical knowledge. Accepting certain assumptions is necessary. FEA progress will be limited until enamel, dentin, periodontal ligament, cancellous, and cortical bone physical properties are better defined (240).

2.9.5. Phases of finite element analysis

The FEA procedure there are three stages to a finite element analysis, phase one setting up the environment , phase two implementing the solution , phase three cleaning up (Figure 2.15) (240).

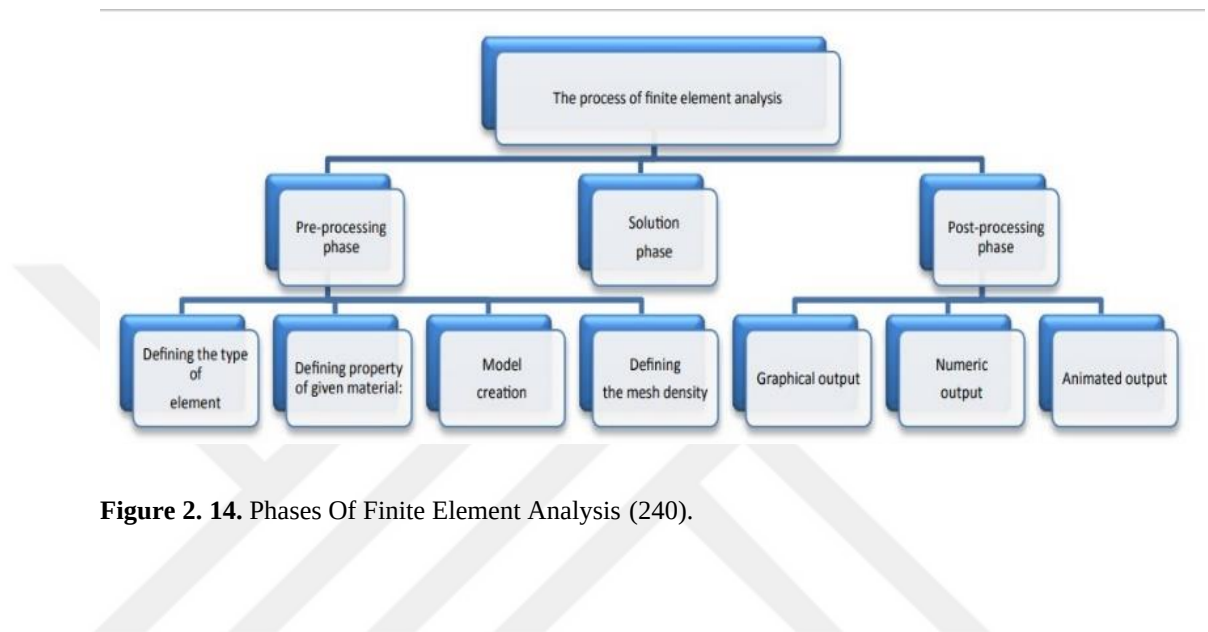


Figure 2. 14. Phases Of Finite Element Analysis (240).

3. MATERIAL AND METHODS

This study was conducted by the approval of Non-Interventional Clinical Research Ethics Board at Yeditepe University in Istanbul under Application Number 202304Y0599 (Appendix-1).

The present study involves the reconstruction of a three-dimensional (3D) model of the human maxilla, which encompasses both cancellous and cortical bone. This model is derived from computed tomography (CT) images obtained from individuals who are edentulous, and it is used for the determination of the best angle to be the least harmful to the surrounding bone.

The aim of this research is to determine the best angle for pterygoid implants that results in the least amount of bone resorption and the least amount of deformation in the bone tissue around the implant.

In our study, we evaluated the effect of axial and lateral forces on a pterygoid dental implant placed at 5 different angle degrees (45,55,65,75,and 85) , according to the Frankfort Horizontal Plane are evaluated. The implant is secured within the pterygoid plate of the sphenoid bone, passing through the maxillary and palatine bones. The angulation of the implant is determined by the inclination of the maxillary sinus floor and the height of the tuberosity bone, ranging between 45° and 85°. The anchorage of the implant is achieved using both monocortical and bicortical fixation, which was determined by the finite element analysis method (FEA). A computer equipped with an Intel(R) Core(TM) i5-1035G1 CPU @ 1.00GHz 1.19GHz processor, 250 GB SSD (Solid State Drive), 8 GB RAM, and a Windows 11 professional 64-bit operating system was used for arranging and making the 3D network structure more homogeneous, creating the 3D solid model, and FEA operation. The facial region of a 58-year-old male patient with atrophic maxilla was planned to be treated only with an angled pterygoid implant and was imaged in DICOM format with CT. Raw DICOM data with a section thickness of 0.3 mm was loaded.

The maxilla in millimetric sections of a completely edentulous patient was imaged in DICOM format with cone beam tomography. The DICOM file, which was obtained with 536 x 536 resolution and 0.3 mm thick sections of the raw data, was loaded into

MIMICS Research 21.0 software (Materialise, Leuven, Belgium), a software with which images can be reconstructed in a computer environment. Simplification and reformatting operations were performed on the images reconstructed with the software. In MIMICS software, a 3D models of the bone tissues, separated on the sections, were created.

The 3D model was generated symmetrically using simplification techniques in the MIMICS software. Asymmetrical regions were introduced, and the model was then converted into a smooth surface composed of elements with consistent proportions. The modeling of the upper jawbone was successfully finalized and saved in the ".step" format. With the help of the 3-matic Research 13.0 program, a 3D computer-aided design model (CAD) of the pterygoid maxilla complex was obtained. (Figure 3.1). A pterygoid dental implant with a diameter of 3.5 mm and a length of 16 mm, conical form, and special thread design was placed with the SOLIDWORKS software (Dassault Systèmes, Vélizy-Villacoublay, France). After the modeling process was completed, a three-dimensional computer-aided design model (CAD) was obtained (Figure 3.2).

The elastic modulus and poisson ratio values of the materials are shown in table 3.1 used in the study (261).

Table 3.1. Mechanical properties of materials used in the 3D finite models

Material	Elastic modulus (E) (MPa)	Poisson ratio (ν)
Implant (Ti-6Al-4V) alloy	110,000	0.35
Cortical bone	13,700	0.30
Cancellous bone	1,370	0.30

Ten models designed with the SOLIDWORKS program, 5 models monocortical pterygoid dental implant (end border of crest and cancellous bone) and 5 models bicortical (between crest and basal bone, 1 mm outside the pterygoid process) were placed at 45, 55, 65, 75, and 85 angled degrees according to the Frankfort Horizontal Plane.

The Frankfort Horizontal Plane is defined as the plane that intersects the most superior section of the "Porion" on both sides and the most inferior piece of the "Orbitale" on both sides (200).

We determined the Frankfort Horizontal Plane on the model (Figure 3.1).

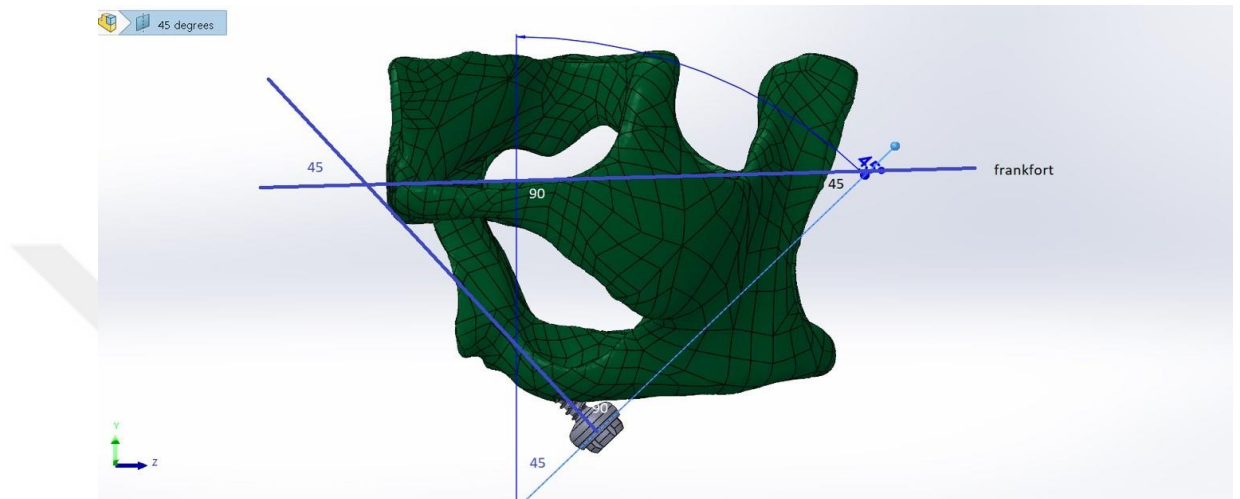


Figure 3. 1. The Frankfort Horizontal Plane is to be determined above the model.

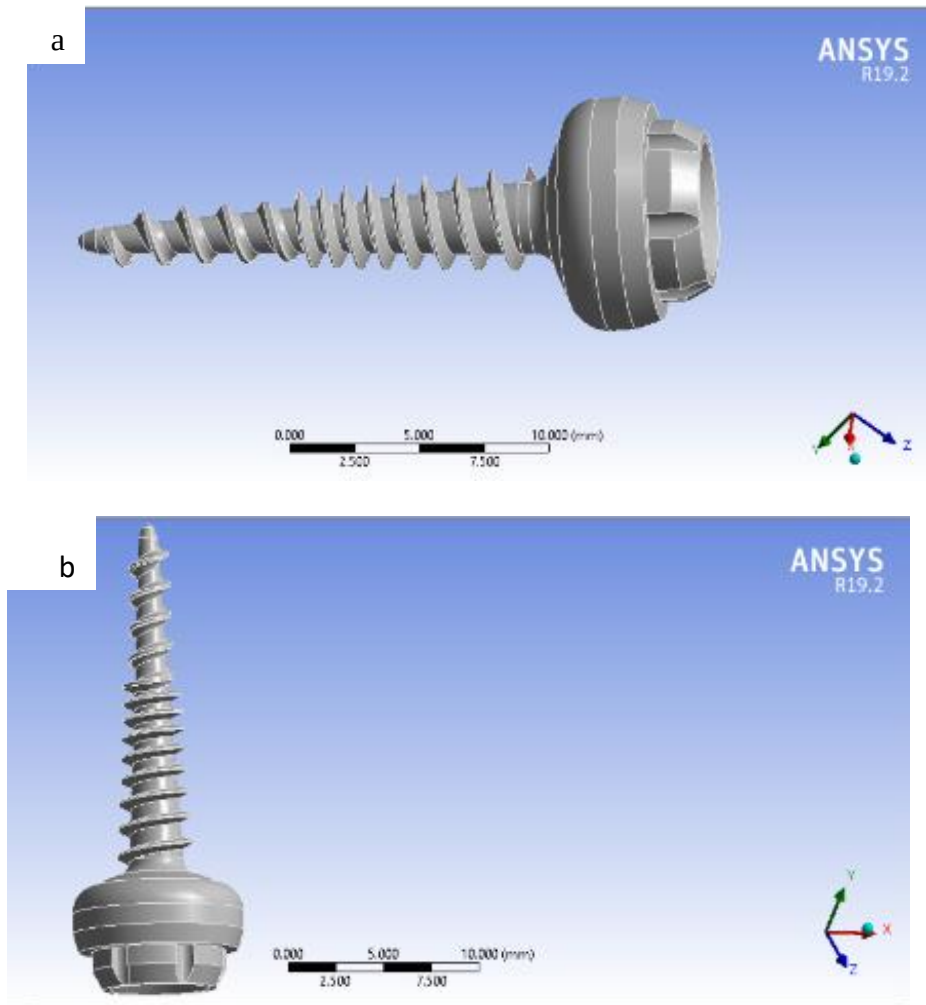


Figure 3. 2. (a) Horizontal view of pterygoid implant model image, (b) Vertical view of pterygoid implant model image

3.1.Created models

A control model, in which no implant was placed, was created.

Implants are placed at 45, 55, 65, 75, and 85 angled degrees according to the Frankfort Horizontal Plane, monocortically in 5 models and bicortically in 5 models.

Model 0 : Control model without pterygoid implant placement (Figure 3.2)

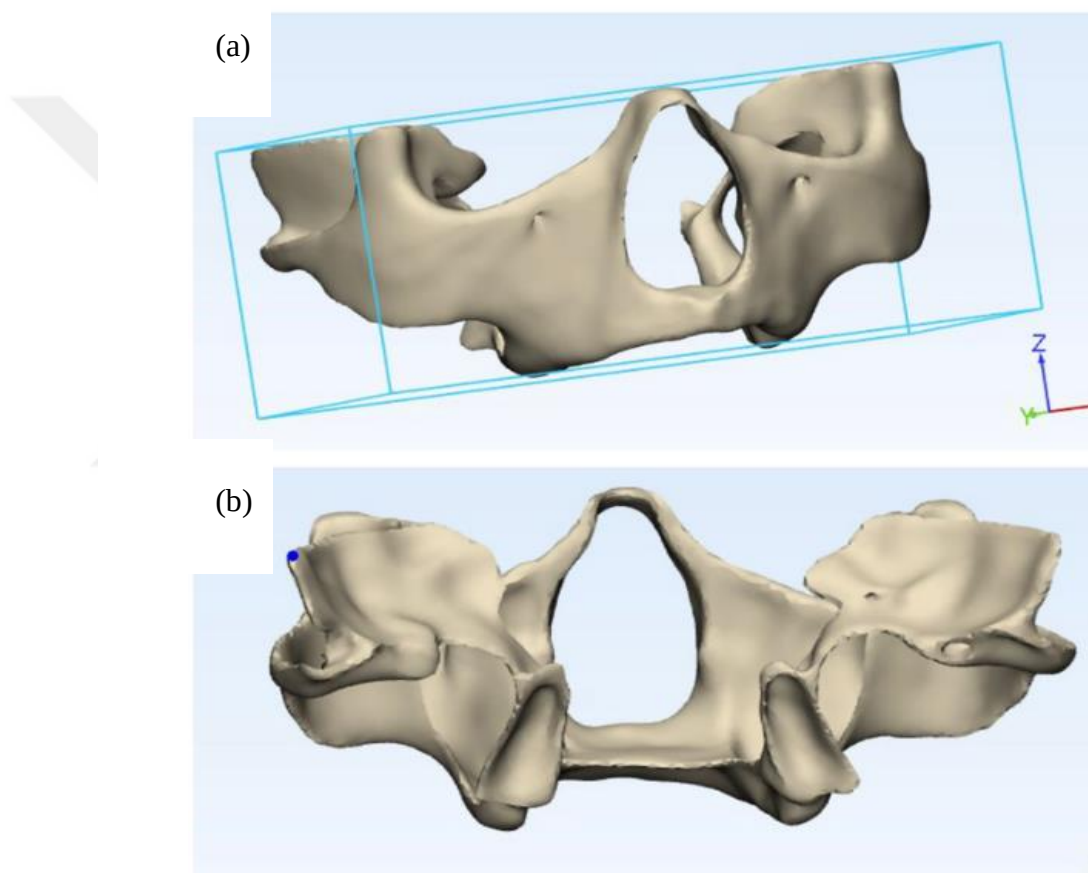


Figure 3. 3. (a) Frontal view, (b) Occipital view of the control model without pterygoid implant placement.

Table 3.2. FEA models

Model name	Angle degree according to the Frankfort Horizontal Plane	Monocortical/Bicortical
1-A	45	MONOCORTICAL
1-B	45	BICORTICAL
2-A	55	MONOCORTICAL
2-B	55	BICORTICAL
3-A	65	MONOCORTICAL
3-B	65	BICORTICAL
4-A	75	MONOCORTICAL
4-B	75	BICORTICAL
5-A	85	MONOCORTICAL
5-B	85	BICORTICAL

Model 1-A : Pterygoid dental implant placed with 45 angle degree monocortically in the right pterygomaxillary region (Figure 3.4).

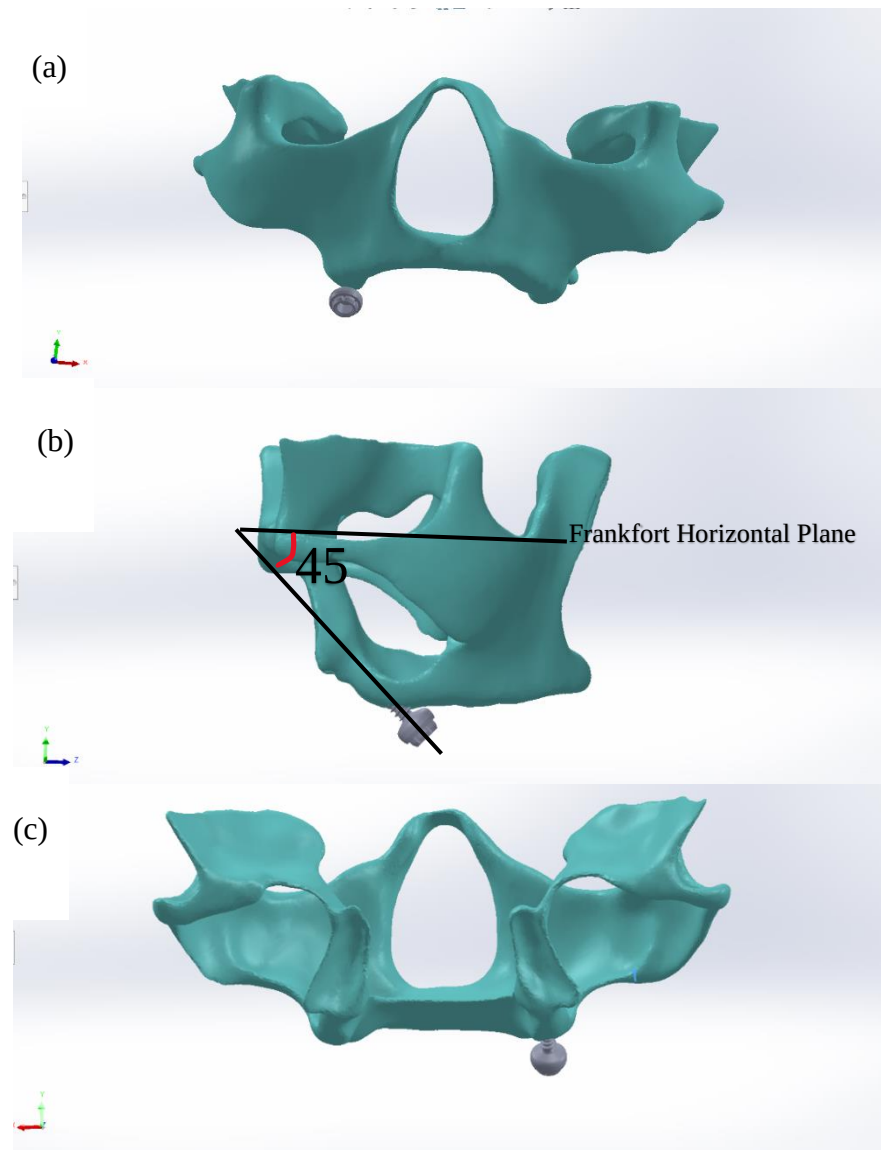


Figure 3. 4. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 45 degree monocortically in the right pterygomaxillary region.

Model 1-B : Pterygoid dental implant placed with 45 angle degree bicortically in the pterygomaxillary region(Figure 3.5).

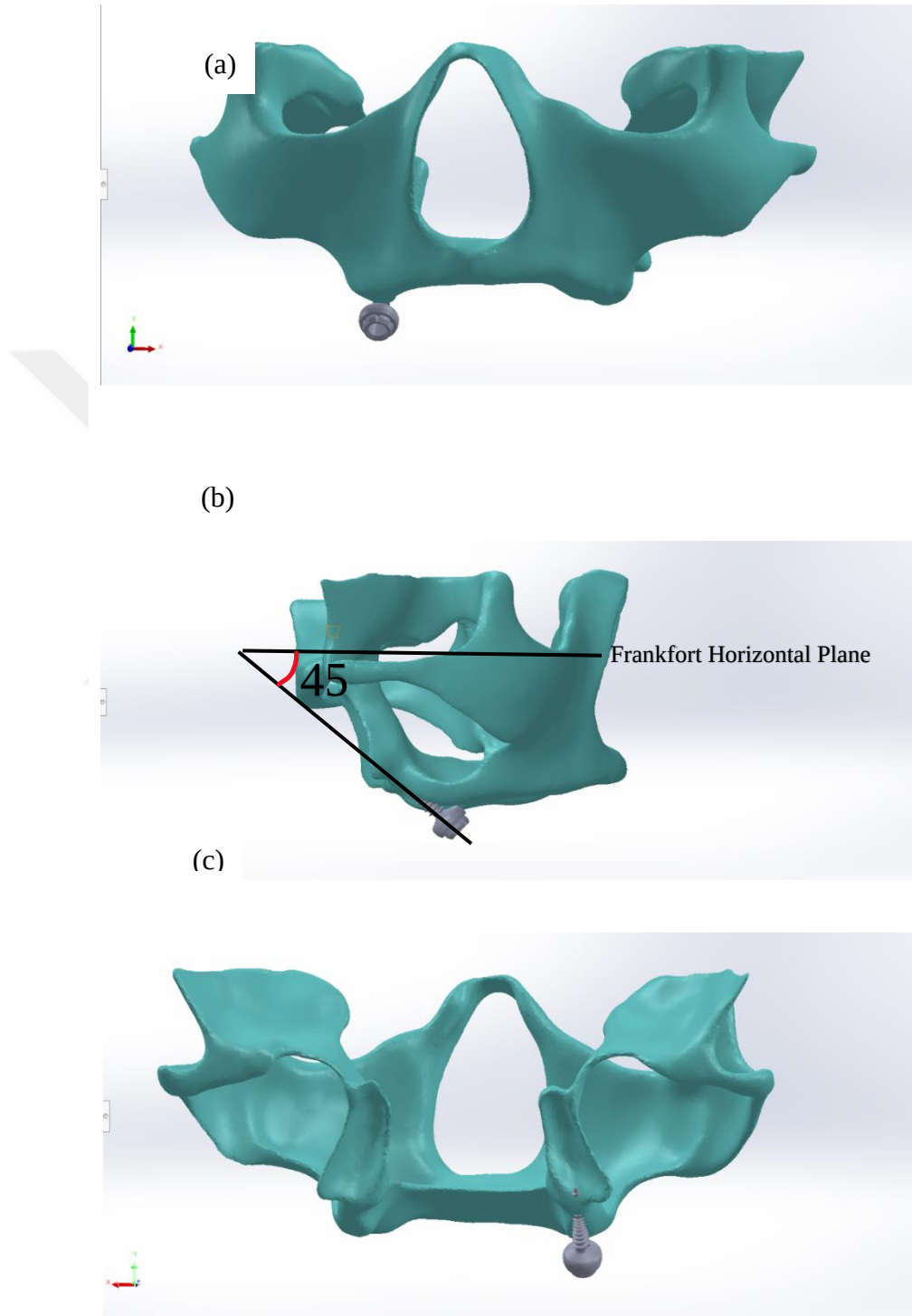


Figure 3.5. (a) Frontal view, (b) Lateral view, (c) Occipital view, pterygoid dental implant placed angled with 45 degree bicortically in the right pterygomaxillary region.

Model 2-A : Pterygoid dental implant placed with 55 angle degree monocortically in the right pterygomaxillary region (Figure 3.6).

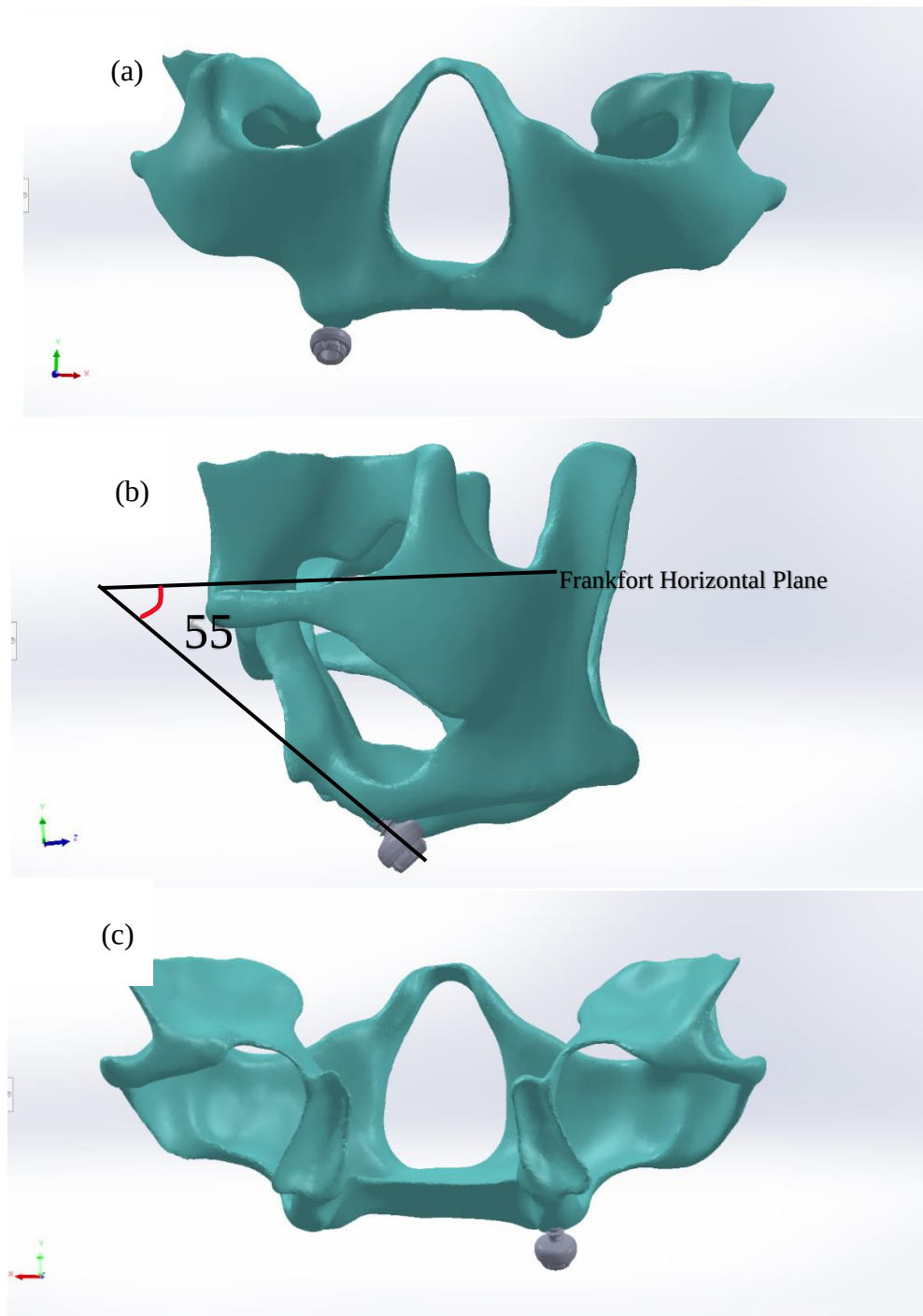


Figure 3. 6. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 55 degree monocortically in the right pterygomaxillary region.

Model 2-B : Pterygoid dental implant placed with 55 angle degree bicortically in the right pterygomaxillary region (Figure 3.7).

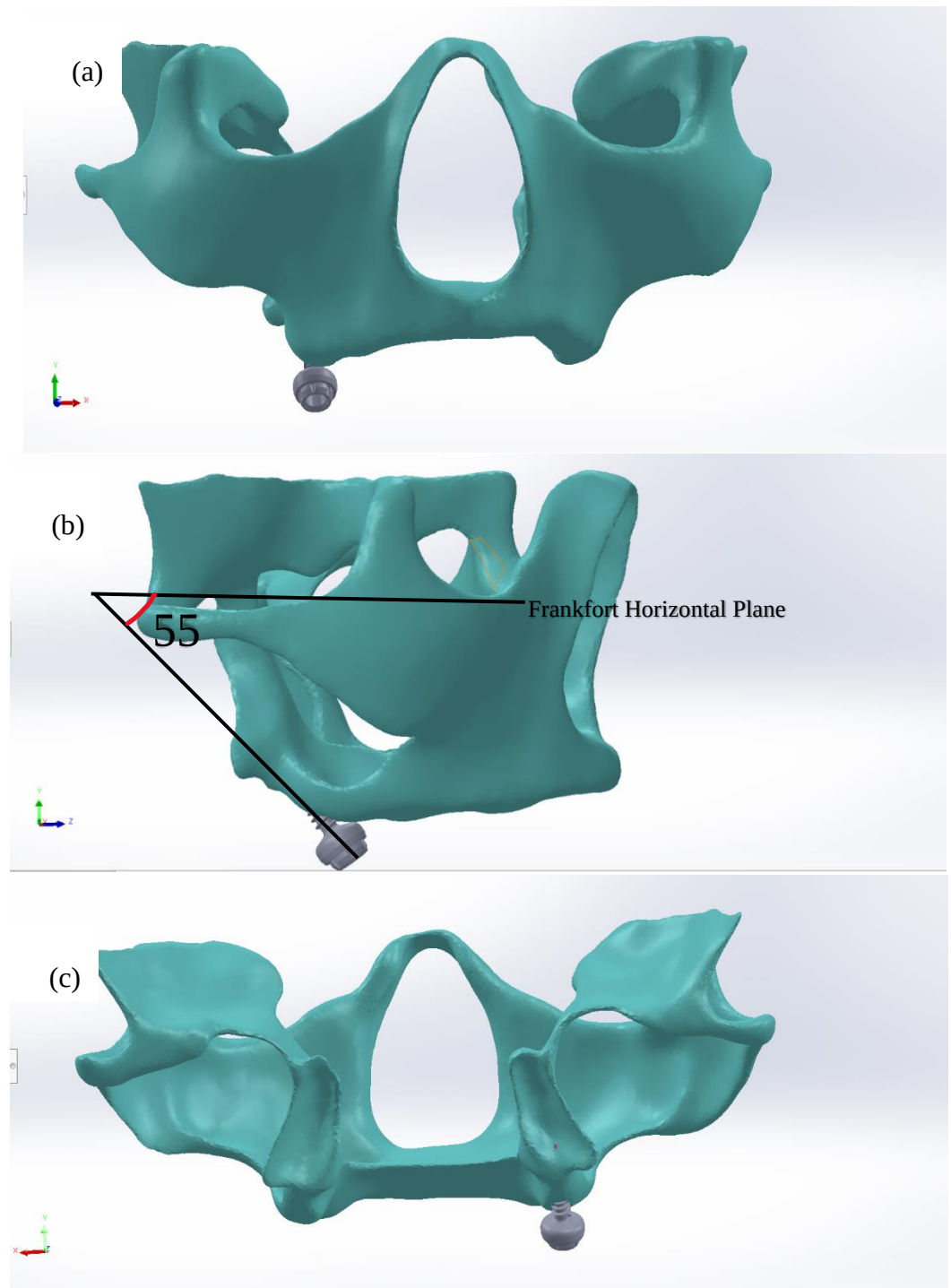


Figure 3. 7. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 55 degree bicortically in the right pterygomaxillary region.

Model 3-A : Pterygoid dental implant placed with 65 angle degree monocortically in the right pterygomaxillary region (Figure 3.8).

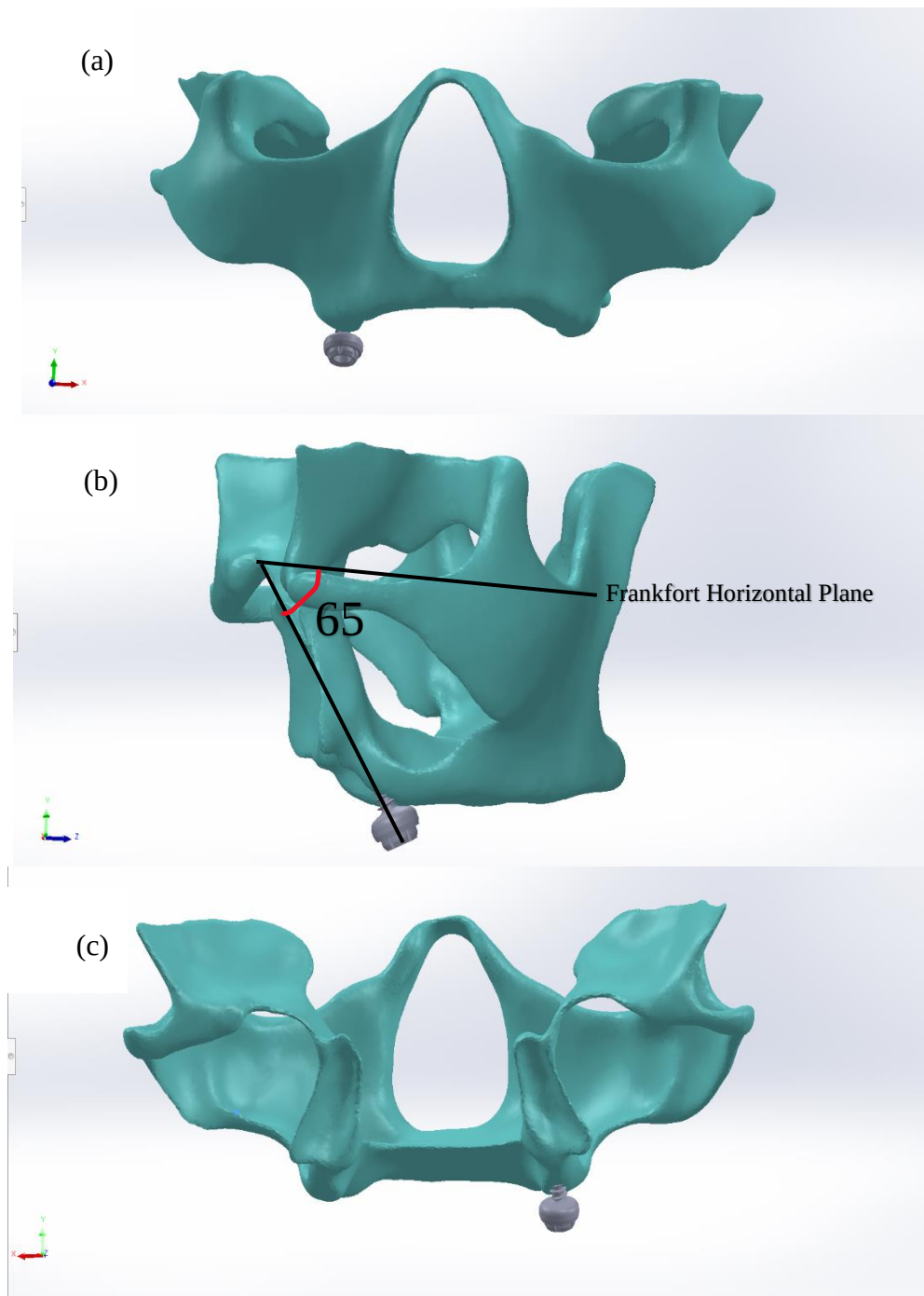


Figure 3. 8. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 65 degree monocortically in the right pterygomaxillary region.

Model 3-B : Pterygoid dental implant placed with 65 angle degree bicortically in the right pterygomaxillary region (Figure 3.9).

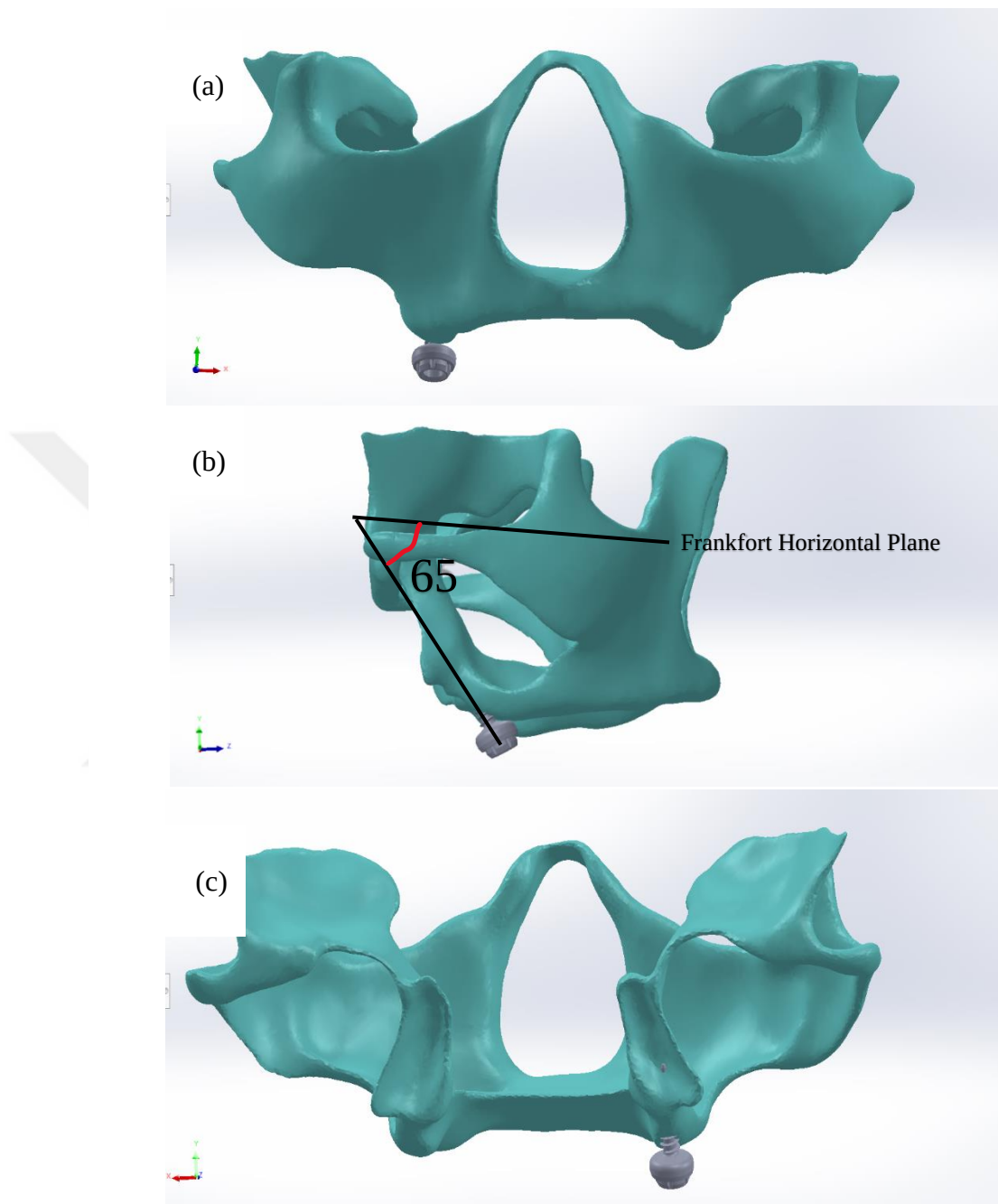


Figure 3. 9. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 65 degree bicortically in the right pterygomaxillary region.

Model 4-A : Pterygoid dental implant placed with 75 angle degree monocortically in the right pterygomaxillary region (Figure 3.10).

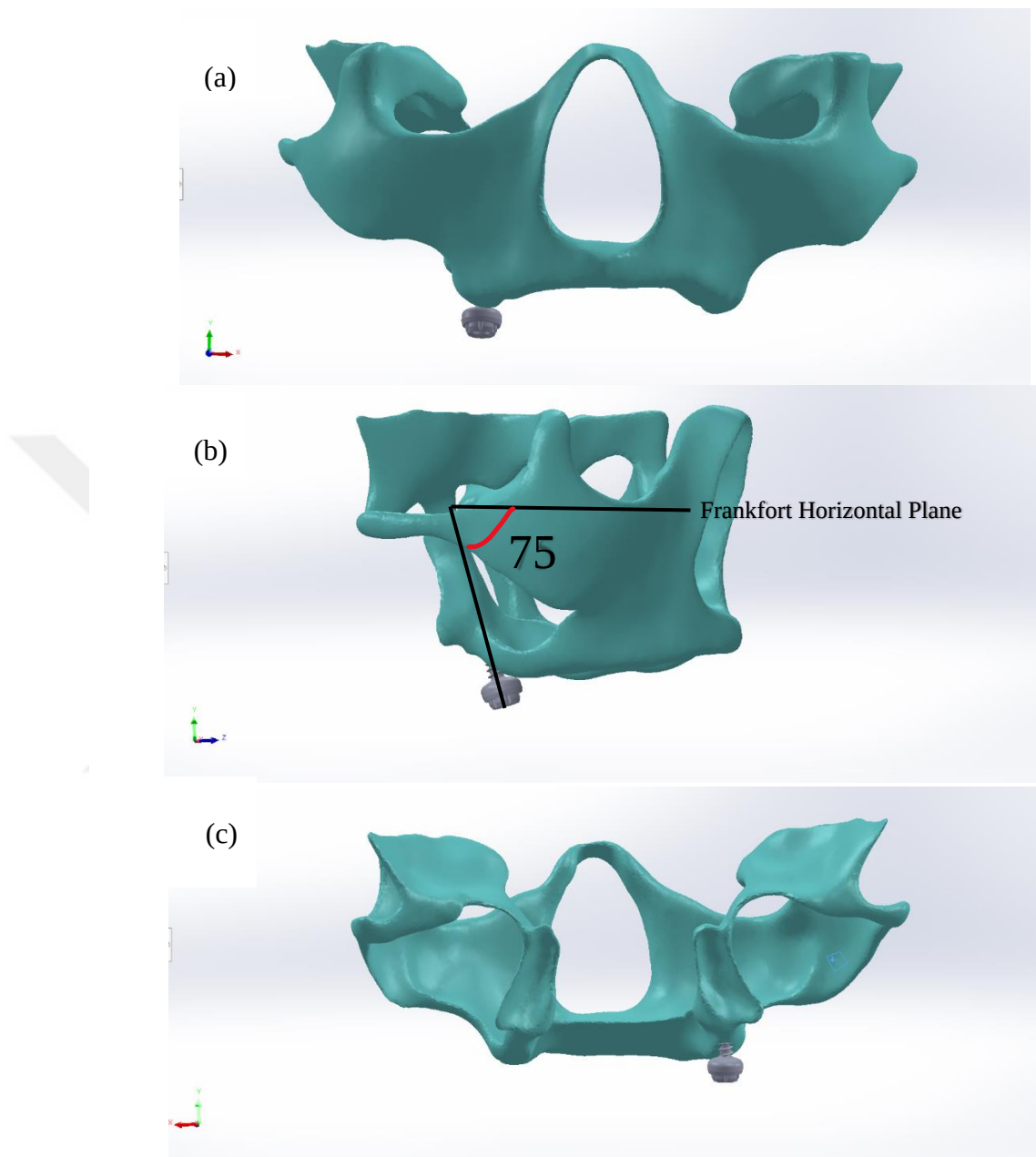


Figure 3. 10. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 75 degree monocortically in the right pterygomaxillary region.

Model 4-B : Pterygoid dental implant placed with 75 angle degree bicortically in the right pterygomaxillary region (Figure 3.11).

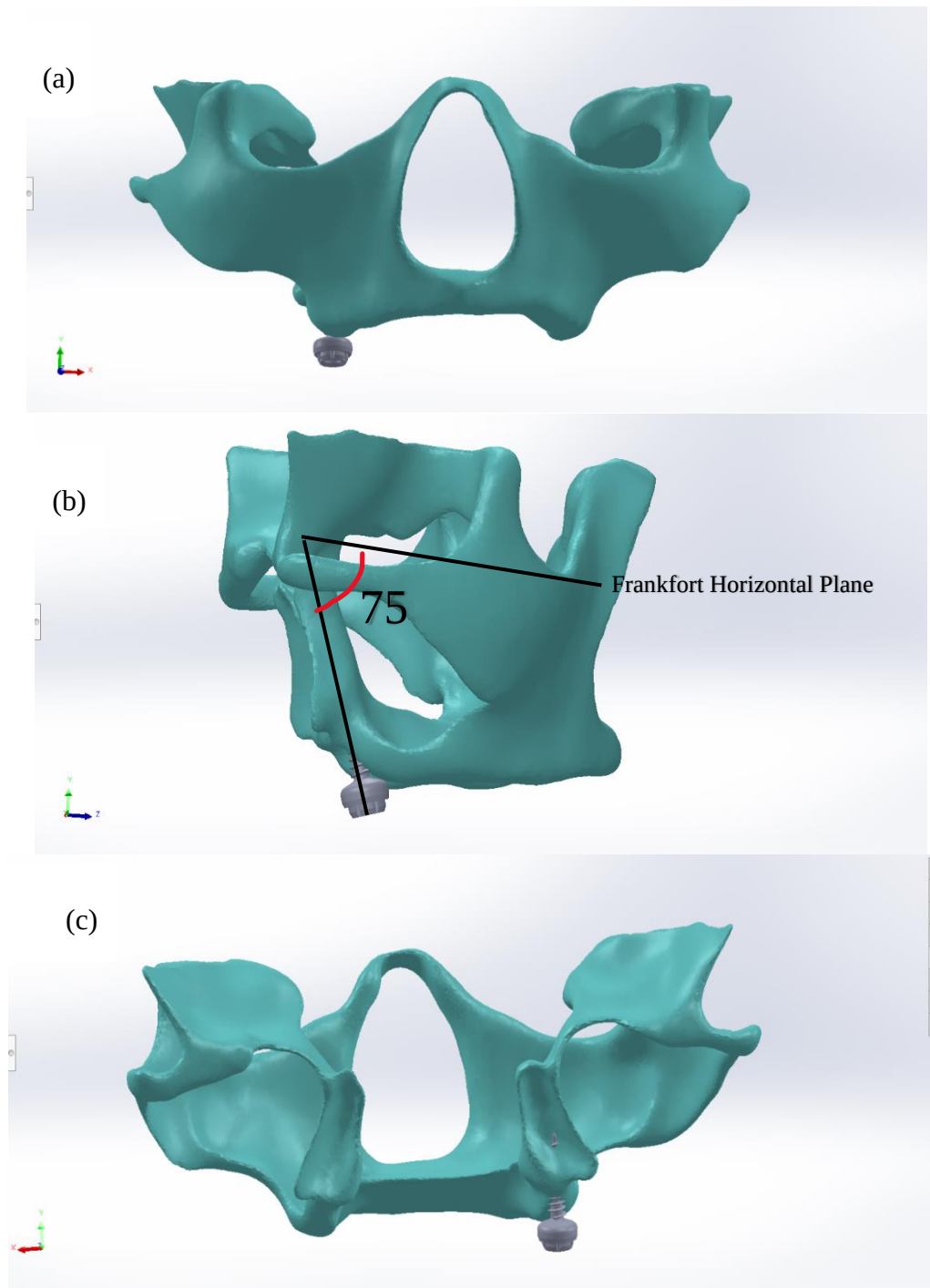


Figure 3. 11. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 75 degree bicortically in the right pterygomaxillary region.

Model 5-A : Pterygoid dental implant placed with 85 angle degree monocortically in the right pterygomaxillary region (Figure 3.12).

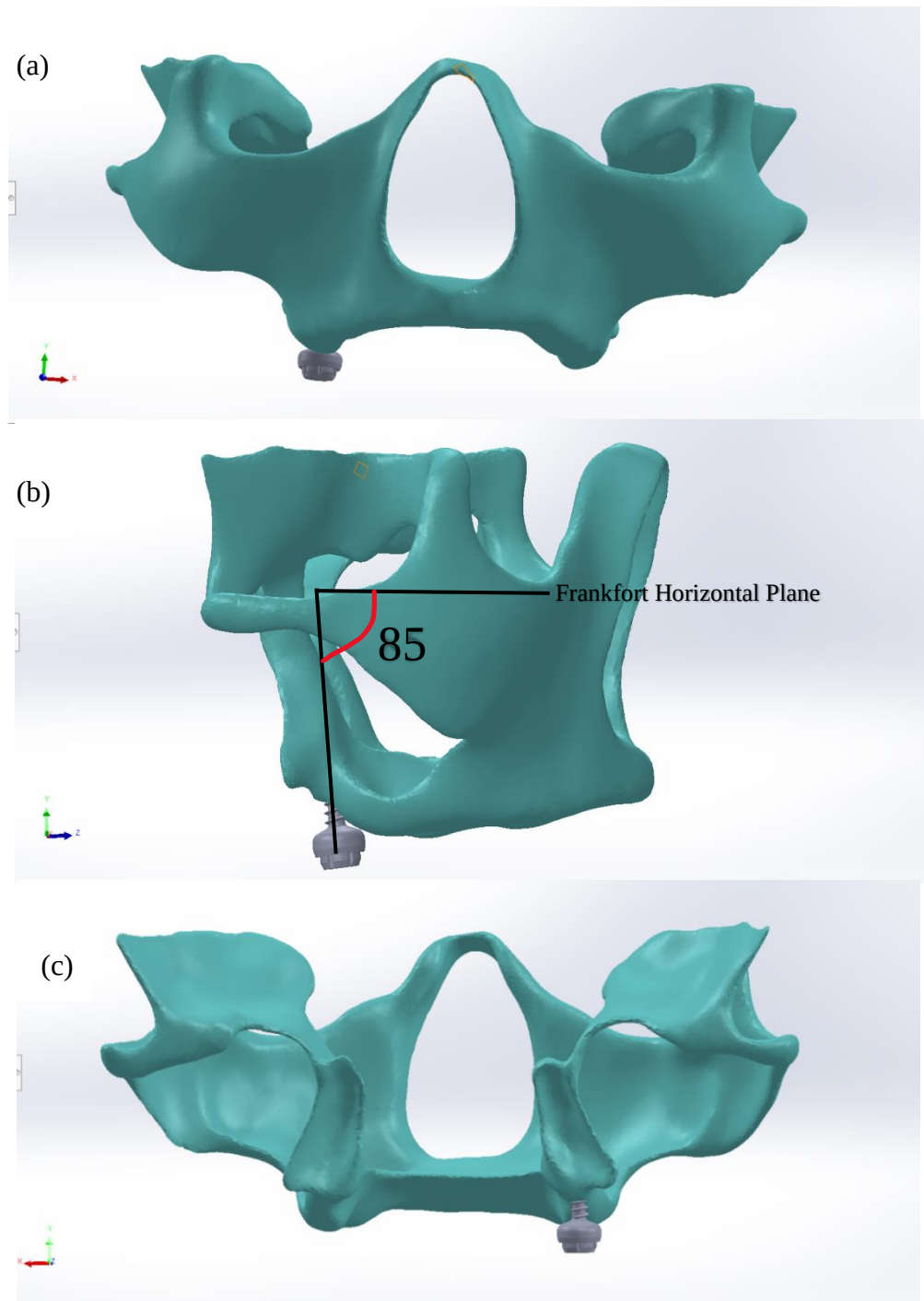


Figure 3. 12. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 85 degree monocortically in the right pterygomaxillary region.

Model 5-B : Pterygoid dental implant placed with 85 angle degree bicortically in the right pterygomaxillary region (Figure 3.13).

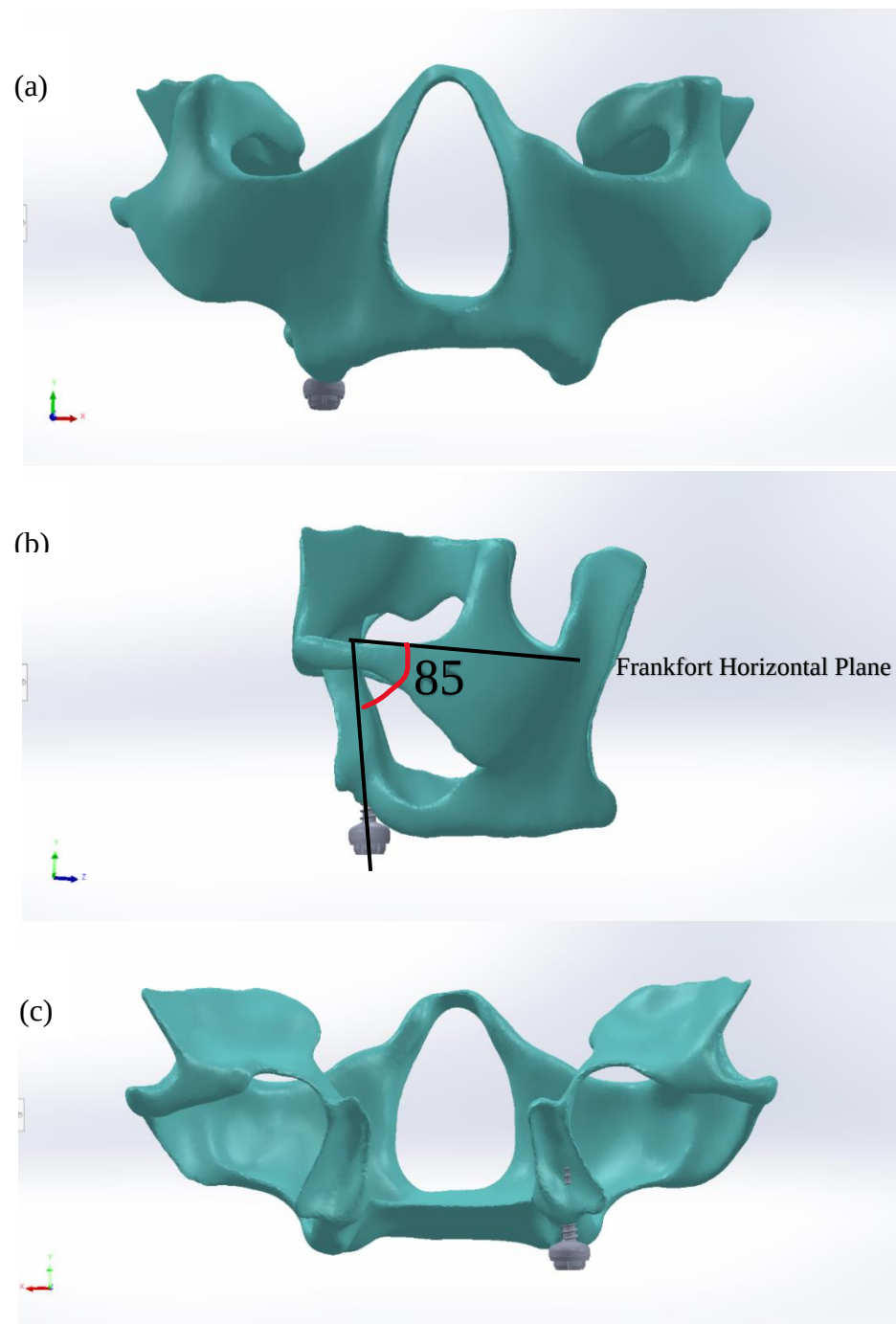


Figure 3. 13. (a) Frontal view, (b) Lateral view, (c) Occipital view, Pterygoid dental implant placed angled with 85 degree bicortically in the right pterygomaxillary region.

The CAD models were imported to the FEA software ANSYS program for the purpose of creating loading conditions (Workbench 19.2; ANSYS Inc., Providence, RI, USA) . The network structure with this software (mesh) is formed , pterygoid implant and bone contact surfaces have an edge length of 0.5 mm, the rest of the model was divided into a 2 mm tetrahedral structure (Figure 3.14). The average number of elements in the models was determined as 59044, and the number of nodes was determined as 102132 . This helps to avoid errors and ensures that the model accurately represents the physical system being analyzed.

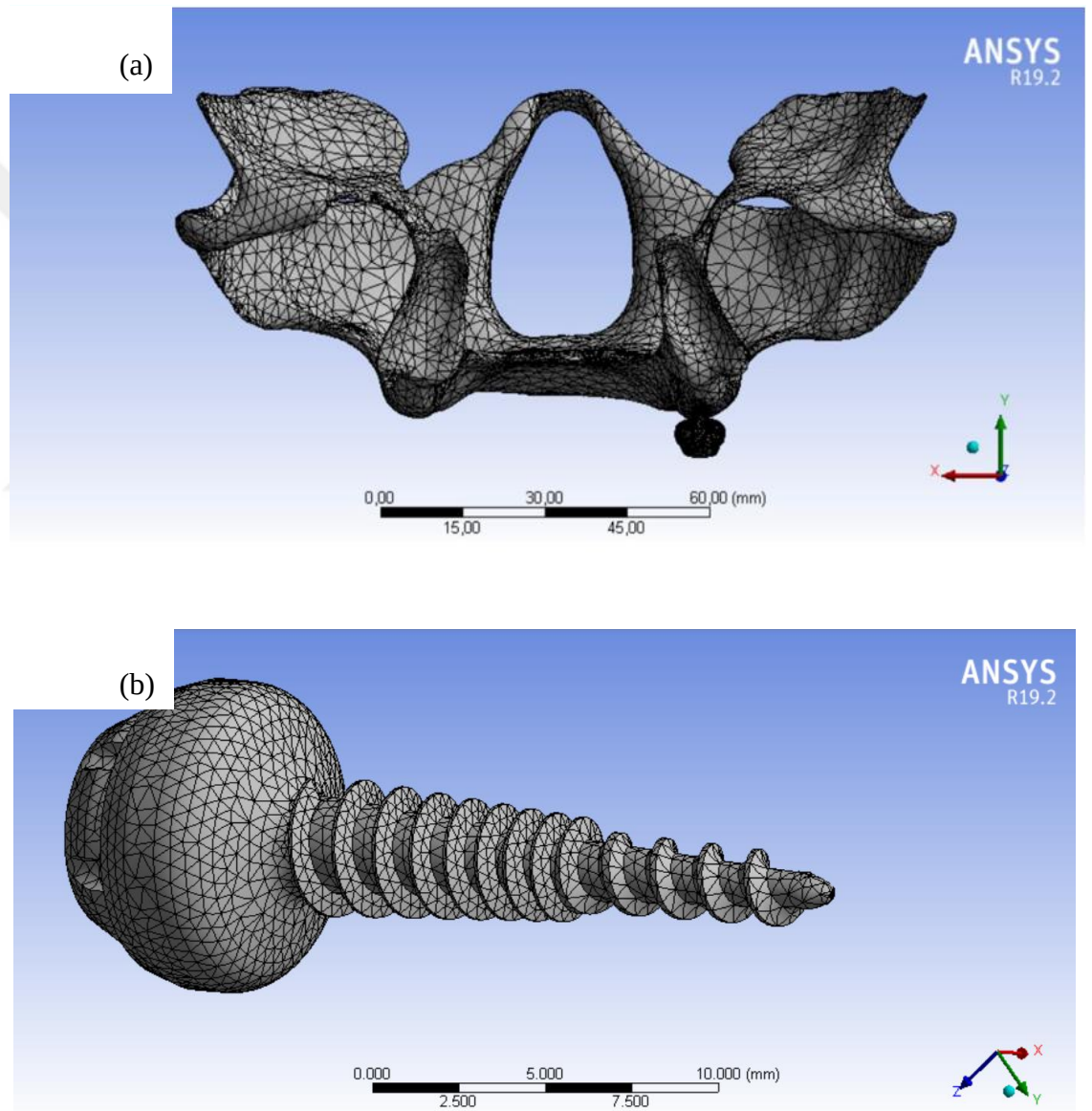


Figure 3. 14. (a) Edentulous maxilla and surrounding bone model image with network structure (b) Pterygoid implant model image with network structure.

The Ti-6Al-4V alloy was selected as the implant material for the pterygoid implant. The elastic modulus of that alloy was determined as 110,000 MPa and the Poisson ratio was determined as 0.33 (261). The contact surfaces between the implant body and bone were deemed to have connected, indicating osseointegration (187). Each DOF (degree of freedom) from the lower and lateral regions of cortical and trabecular bone, fixed to have '0' motion, creates direct boundary conditions. Prior to applying force, the boundary conditions of the maxilla are established. The maxilla is a bone in the human skull that forms the upper jaw and contains the upper teeth. Due to its elastic nature, both the cortical and cancellous bones exhibit linear and homogenous characteristics. So the fixation was performed on the zygomatic region. (Figure 3.15).

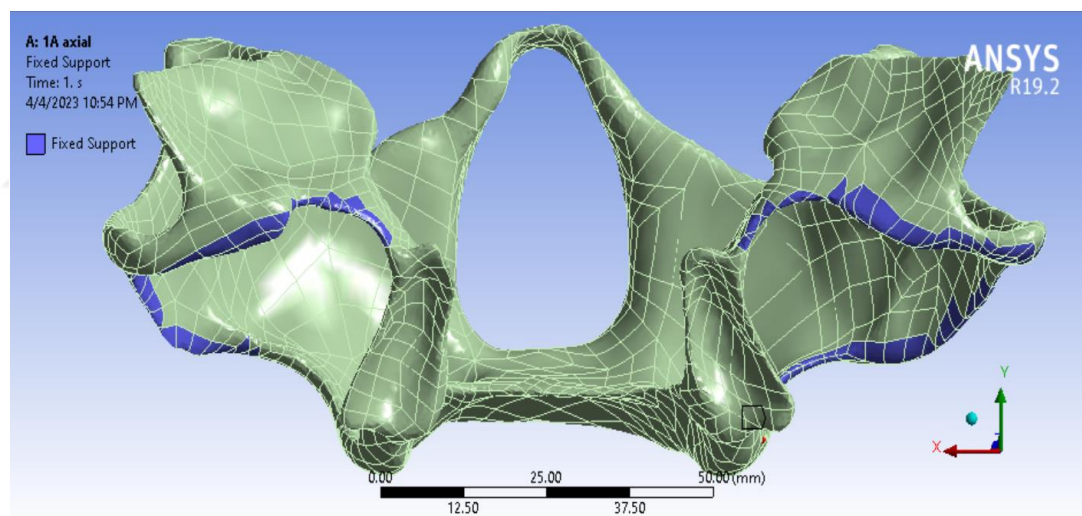
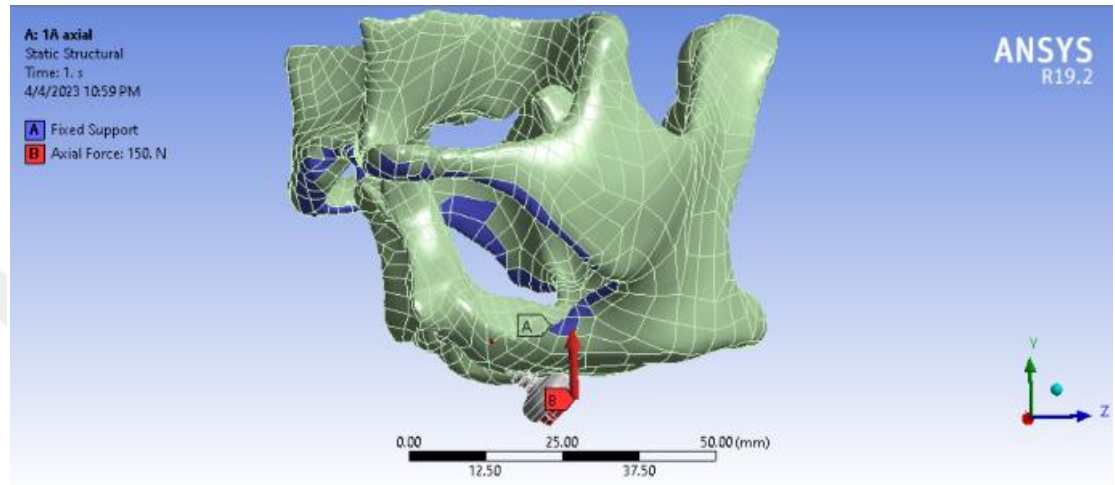


Figure 3. 15. Image of the regions where the model is fixed

Three different load scenarios were explored to simulate stress and strain with the following conditions: (1) 150-N axial loading and (2) 50-N lateral loading and (3) 150-N axial loading with simultaneous 50-N lateral loading (Figure 3.16) (Figure 3.17) (178). The loadings were evenly applied to the occlusal surface over the abutment (241,242).

(a)



(b)

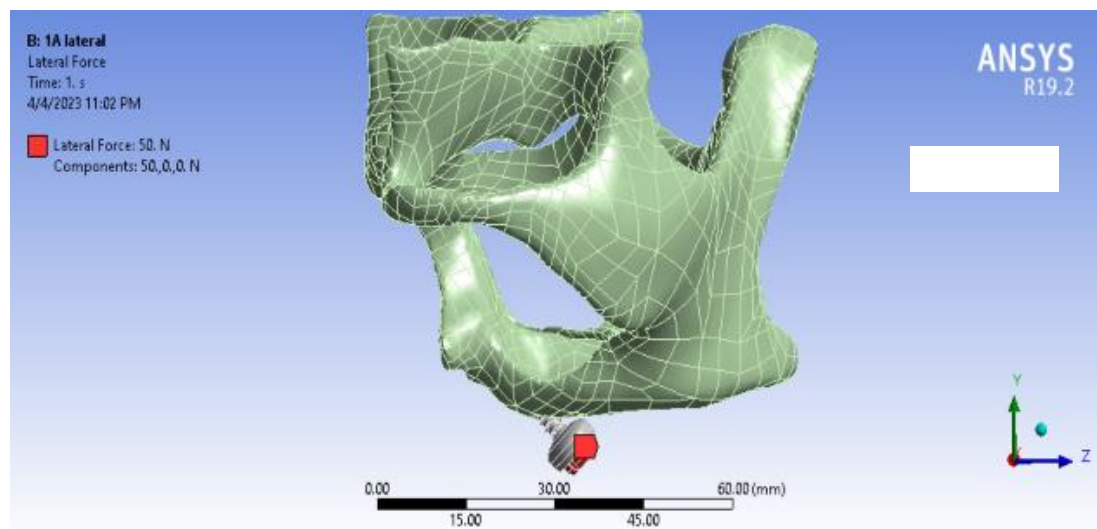
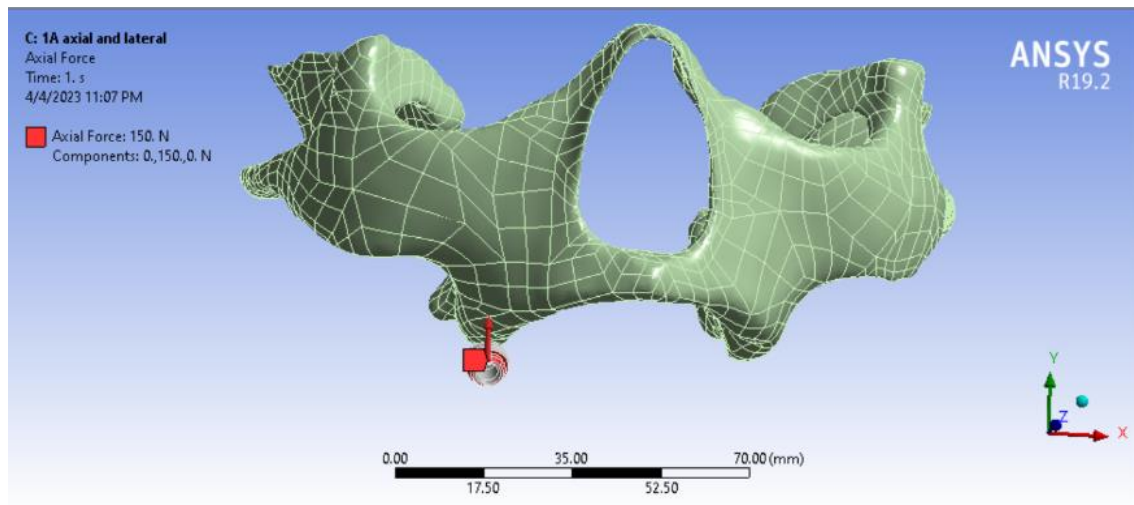


Figure 3. 16. (a) Lateral view of axial direction, (b) Lateral view of lateral direction, the application direction and the image of the implant relationship with the application area .

(a)



(b)

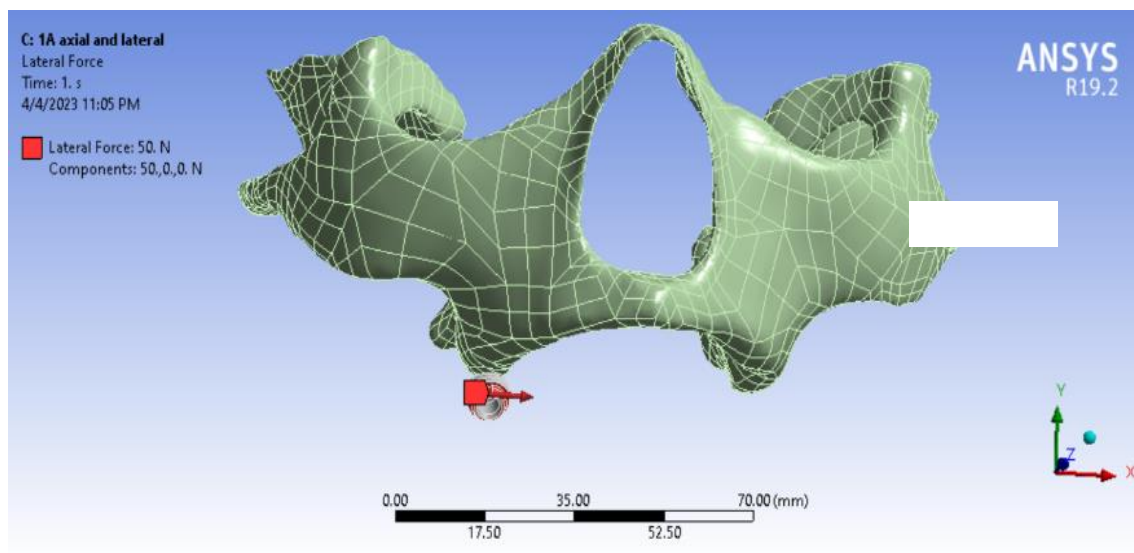


Figure 3. 17. (a) Frontal view of axial direction, (b) Frontal view of lateral direction, the application direction and the image of the implant relationship with the application area .

3.2 Statistical evaluation

Statistical analysis will not be conducted on the results received from finite element analysis (FEA), as they are derived from precise mathematical calculations without any variation. The analysis findings for each model are shown in a table. Comparisons will be conducted using bar graphs, and stress distributions on the model will be visualized with figures.

Statistical evaluation of finite element analysis (FEA) values is often not performed for several reasons. One primary factor is the assumption that the input parameters and model assumptions are deterministic and well-defined, leading to a single, precise result. Additionally, FEA is commonly used for structural analysis, where variability may be addressed through safety factors rather than statistical analysis.

Since the values obtained as a result of FEA are the result of mathematical calculations without variance, statistical analysis of these values is not performed. Analysis results for each model are given in a table and comparisons were made with bar graphs and stress distributions on the model were shown with figures. Because the numbers that will come out of FEA calculations are logical and don't take into account variation, they are not analyzed statistically.

4. Results

4.1.Stress

4.1.1. 150-N axial force application

150-N axial force were applied on the occlusal surface above the abutment of a pterygoid dental implant with monocortical (end border of crest and cancellous bone) and bicortical (between crest and basal bone) placed at 45,55,65,75, and 85 angle degrees according to the Frankfort Horizontal Plane, the loadings were uniformly distributed .

Maximum Von Mises Stress values and location on the implant's body are shown in table 4.1 , (Figure 4.1). The greatest stress in all models was recorded at 672.82 MPa in 45 angle degree bicortically placed model . The lowest value 75.898 MPa was recorded in 85 angle degree monocortically placed model.

Maximum Von Mises Stress values and location on the surrounding bone are shown in table 4.1, (Figure 4.1). The greatest stress in all models was recorded at 137.97 MPa in 45 angle degree bicortically placed model . The lowest value was recorded in 85 angle degree bicortically placed model as 29.927 Mpa .

Table 4.1. Von Mises Stress and location under 150N axial loading

Models	Maximum stress in implant MPa	Maximum stress in implant location	Maximum stress in bone MPa	Maximum stress in bone location
1-A	515.64	Abutment connection area of the pterygoid implant	125.81	Crestal bone at pterygoid implant
1-B	672.82	Abutment connection area of the pterygoid implant	137.97	Crestal bone at pterygoid implant
2-A	278.35	Abutment connection area of the pterygoid implant	92.282	Crestal bone at pterygoid implant
2-B	321.86	Abutment connection area of the pterygoid implant	88.64	Crestal bone at pterygoid implant
3-A	248.8	Abutment connection area of the pterygoid implant	60.799	Crestal bone at pterygoid implant
3-B	240.02	Abutment connection area of the pterygoid implant	54.578	Crestal bone at pterygoid implant
4-A	148.97	Abutment connection area of the pterygoid implant	43.028	Crestal bone at pterygoid implant
4-B	164.57	Abutment connection area of the pterygoid implant	116.19	Crestal bone at pterygoid implant

5-A	75.898	Abutment connection area of the pterygoid implant	110.52	Crestal bone at pterygoid implant
5-B	89.163	Abutment connection area of the pterygoid implant	29.927	Crestal bone at pterygoid implant

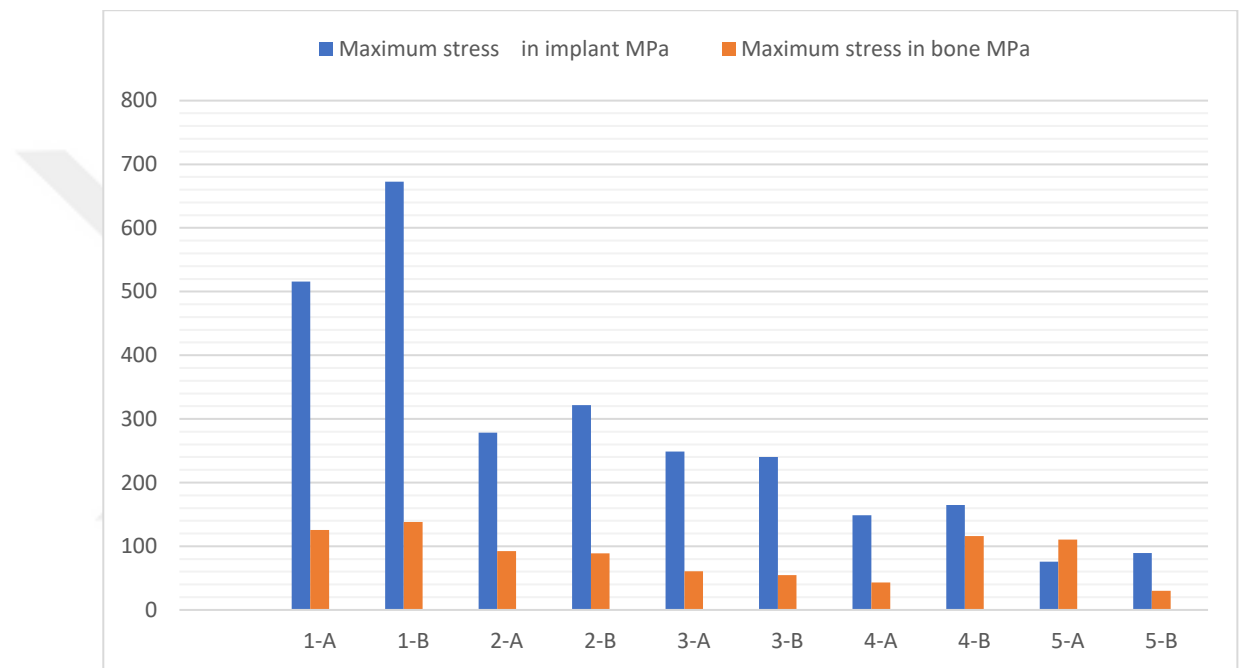


Figure 4. 1. Maximum stress in the implant and surrounding bone for each model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.2), under 150-N axial force application .

Maximum equivalent stress was measured at 515.64 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 125.81 Mpa, as shown in (Table 4.1).

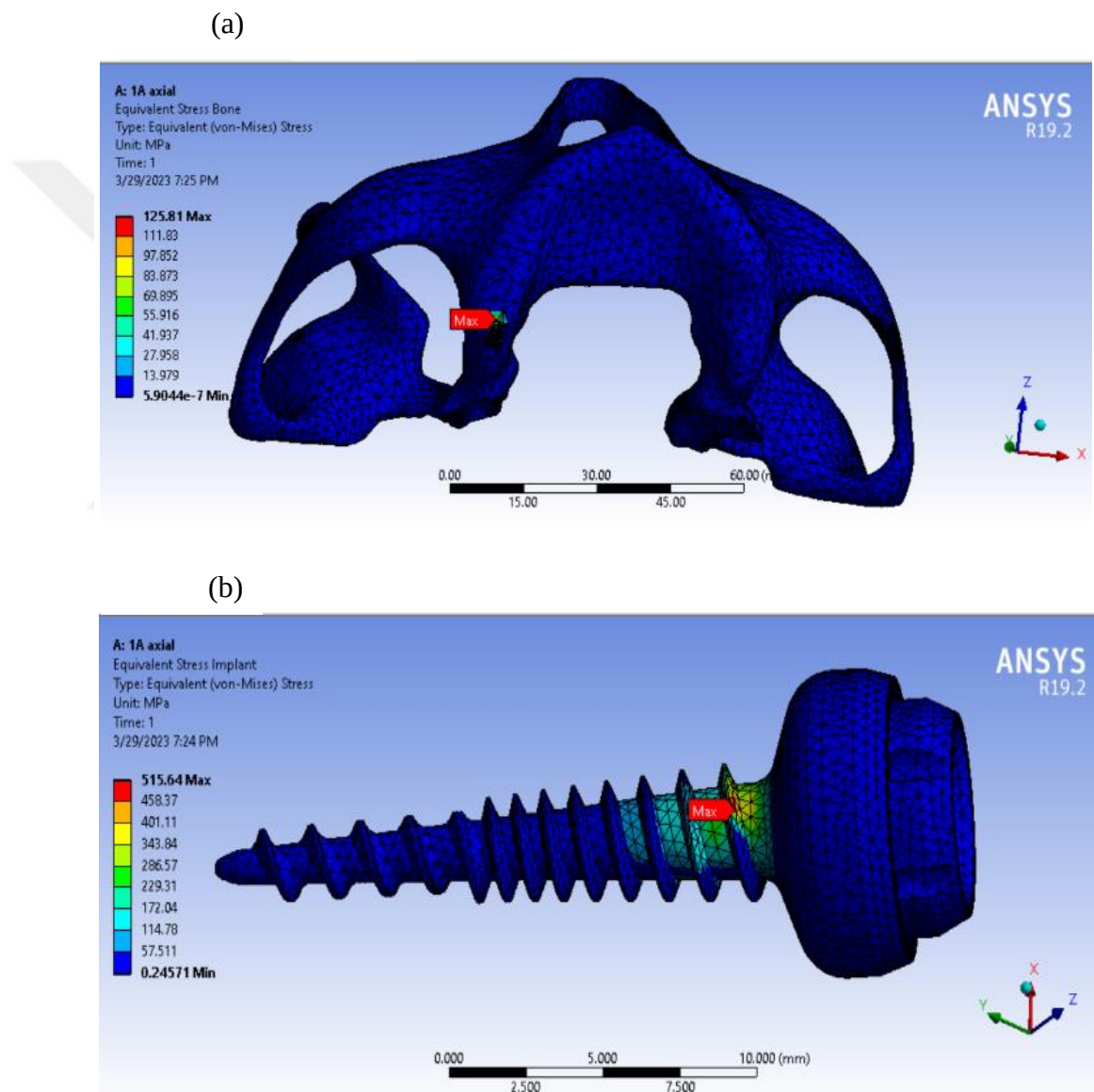
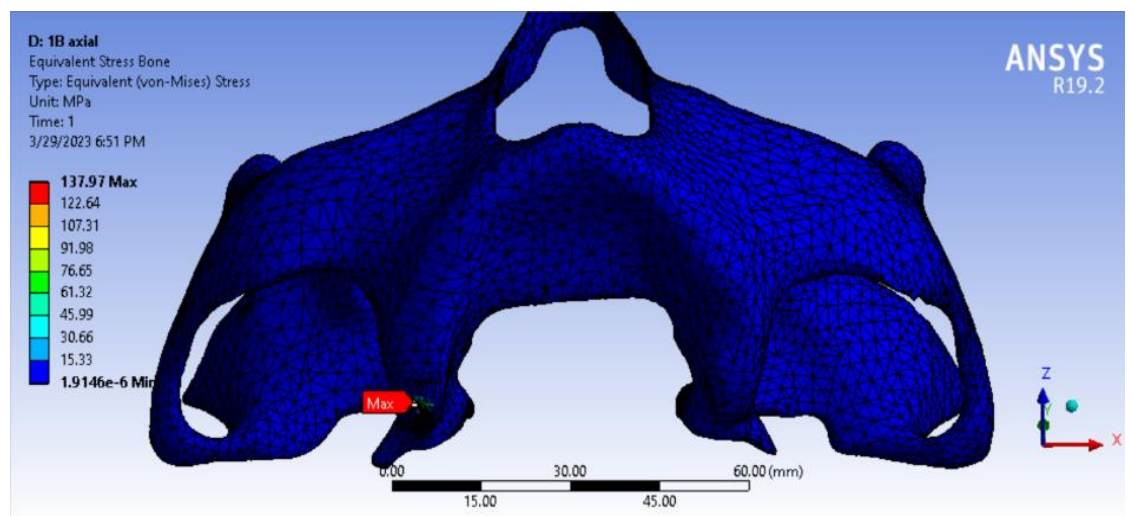


Figure 4. 2. (a) Maximum stress on surrounding bone for 1A model under 150N axial loading (b) Maximum stress on implant for 1A model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.3), under 150N axial force application .

Maximum equivalent stress was measured at 672.82 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 137.97 Mpa, as shown in (Table 4.1).

(a)



(b)

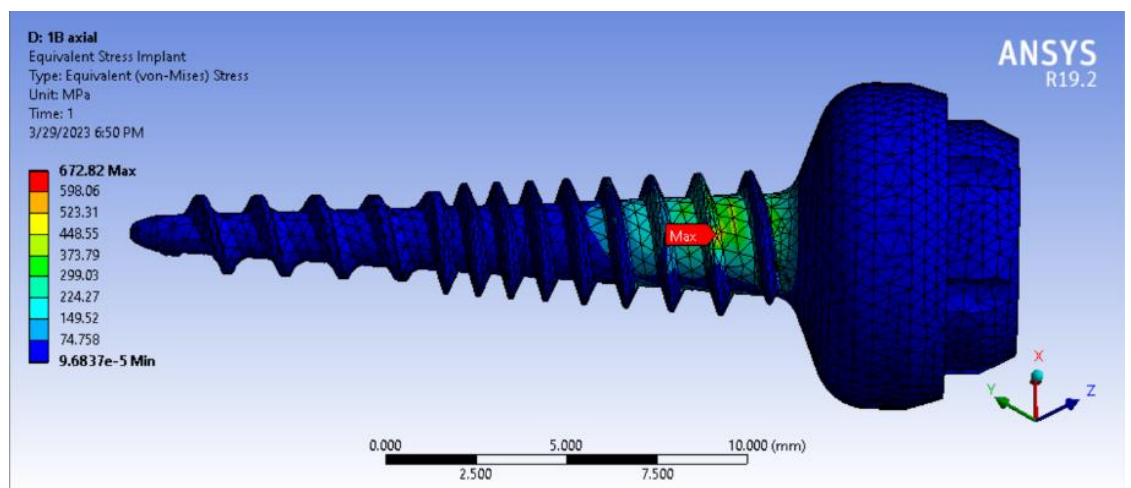


Figure 4. 3. (a) Maximum stress on surrounding bone for 1B model under 150N axial loading (b) Maximum stress on implant for 1Bmodel under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.4), under 150-N axial force application .

Maximum equivalent stress was measured at 278.35 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 92.282 Mpa, as shown in (Table 4.1).

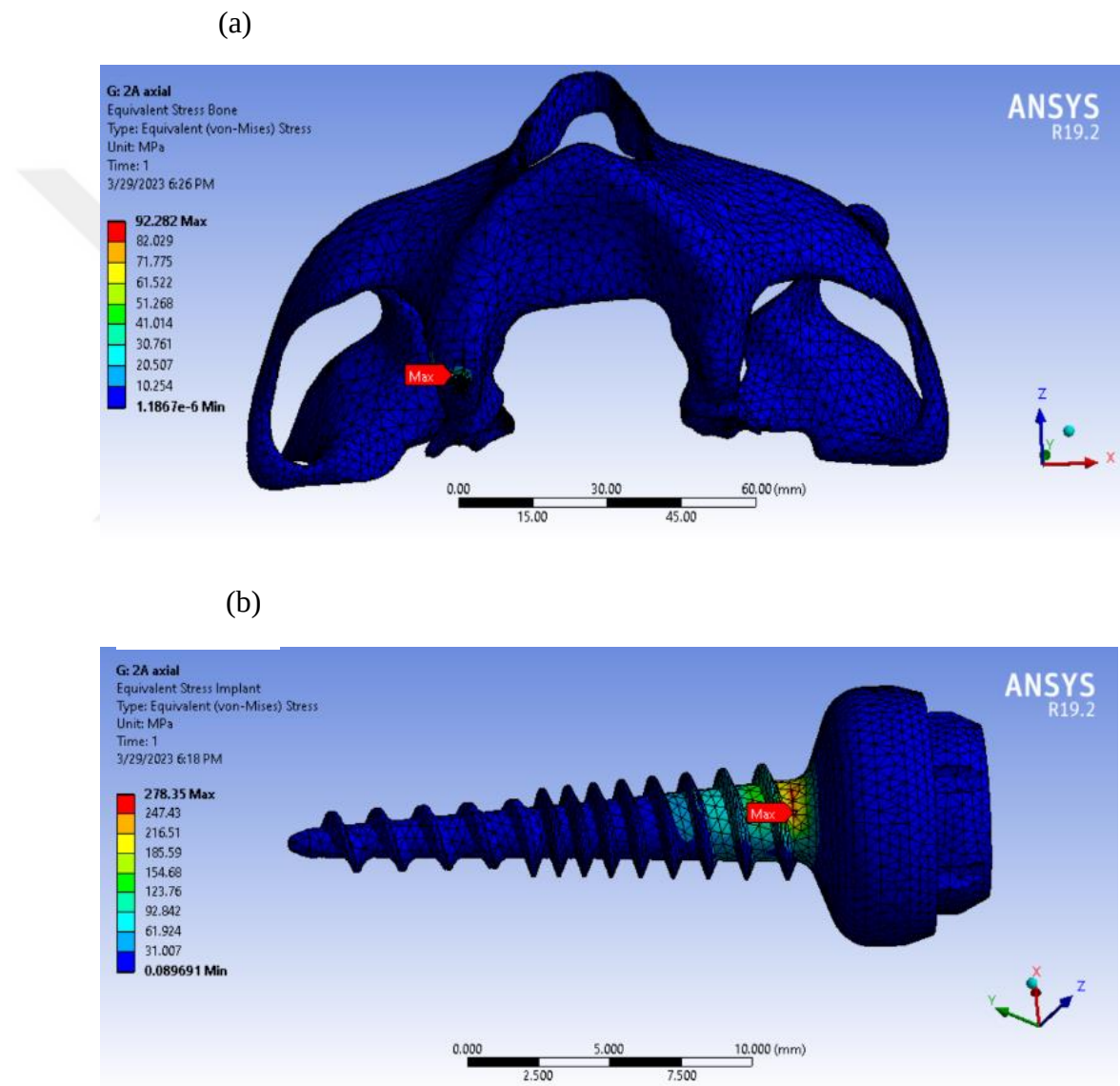
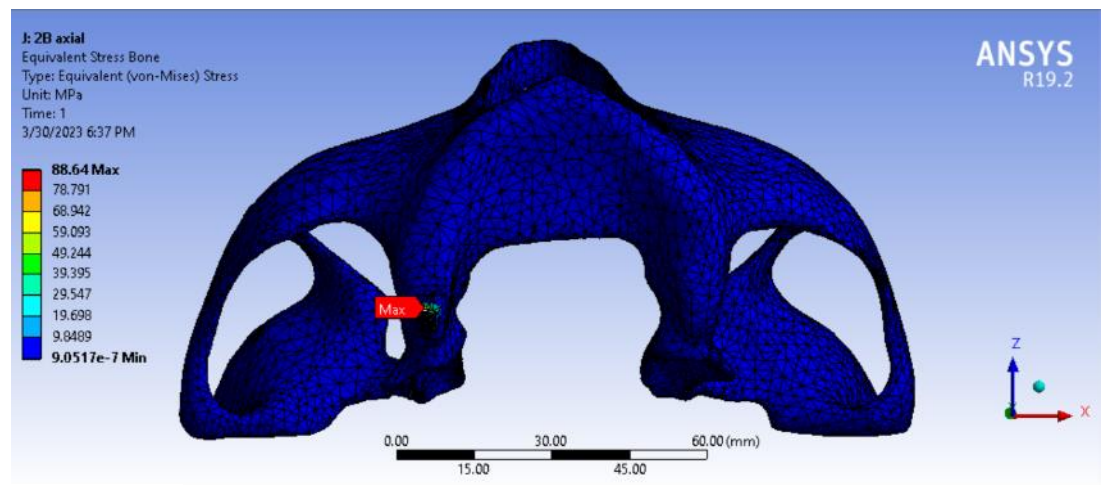


Figure 4. 4. (a) Maximum stress on surrounding bone for 2A model under 150N axial loading (b) Maximum stress on implant for 2A model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.5), under 150N axial force application .

Maximum equivalent stress was measured at 321.86 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 88.64 Mpa, as shown in (Table 4.1).

(a)



(b)

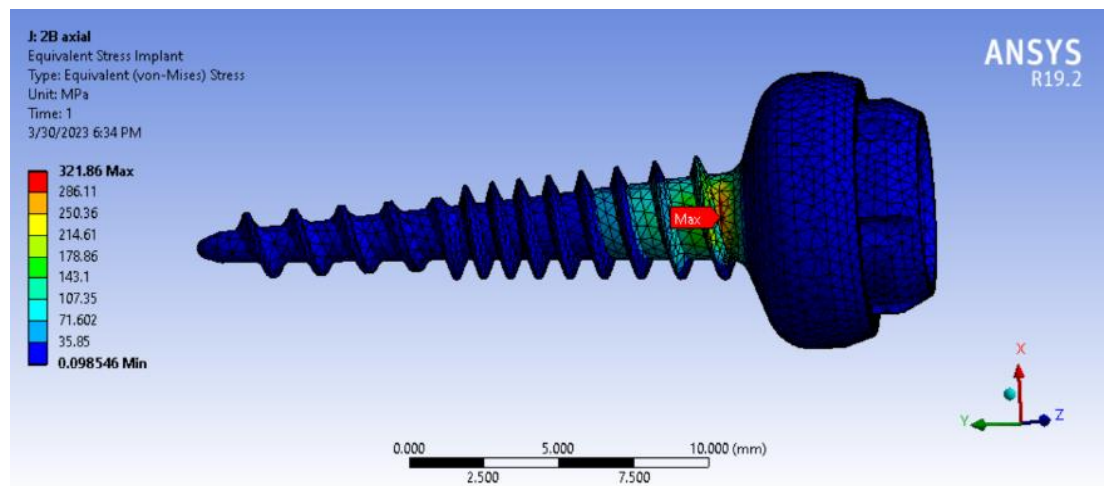
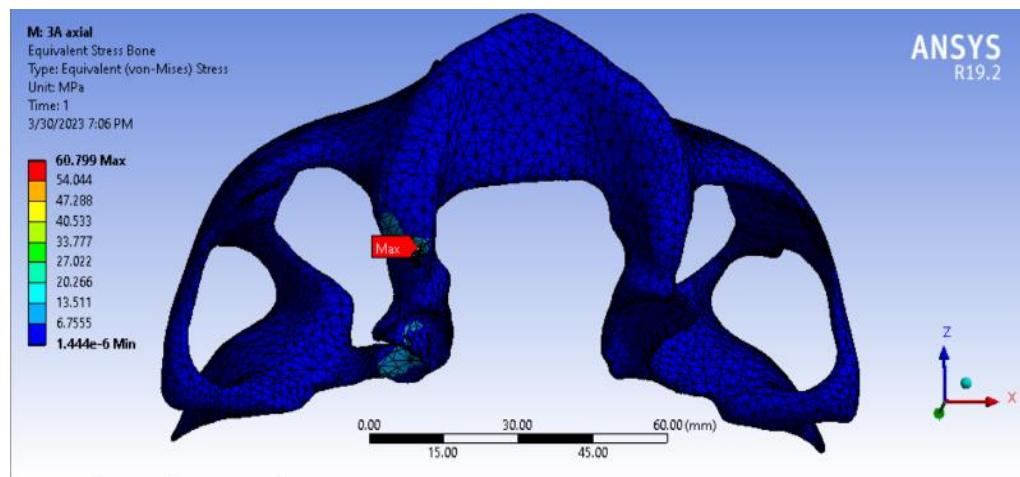


Figure 4. 5. (a) Maximum stress on surrounding bone for 2B model under 150N axial loading (b) Maximum stress on implant for 2B model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.6), under 150-N axial force application .

Maximum equivalent stress was measured at 248.8 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 60.799 Mpa, as shown in (Table 4.1).

(a)



(b)

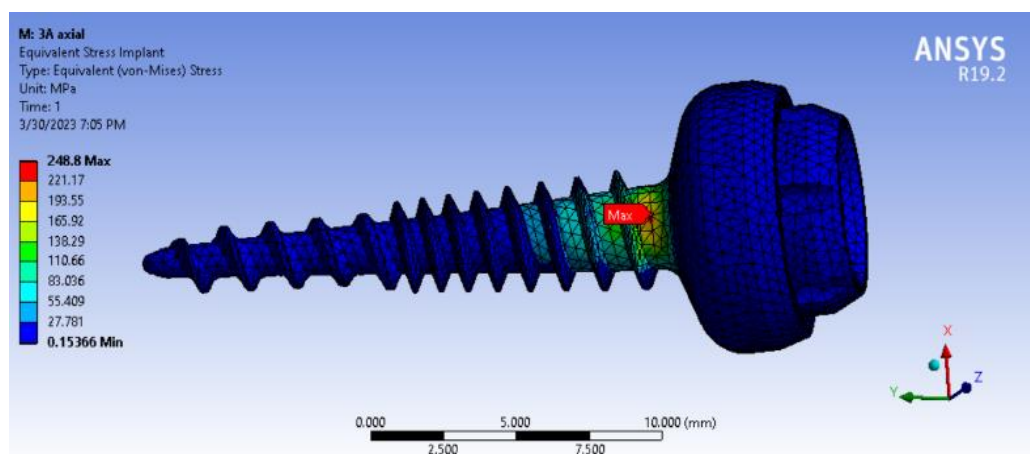
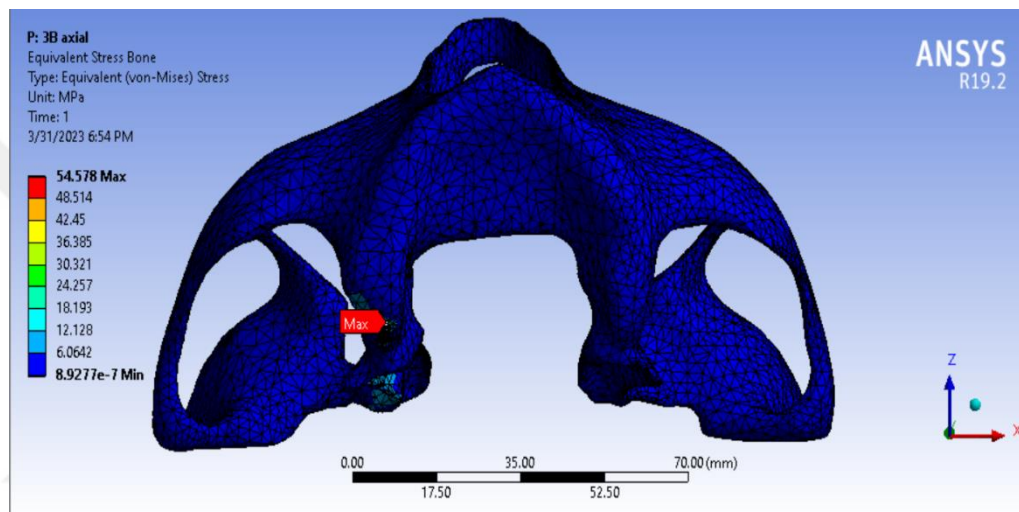


Figure 4. 6. (a) Maximum stress on surrounding bone for 3A model under 150N axial loading (b) Maximum stress on implant for 3A model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.7), under 150-N axial force application .

Maximum equivalent stress was measured at 240.02 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 54.578 Mpa, as shown in (Table 4.1).

(a)



(b)

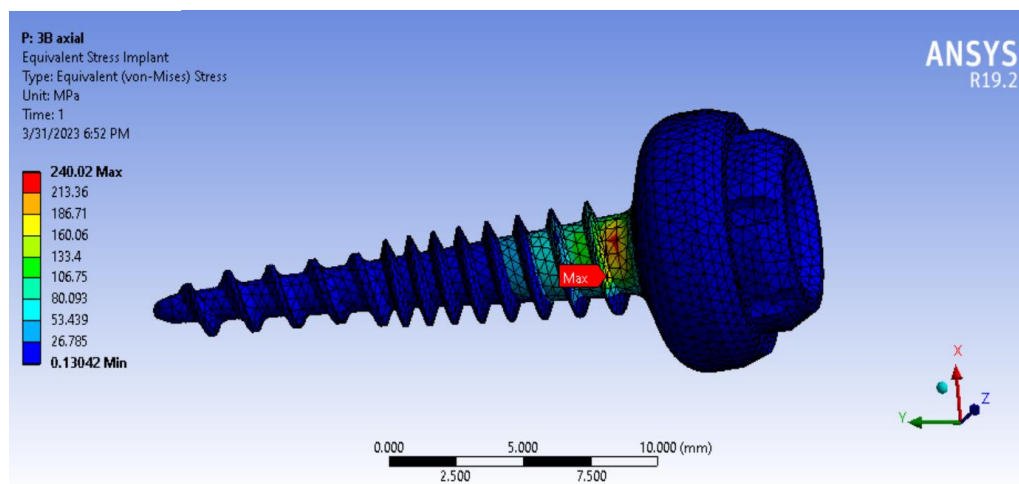
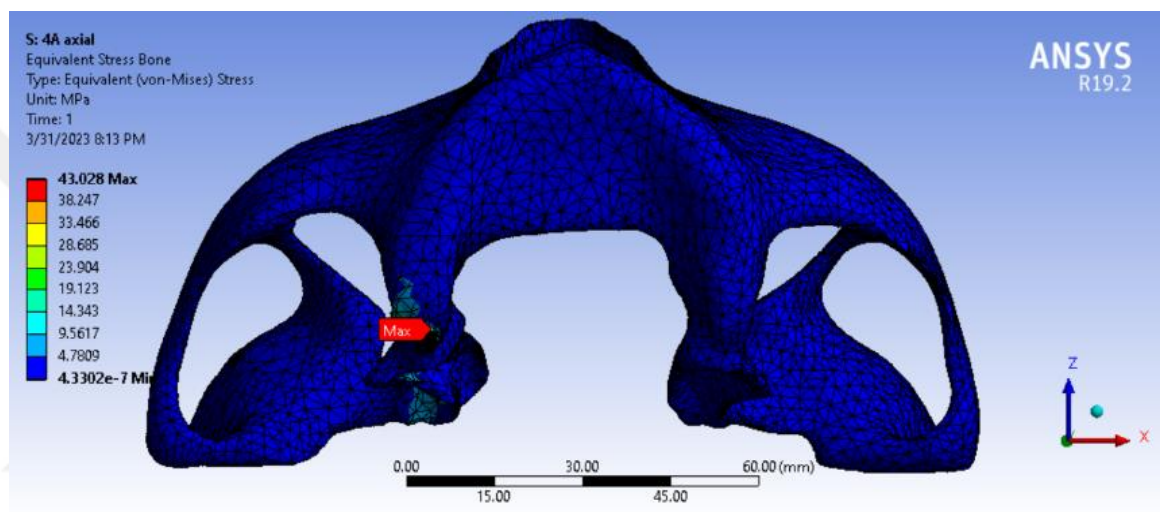


Figure 4. 7. (a) Maximum stress on surrounding bone for 3B model under 150N axial loading (b) Maximum stress on implant for 3B model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.8), under 150-N axial force application .

Maximum equivalent stress was measured at 148.97 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 43.028 Mpa, as shown in (Table 4.1).

(a)



(b)

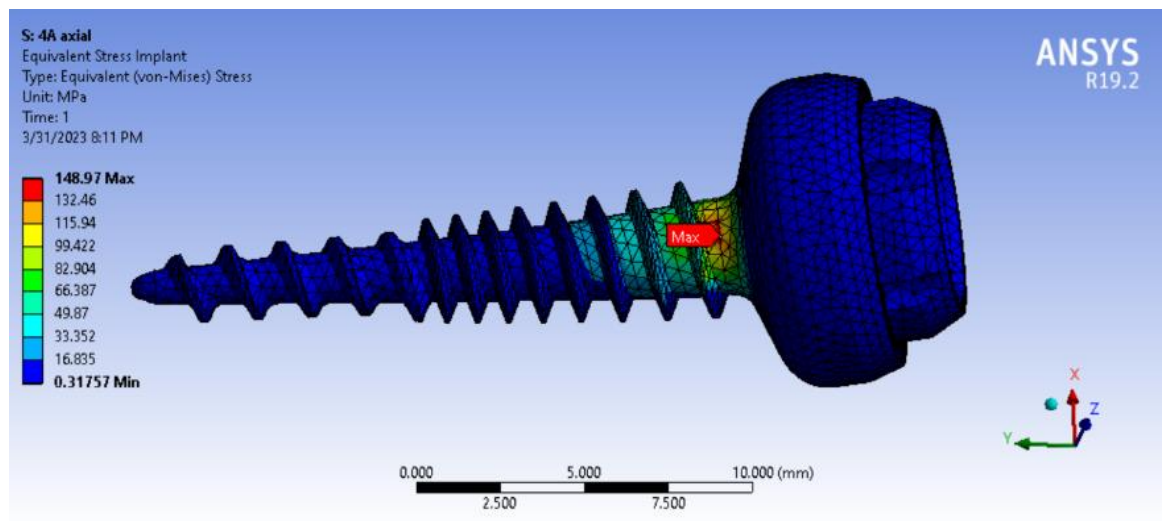
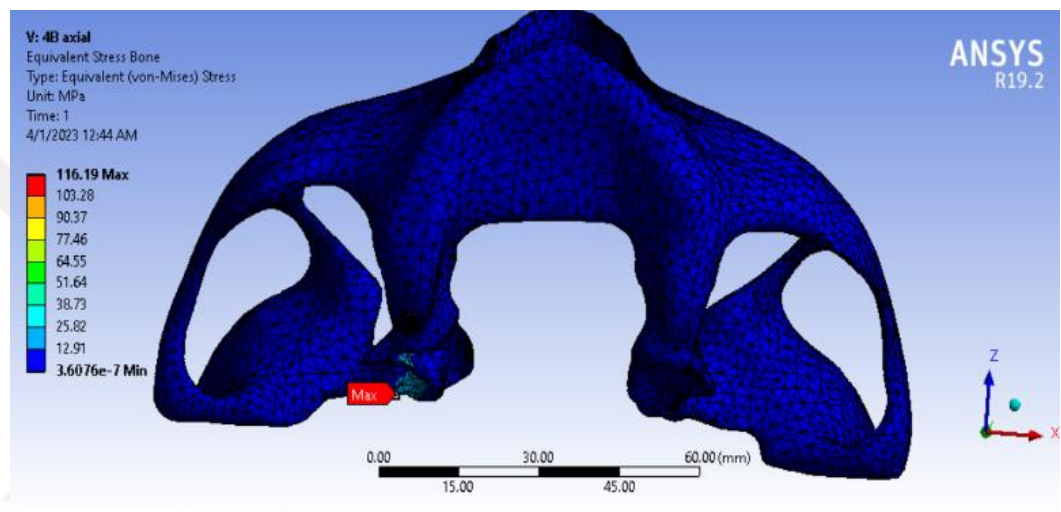


Figure 4. 8. (a) Maximum stress on surrounding bone for 4A model under 150N axial loading (b) Maximum stress on implant for 4A model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.9), under 150-N axial force application .

Maximum equivalent stress was measured at 164.57 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 116.19 Mpa, as shown in (Table 4.1).

(a)



(b)

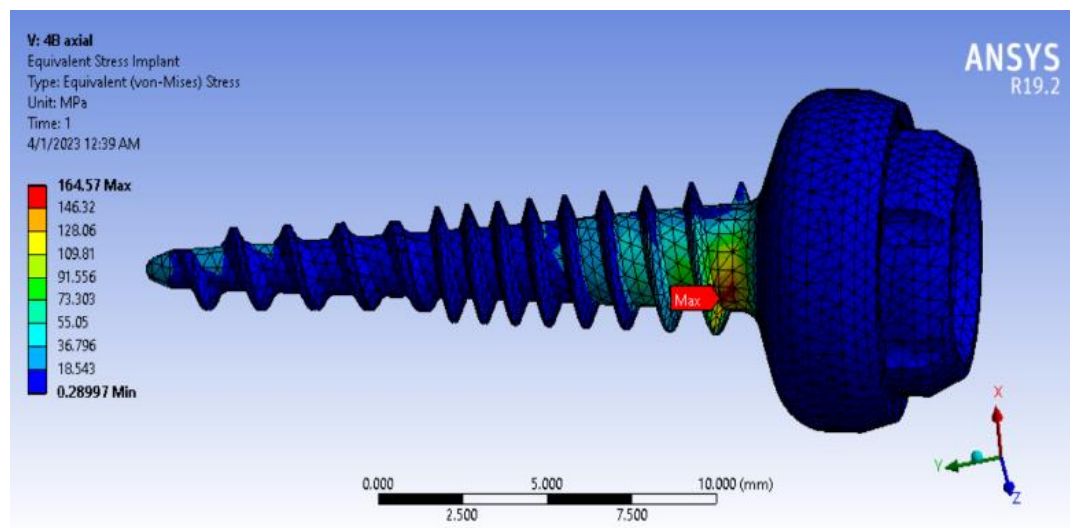
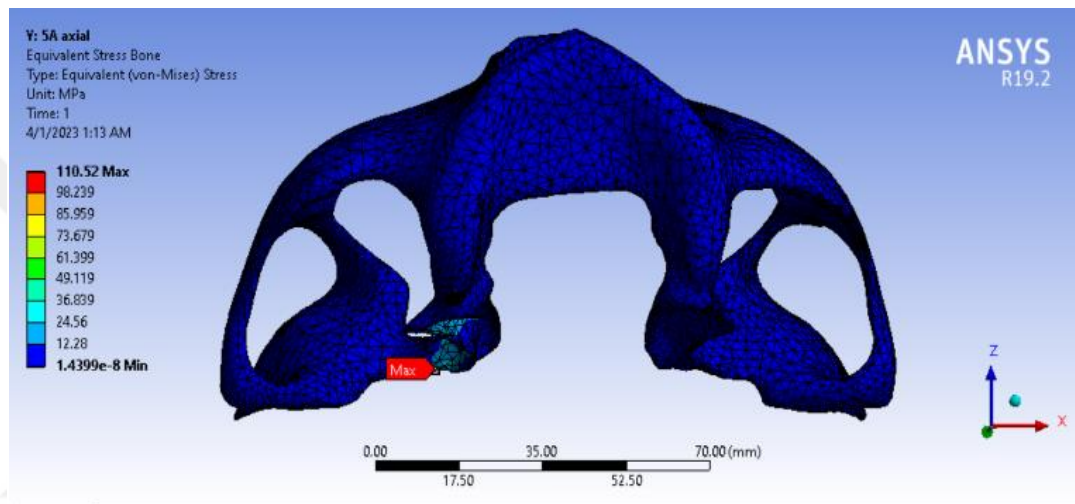


Figure 4. 9. (a) Maximum stress on surrounding bone for 4B model under 150N axial loading (b) Maximum stress on implant for 4B model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.10), under 150-N axial force application .

Maximum equivalent stress was measured at 75.898 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 110.52 Mpa, as shown in (Table 4.1).

(a)



(b)

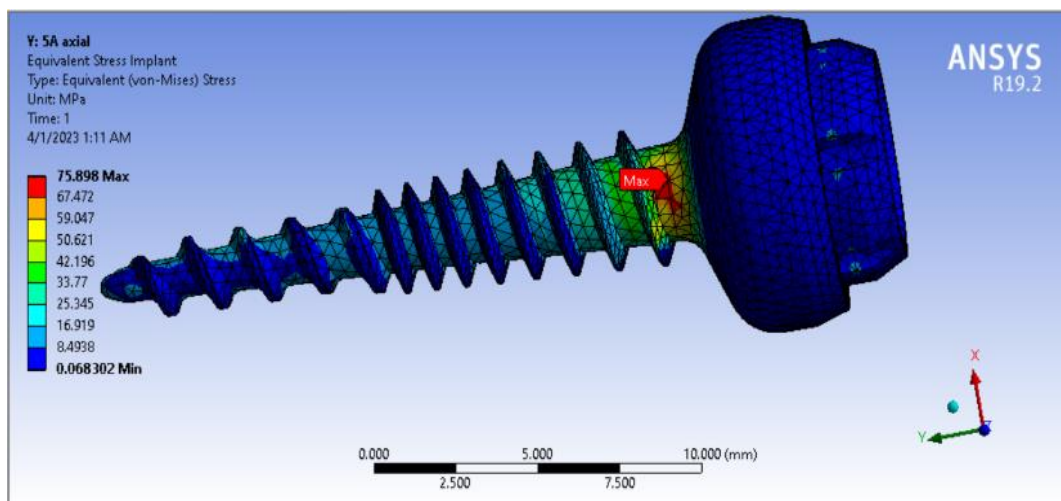
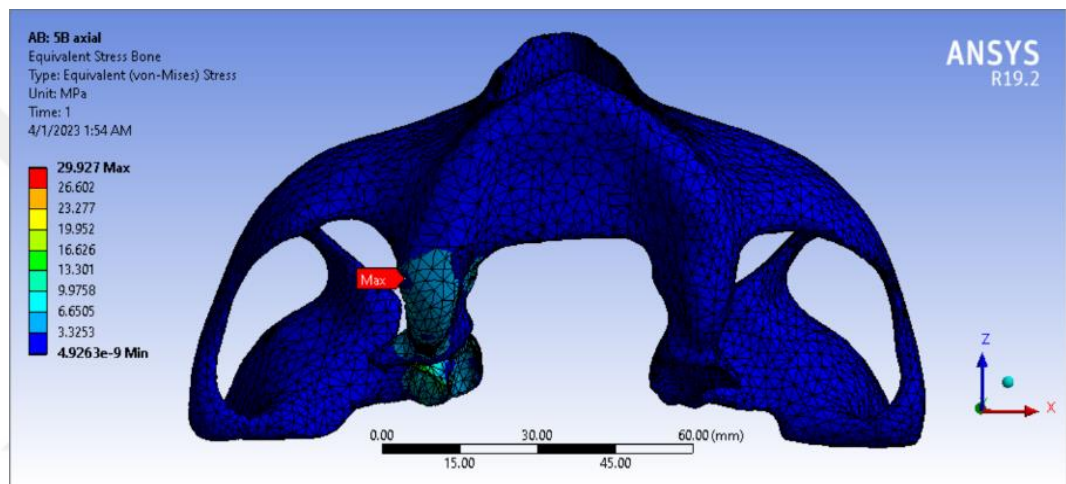


Figure 4. 10. (a) Maximum stress on surrounding bone for 5A model under 150N axial loading (b) Maximum stress on implant for 5A model under 150N axial loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.11), under 150-N axial force application .

Maximum equivalent stress was measured at 89.163 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 29.927 Mpa, as shown in (Table 4.1).

(a)



(b)

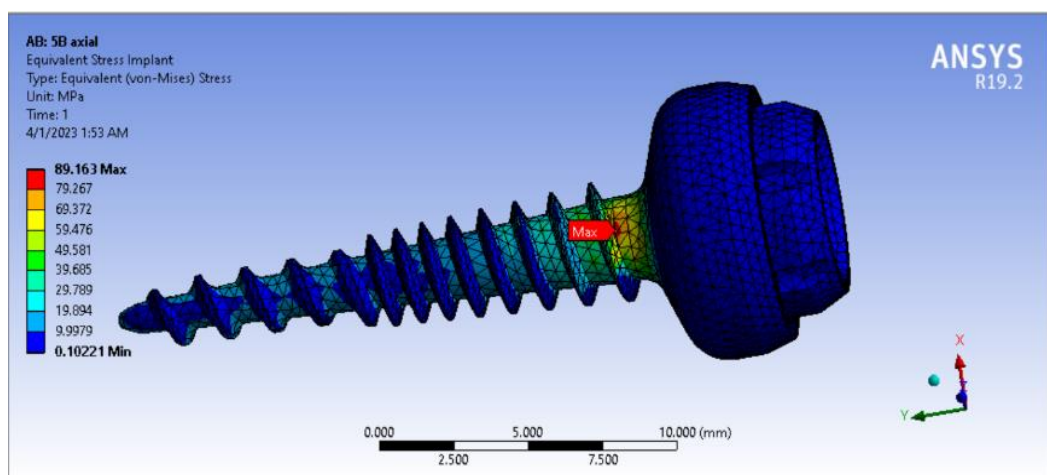


Figure 4. 11. (a) Maximum stress on surrounding bone for 5B model under 150N axial loading
(b) Maximum stress on implant for 5B model under 150N axial loading

4.1.2. 50-N lateral force application

50-N lateral load were applied on the occlusal surface above the abutment of the pterygoid dental implant monocortically (end border of the crest and cancellous bone) and bicortically (between the crest and basal bone) placed at 45, 55, 65, 75, and 85 angle degrees according to the Frankfort Horizontal Plane, the loadings were uniformly distributed .

Maximum Von Mises Stress values and location on the implant's body are shown in table 4.2 , (Figure 4.12). The greatest stress in all models was recorded at 348.69 MPa in 45 angle degree bicortically placed model . The lowest value is 158.18 MPa, was recorded in 75 angle degree monocortically placed model.

Maximum Von Mises Stress values and location on the surrounding bone are shown in table 4.2, (Figure 4.12). The greatest stress in all models was recorded at 82.317 MPa in 45 angle degree bicortically placed model . The lowest value was recorded in 65 angle degree bicortically placed model as 43.378 Mpa .

Table 4.2. Von Mises Stress and location under 50N lateral loading

Models	Maximum stress in implant MPa	Maximum stress in implant location	Maximum stress in bone MPa	Maximum stress in bone location
1A	211.79	Abutment connection area of the pterygoid abutment	58.154	Crestal bone at pterygoid implant
1B	348.69	Abutment connection area of the pterygoid abutment	82.317	Crestal bone at pterygoid implant
2A	159.59	Abutment connection area of the pterygoid abutment	62.027	Crestal bone at pterygoid implant
2B	175.74	Abutment connection area of the pterygoid abutment	59.884	Crestal bone at pterygoid implant
3A	172.77	Abutment connection area of the pterygoid abutment	51.187	Crestal bone at pterygoid implant
3B	225.03	Abutment connection area of the pterygoid abutment	43.378	Crestal bone at pterygoid implant

4A	158.18	Abutment connection area of the pterygoid abutment	48.522	Crestal bone at pterygoid implant
4B	184.49	Abutment connection area of the pterygoid abutment	51.019	Crestal bone at pterygoid implant
5A	222.43	Abutment connection area of the pterygoid abutment	53.076	Crestal bone at pterygoid implant
5B	278.52	Abutment connection area of the pterygoid abutment	51.888	Crestal bone at pterygoid implant

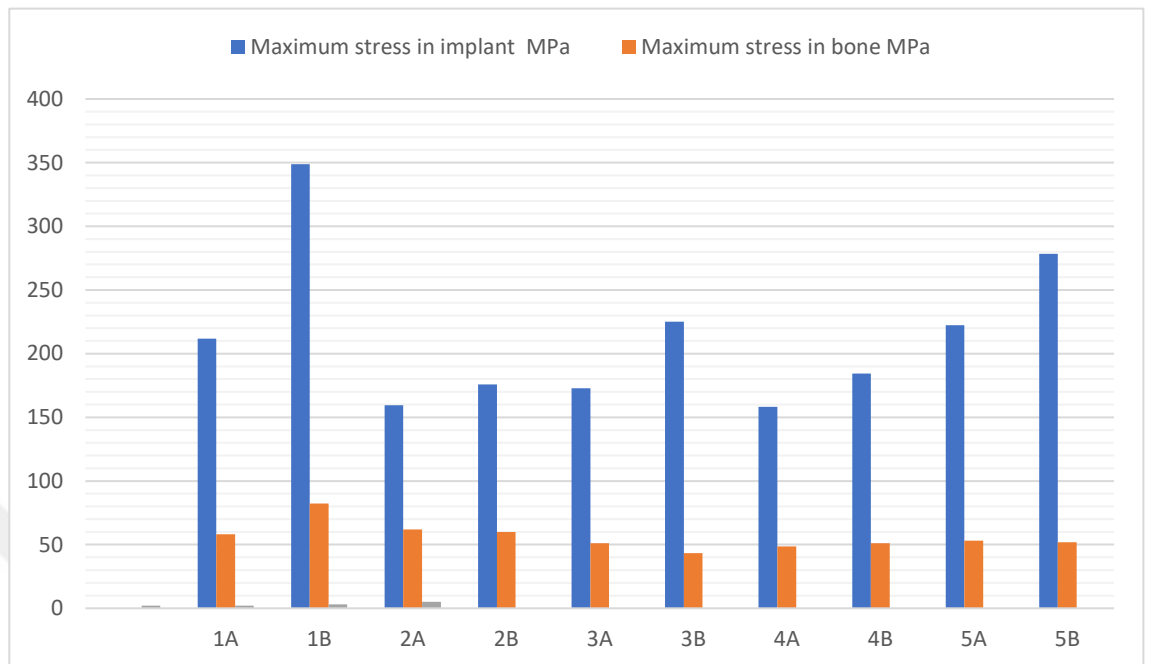
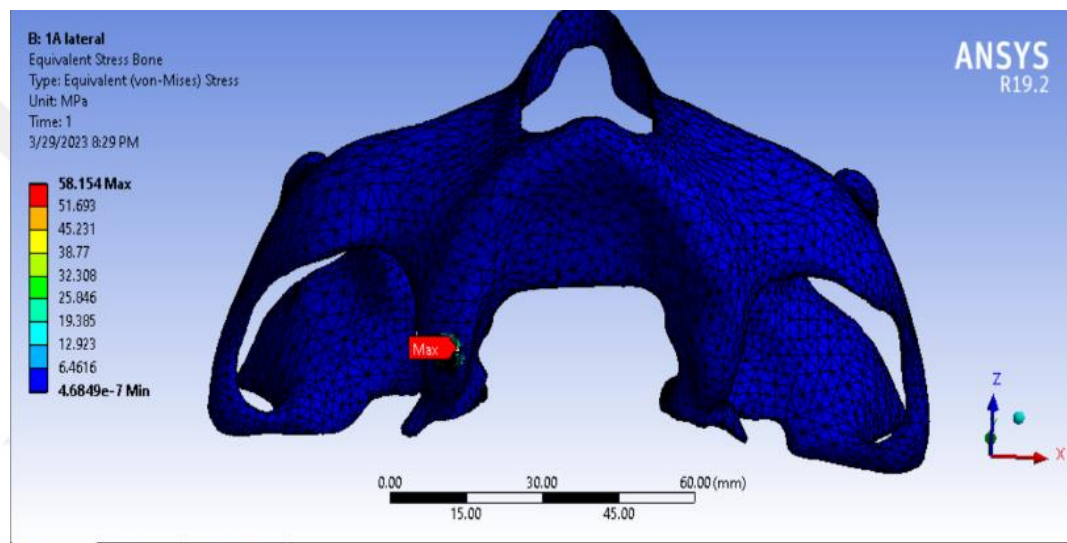


Figure 4. 12. Maximum stress in implant and surrounding bone for each model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.13), under 50-N lateral force application.

Maximum equivalent stress was measured at 211.79 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 58.154 Mpa, as shown in (Table 4.2).

(a)



(b)

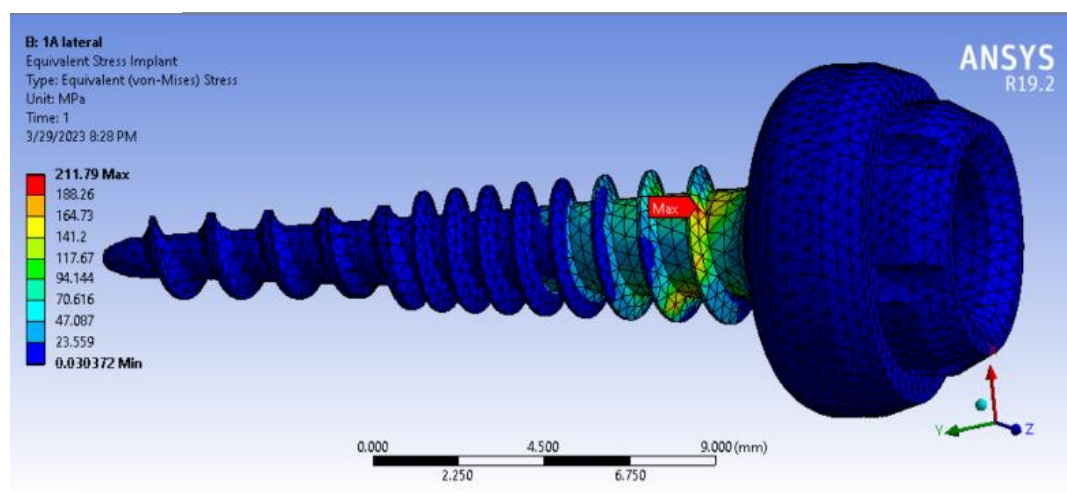
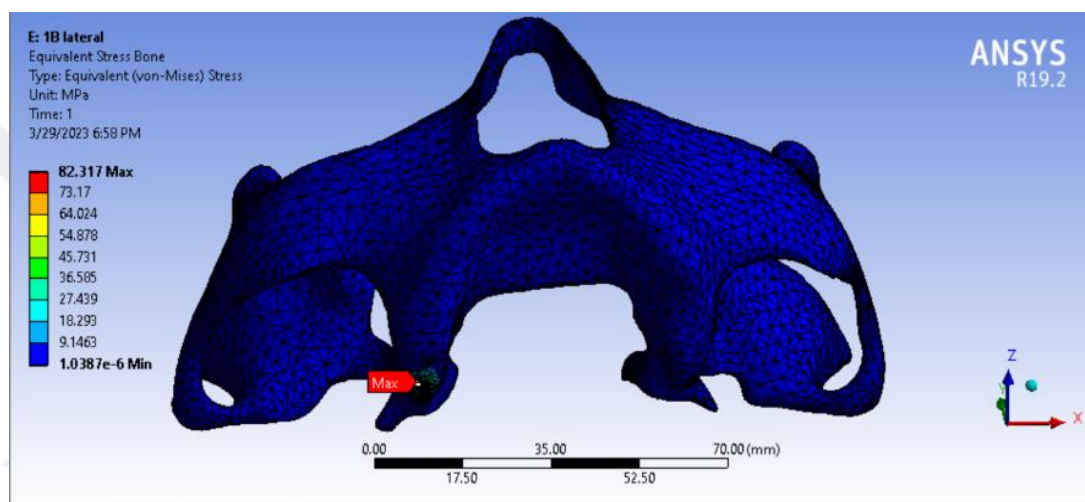


Figure 4. 13. (a) Maximum stress on surrounding bone for 1A model under 50N lateral loading (b) Maximum stress on implant for 1A model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.14), under 50-N lateral force application.

Maximum equivalent stress was measured at 384.69 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 82.317 Mpa, as shown in (Table 4.2).

(a)



(b)

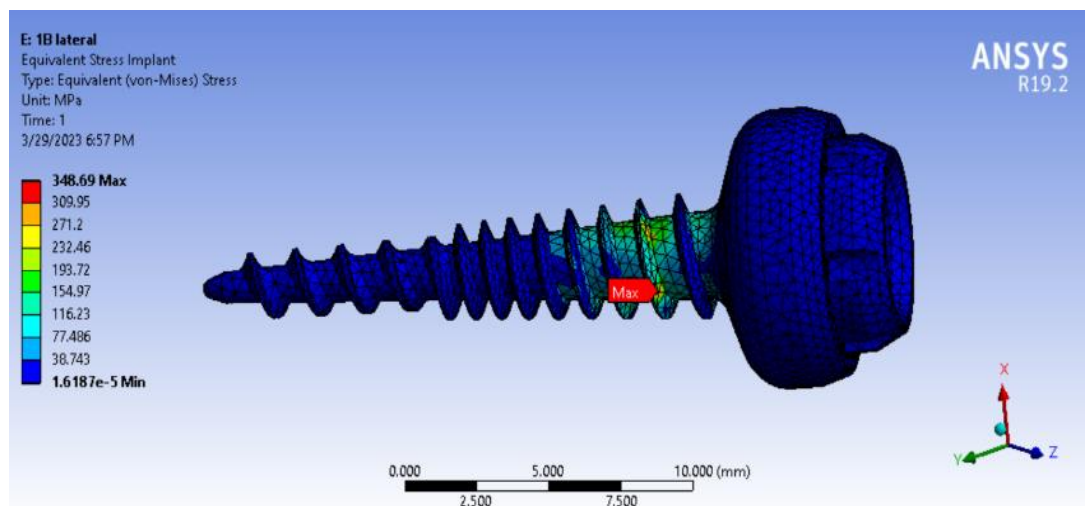
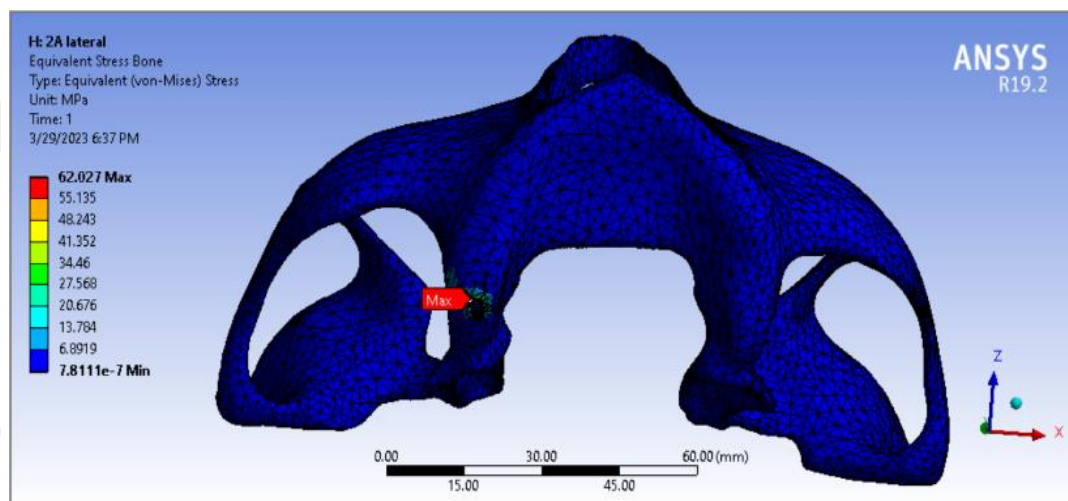


Figure 4. 14. (a) Maximum stress on surrounding bone for 1B model under 50N lateral loading (b) Maximum stress on implant for 1B model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.15), under 50-N lateral force application.

Maximum equivalent stress was measured at 159.59 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 62.027 Mpa, as shown in (Table 4.2).

(a)



(b)

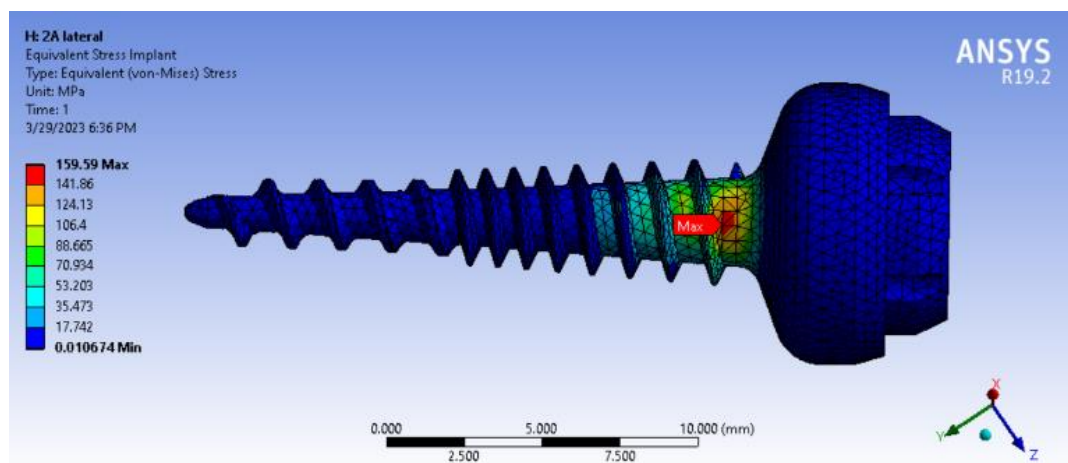
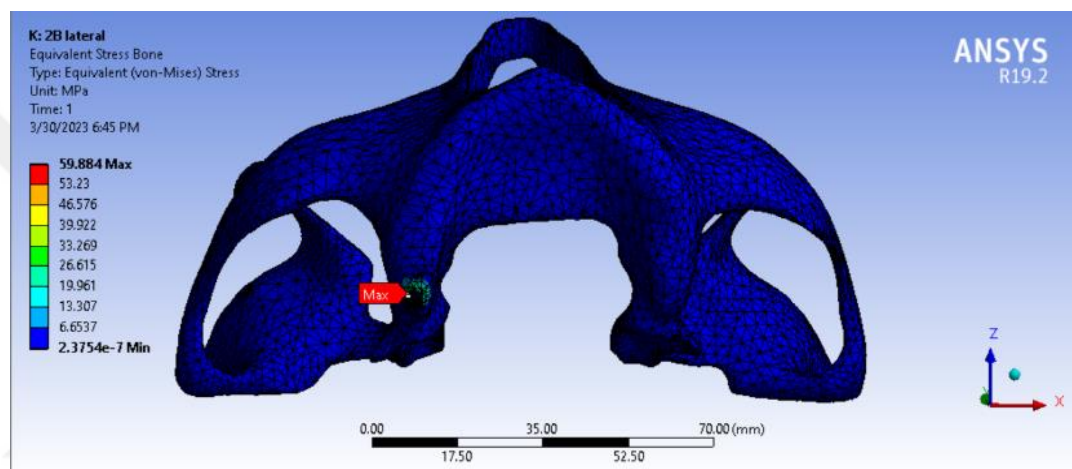


Figure 4. 15. (a) Maximum stress on surrounding bone for 2A model under 50N lateral loading (b) Maximum stress on implant for 2A model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.16), under 50-N lateral force application.

Maximum equivalent stress was measured at 175.74 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 59.884 Mpa, as shown in (Table 4.2).

(a)



(b)

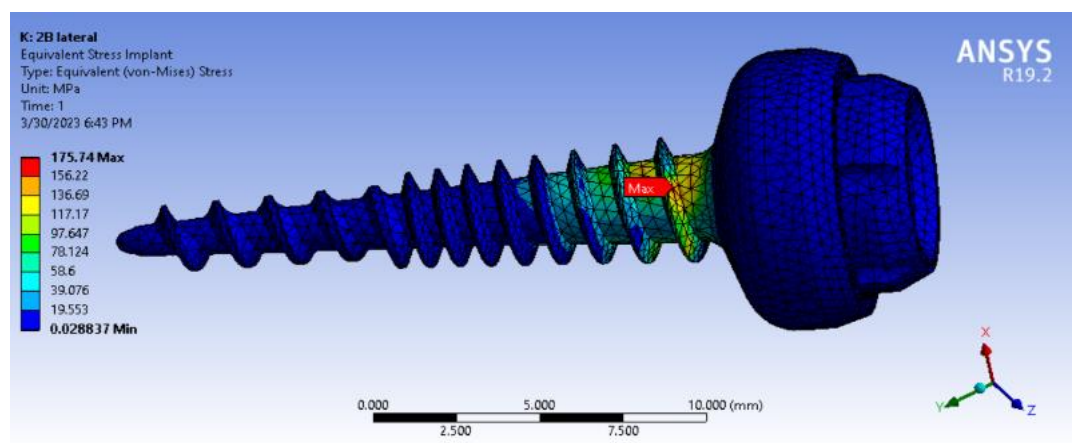
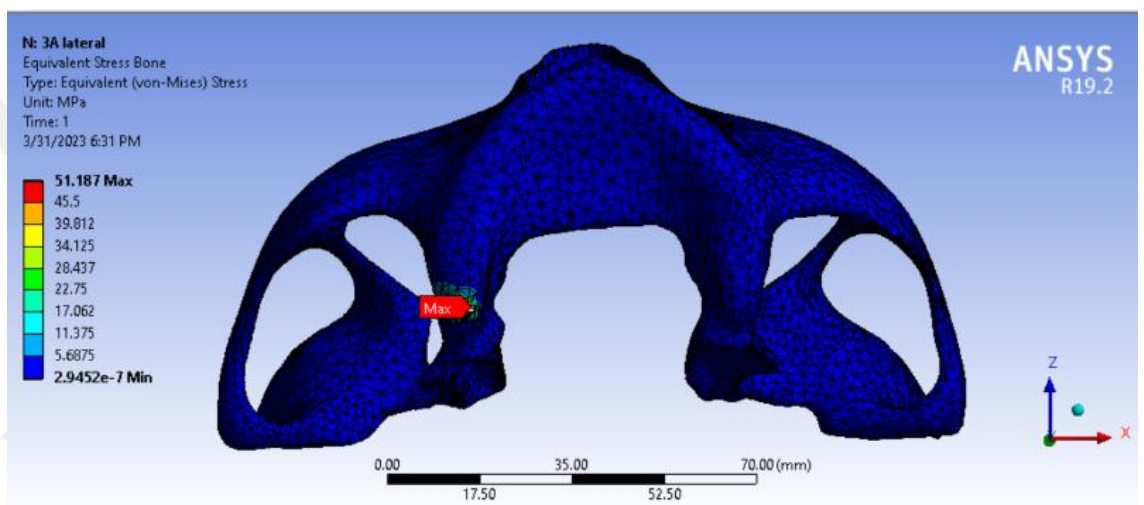


Figure 4. 16. (a) Maximum stress on surrounding bone for 2B model under 50N lateral loading (b) Maximum stress on implant for 2B model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.17), under 50-N lateral force application.

Maximum equivalent stress was measured at 172.77 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 51.187 Mpa, as shown in (Table 4.2).

(a)



(b)

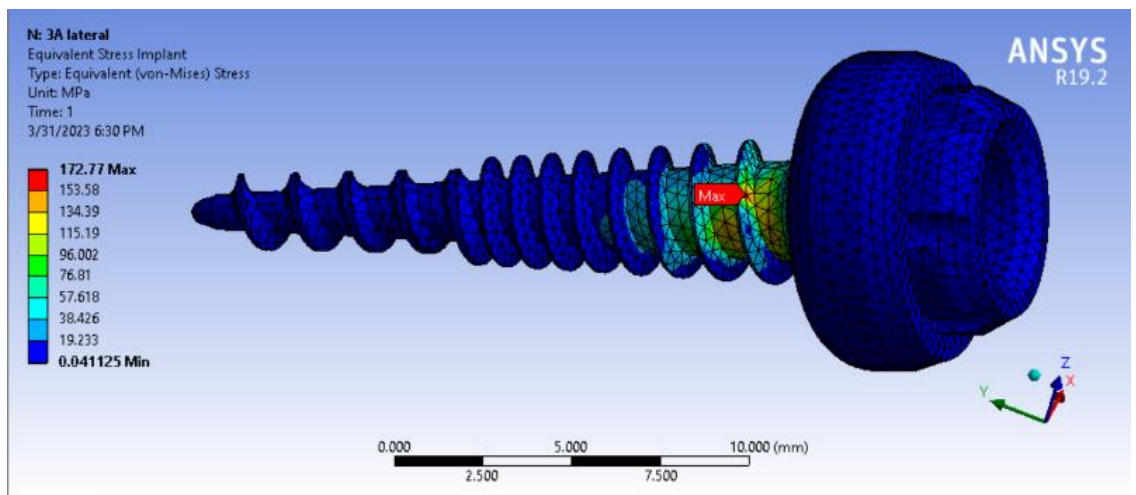
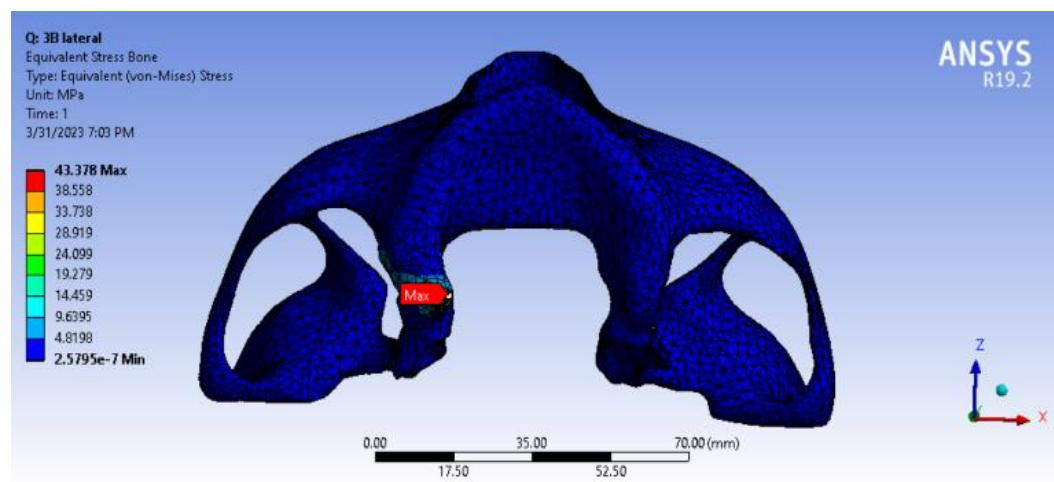


Figure 4. 17. (a) Maximum stress on surrounding bone for 3A model under 50N lateral loading (b) Maximum stress on implant for 3A model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.18), under 50-N lateral force application.

Maximum equivalent stress was measured at 225.03 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 43.378 Mpa, as shown in (Table 4.2).

(a)



(b)

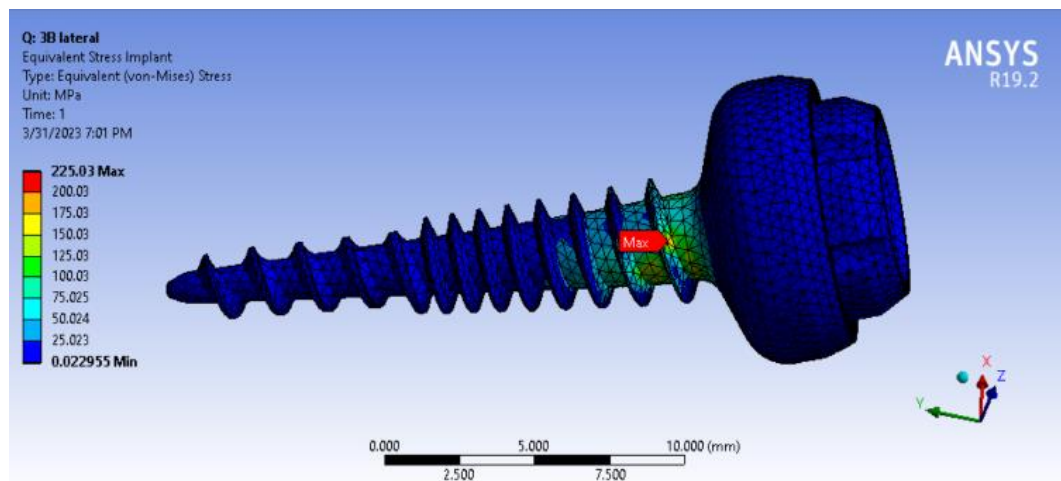
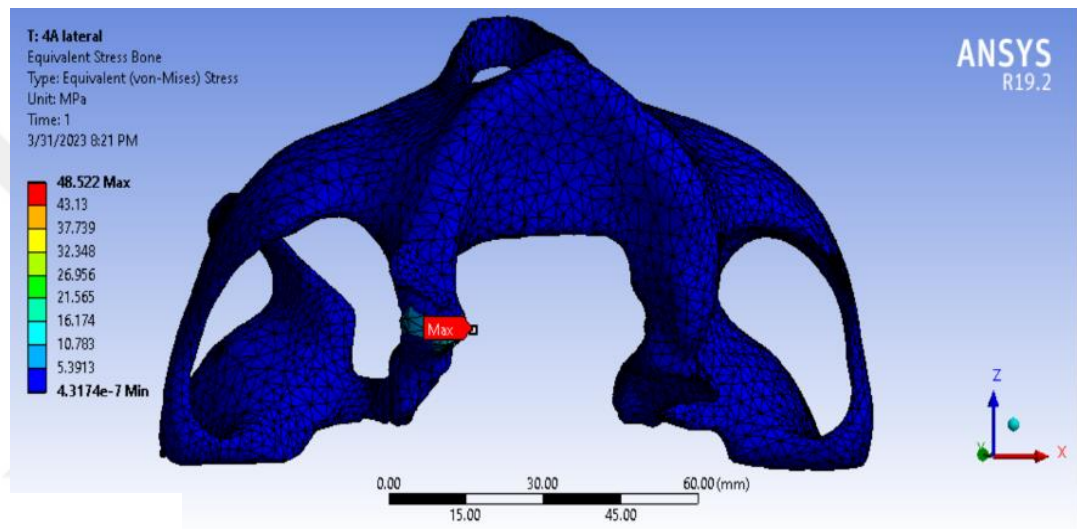


Figure 4. 18. (a) Maximum stress on surrounding bone for 3B model under 50N lateral loading (b) Maximum stress on implant for 3B model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.19), under 50-N lateral force application.

Maximum equivalent stress was measured at 158.18 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 48.522 Mpa, as shown in (Table 4.2).

(a)



(b)

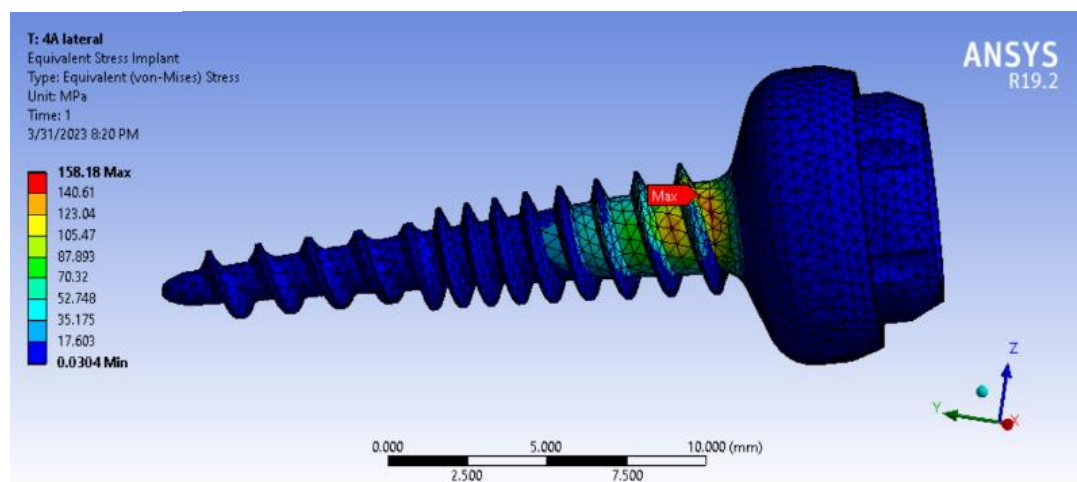
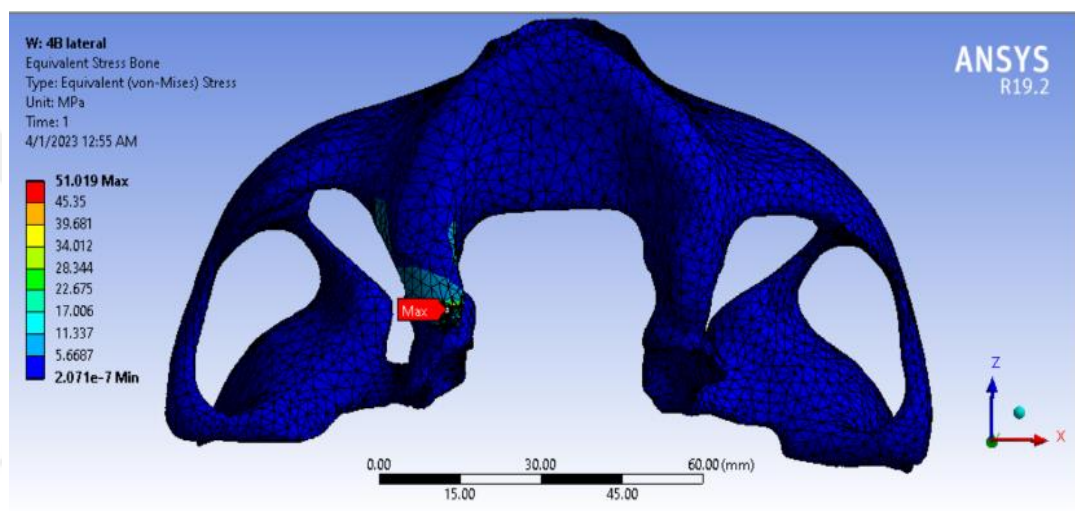


Figure 4. 19. (a) Maximum stress on surrounding bone for 4A model under 50N lateral loading (b) Maximum stress on implant for 4A model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.20), under 50-N lateral force application.

Maximum equivalent stress was measured at 184.49 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 51.019 Mpa, as shown in (Table 4.2).

(a)



(b)

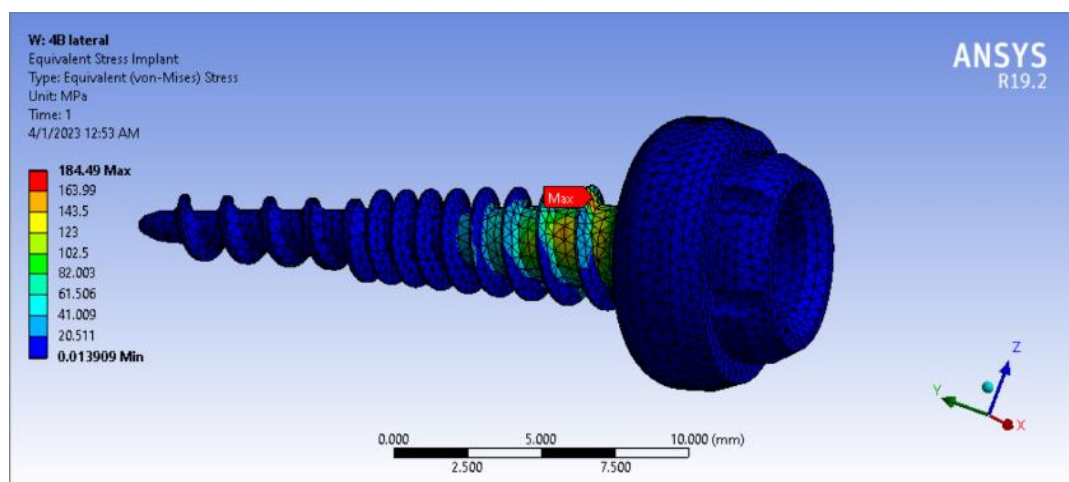
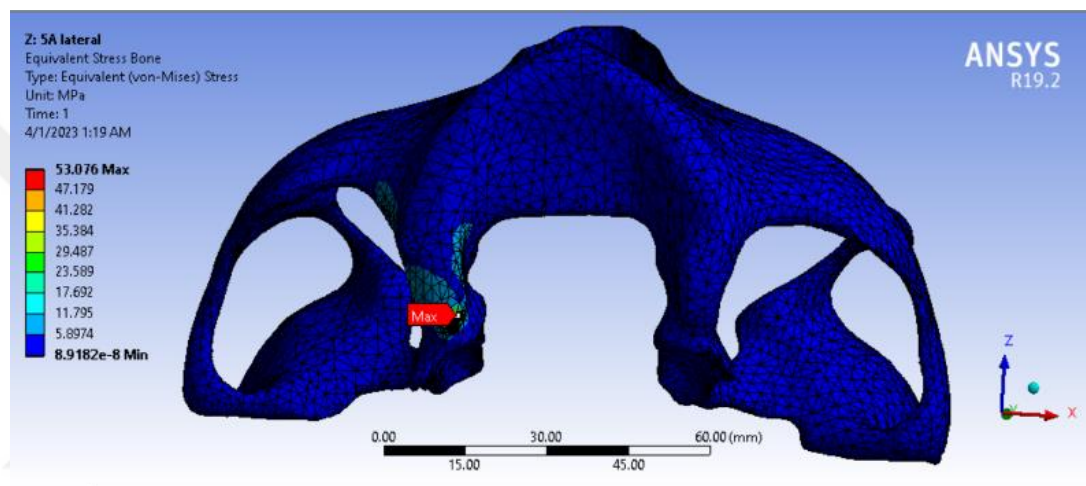


Figure 4. 20. (a) Maximum stress on surrounding bone for 4B model under 50N lateral loading (b) Maximum stress on implant for 4B model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.21), under 50-N lateral force application.

Maximum equivalent stress was measured at 222.43 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 53.076 Mpa, as shown in (Table 4.2).

(a)



(b)

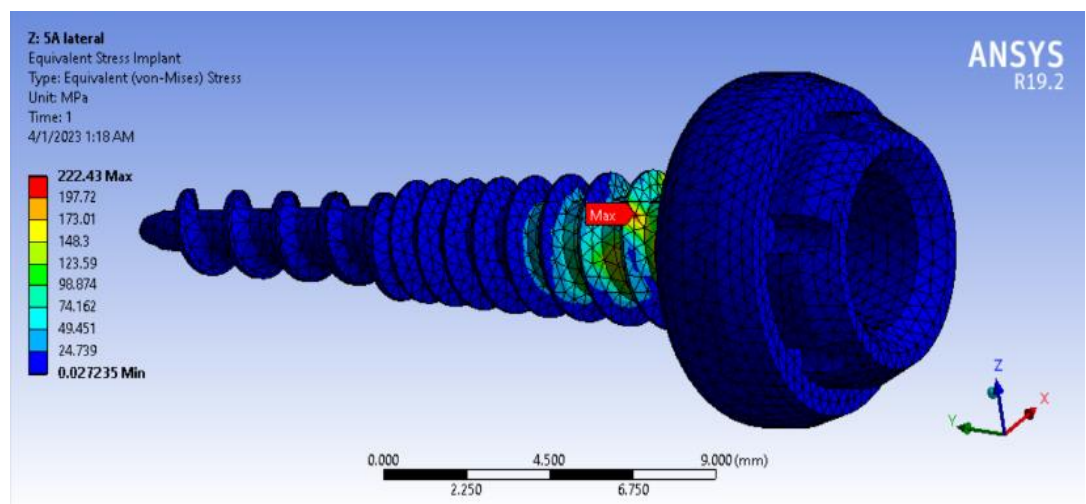
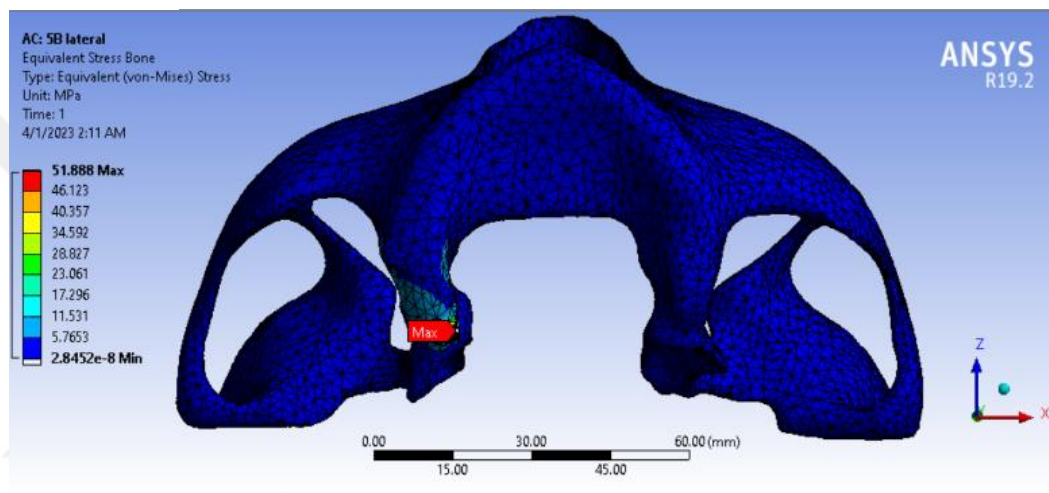


Figure 4. 21. (a) Maximum stress on surrounding bone for 5A model under 50N lateral loading (b) Maximum stress on implant for 5A model under 50N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.22), under 50-N lateral force application.

Maximum equivalent stress was measured at 278.52 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 51.888 Mpa, as shown in (Table 4.2).

(a)



(b)

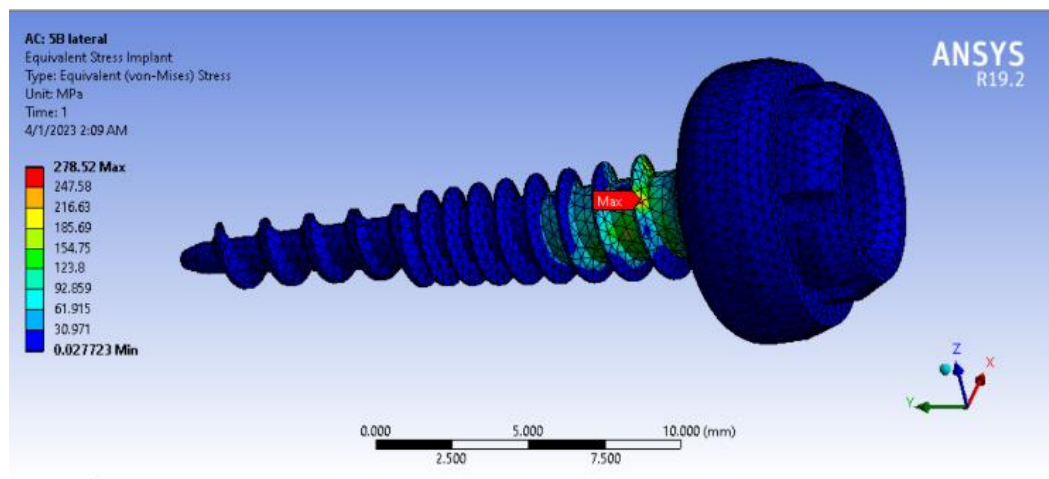


Figure 4. 22. (a) Maximum stress on surrounding bone for 5B model under 50N lateral loading (b) Maximum stress on implant for 5B model under 50N lateral loading

4.1.3. Simultaneous application of 150-N axial and a 50-N lateral forces

150-N axial load and a 50-N lateral load simultaneously were applied on the occlusal surface above the abutment of a pterygoid dental implant with monocortical (end border of crest and cancellous bone) and bicortical (between crest and basal bone) placed at 45, 55, 65, 75, and 85 angle degrees according to the Frankfort Horizontal Plane, the loadings were uniformly distributed .

Maximum Von Mises Stress values and location on the implant's body are shown in table 4.3 , (Figure 4.23). The greatest stress in all models was recorded at 527.88 MPa in 45 angle degree bicortically placed model . The lowest value is 214.06 MPa, was recorded in 75 angle degree monocortically placed model.

Maximum Von Mises Stress values and location on the surrounding bone are shown in table 4.3 , (Figure 4.23). The greatest stress in all models was recorded at 130.86 MPa in 75 angle degree bicortically placed model . The lowest value was recorded in 75 angle degree monocortically placed model as 59.253 Mpa.

Table 4.3. Von Mises Stress and location under 150-N axial loading with simultaneous 50-N lateral loading

Models	Maximum stress in implant MPa	Maximum stress in implant location	Maximum stress in bone MPa	Maximum stress in bone location
1A	451.62	Abutment connection area of the pterygoid abutment	111.88	Crestal bone at pterygoid implant
1B	527.88	Abutment connection area of the pterygoid abutment	116.23	Crestal bone at pterygoid implant
2A	313.23	Abutment connection area of the pterygoid abutment	74.836	Crestal bone at pterygoid implant
2B	377.71	Abutment connection area of the pterygoid abutment	75.124	Crestal bone at pterygoid implant
3A	280.23	Abutment connection area of the pterygoid abutment	76.471	Crestal bone at pterygoid implant
3B	276.06	Abutment connection area of the pterygoid abutment	73.458	Crestal bone at pterygoid implant
4A	214.06	Abutment connection area of the pterygoid abutment	59.253	Crestal bone at pterygoid implant
4B	244.03	Abutment connection area of the pterygoid abutment	130.86	Crestal bone at pterygoid implant

5A	226.67	Abutment connection area of the pterygoid abutment	129.65	Crestal bone at pterygoid implant
5B	282.7	Abutment connection area of the pterygoid abutment	67.359	Crestal bone at pterygoid implant

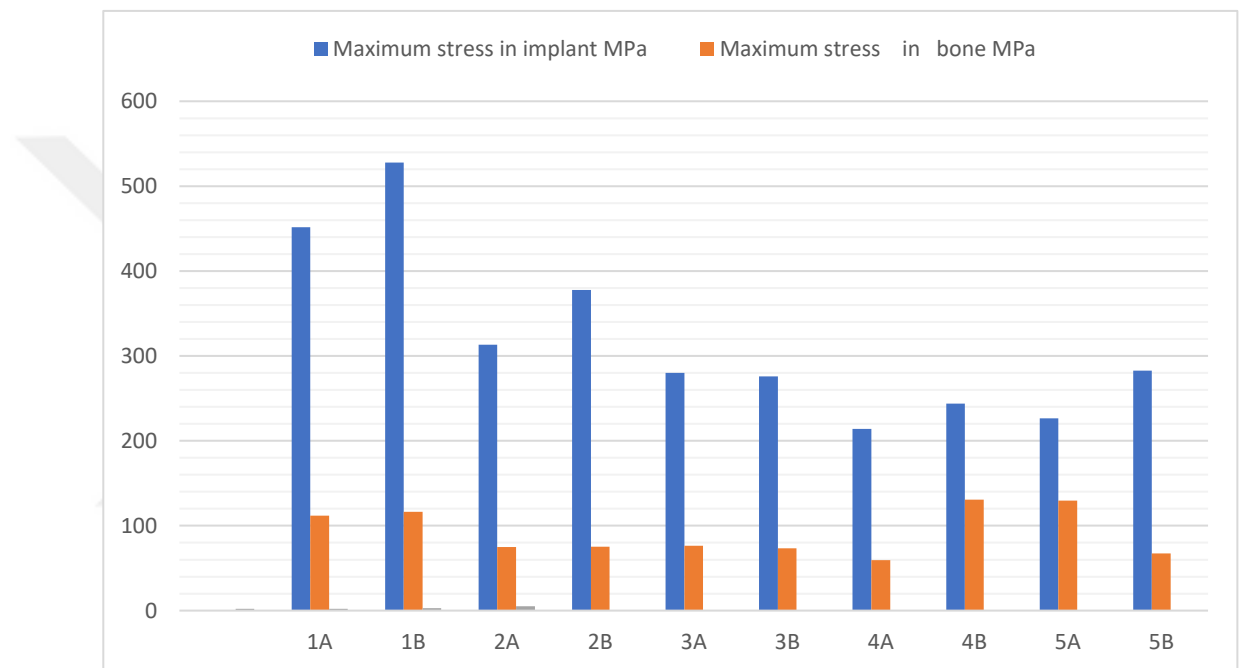


Figure 4. 23. Maximum stress in the implant and surrounding bone for each model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.24), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 451.62 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 111.88 Mpa, as shown in (Table 4.3).

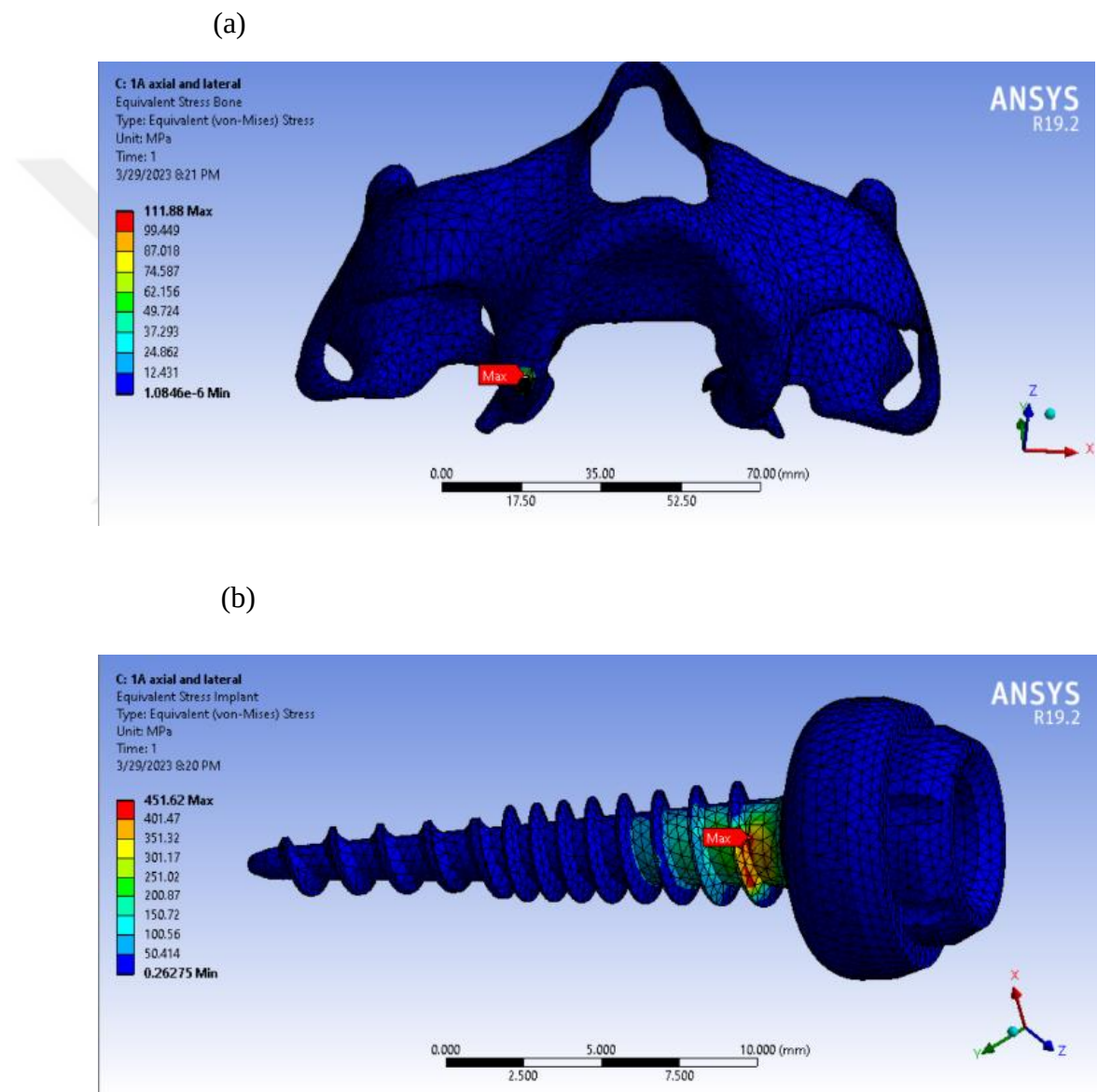
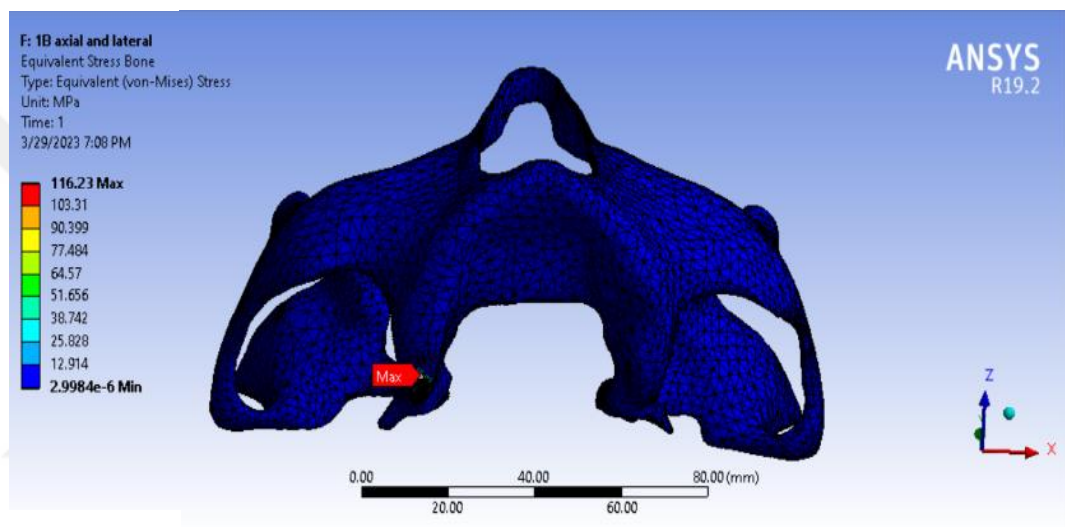


Figure 4. 24. (a) Maximum stress on surrounding bone for 1A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 1A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.25), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 527.88 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 116.23 Mpa, as shown in (Table 4.3).

(a)



(b)

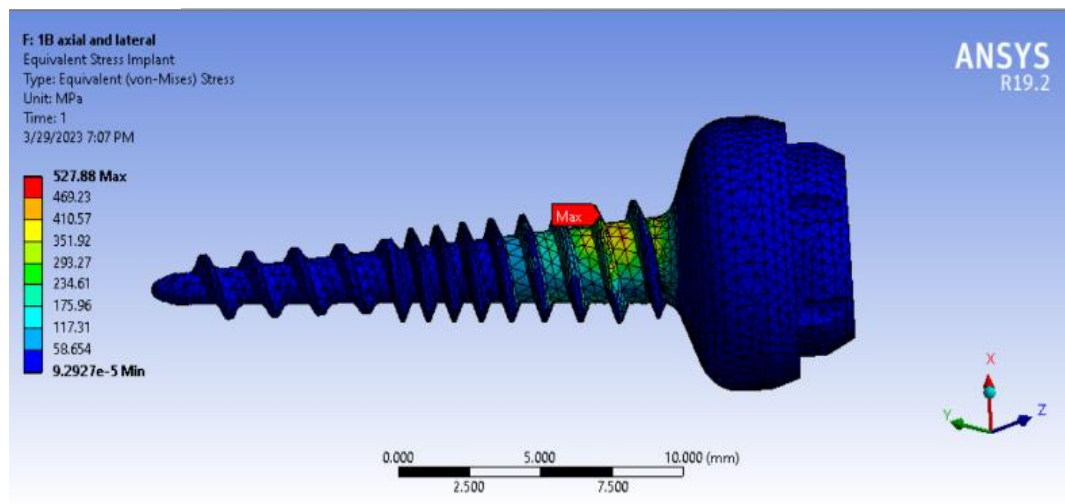
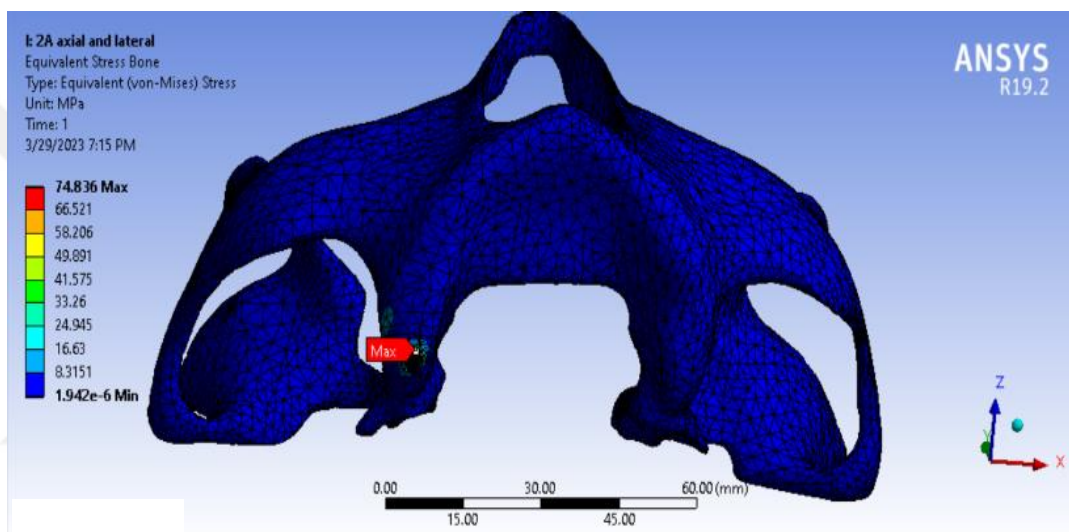


Figure 4. 25. (a) Maximum stress on surrounding bone for 1B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 1B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.26), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 313.23 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 74.836 Mpa, as shown in (Table 4.3).

(a)



(b)

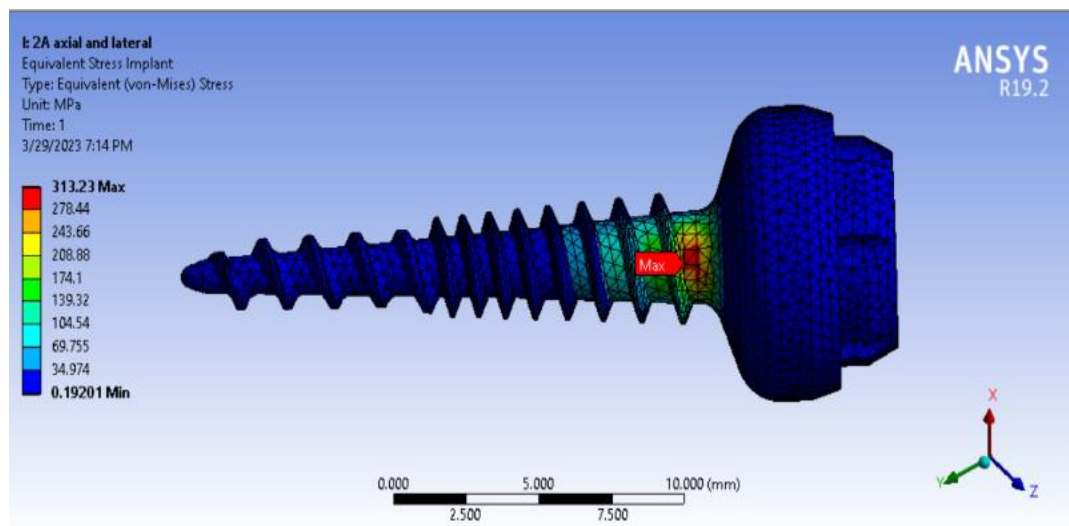
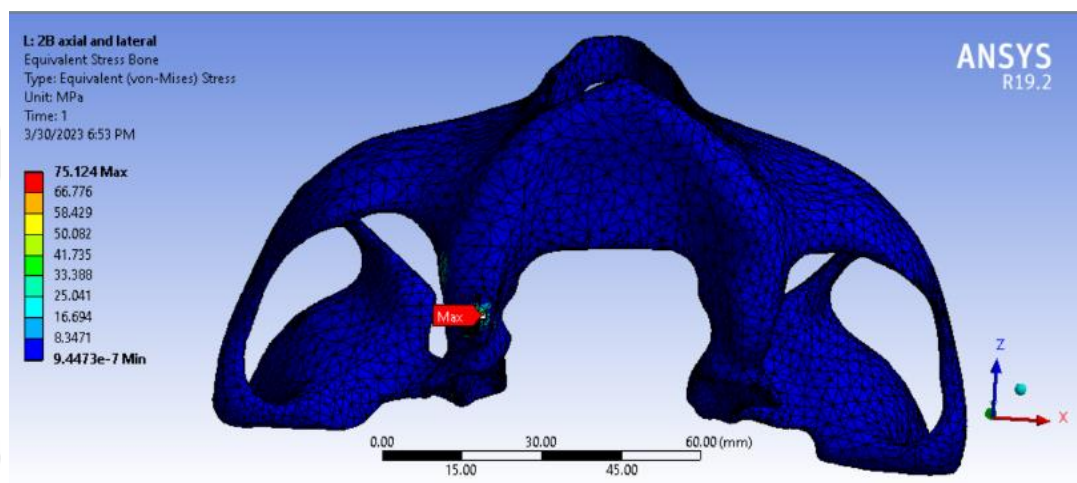


Figure 4. 26. (a) Maximum stress on surrounding bone for 2A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 2A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.27), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 377.71 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 75.124 Mpa, as shown in (Table 4.3).

(a)



(b)

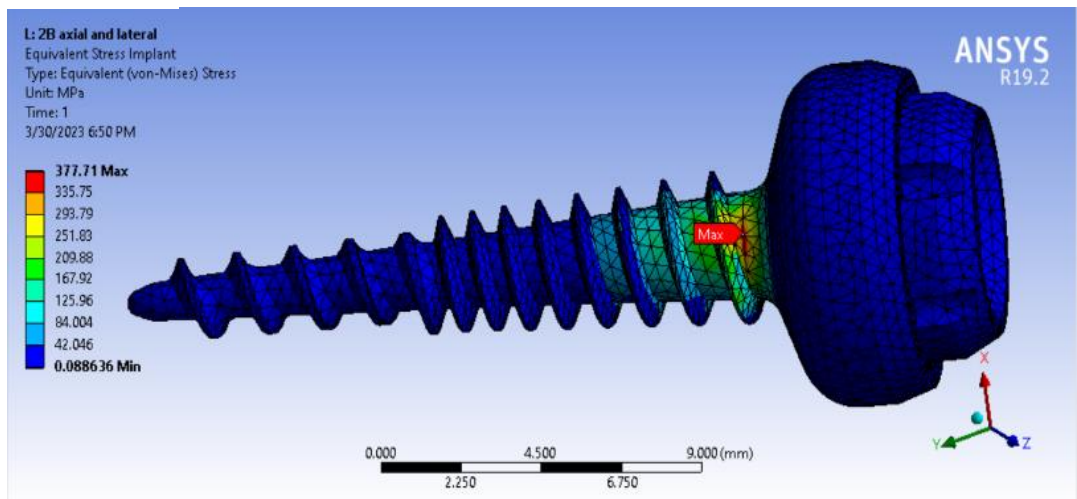
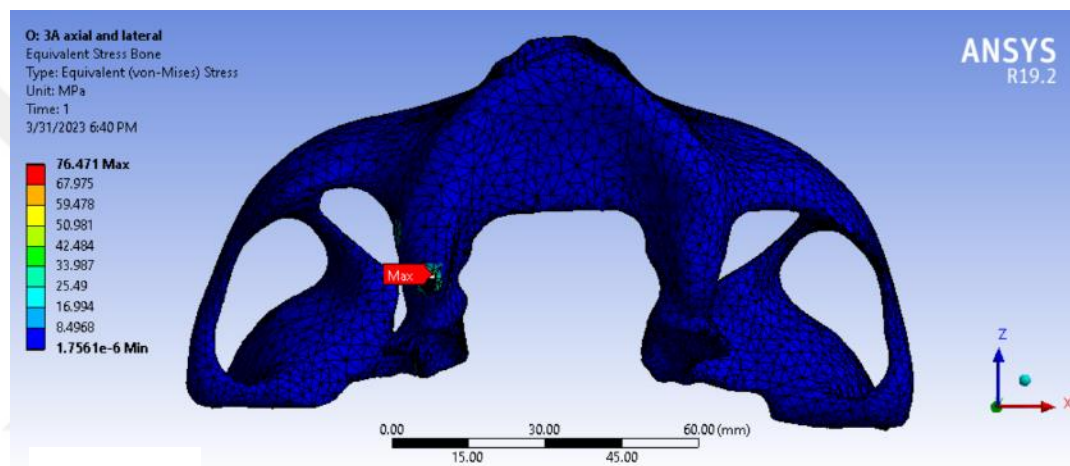


Figure 4. 27. (a) Maximum stress on surrounding bone for 2B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 2B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.28), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 280.23 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 76.471 Mpa, as shown in (Table 4.3).

(a)



(b)

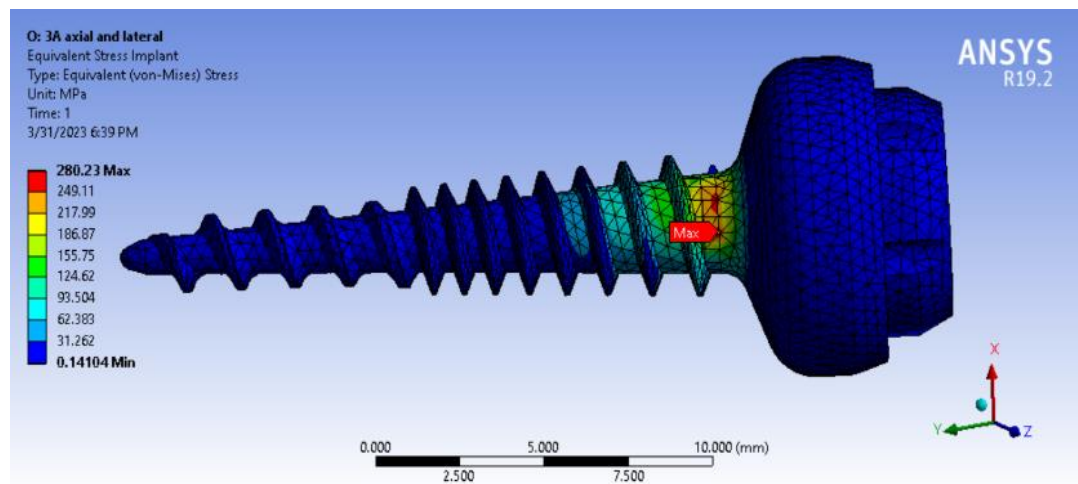
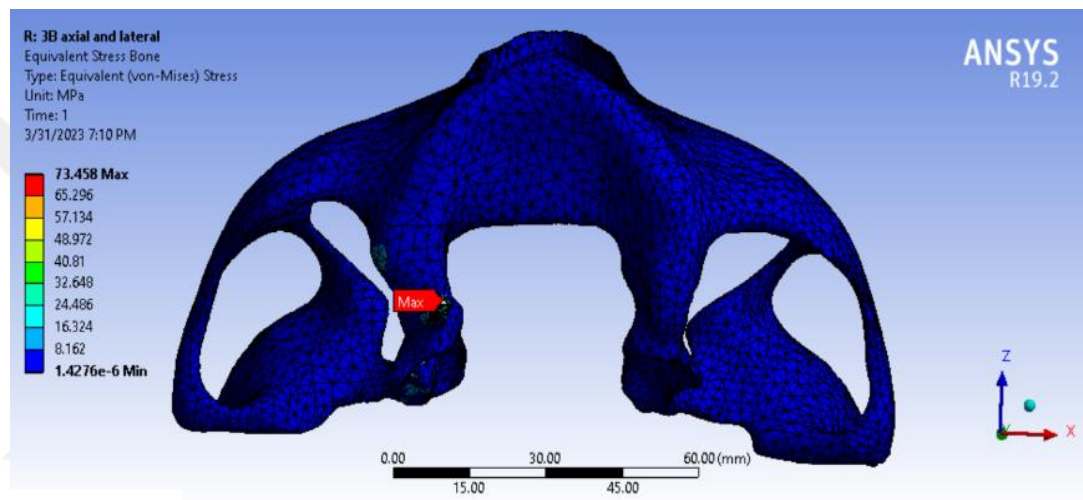


Figure 4. 28. (a) Maximum stress on surrounding bone for 3A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 3A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.29), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 276.06 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 73.458 Mpa, as shown in (Table 4.3).

(a)



(b)

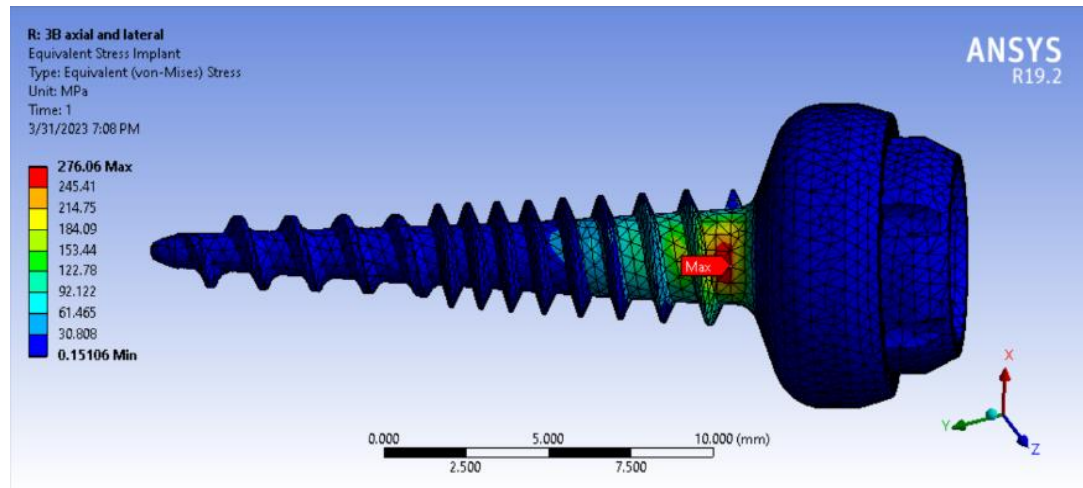
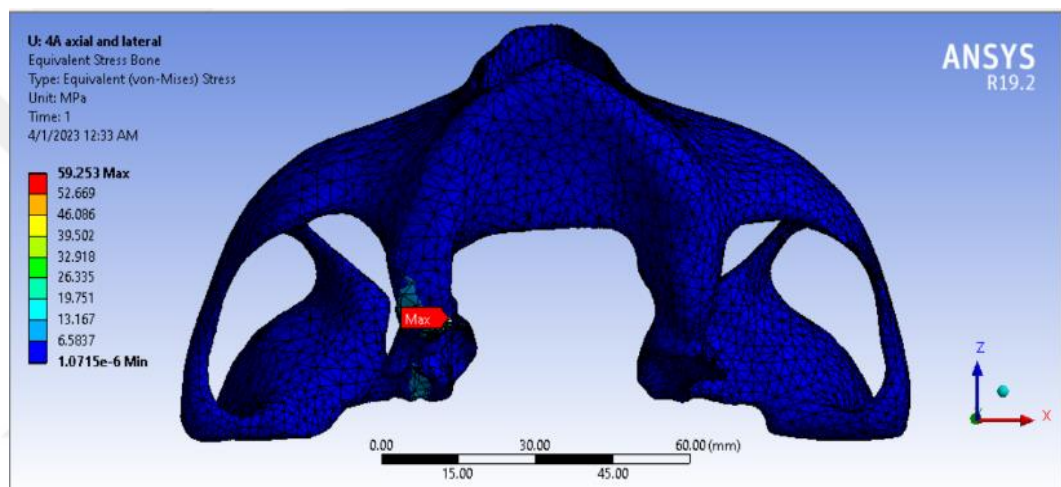


Figure 4. 29. (a) Maximum stress on surrounding bone for 3B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 3B model under 150-N axial loading with simultaneous 50-N lateral loading.

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.30), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 214.06 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 59.253 Mpa, as shown in (Table 4.3).

(a)



(b)

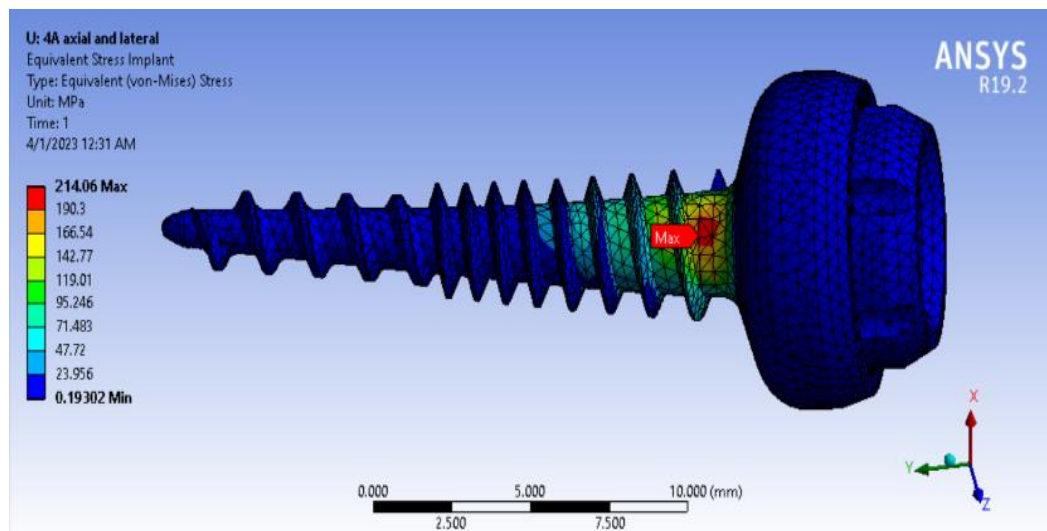
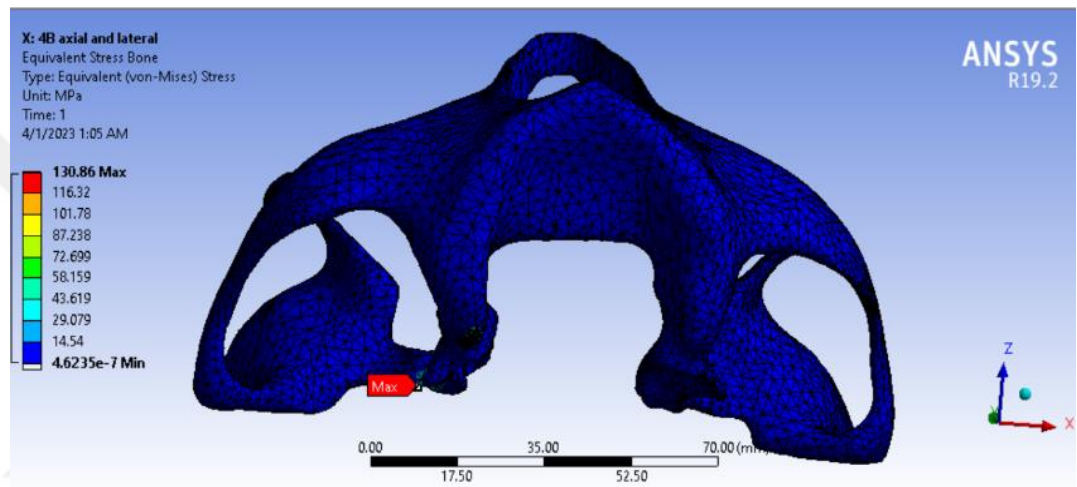


Figure 4. 30. (a) Maximum stress on surrounding bone for 4A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 4A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.31), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 244.03 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 130.86 Mpa, as shown in (Table 4.3).

(a)



(b)

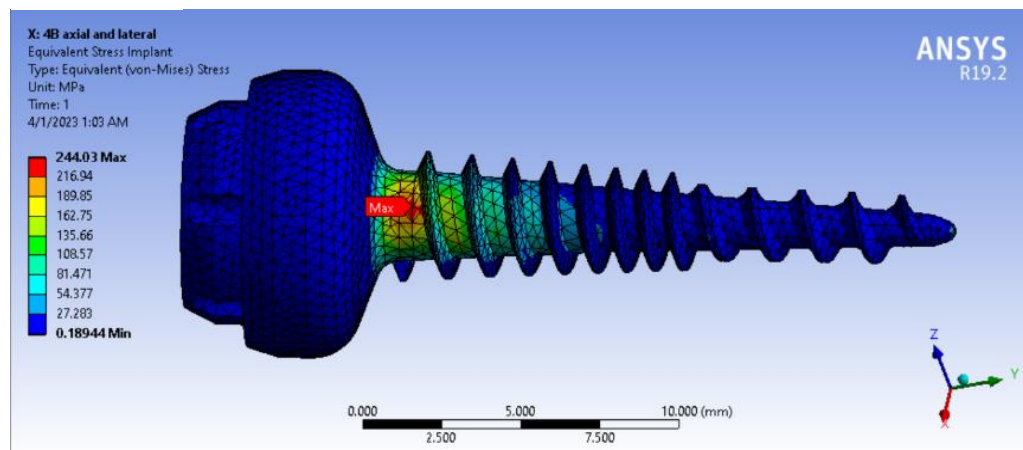
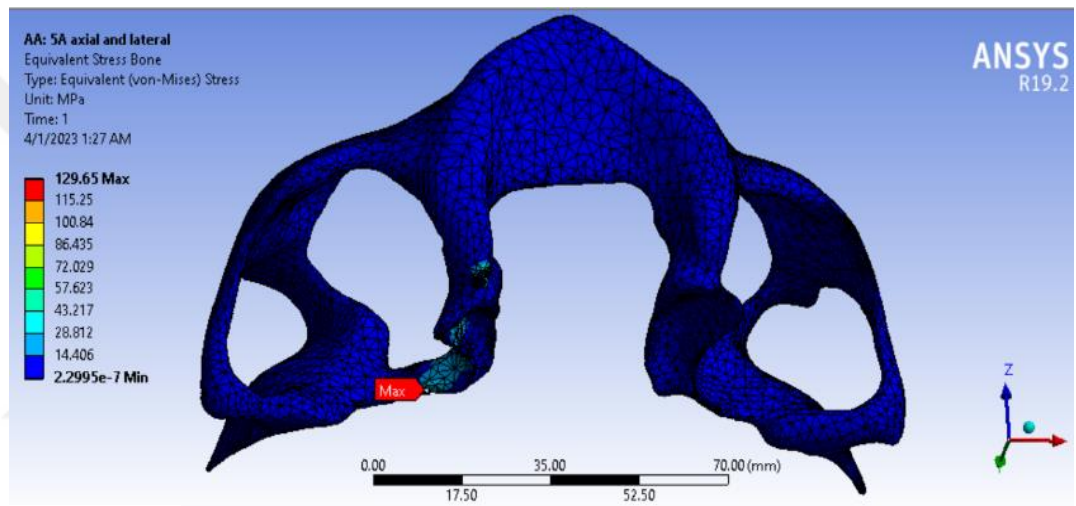


Figure 4. 31. (a) Maximum stress on surrounding bone for 4B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 4B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.32), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 226.67 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 129.65 Mpa, as shown in (Table 4.3).

(a)



(b)

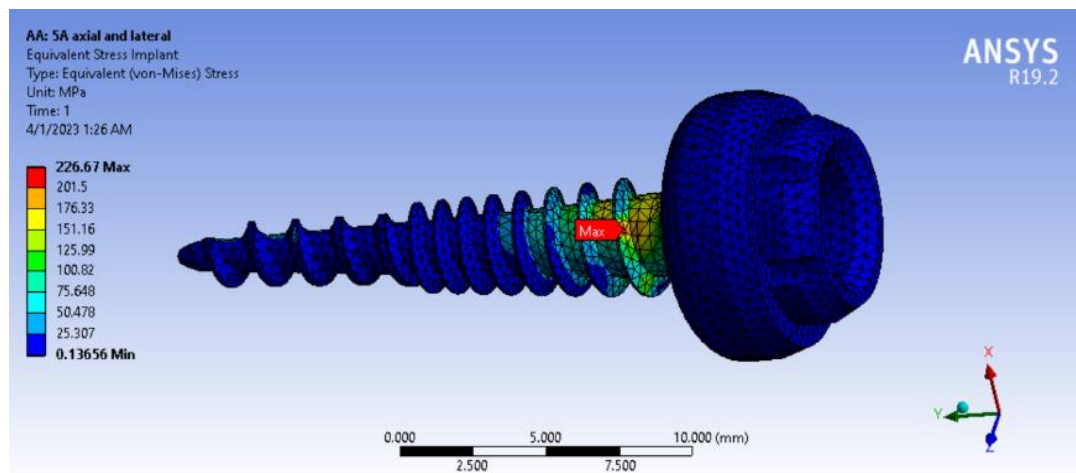
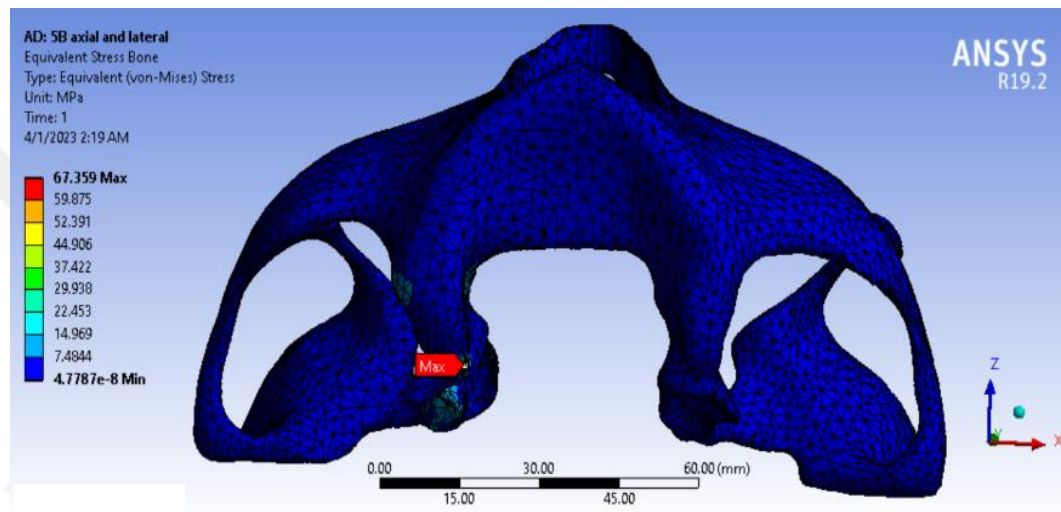


Figure 4. 32. (a) Maximum stress on surrounding bone for 5A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 5A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent stress relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.33), under 150-N axial with simultaneous 50-N lateral application.

Maximum equivalent stress was measured at 282.7 Mpa on the titanium implant, and the maximum equivalent stress value on the surrounding bone was recorded at 67.359 Mpa, as shown in (Table 4.3).

(a)



(b)

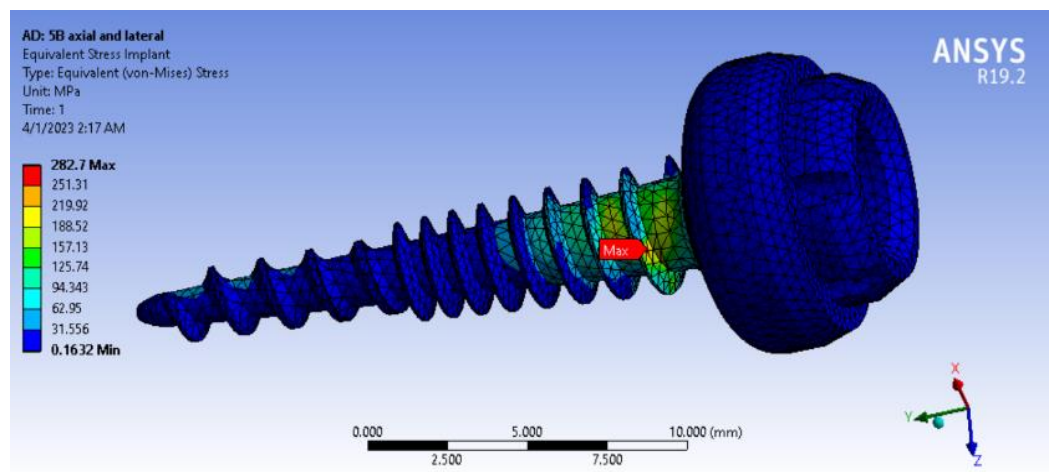


Figure 4. 33. (a) Maximum stress on surrounding bone for 5B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum stress on implant for 5B model under 150-N axial loading with simultaneous 50-N lateral loading.

4.2.Strain

4.2.1. 150-N axial force application

Uniformly distributed loadings of 150 N axial force were applied to the occlusal surface above the abutment of a pterygoid dental implant at 45, 55, 65, 75, and 85 angle degrees (monocortical and bicortical) according to the Frankfort Horizontal Plane .

Maximum equivalent strain values (mm/mm) and location on the implant's body are shown in table 4.4 , (Figure 4.34). The greatest strain in all models was recorded at 0.0062863 mm/mm in 45 angle degree bicortically placed model . The lowest value was recorded in 85 angle degree monocortically placed model at 0.00071347 mm/mm .

Maximum equivalent strain values (mm/mm) and location on the surrounding bone are shown in table 4.4 , (Figure 4.34). The greatest strain in all models was recorded at 0.01179 mm/mm in 45 angle degree bicortically placed model . The lowest value was recorded in 85 angle degree bicortically placed model at 0.0031925 mm/mm .

Table 4.4. Total integrated strain and location under 150N axial loading

Models	Maximum strain in implant mm/mm	Maximum strain in implant location	Maximum strain in bone mm/mm	Maximum strain in bone location
1A	0.0047803	Abutment connection area of the pterygoid abutment	0.010045	Crestal bone at pterygoid implant
1B	0.0062863	Abutment connection area of the pterygoid abutment	0.01179	Crestal bone at pterygoid implant
2A	0.0026764	Abutment connection area of the pterygoid abutment	0.0069947	Crestal bone at pterygoid implant
2B	0.0030974	Abutment connection area of the pterygoid abutment	0.0071572	Crestal bone at pterygoid implant
3A	0.0023491	Abutment connection area of the pterygoid abutment	0.0046206	Crestal bone at pterygoid implant
3B	0.0022635	Abutment connection area of the pterygoid abutment	0.0052826	Crestal bone at pterygoid implant
4A	0.0014674	Abutment connection area of the pterygoid abutment	0.0036724	Crestal bone at pterygoid implant
4B	0.0016005	Abutment connection area of the pterygoid abutment	0.0096716	Crestal bone at pterygoid implant

5A	0.00071347	Abutment connection area of the pterygoid abutment	0.010868	Crestal bone at pterygoid implant
5B	0.00081511	Abutment connection area of the pterygoid abutment	0.0031925	Crestal bone at pterygoid implant

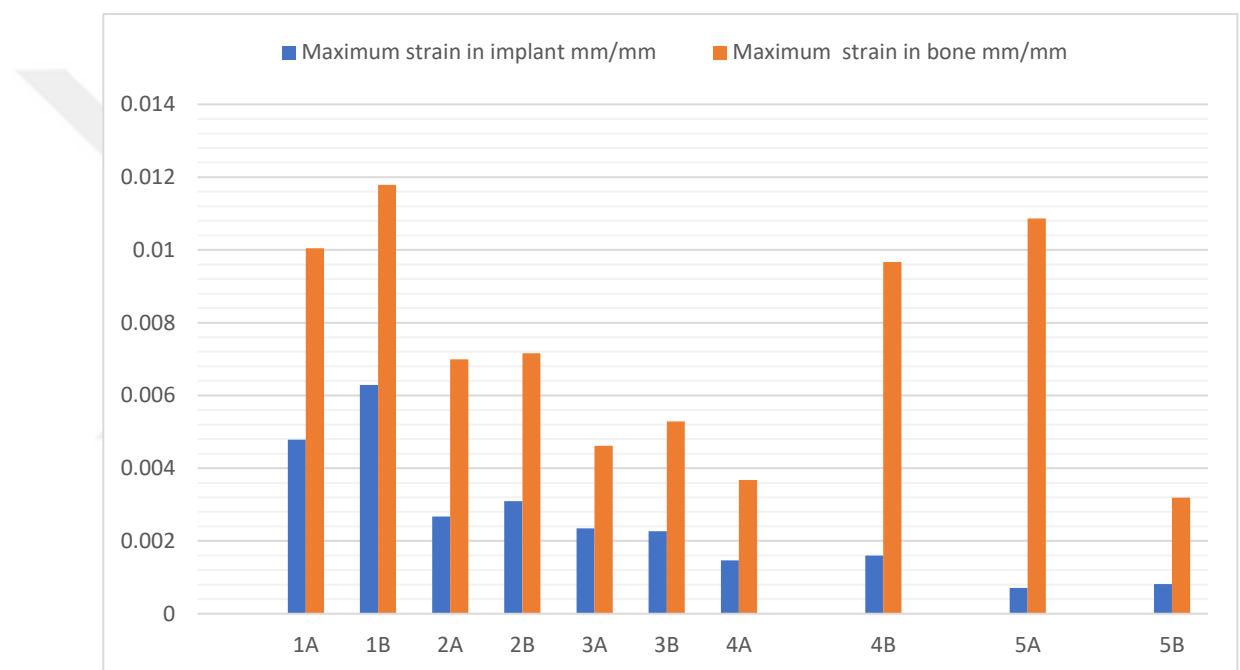
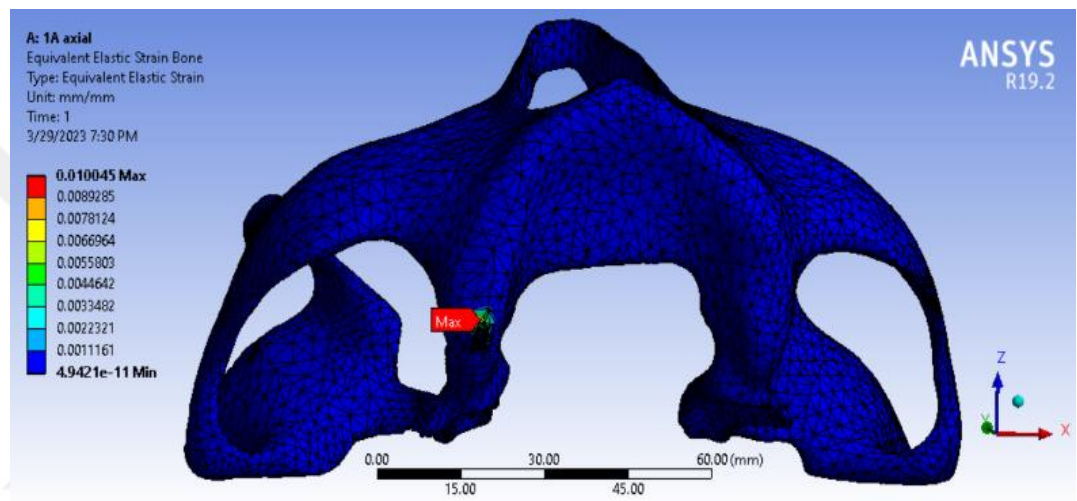


Figure 4. 34. Maximum strain in implant and surrounding bone for each model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.35), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0047803 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.010045 mm/mm, as shown in (Table 4.4).

(a)



(b)

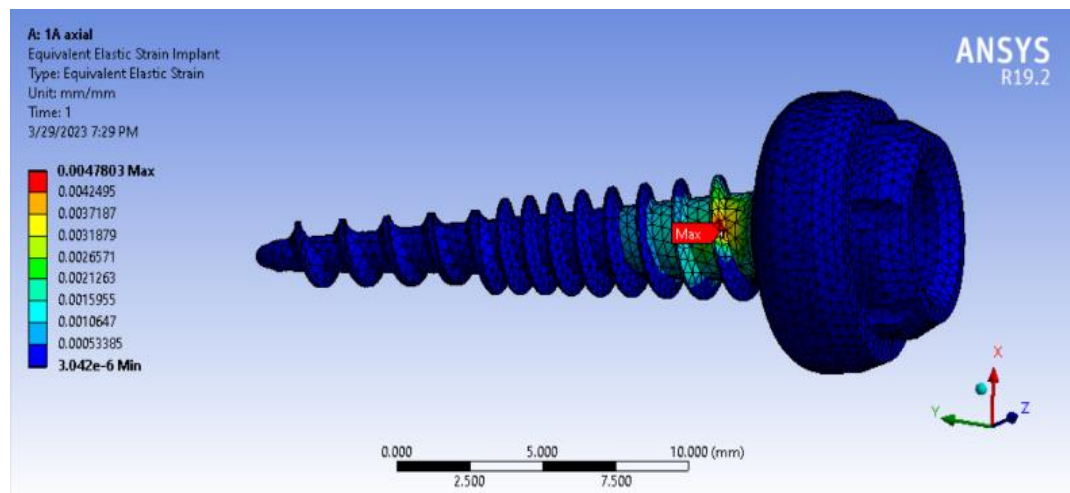
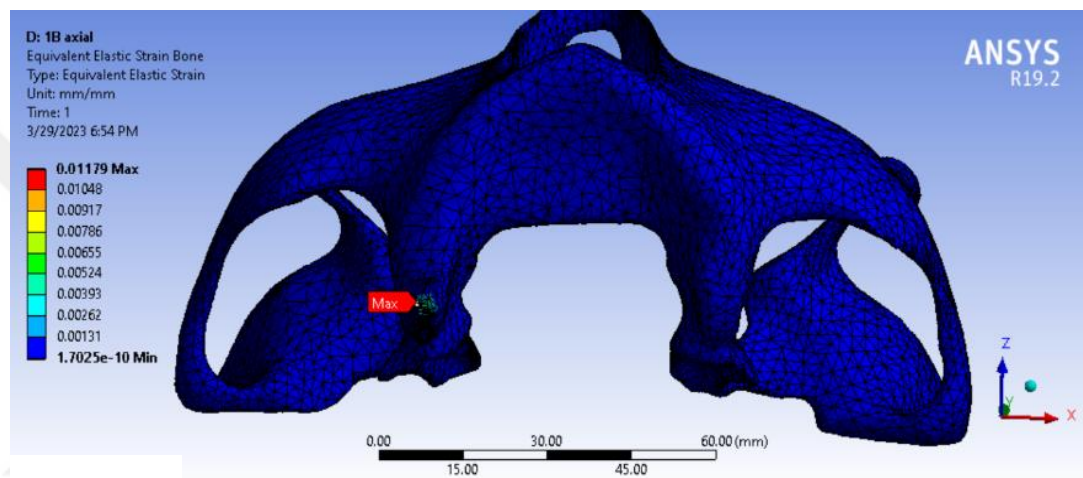


Figure 4. 35. (a) Maximum strain on surrounding bone for 1A model under 150N axial loading (b) Maximum strain on implant for 1A model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.36), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0062863 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.01179 mm/mm , as shown in (Table 4.4).

(a)



(b)

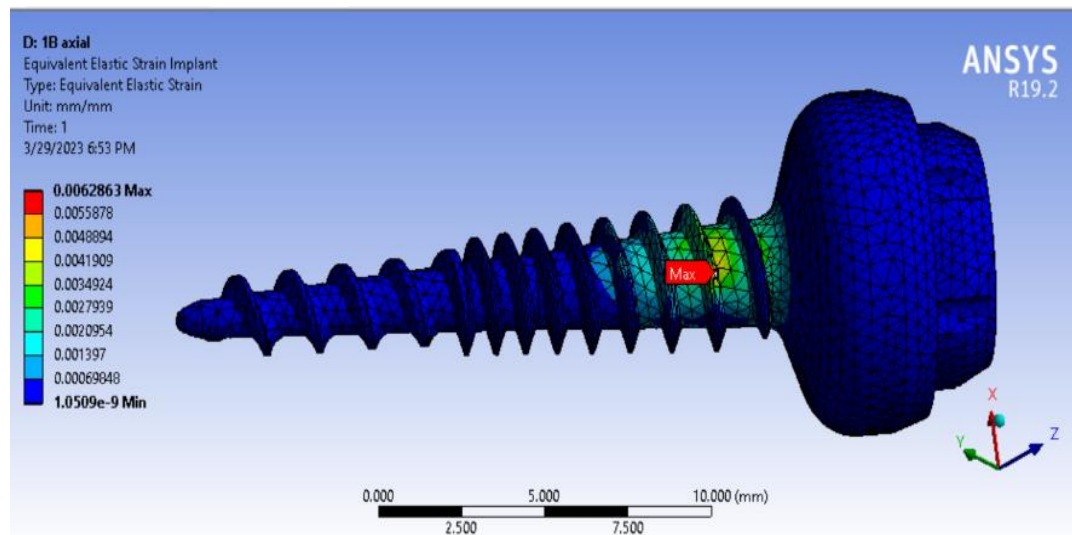
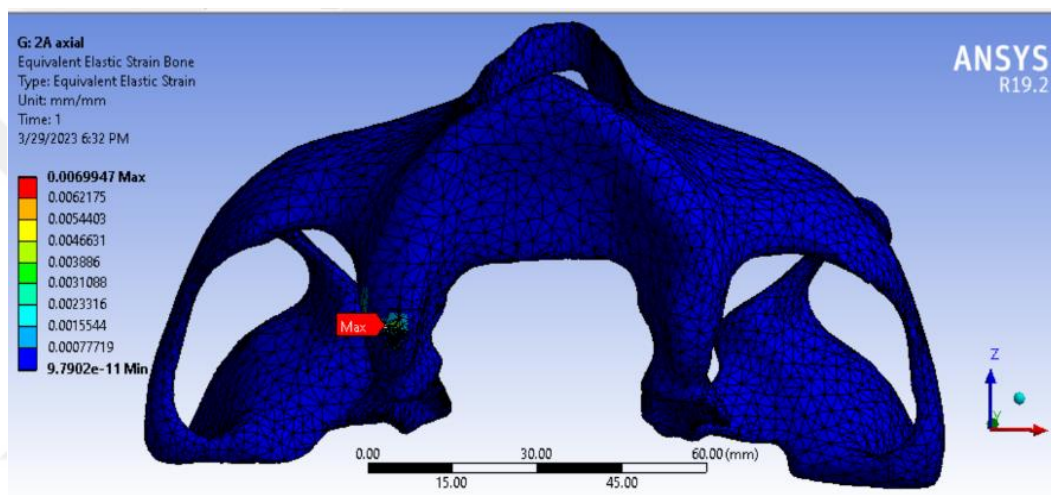


Figure 4. 36. (a) Maximum strain on surrounding bone for 1B model under 150N axial loading (b) Maximum strain on implant for 1B model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.37), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0026764 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0069947 mm/mm, as shown in (Table 4.4).

(a)



(b)

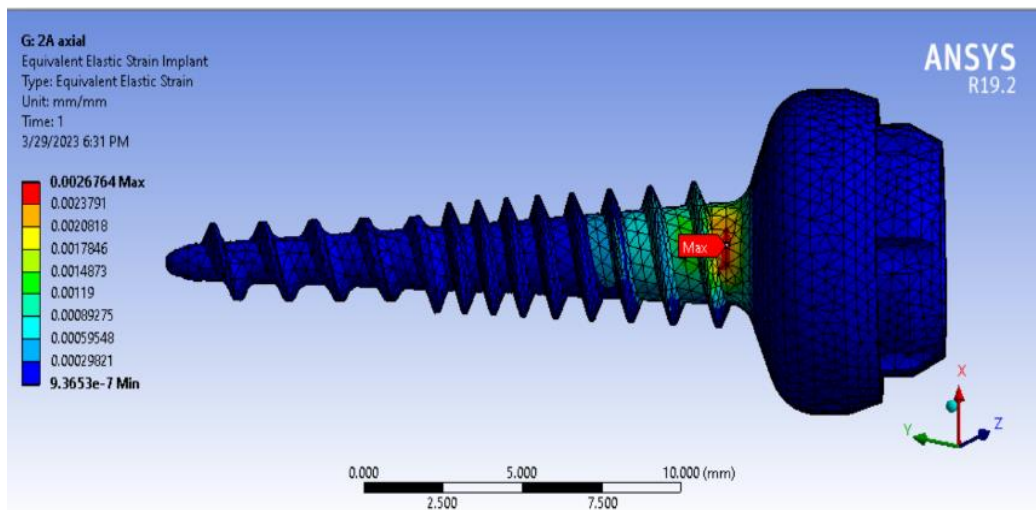
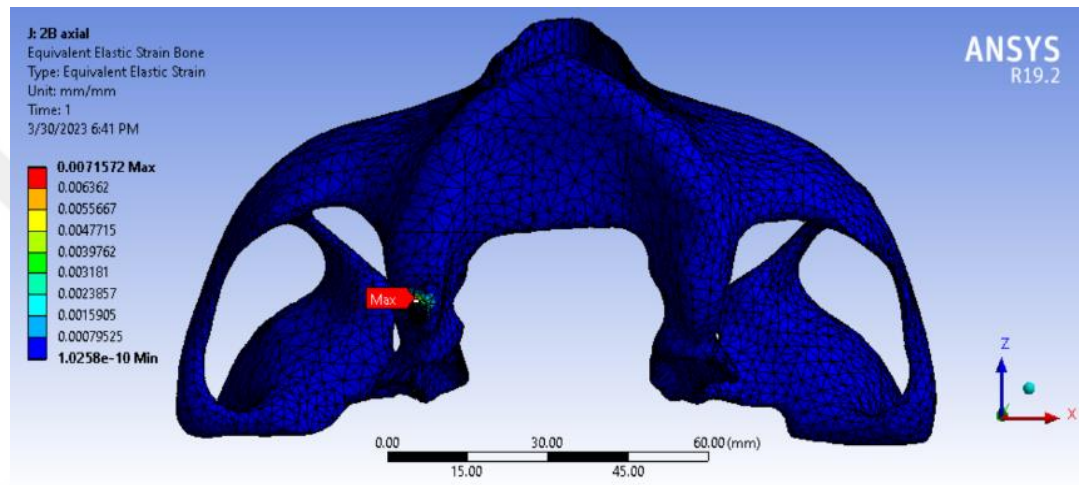


Figure 4. 37. (a) Maximum strain on surrounding bone for 2A model under 150N axial loading (b) Maximum strain on implant for 2A model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.38), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0030974 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0071572 mm/mm, as shown in (Table 4.4).

(a)



(b)

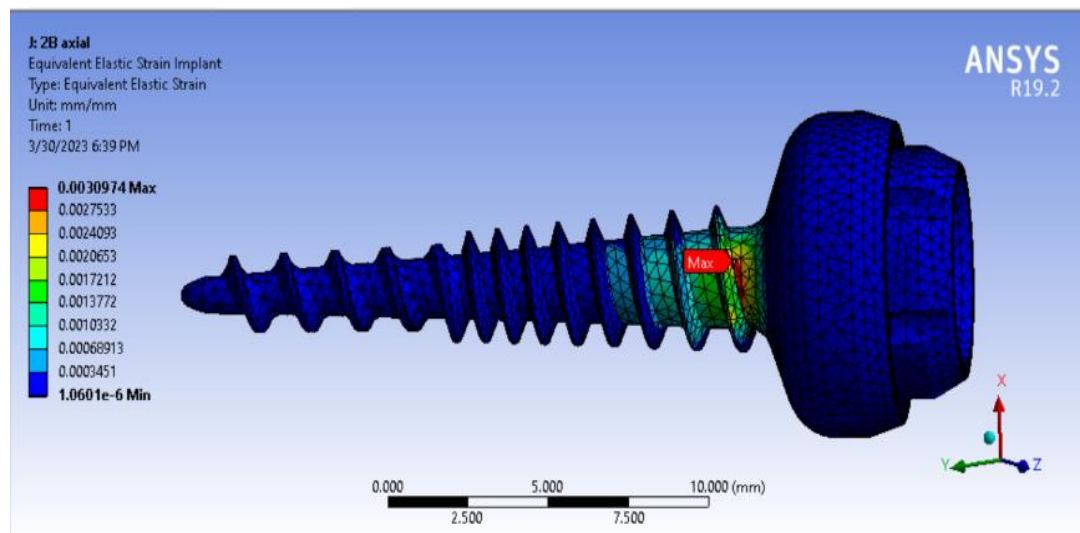
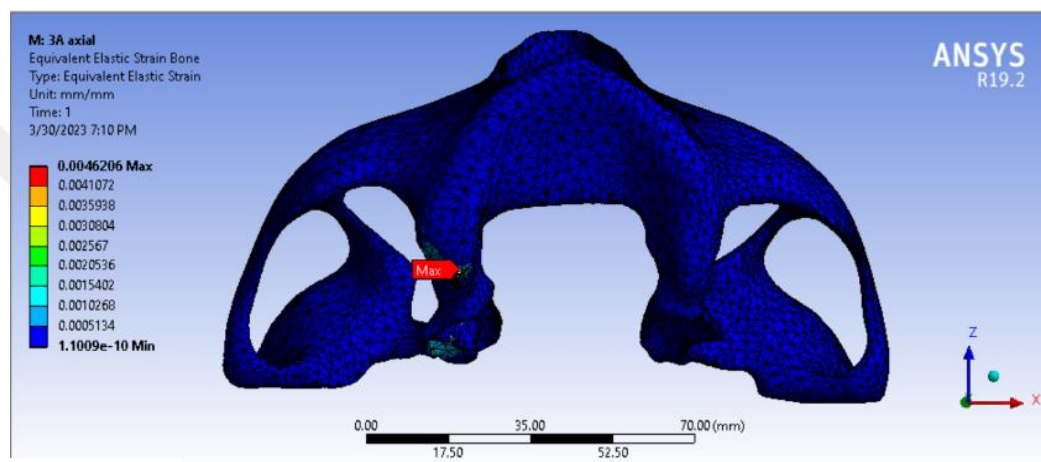


Figure 4. 38. (a) Maximum strain on surrounding bone for 2B model under 150N axial loading (b) Maximum strain on implant for 2B model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.39), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0023491 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0046206 mm/mm, as shown in (Table 4.4).

(a)



(b)

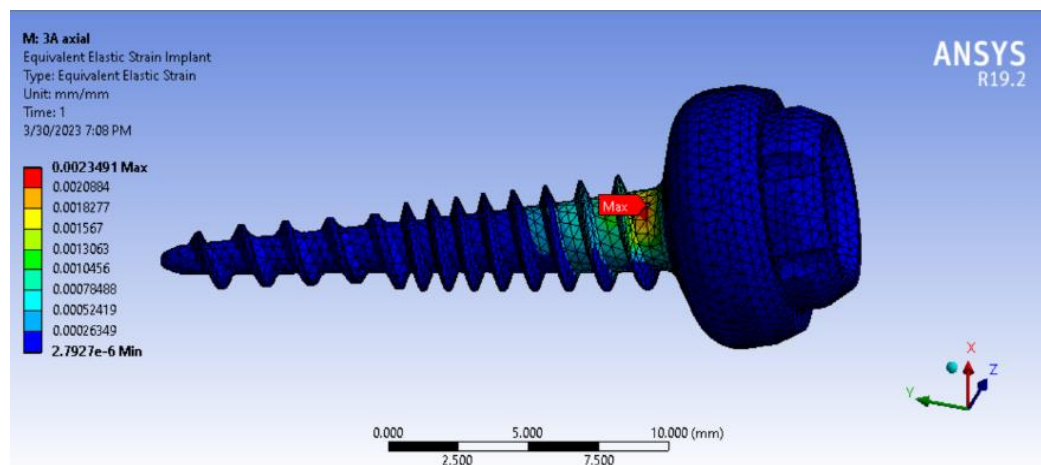
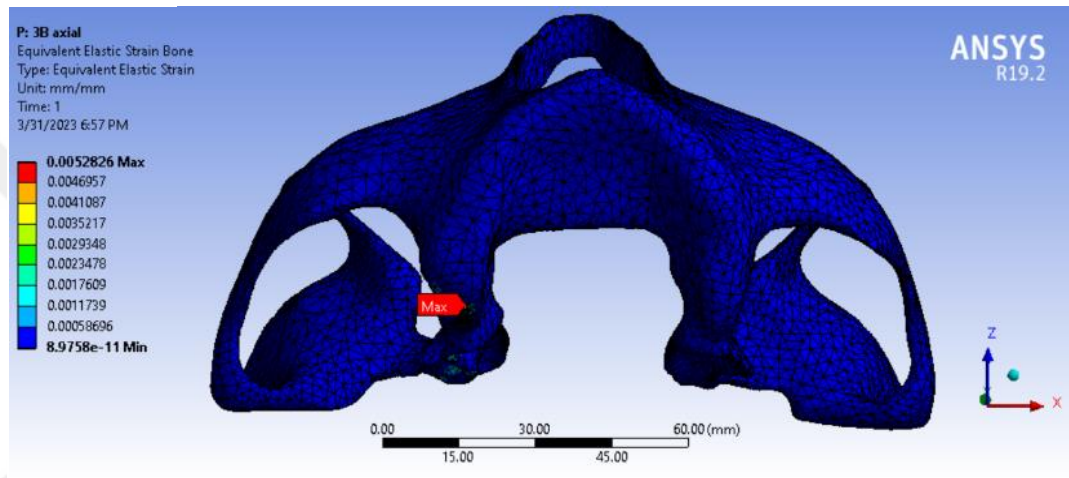


Figure 4. 39. (a) Maximum strain on surrounding bone for 3A model under 150N axial loading (b) Maximum strain on implant for 3A model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.40), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0022635 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0052826 mm/mm, as shown in (Table 4.4).

(a)



(b)

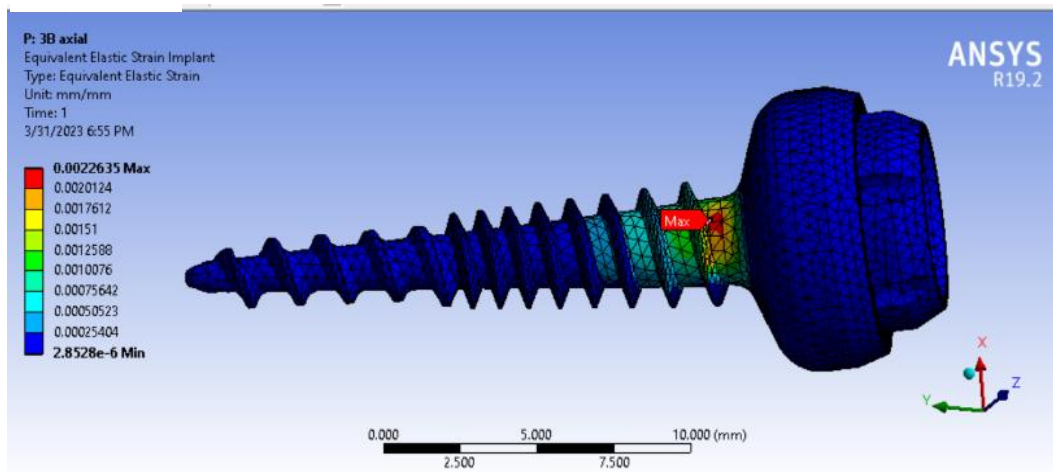
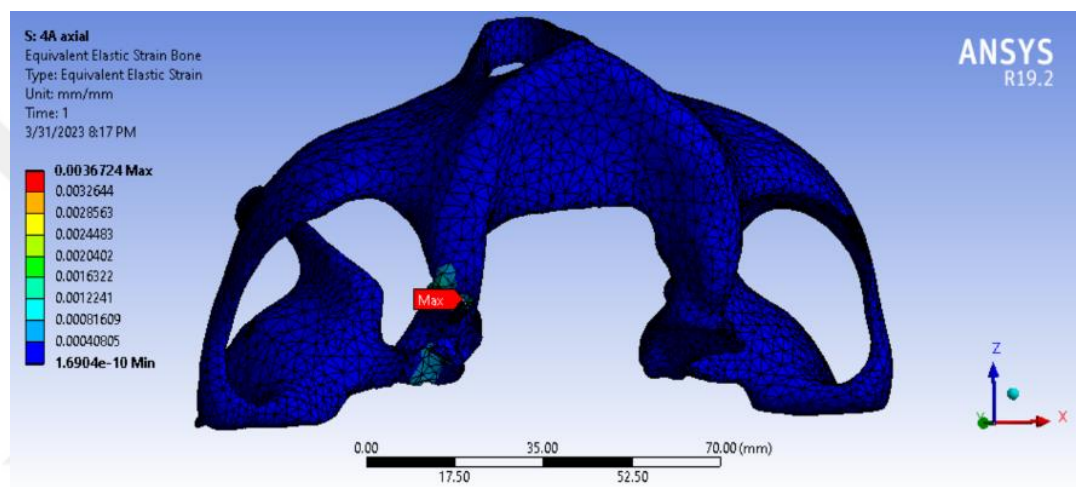


Figure 4. 40. (a) Maximum strain on surrounding bone for 3B model under 150N axial loading (b) Maximum strain on implant for 3B model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.41), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0014674 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0036724 mm/mm, as shown in (Table 4.4).

(a)



(b)

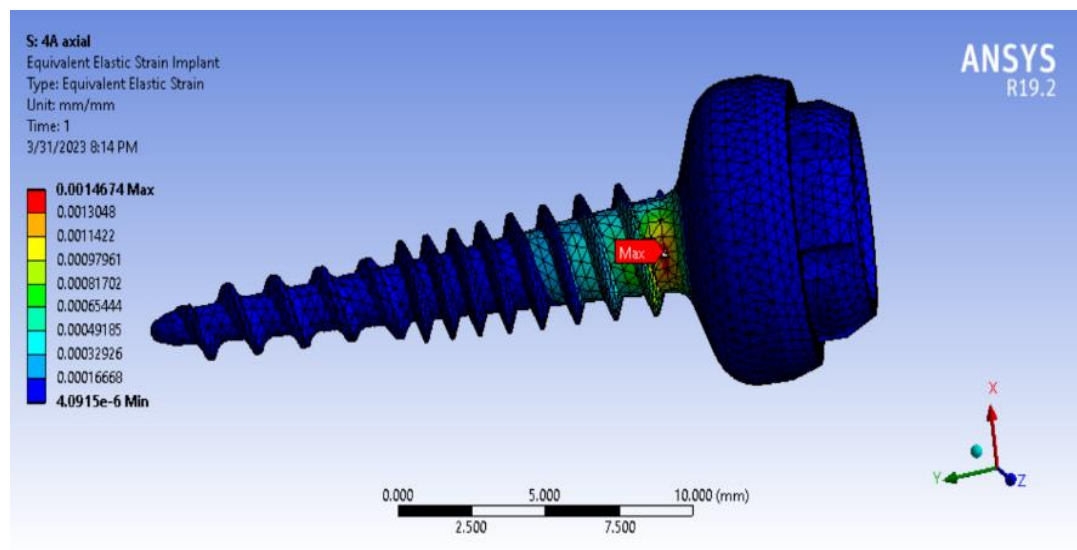
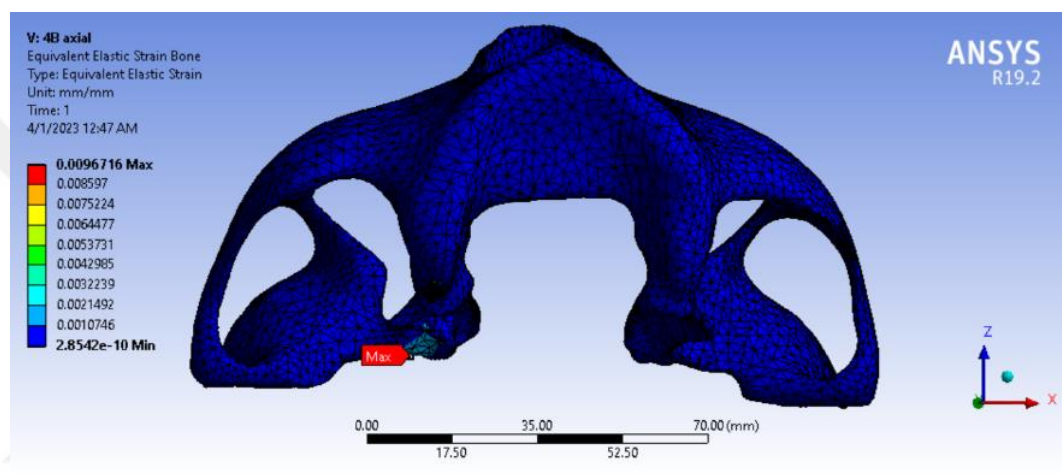


Figure 4. 41. (a) Maximum strain on surrounding bone for 4A model under 150N axial loading (b) Maximum strain on implant for 4A model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.42), under 150-N axial force application.

Maximum equivalent strain was measured at 0.0016005 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0096716 mm/mm, as shown in (Table 4.4).

(a)



(b)

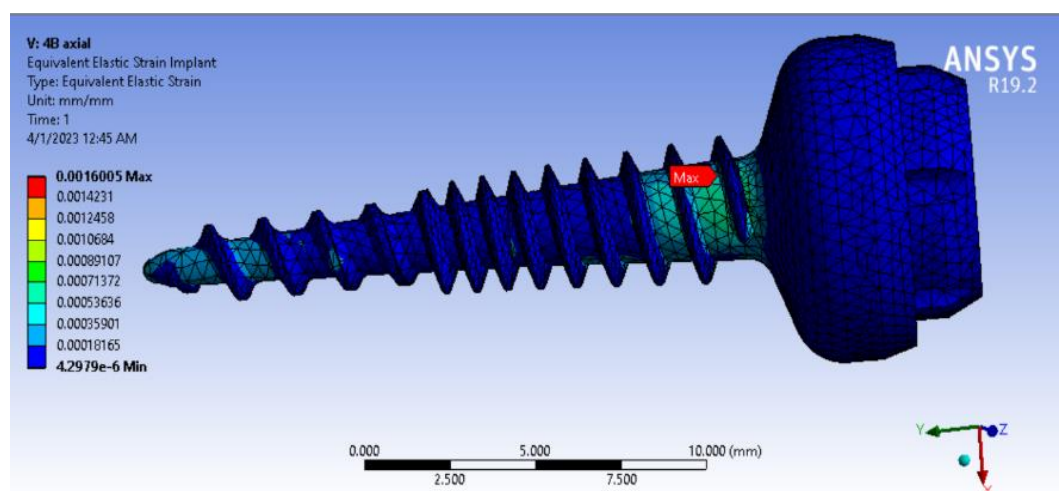
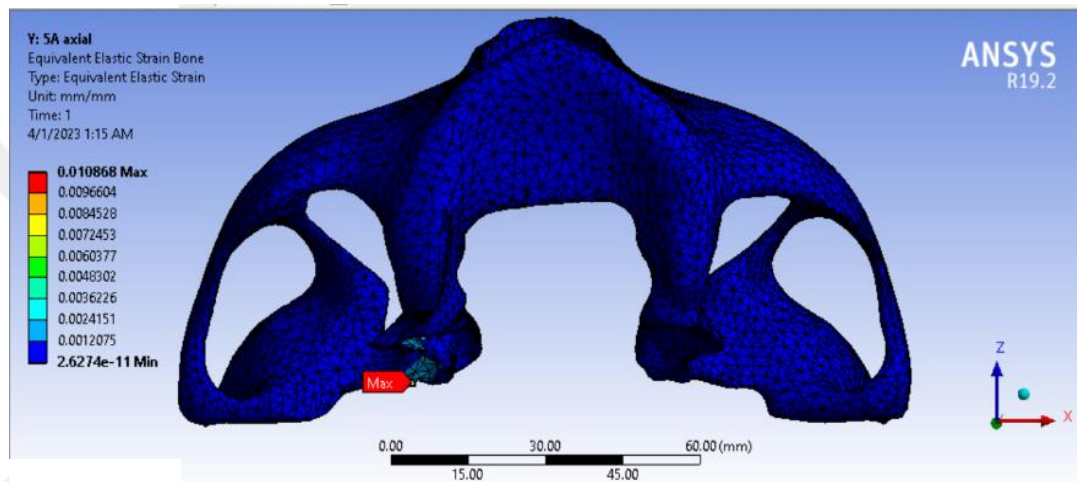


Figure 4. 42. (a) Maximum strain on surrounding bone for 4B model under 150N axial loading (b) Maximum strain on implant for 4B model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.43), under 150-N axial force application.

Maximum equivalent strain was measured at 0.00071347 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.010868 mm/mm, as shown in (Table 4.4).

(a)



(b)

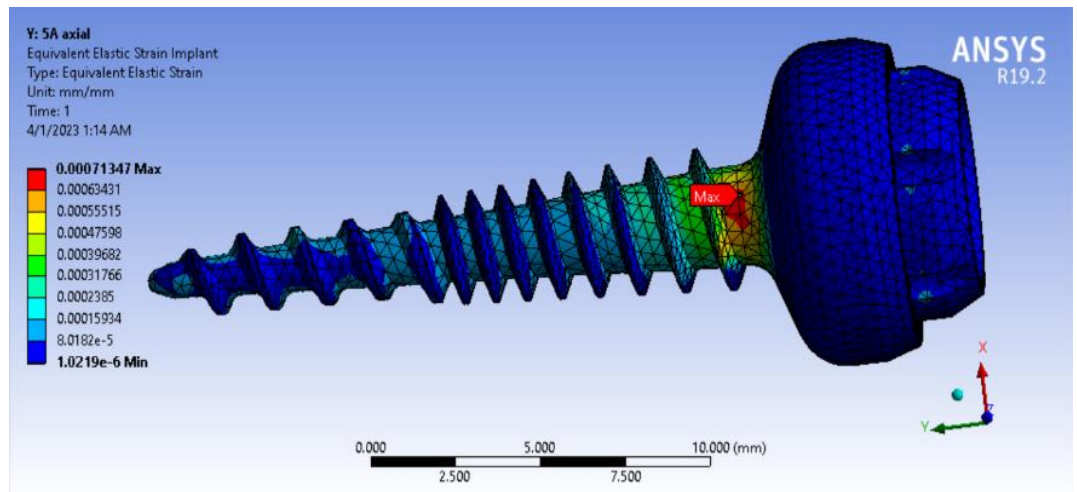
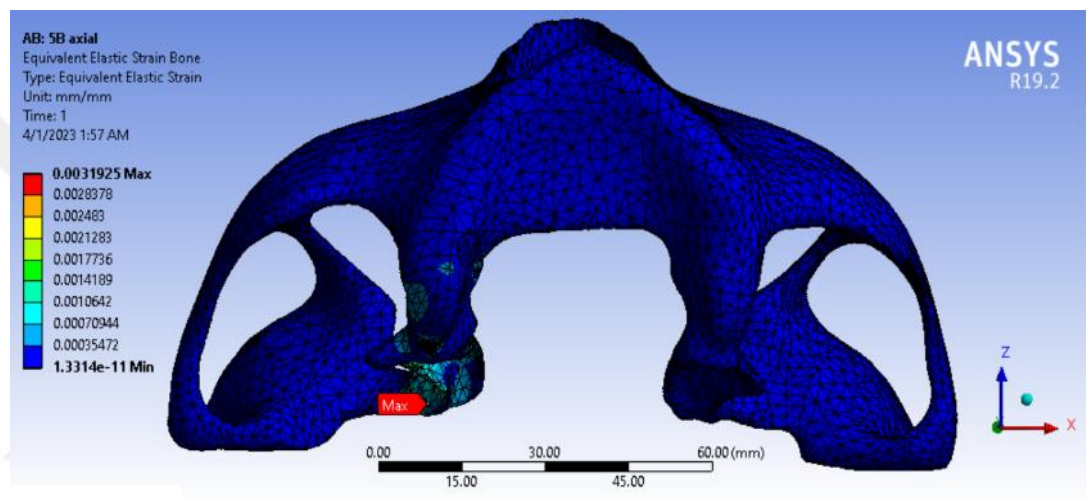


Figure 4. 43. (a) Maximum strain on surrounding bone for 5A model under 150N axial loading (b) Maximum strain on implant for 5A model under 150N axial loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.44), under 150-N axial force application.

Maximum equivalent strain was measured at 0.00081511 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0031925 mm/mm, as shown in (Table 4.4).

(a)



(b)

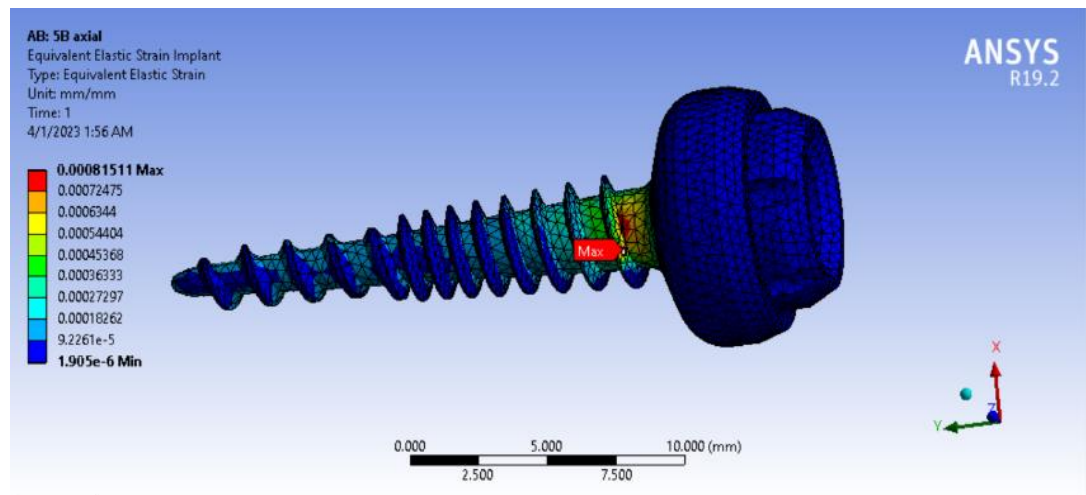


Figure 4. 44. (a) Maximum strain on surrounding bone for 5B model under 150N axial loading (b) Maximum strain on implant for 5B model under 150N axial loading

4.2.2. 50-N lateral force application

Uniformly distributed loadings of 50-N lateral force were applied to the occlusal surface above the abutment of a pterygoid dental implant at 45, 55, 65, 75, and 85 angle degrees (monocortical and bicortical) according to the Frankfort Horizontal Plane .

Maximum equivalent strain values (mm/mm) and location on the implant's body are shown in table 4.5 , (Figure 4.45). The greatest strain in all models was recorded at 0.0032362 mm/mm in 45 angle degree bicortically placed model . The lowest value was recorded in 55 angle degree monocortically placed model at 0.0014535 mm/mm .

Maximum equivalent strain values (mm/mm) on the surrounding bone are shown in table 4.5 , (Figure 4.45). The greatest strain in all models was recorded at 0.0061644 mm/mm in 45 angle degree bicortically placed model . The lowest value was recorded in 65 angle degree bicortically placed model at 0.0033381 mm/mm .

Table 4.5. Total integrated strain and location under 50N lateral loading

Models	Maximum strain in implant mm/mm	Maximum strain in implant location	Maximum strain in bone mm/mm	Maximum strain in bone location
1A	0.0018547	Abutment connection area of the pterygoid abutment	0.0053596	Crestal bone at pterygoid implant
1B	0.0032362	Abutment connection area of the pterygoid abutment	0.0061644	Crestal bone at pterygoid implant
2A	0.0014535	Abutment connection area of the pterygoid abutment	0.0058027	Crestal bone at pterygoid implant
2B	0.0016074	Abutment connection area of the pterygoid abutment	0.0045003	Crestal bone at pterygoid implant
3A	0.00162	Abutment connection area of the pterygoid abutment	0.0038308	Crestal bone at pterygoid implant
3B	0.002132	Abutment connection area of the pterygoid abutment	0.0033381	Crestal bone at pterygoid implant
4A	0.0015503	Abutment connection area of the pterygoid abutment	0.0036611	Crestal bone at pterygoid implant
4B	0.0019249	Abutment connection area of the pterygoid abutment	0.0037555	Crestal bone at pterygoid implant

5A	0.0021076	Abutment connection area of the pterygoid abutment	0.0040904	Crestal bone at pterygoid implant
5B	0.0026334	Abutment connection area of the pterygoid abutment	0.0038909	Crestal bone at pterygoid implant

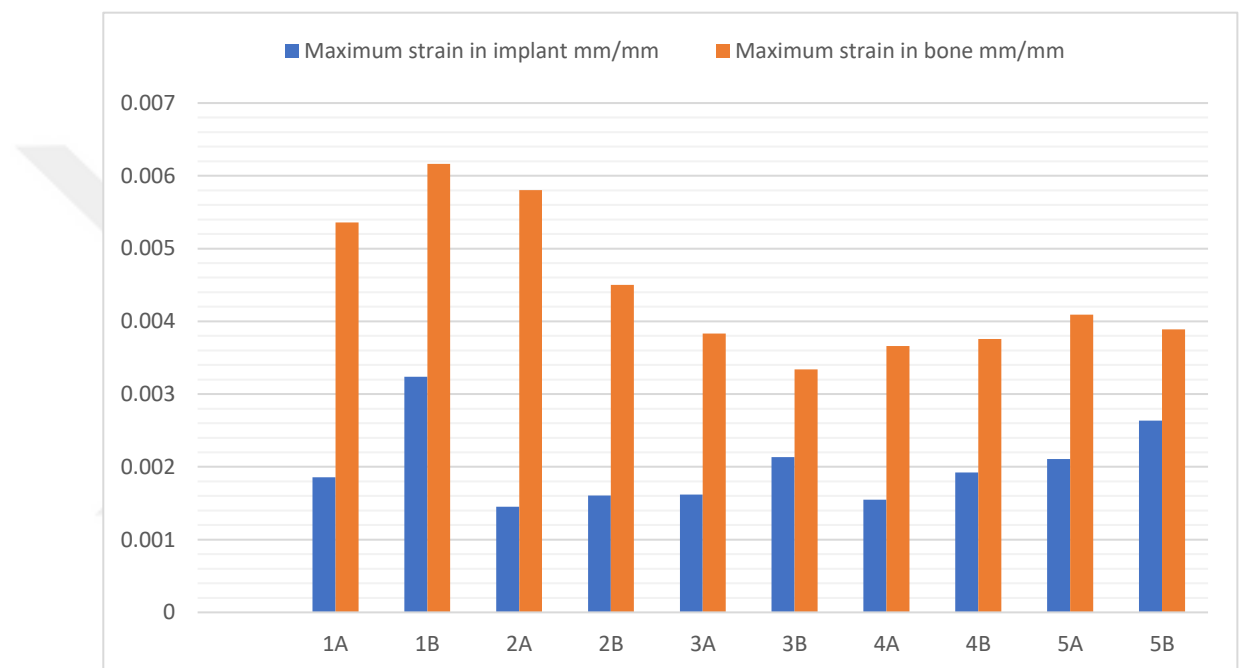
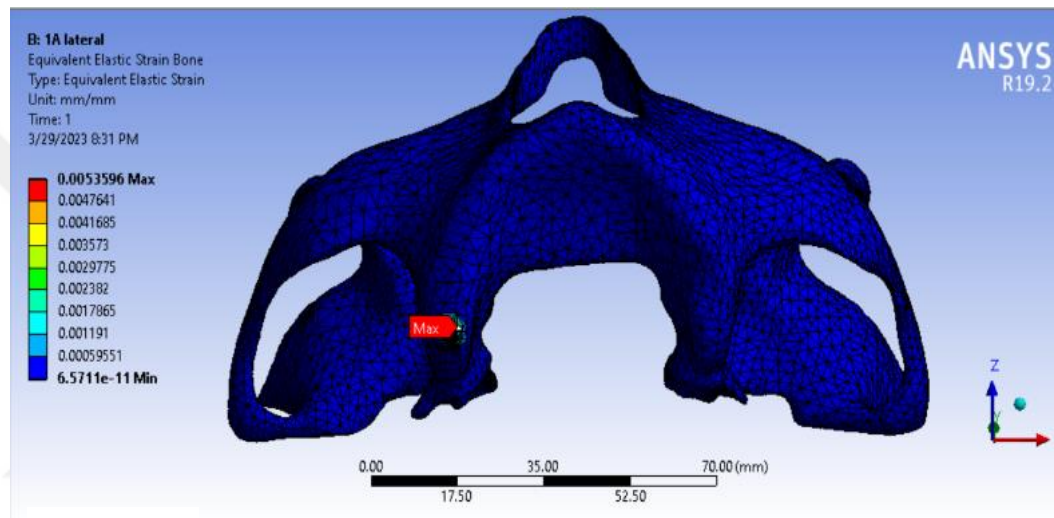


Figure 4. 45. Maximum strain in implant and surrounding bone for each model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.46), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0018547 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0053596 mm/mm, as shown in (Table 4.5).

(a)



(b)

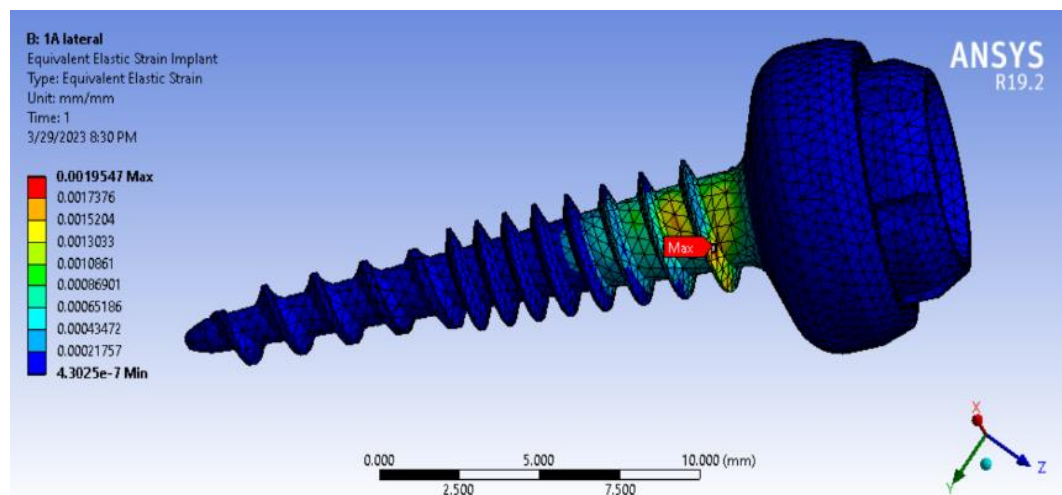
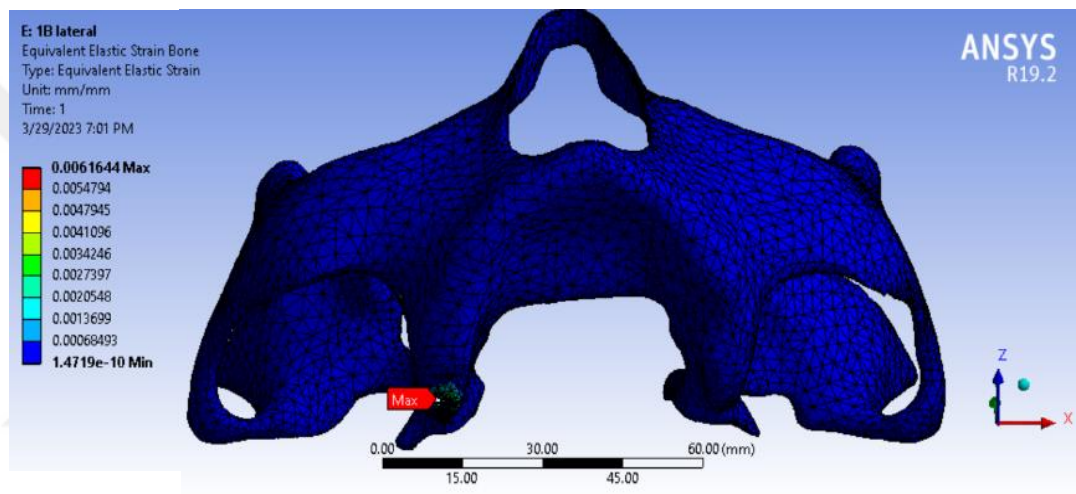


Figure 4. 46. (a) Maximum strain on surrounding bone for 1A model under 50N lateral loading (b) Maximum strain on implant for 1A model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.47), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0032362 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0061644 mm/mm, as shown in (Table 4.5).

(a)



(b)

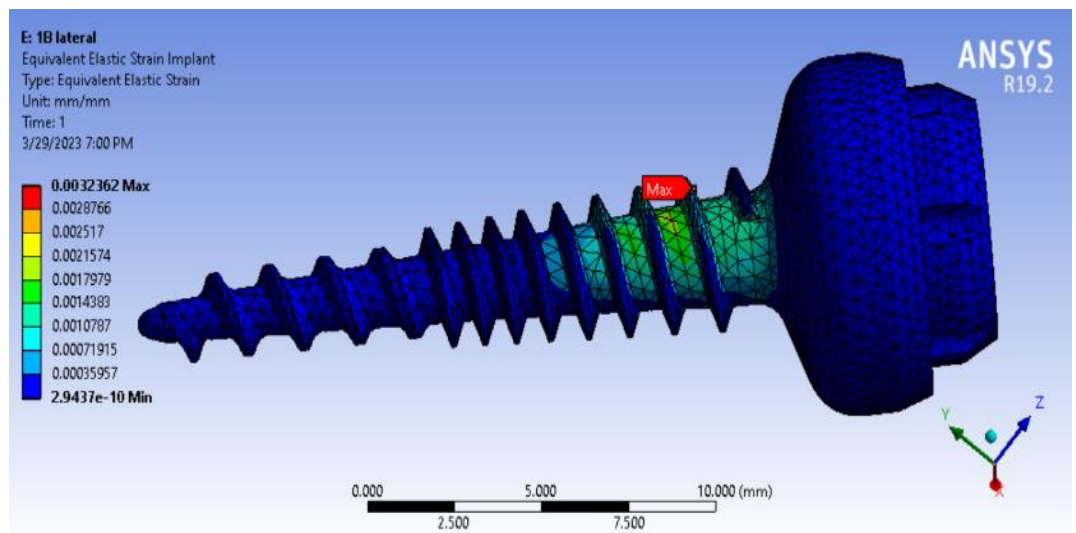
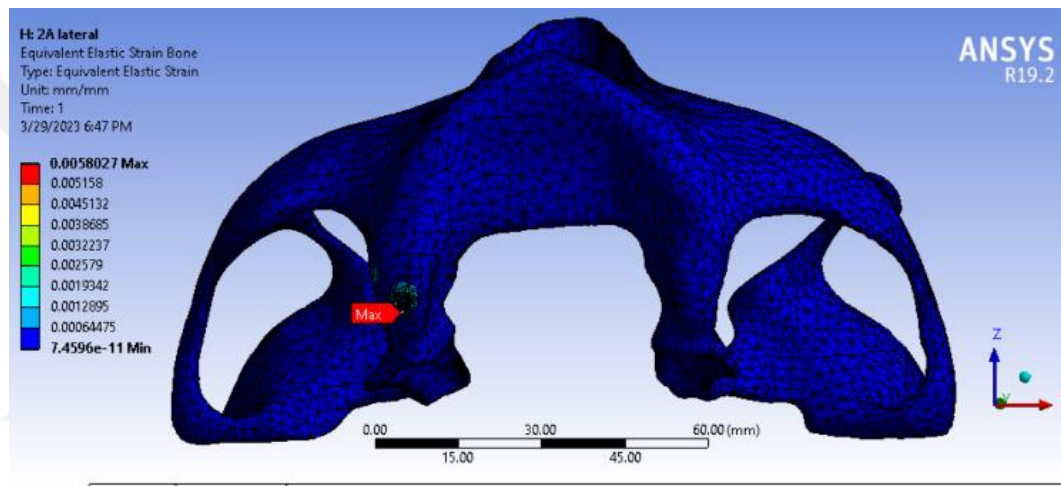


Figure 4. 47. (a) Maximum strain on surrounding bone for 1B model under 50N lateral loading (b) Maximum strain on implant for 1B model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.48), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0014535 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0058027 mm/mm, as shown in (Table 4.5).

(a)



(b)

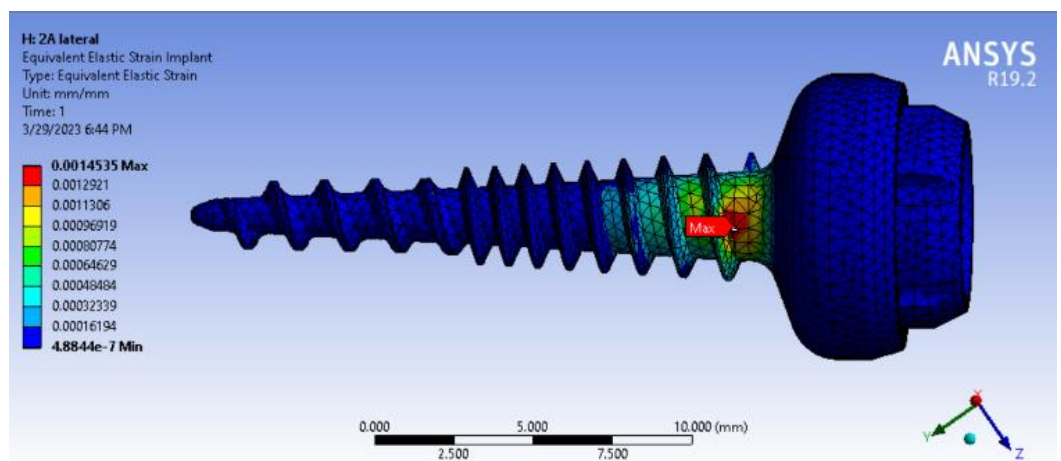
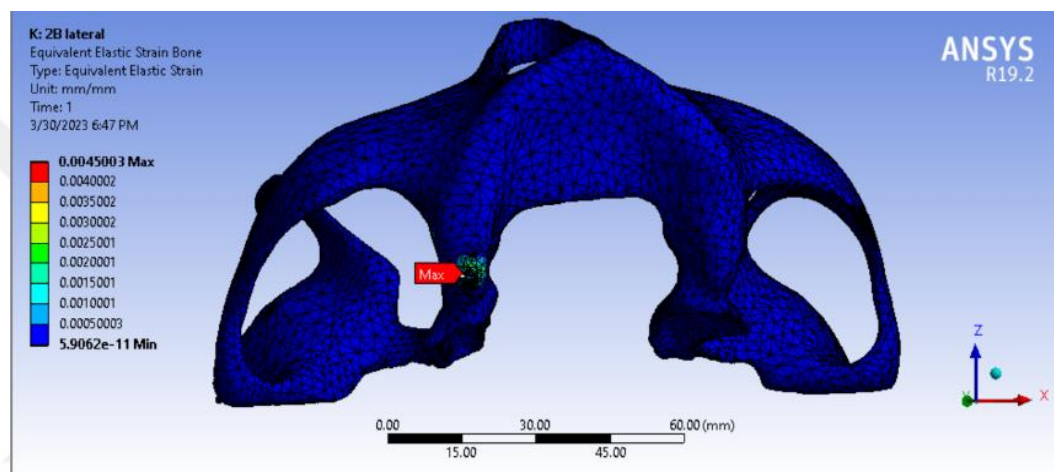


Figure 4. 48. (a) Maximum strain on surrounding bone for 2A model under 50N lateral loading (b) Maximum strain on implant for 2A model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.49), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0016074 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0045003 mm/mm, as shown in (Table 4.5).

(a)



(b)

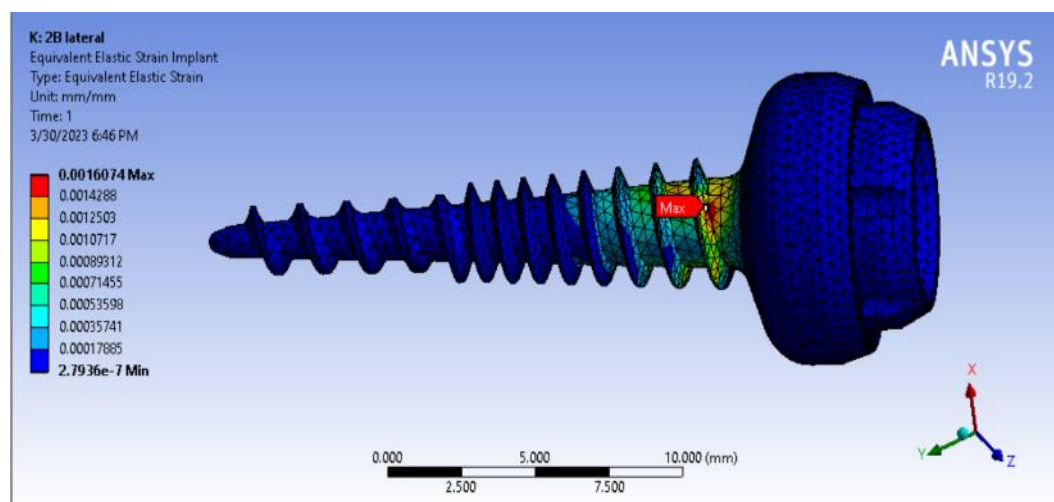
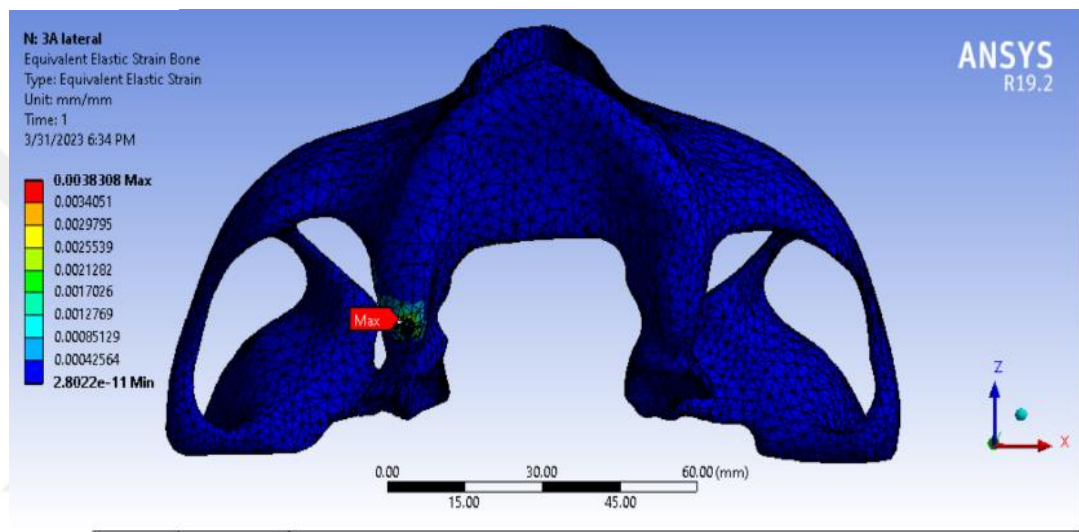


Figure 4. 49. (a) Maximum strain on surrounding bone for 2B model under 50N lateral loading (b) Maximum strain on implant for 2B model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.50) , under 50N lateral force application.

Maximum equivalent strain was measured at 0.00162 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0038308 mm/mm, as shown in (Table 4.5).

(a)



(b)

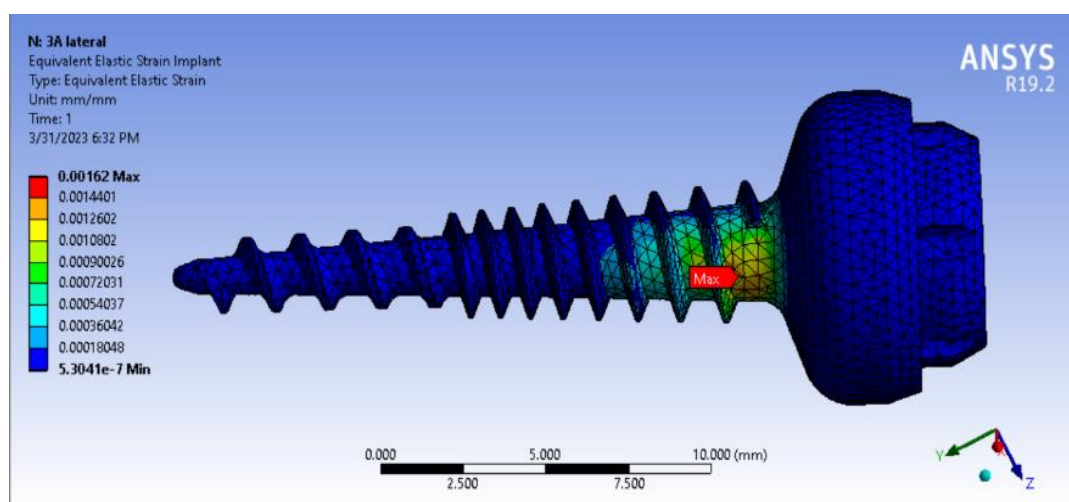
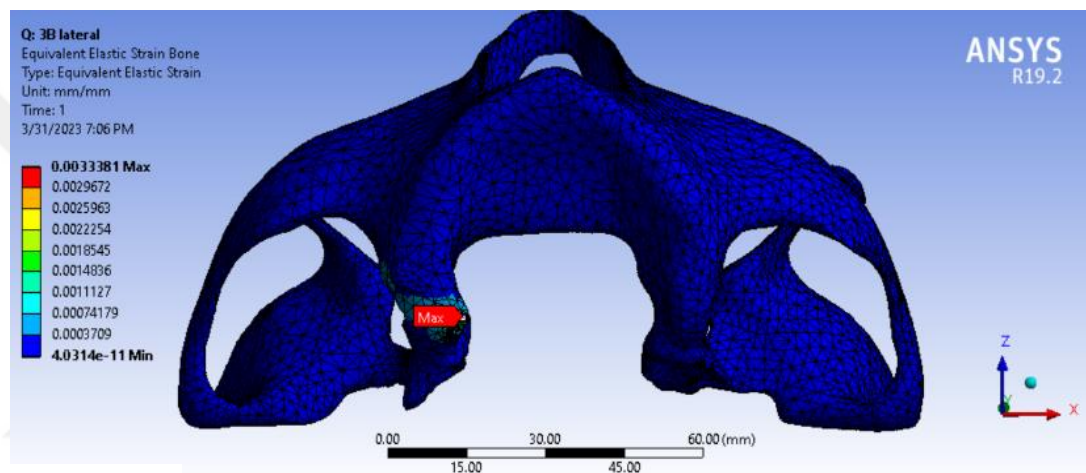


Figure 4. 50. (a) Maximum strain on surrounding bone for 3A model under 50N lateral loading (b) Maximum strain on implant for 3A model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.51), under 50N lateral force application.

Maximum equivalent strain was measured at 0.002132 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0033381 mm/mm, as shown in (Table 4.5).

(a)



(b)

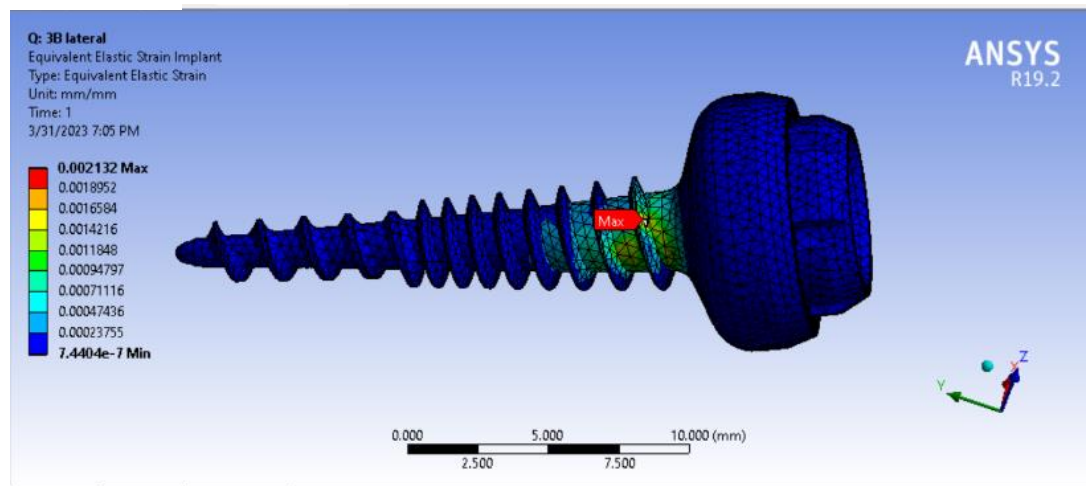
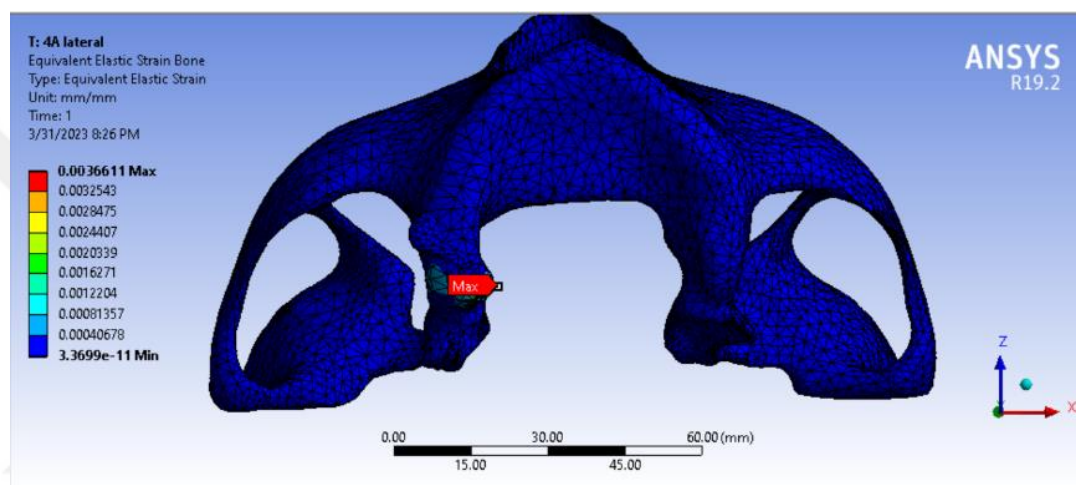


Figure 4. 51. (a) Maximum strain on surrounding bone for 3B model under 50N lateral loading (b) Maximum strain on implant for 3B model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.52), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0015503 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0036611 mm/mm, as shown in (Table 4.5).

(a)



(b)

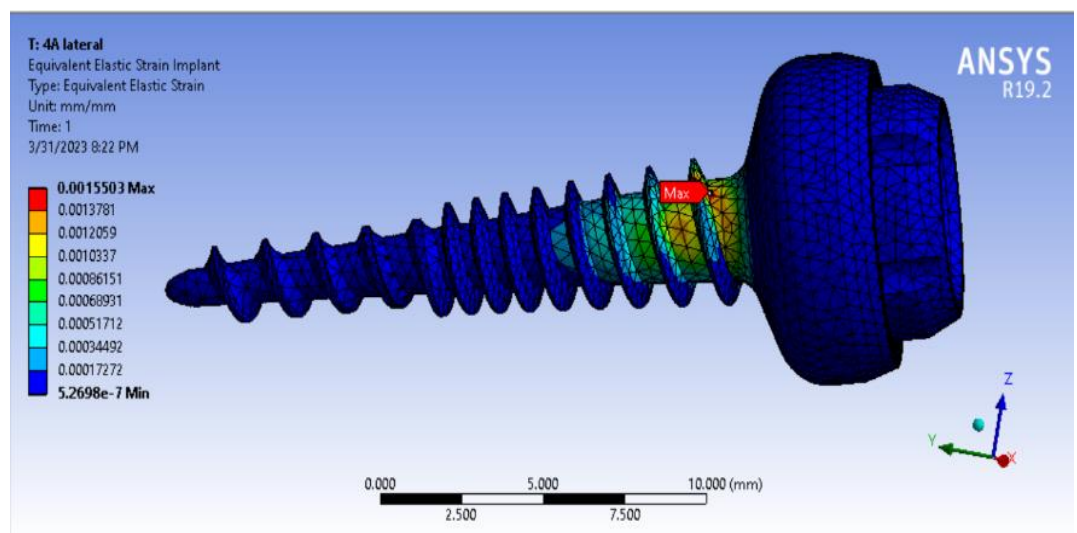
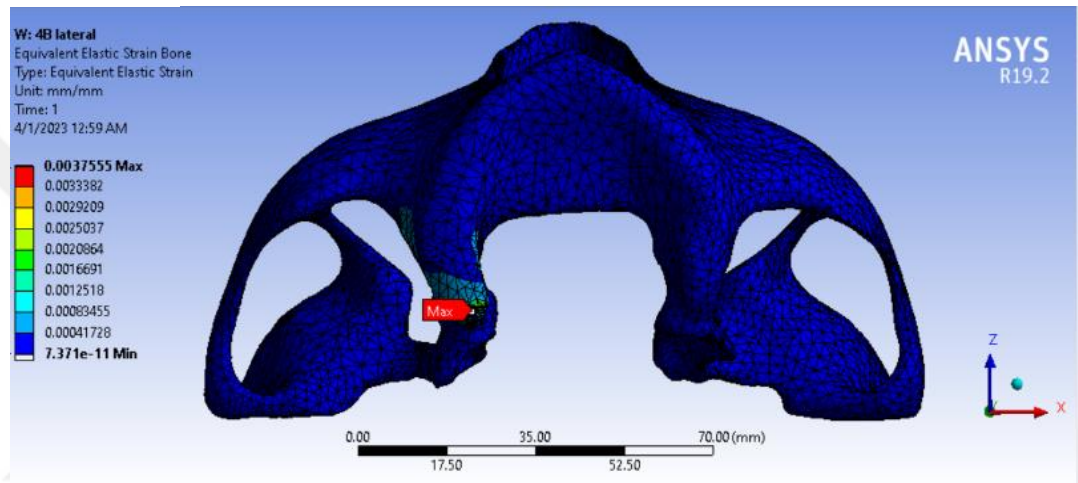


Figure 4. 52. (a) Maximum strain on surrounding bone for 4A model under 50N lateral loading (b) Maximum strain on implant for 4A model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.53), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0019249 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0037555 mm/mm, as shown in (Table 4.5).

(a)



(b)

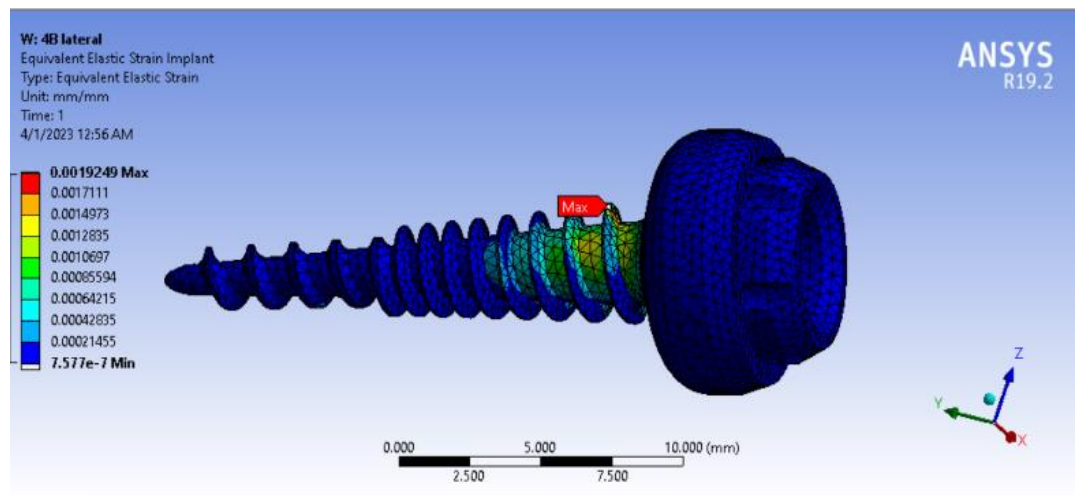
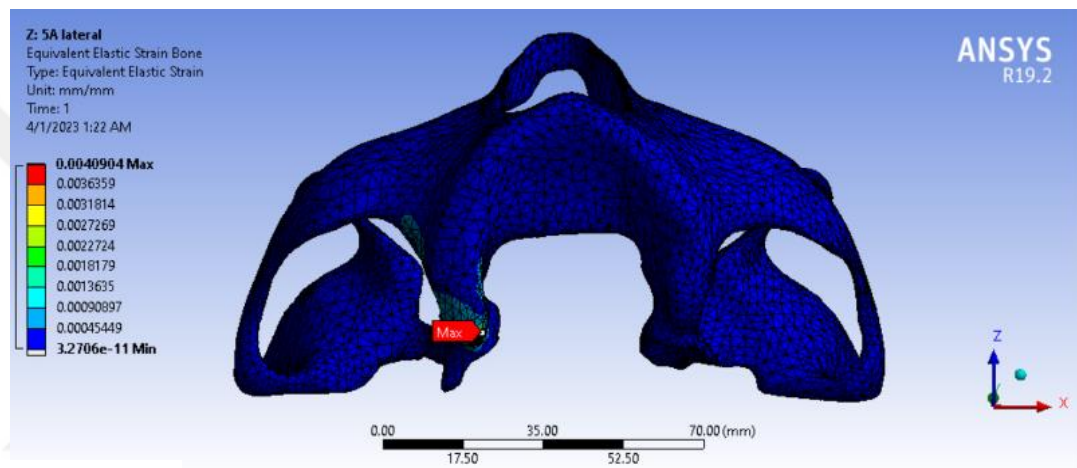


Figure 4. 53. (a) Maximum strain on surrounding bone for 4B model under 50N lateral loading (b) Maximum strain on implant for 4B model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.54), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0021076 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0040904 mm/mm, as shown in (Table 4.5).

(a)



(b)

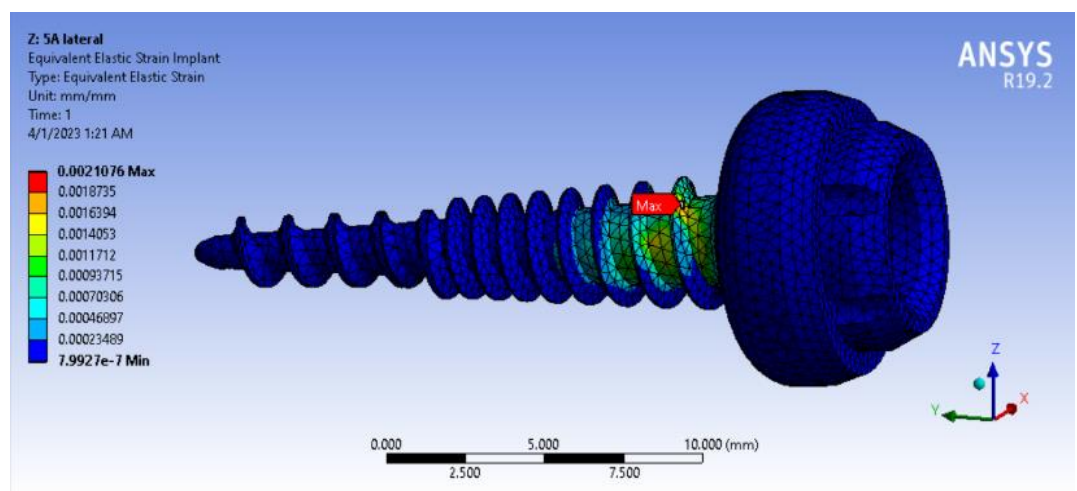
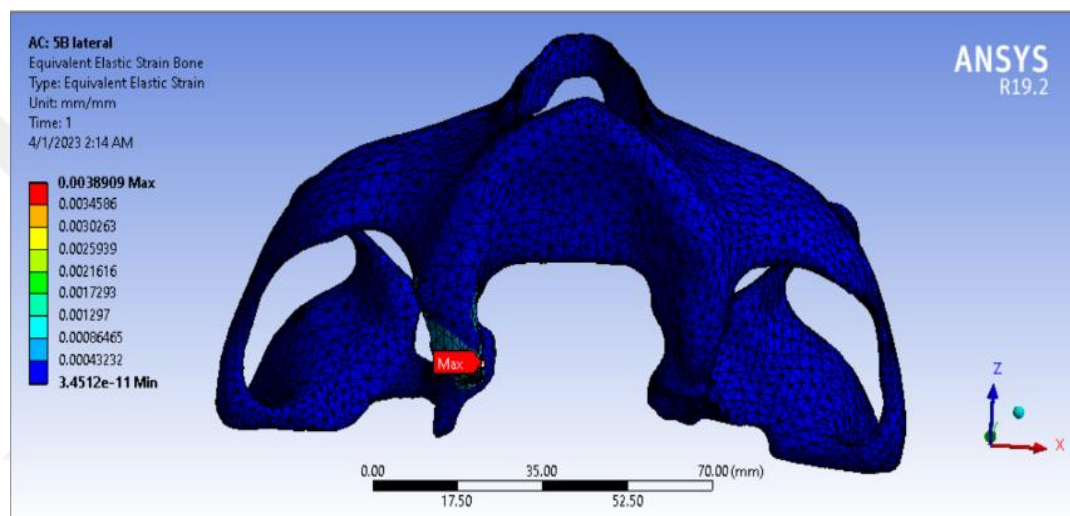


Figure 4. 54. (a) Maximum strain on surrounding bone for 5A model under 50N lateral loading (b) Maximum strain on implant for 5A model under 50N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.55), under 50N lateral force application.

Maximum equivalent strain was measured at 0.0026334 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0038909 mm/mm, as shown in (Table 4.5).

(a)



(b)

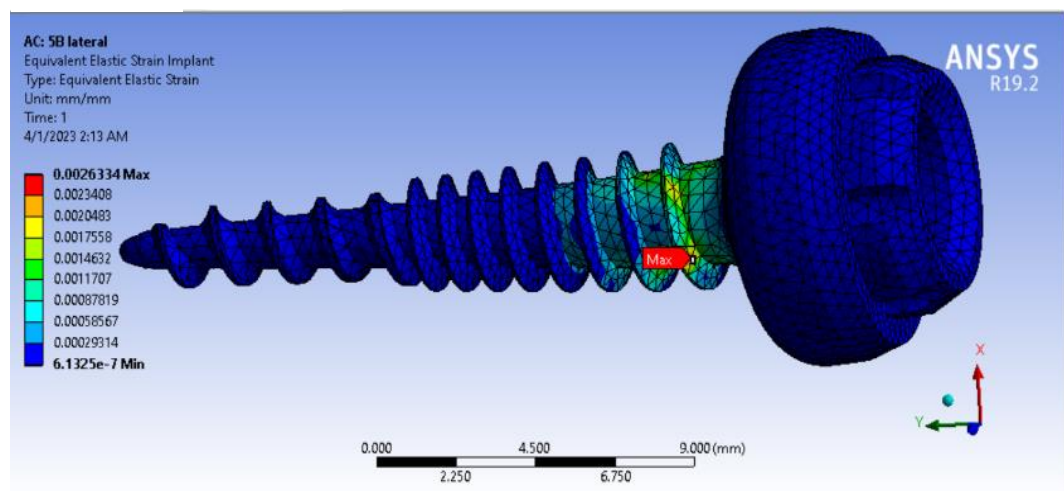


Figure 4. 55. (a) Maximum strain on surrounding bone for 5B model under 50N lateral loading (b) Maximum strain on implant for 5B model under 50N lateral loading

4.2.3. Simultaneous application of 150-N axial and a 50-N lateral forces

Uniformly distributed loadings of 150-N axial and a 50-N lateral simultaneously forces were applied to the occlusal surface above the abutment of a pterygoid dental implant at 45, 55, 65, 75, and 85 degree angled (monocortical and bicortical) according to the Frankfort Horizontal Plane.

Maximum equivalent strain values (mm/mm) and location on the implant's body are shown in table 4.6, (Figure 4.56). The greatest strain in all models was recorded at 0.0052302 mm/mm in 45 angle degree bicortically placed model. The lowest value was recorded in 75 angle degree monocortically placed model at 0.00205 mm/mm.

Maximum equivalent strain values (mm/mm) and location on the surrounding bone are shown in table 4.6, (Figure 4.56). The greatest strain in all models was recorded at 0.012691 mm/mm in 85 angle degree monocortically placed model. The lowest value was recorded in 55 angle degree monocortically placed model at 0.0029189 mm/mm.

Table 4.6. Total integrated strain and location Under 150-N axial loading with simultaneous 50-N lateral loading

Models	Maximum strain in implant mm/mm	Maximum strain in implant location	Maximum strain in bone mm/mm	Maximum strain in bone location
1A	0.0043489	Abutment connection area of the pterygoid abutment	0.0098795	Crestal bone at pterygoid implant
1B	0.0052302	Abutment connection area of the pterygoid abutment	0.0088015	Crestal bone at pterygoid implant
2A	0.0029189	Abutment connection area of the pterygoid abutment	0.0029189	Crestal bone at pterygoid implant
2B	0.0041207	Abutment connection area of the pterygoid abutment	0.0062386	Crestal bone at pterygoid implant
3A	0.0026606	Abutment connection area of the pterygoid abutment	0.0058053	Crestal bone at pterygoid implant
3B	0.0026275	Abutment connection area of the pterygoid abutment	0.0069068	Crestal bone at pterygoid implant
4A	0.00205	Abutment connection area of the pterygoid abutment	0.0049784	Crestal bone at pterygoid implant
4B	0.0023643	Abutment connection area of the pterygoid abutment	0.010876	Crestal bone at pterygoid implant

5A	0.0020939	Abutment connection area of the pterygoid abutment	0.012691	Crestal bone at pterygoid implant
5B	0.0026181	Abutment connection area of the pterygoid abutment	0.004925	Crestal bone at pterygoid implant

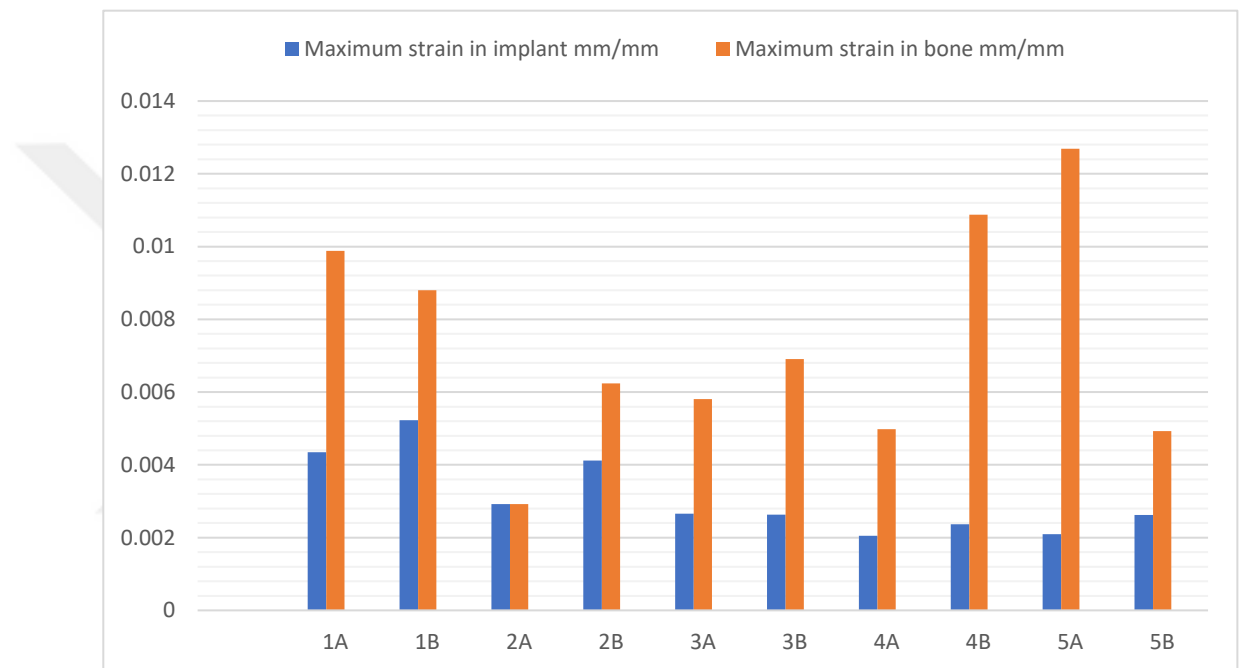


Figure 4. 56. Maximum strain in implant and surrounding bone for each model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 45 angle degree according to Frankfort Horizontal Plane is shown in (Figure 4.57), under 150-N axial with simultaneous 50-N lateral force

Maximum equivalent strain was measured at 0.0043489 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0098795 mm/mm, as shown in (Table 4.6).

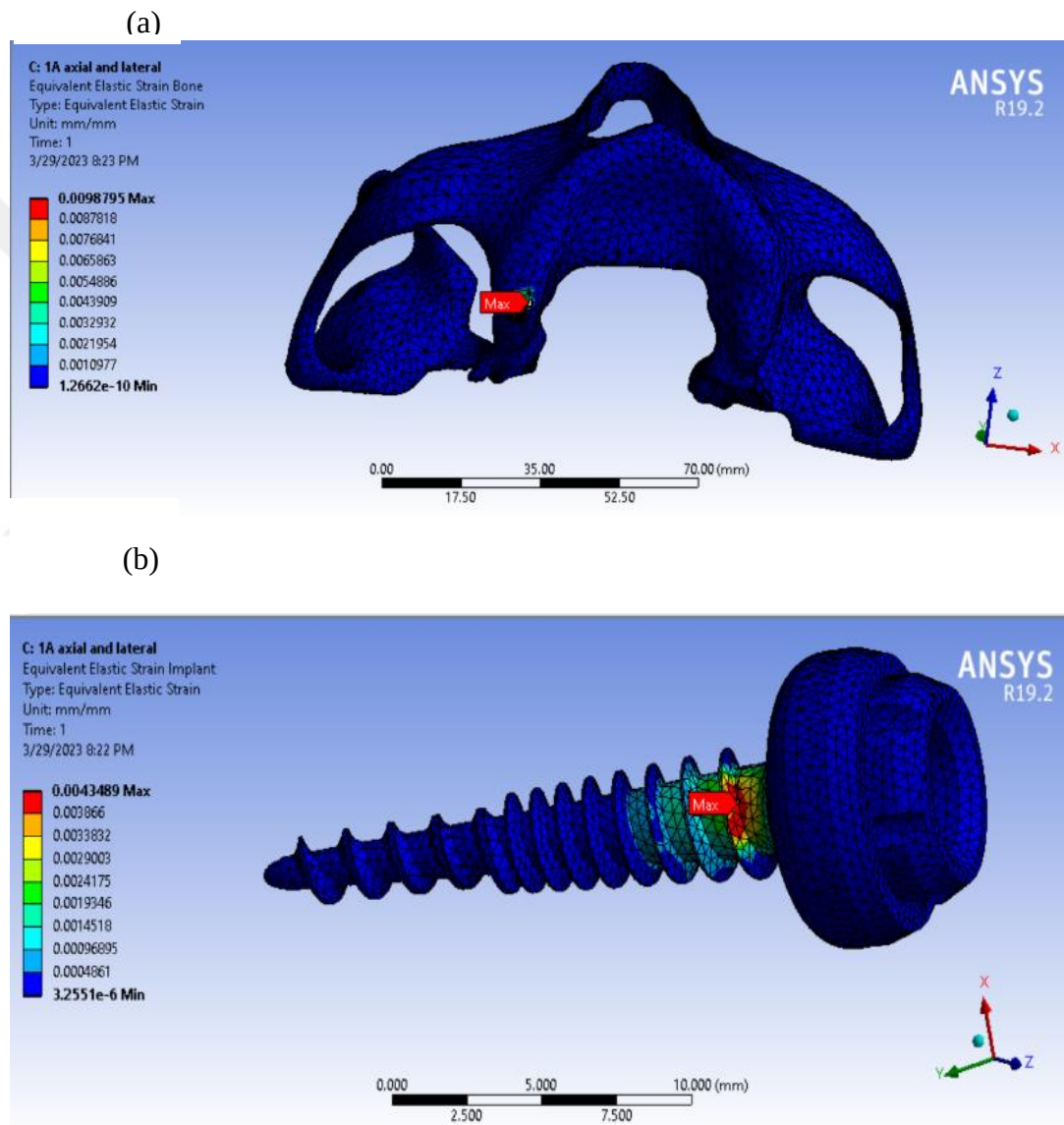
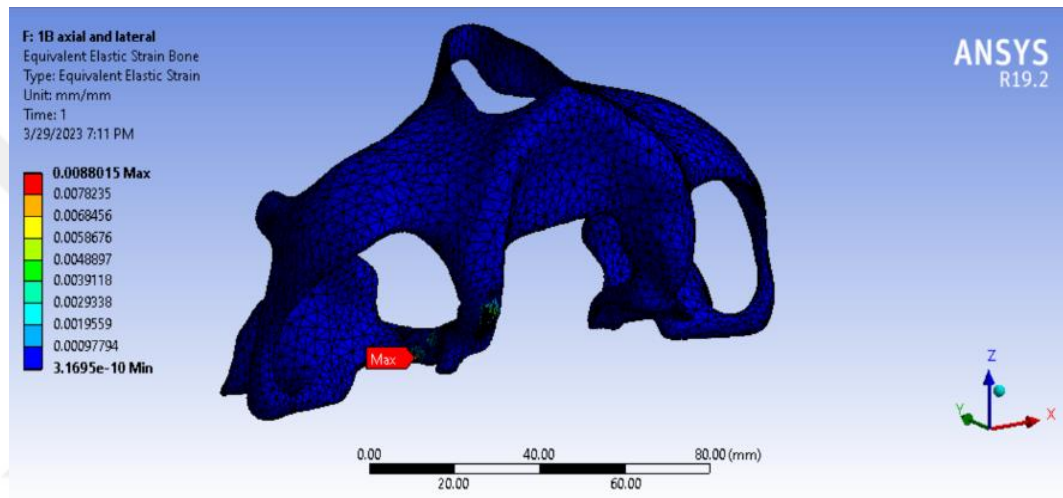


Figure 4. 57. (a) Maximum strain on surrounding bone for 1A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 1A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 45 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.58), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0052302 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0088015 mm/mm, as shown in (Table 4.6).

(a)



(b)

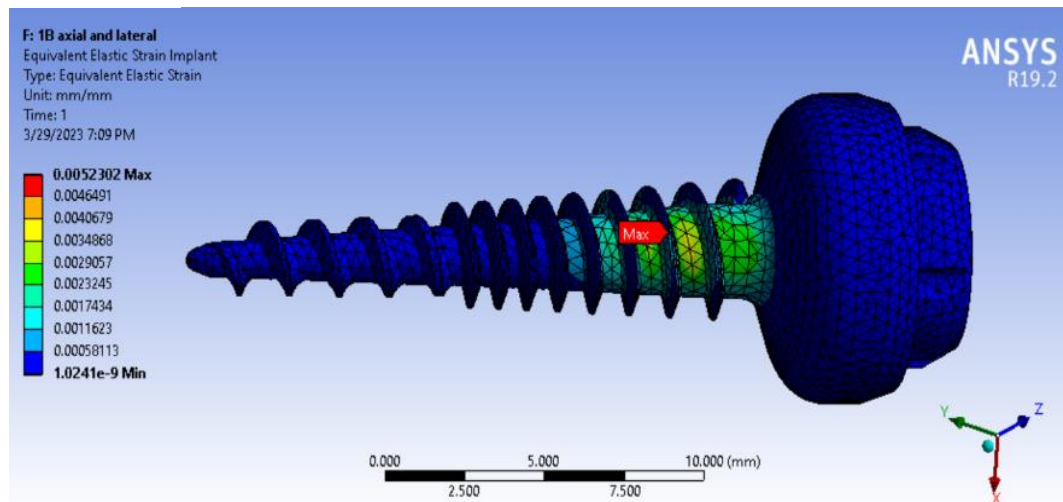


Figure 4. 58. (a) Maximum strain on surrounding bone for 1B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 1B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.59), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0029189 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0070871 mm/mm, as shown in (Table 4.6).

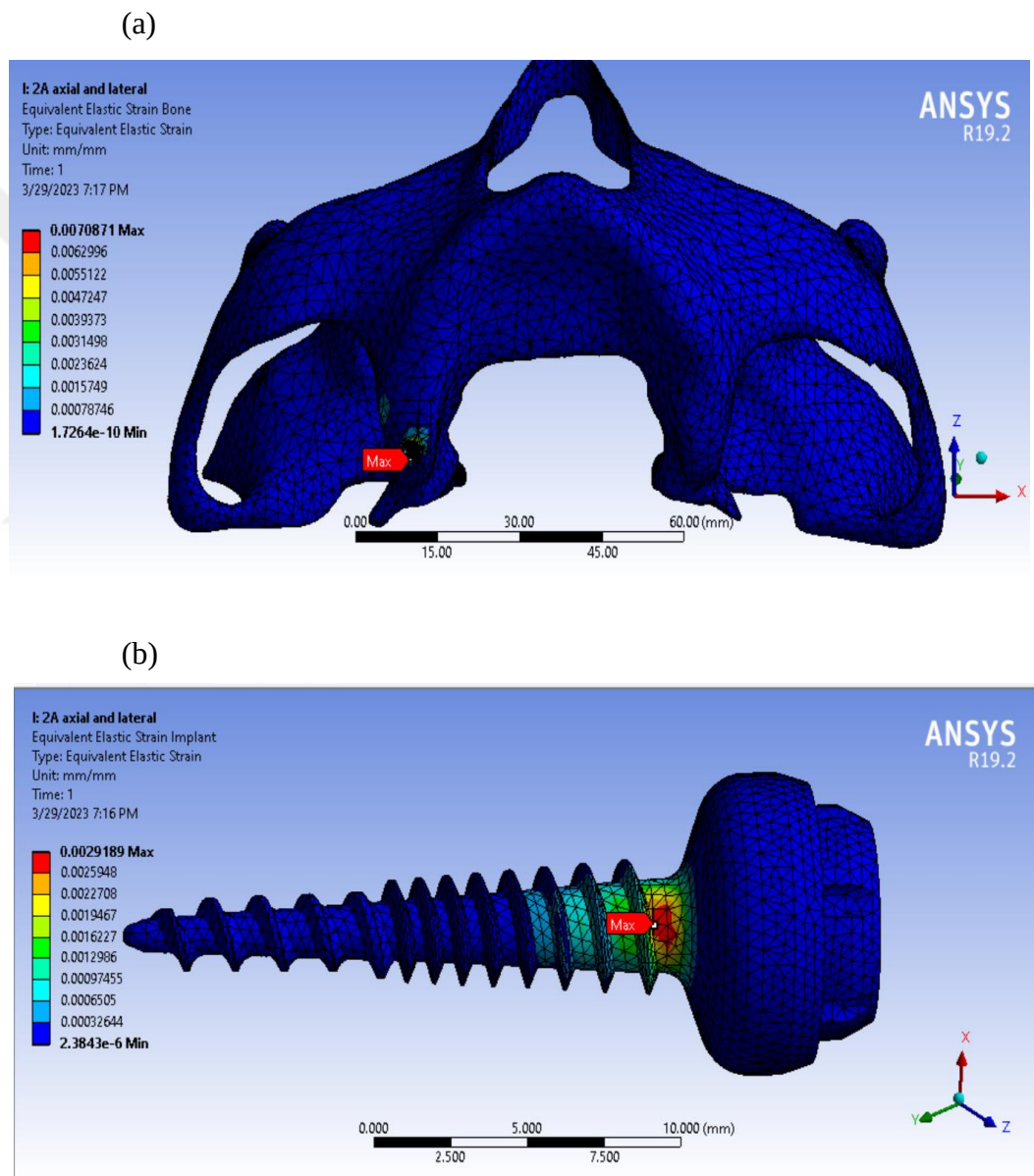
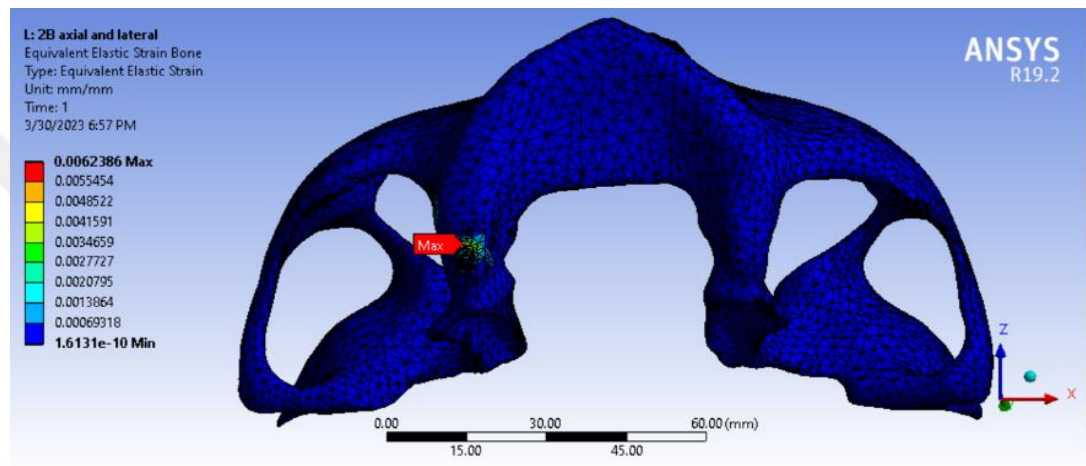


Figure 4. 59. (a) Maximum strain on surrounding bone for 2A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 2A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 55 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.60), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0041207 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0062386 mm/mm, as shown in (Table 4.6).

(a)



(b)

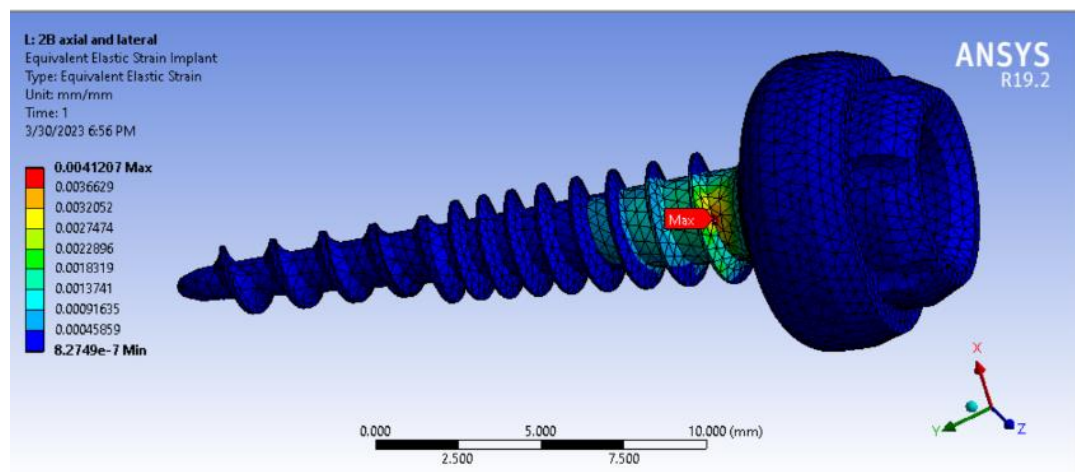
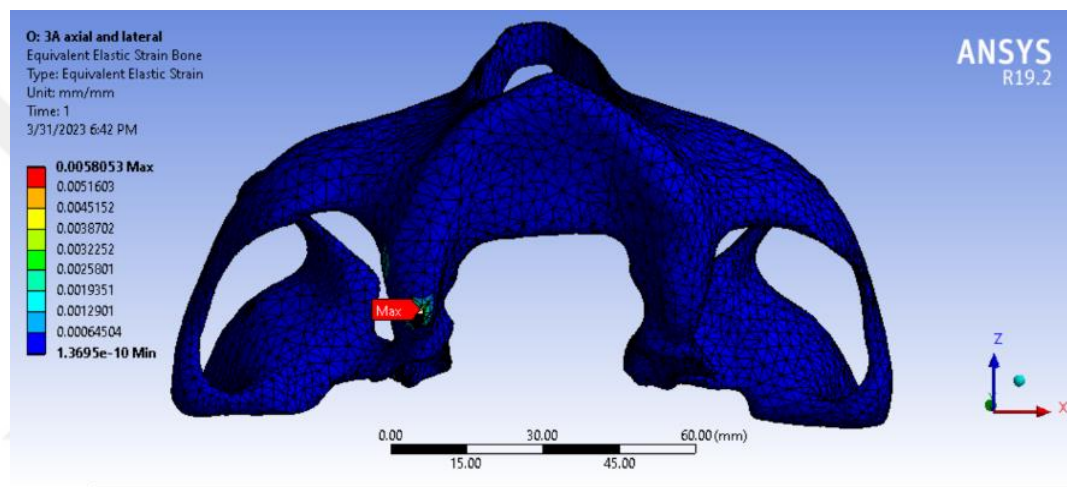


Figure 4. 60. (a) Maximum strain on surrounding bone for 2B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 2B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.61), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0026606 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0058053 mm/mm, as shown in (Table 4.6).

(a)



(b)

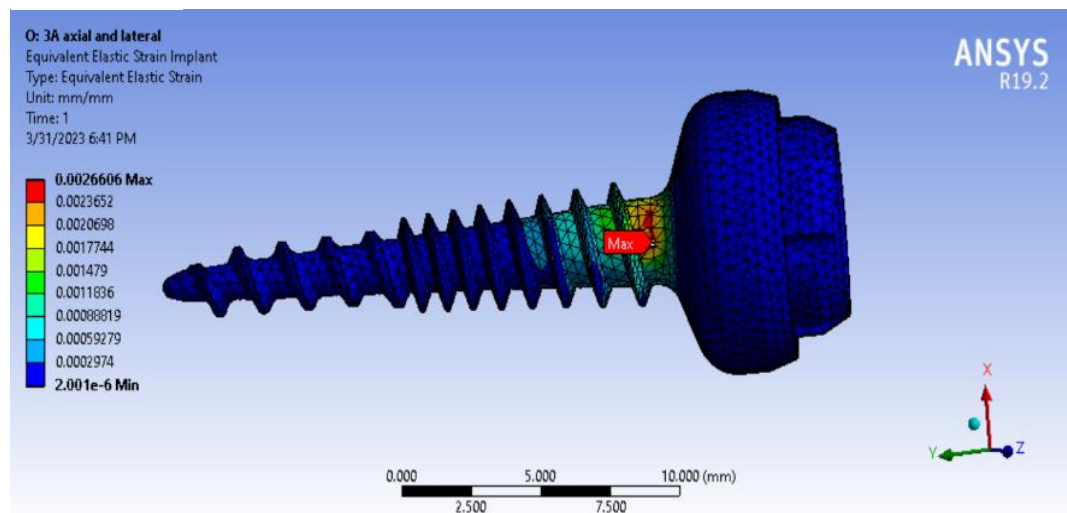
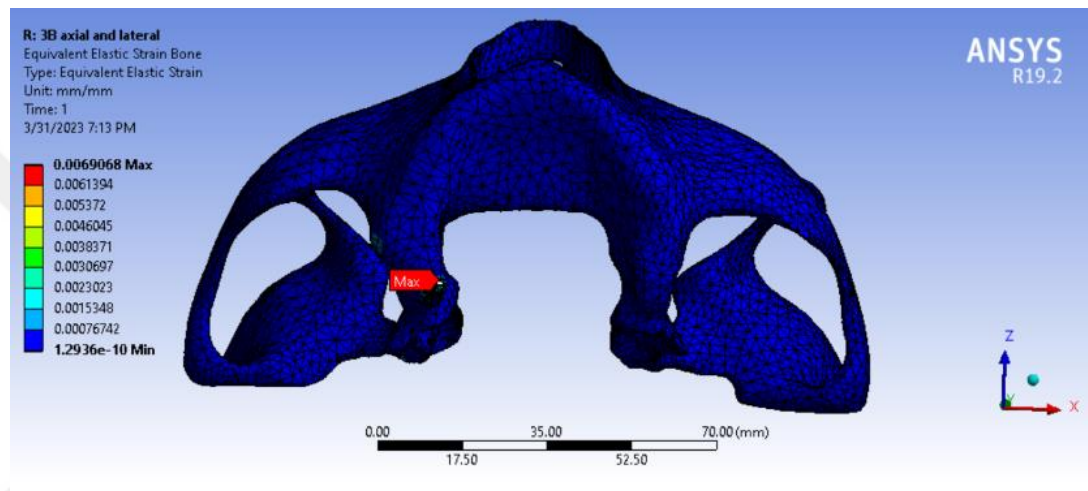


Figure 4. 61. (a) Maximum strain on surrounding bone for 3A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 3A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 65 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.62), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0026275 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0069068 mm/mm, as shown in (Table 4.6).

(a)



(b)

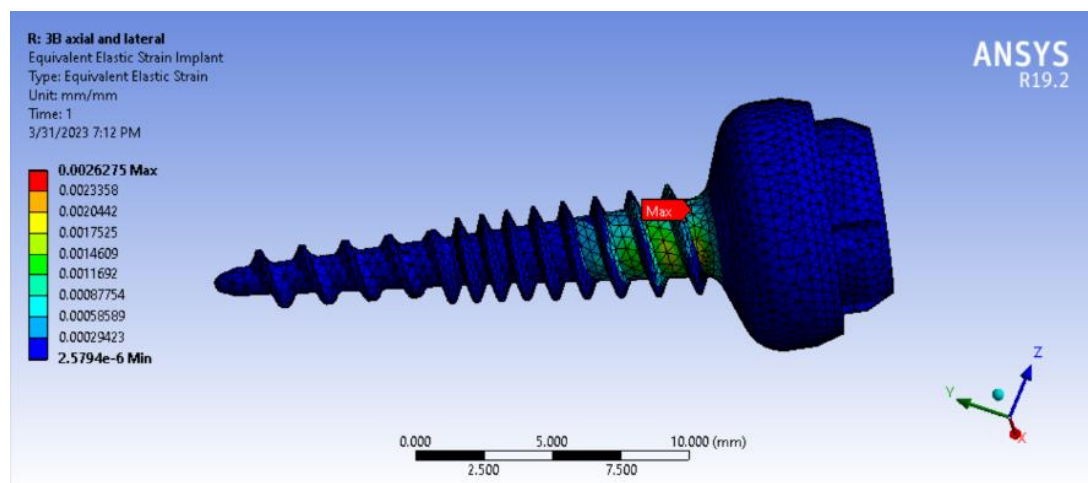
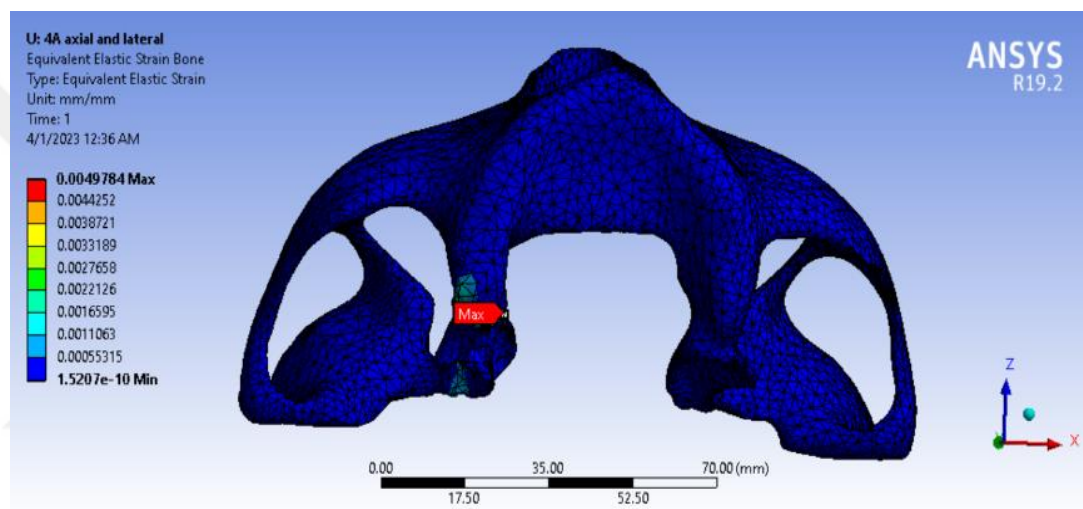


Figure 4. 62. (a) Maximum strain on surrounding bone for 3B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 3B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.63), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.00205 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.0049784 mm/mm, as shown in (Table 4.6).

(a)



(b)

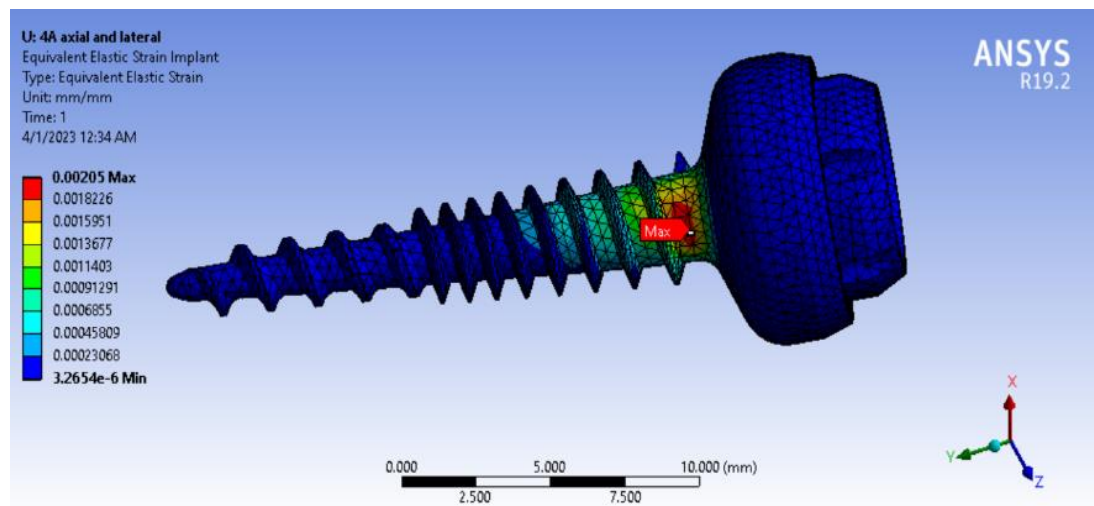
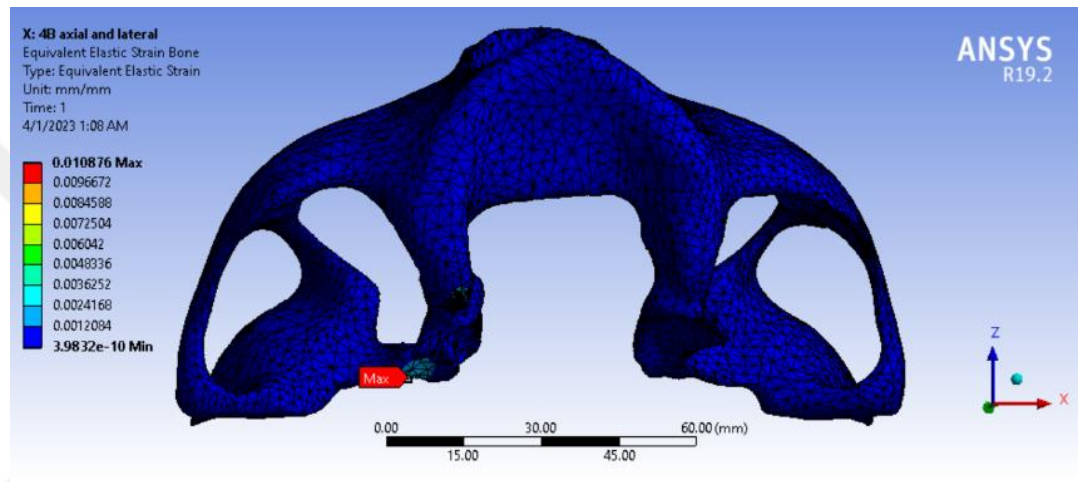


Figure 4. 63. (a) Maximum strain on surrounding bone for 4A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 4A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 75 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.64), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0023643 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.010876 mm/mm, as shown in (Table 4.6).

(a)



(b)

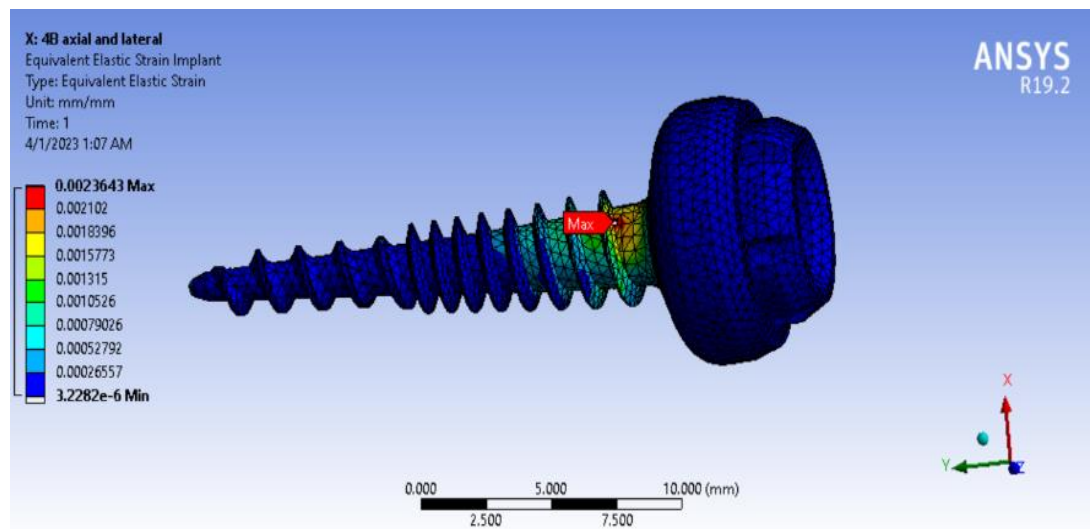


Figure 4. 64. (a) Maximum strain on surrounding bone for 4B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 4B model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed monocortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.65), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0020939 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.012691 mm/mm, as shown in (Table 4.6).

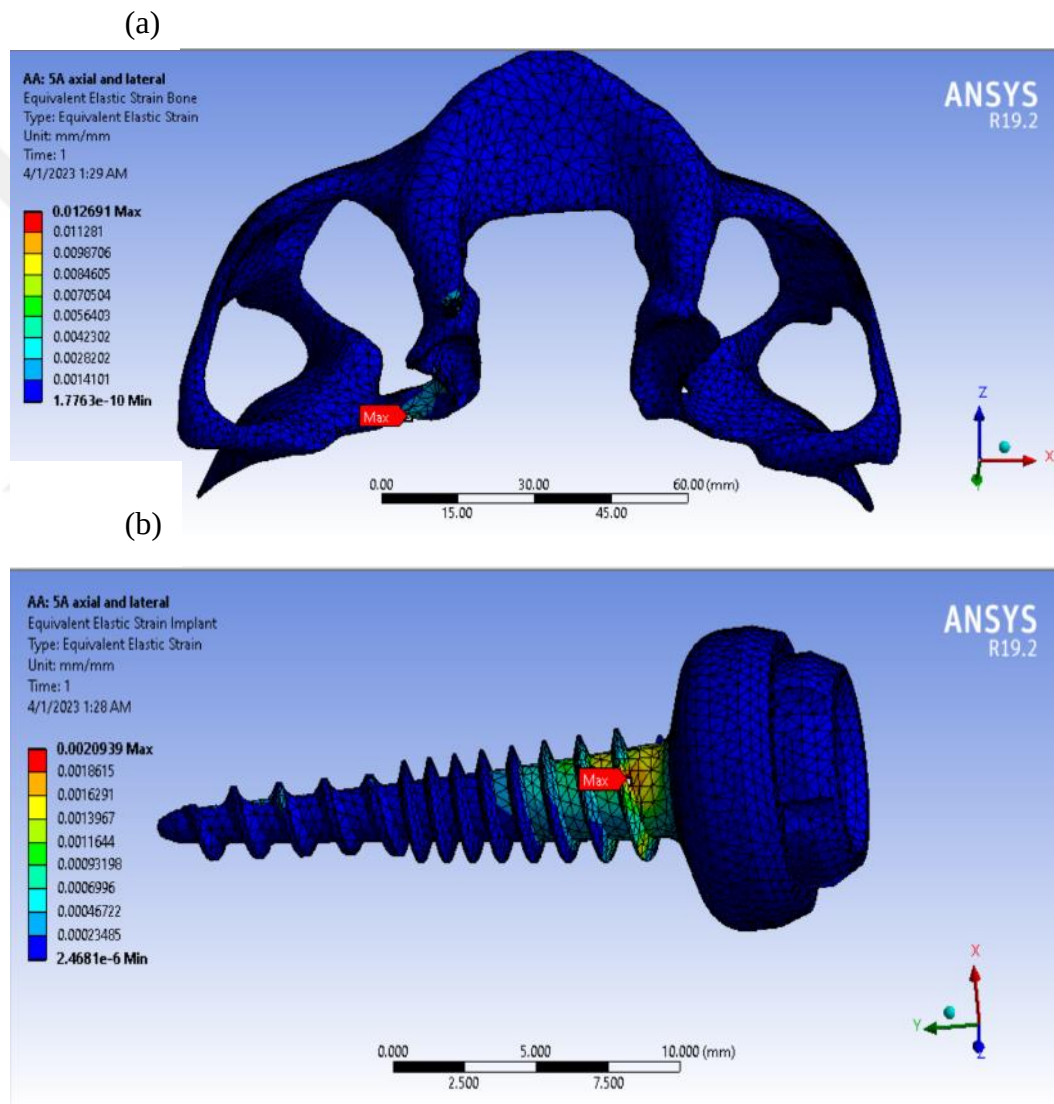
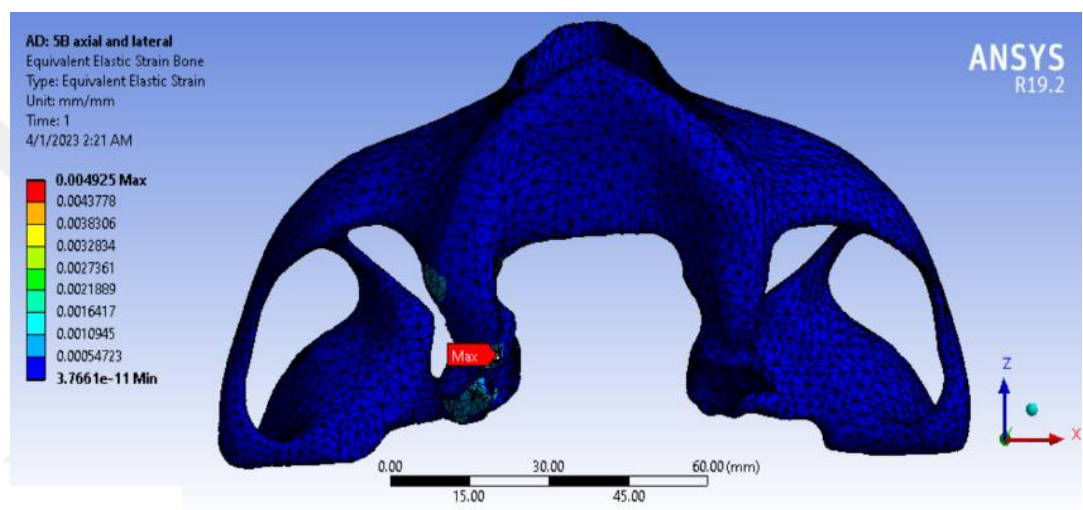


Figure 4. 65. (a) Maximum strain on surrounding bone for 5A model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 5A model under 150-N axial loading with simultaneous 50-N lateral loading

Equivalent strain relative to a pterygoid dental implant placed bicortically with an 85 angle degree according to the Frankfort Horizontal Plane is shown in (Figure 4.66), under 150-N axial with simultaneous 50-N lateral force application.

Maximum equivalent strain was measured at 0.0026181 mm/mm on the titanium implant, and the maximum equivalent strain value on the surrounding bone was recorded at 0.004925 mm/mm, as shown in (Table 4.6).

(a)



(b)

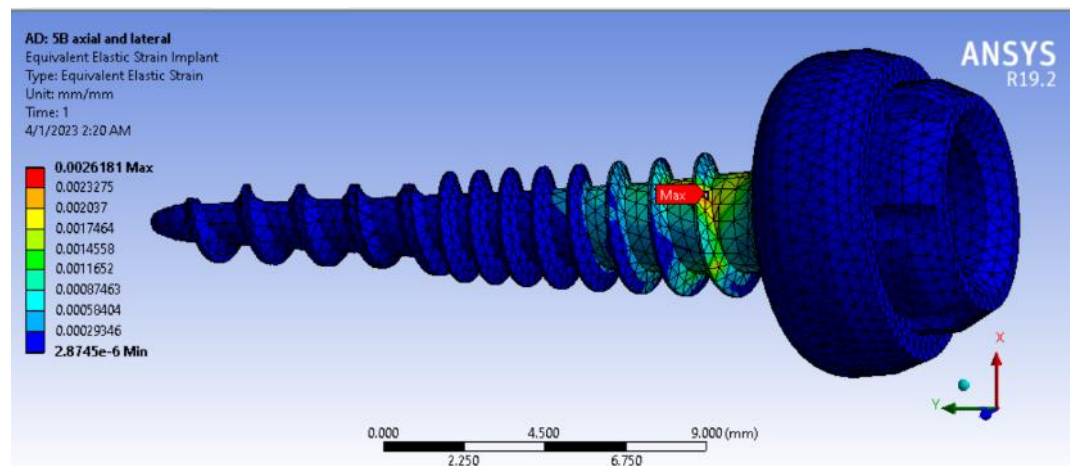


Figure 4. 66. (a) Maximum strain on surrounding bone for 5B model under 150-N axial loading with simultaneous 50-N lateral loading (b) Maximum strain on implant for 5B model under 150-N axial loading with simultaneous 50-N lateral loading

4.A. Maximum and minimum stress values on surrounding bone

Von Mises Stress values on the surrounding bone of all models under three forces are shown in table 4.7, (Figure 4.67).

The highest stress value on bone under three forces is shown in the 1B model (Pterygoid dental implant placed bicortically with 45 degree in the pterygomaxillary region) .

The lowest stress value on bone under three forces is shown in the 4A model (Pterygoid dental implant placed monocortically with 75 degree in the pterygomaxillary region) .

Table 4.7. Von Mises Stress values on surrounding bone of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

	150 Axial force	50 Lateral Force	150 Axial and 50 lateral Force
	Bone stress	Bone stress	Bone stress
1A	125.81	58.154	111.88
1B	137.97	82.317	116.23
2A	92.282	62.027	74.836
2B	88.64	59.884	75.124
3A	60.799	51.187	76.471
3B	54.578	43.378	73.458
4A	43.028	48.522	59.253
4B	116.19	51.019	130.86
5A	110.52	53.076	129.65
5B	29.927	51.888	67.359

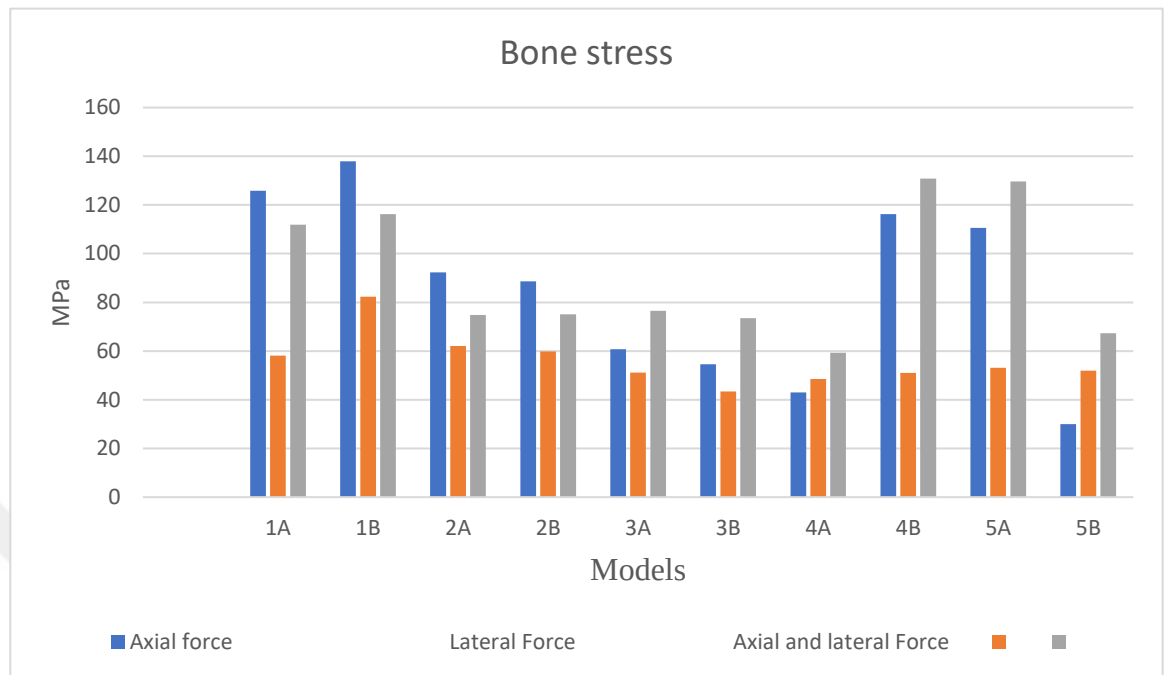


Figure 4. 67. Von Mises Stress values on surrounding bone of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

4.B. Maximum and minimum stress values on implant

Von Mises Stress values on implant titanium under three forces are shown in table 4.8, (Figure 4.68).

The highest stress value on the implant under three forces is shown in the 1B model (Pterygoid dental implant placed bicortically with 45 degree in the pterygomaxillary region) .

The lowest stress values on the implant under three forces are shown in the 4A model (Pterygoid dental implant placed monocortically with 75 degree in the pterygomaxillary region) and the 4B model (Pterygoid dental implant placed bicortically with 75 degree in the pterygomaxillary region)

Table 4.8. Von Mises Stress values on pytergoid implant's titanium of all models under 150- N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

	Axial force	Lateral Force	Axial and lateral
	Implant stress	Implant stress	Implant stress
1A	515.64	211.79	451.62
1B	672.82	348.69	527.88
2A	278.35	159.59	313.23
2B	321.86	175.74	377.71
3A	248.8	172.77	280.23
3B	240.02	225.03	276.06
4A	148.97	158.18	214.06
4B	164.57	184.49	244.03
5A	75.898	222.43	226.67
5B	89.163	278.52	282.7

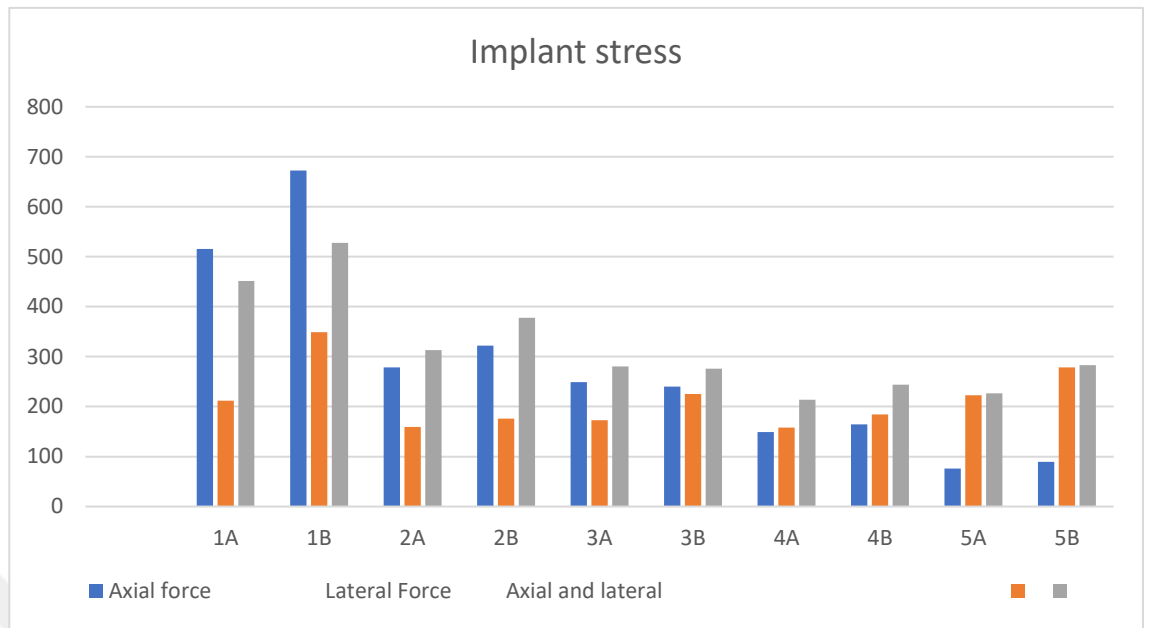


Figure 4. 68. Von Mises Stress values on pytergoid implant's titanium of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

4.C. Maximum and minimum strain values on surrounding bone

Strain values on the surrounding bone under three forces are shown in table 4.9 , (Figure 4.69) .

The highest strain value on bone under three forces is shown in the 1B model (Pterygoid dental implant placed bicortically with 45 degree in the pterygomaxillary region).

The lowest strain value on the bone under three forces is shown in the 4A model (Pterygoid dental implant placed monocortically with 75 degree in the pterygomaxillary region) .

Table 4.9. Strain values on surrounding bone of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

	Axial Force	Lateral Force	Axial and Lateral Force
	Bone strain	Bone strain	Bone strain
1A	0.010045	0.0053596	0.0098795
1B	0.01179	0.0061644	0.0088015
2A	0.0069947	0.0058027	0.0029189
2B	0.0071572	0.0045003	0.0062386
3A	0.0046206	0.0038308	0.0058053
3B	0.0052826	0.0033381	0.0069068
4A	0.0036724	0.0036611	0.0049784
4B	0.0096716	0.0037555	0.010876
5A	0.010868	0.0040904	0.012691
5B	0.0031925	0.0038909	0.004925

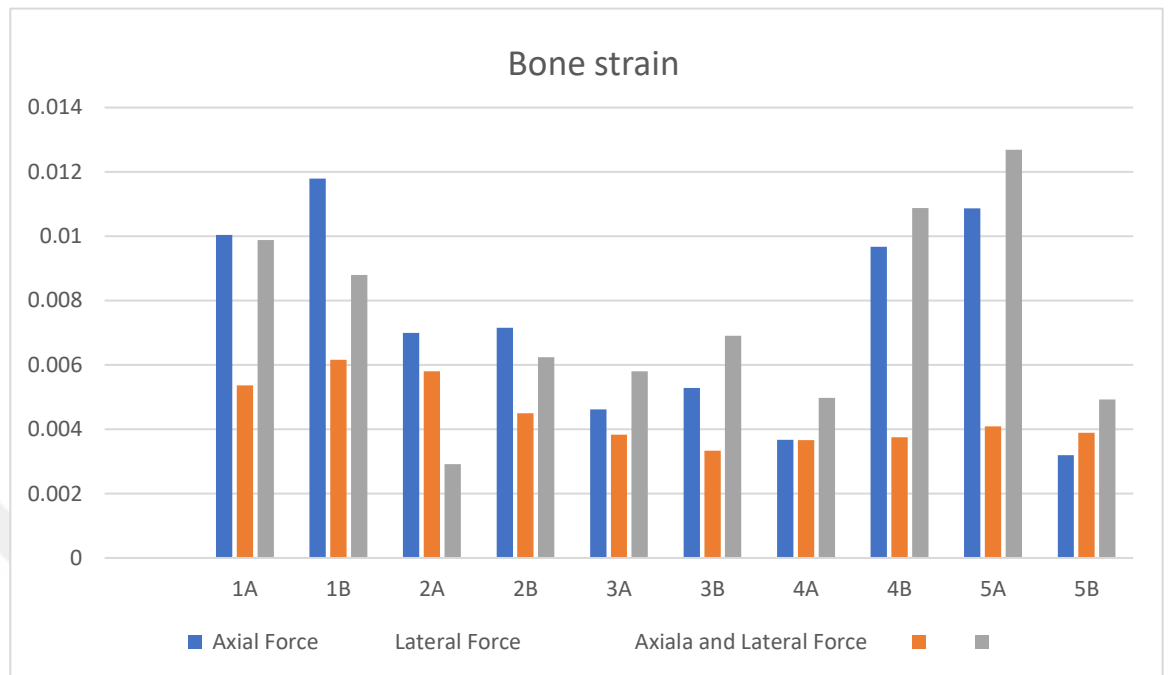


Figure 4. 69. Strain values on surrounding bone of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

4.D. Maximum and minimum strain values on implant

Strain values on the implant titanium under three forces are shown in table 4.10, (Figure 4.70).

The highest strain value on the implant under three forces is shown in the 1B model (Pterygoid dental implant placed bicortically with 45 degree in the pterygomaxillary region) .

The lowest strain values on the implant under three forces are shown in the 4A model (Pterygoid dental implant placed monocortically with 75 degree in the pterygomaxillary region) and the 5A model (Pterygoid dental implant placed monocortically with 85 degree in the pterygomaxillary region).

Table 4.10. Strain values on pytergoid implant's titanium of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

	Axial Force	Lateral Force	Axial and Lateral Force
	Implant strain	Implant strain	Implant strain
1A	0.0047803	0.0018547	0.0043489
1B	0.0062863	0.0032362	0.0052302
2A	0.0026764	0.0014535	0.0029189
2B	0.0030974	0.0016074	0.0041207
3A	0.0023491	0.00162	0.0026606
3B	0.0022635	0.002132	0.0026275
4A	0.0014674	0.0015503	0.00205
4B	0.0016005	0.0019249	0.0023643
5A	0.00071347	0.0021076	0.0020939
5B	0.00081511	0.0026334	0.0026181

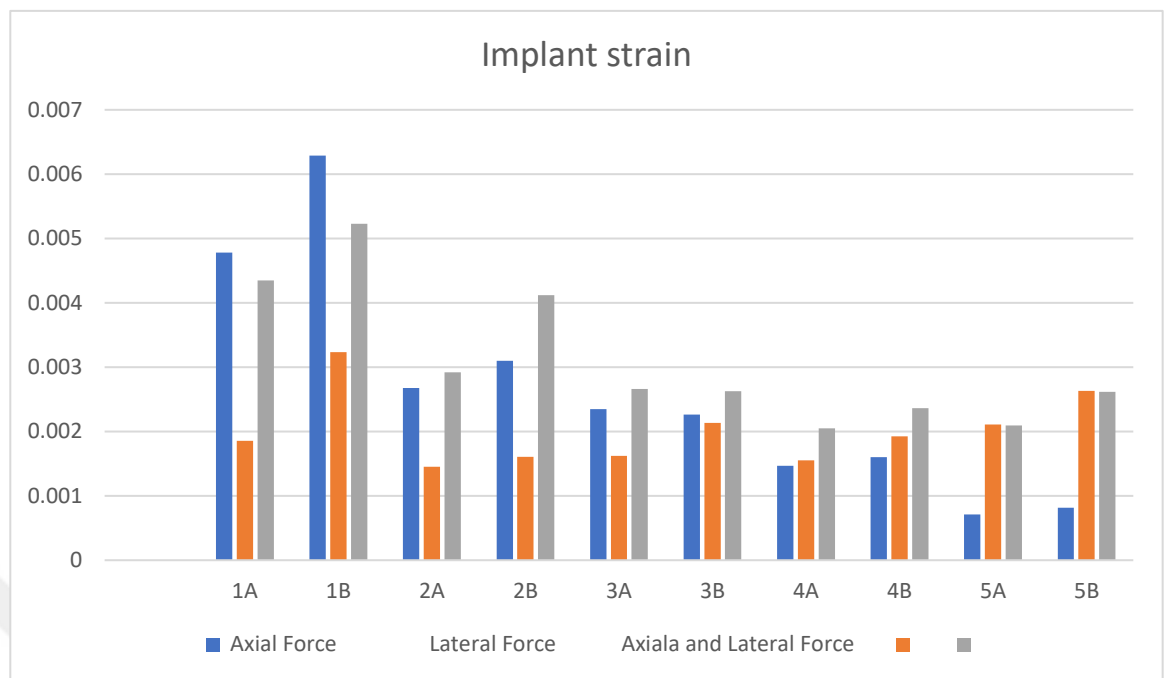


Figure 4. 70. Von Mises Strain values on pytergoid implant's titanium of all models under 150-N axial force , 50-N lateral force , 150-N axial loading with simultaneous 50-N lateral loading force

5. Discussion

The most recent studies on demographic trends have shown an increase in the number of elderly people, a phenomenon seen in almost every country around the world. According to a United Nations report issued in 2020, the population of people aged 65 and above is 703 million, and it is predicted to quadruple in thirty years. Moreover, the number of people aged 80 and above is 143 million, and it is anticipated to quadruple by 2050 (243). Age plays a major role in the epidemiology of edentulism, and it is clear that older people are most likely to be affected by edentulism (206).

Edentulism is a widespread phenomenon described as the complete loss of the entire teeth. Additionally, the World Health Organization considers edentulous patients to be physically impaired, disabled, and handicapped (245). The estimated edentulous population in the United States exceeds 36 million people. Which means approximately 10% of persons aged 18 and above are edentulous, with the rate increasing as age increases (245).

Edentulism among older people is a significant predictor of self-esteem and quality of life, and it is also an early indicator of socioeconomic position (3). Recent trends reveal that the rate of edentulism is an established indication of the population's oral health (244). In a cohort with incident edentulism, edentulism was associated with an elevated risk of all-cause mortality. After adjusting for confounding factors, this connection remained consistent (2). According to the most recent data, there are no gender differences in edentulism; both men and women have approximately equal chances of being edentulous. However, socioeconomic status appears to play a factor. Individuals living below the poverty line had a greater percentage of edentulism, namely 14.3% (247).

The frequency of edentulism among the 65- to 74-year-old population in Europe varies between 15% and 72% (246). Individuals within this same age group in China had a significantly higher likelihood of experiencing complete tooth loss, with an 11-fold increase compared to individuals aged 45 to 54. Furthermore, individuals aged 75 and above demonstrated an even greater susceptibility, with a 24-fold increase in the likelihood of being edentulous compared to the aforementioned age group (245). According to the literature, there is a higher prevalence of smoking habits and smoking-related conditions, such as asthma, emphysema, and cancer, among individuals who are edentulous. Denture wearers have reported a tendency to conceal this fact from their friends, according to health-related quality-of-life studies (245, 248).

There are various consequences of edentulism on the overall patient's health, loss of maxillary teeth in the elderly group has been shown to cause bone atrophy, an increase in cortical bone ratio, a decrease in vascularity, and malnutrition. All these factors have been linked to an increased risk of fracture (5).

In an attempt to compensate for the loss of teeth, some patients resort to dental implants as an alternative and more permanent solution for the problem. However, in the elderly age group, atrophy owing to aging and entire tooth loss in the maxilla, especially posteriorly, is evident, as is a reduction in bone volume due to sinus pneumatization, and adequate bone to accommodate a conventional implant is usually not available (6). Some of these changes are in the shape, structure, and strength of bones, which are related to their elastic modulus (249). The maxillary region has a number of features, such as centripetal resorption of the alveolar process, pneumatization of the maxillary sinuses, the nasal fossa, and the nasopalatal duct, and bone quality that is classified as type 3 or 4 by the Lekholm and Zarb categorization system (117).

When adequate residual bone is available, conventional implant rehabilitation of edentulous jaws has shown high predictability, with success rates ranging from 84–92% (250). This makes dental implants a safe and well-documented therapy for replacing lost teeth. Patients nowadays prefer implant therapy that is minimally invasive and results in less morbidity, but the significantly resorbed maxilla substantially limits conventional implant placement (117,160). As a result, various strategies have been developed during the previous two decades, with varying degrees of success (117). Ridge atrophy and maxillary sinus pneumatization provide a number of problems when it comes to rehabilitating the posterior maxilla with functional and aesthetically pleasing implant-supported prostheses (160).

A wide range of alternative treatment options exist, many of which incorporate the use of bone grafts. Several treatment options are available for addressing various conditions, such as the iliac crest block bone graft, the Le Fort I osteotomy, onlay-type bone grafting techniques, maxillary sinus lift operations in the posterior of the maxilla, tilted implants, trans-zygomatic implants, and implants in the pterygoid process (2,117, 251).

In an attempt to overcome graft operation complications, tubero-ptyergoid implants were introduced in implantology by Tulasne in 1989, who used the idea of Paul Tessier of implantation of dental implants in the posterior part of the maxilla. The approach for implant placement in the pterygoid plate, while eliminating the need for grafting operations, was initially described by Tulasne and Tessier (257).

The most recent study done by Araujo et al. showed a total of 634 people got 1893 pterygoid implants, and the average rate of life for these implants was 94.87% (181). Furthermore, the current study provides more evidence, which explains more precisely that pterygoid implants can effectively be utilized in patients with a deficient posterior maxilla. The Kummar et al. study has shown that pterygoid implants exhibit good success rates, little bone loss, and are well favored by patients. Therefore, they are an excellent option for treating patients with severe atrophic maxilla (184).

The pterygoid implant traverses the maxillary tuberosity and pyramidal process of the palatine bone, afterwards establishing contact with the pterygoid process of the sphenoid bone (8). These implants possess some benefits in comparison to alternative procedures, they reduce the duration of the healing time and facilitate anchorage in the atrophied or resorbed maxilla without the need for sinus lifts or bone grafts, resulting in the attainment of stability and very high rates of long-term success. Besides, the elimination of posterior cantilevers and the improvement of axial loading may be observed (8).

A new study by Bidra et al., which investigated the clinical studies that evaluated the short- and long-term survival of implants placed in the pterygoid area, stated that these implants had a survival rate of 92% after the first year of interval observation, the shortest follow-up time was less than a year. However, the insufficient information about problems that happened after the first year makes it hard to draw conclusions about how long these implants will last (180). Finally, the procedure of implant insertion in the pterygoid process necessitates surgical expertise and a comprehensive understanding of the anatomy of the region (8).

Sun et al. investigated a total of 120 CBCT samples, which are virtually planned pterygoid implants. The mean age of the patients was 56.2 ± 13.2 years. Virtual pterygoid implants were successfully placed in 116 samples according to the criteria. The mean implant length and mean implant length beyond the pterygoid maxillary junction were 16.3 ± 4.2 mm (range, 11.5–18 mm) and 7.1 ± 3.3 mm (range, 1.5–11.4 mm), respectively. They determined that ninety percent of virtually pterygoid implants had a close relationship with the sinus cavity, and these implants had greater lengths when they had no relation with the sinus (216). Recently, the integration of computer-aided design and computer-aided manufacturing (CAD-CAM) techniques has been used within surgical procedures (252). The dental implant placed in the pterygoid region in this study has a length of 16 mm, which is consistent with what was mentioned in the Sun et al. study.

Balshi et al. published a clinical series of pterygoid implants. In 1995, they conducted a pilot trial in which 51 pterygoid implants had machined surfaces. A total of 41 patients received these implants over a period ranging from 1 to 63 months. The overall success rate was 86.3% (212). They raised the sample size to 356 implants in 1999, achieving an 88.2% success rate with a 54-month follow-up (213). In the year 2005, a total of 164 pterygoid implants with treated surfaces were surgically placed. Subsequently, a follow-up period of 54 months was conducted, during which the success rate of these implants was shown to be much greater (96.3%) compared to previous studies (214). The current investigation was carried out to gather data on the biomechanical behavior of pterygoid implants for individuals with total edentulism.

A recent study published by Candel et al. investigated 13 papers that reported a total of 1053 pterygoid implants in 676 patients. They found that the weighted average success of pterygoid implants was 90.7%; bone loss evaluated radiographically ranged between 0 and 4.5 mm. When compared to regular implants, there were no extra problems, and the degree of patient satisfaction with the prosthesis was very high (8). Although clinical examples were reviewed, no studies with in-depth analyses of biomechanical behavior were found. The present study can help develop better treatment plans using this biomechanical examination of pterygoid implants. Therefore, the effect of axial and lateral forces on a pterygoid implant placed at 5 different angles is evaluated.

Recent research conducted by Salinas-Goodier et al. aimed at investigating the morphological parameters of the pterygomaxillary area in relation to pterygoid implants using three-dimensional analysis. Their conclusion emphasized that it is important to do a customized preoperative radiological evaluation. Gender, age, and dental condition were crucial determinants that have a substantial impact on bone density in this particular area (183). In the presented study, it is aimed to investigate stress and strain on a pterygoid dental implants that has been positioned at five angles monocortically and bicortically: 45 degree, 55 degree, 65 degree, 75 degree, and 85 degrees according to the Frankfort Horizontal Plane. This study investigates the optimal angle for a pterygoid implant that minimizes bone resorption and distortion.

Five pterygoid implants were implanted at various angles according to the Frankfort Horizontal Plane. In three different loading conditions, FEA was used to analyze the maximum equivalent stress and maximum equivalent strain in ten models under 150-N axial loading, 50-N lateral loading, and 150-N axial loading with simultaneous 50-N lateral loading for 1 second. The findings of the present study show that the maximum stress and strain values on bone under the three types of loading were detected in the crestal bone of the majority of models, and also found that the connection abutment area of most models had the highest levels of stress and strain in the pterygoid implant under all three types of loads. This is consistent with the results shown by the Wilkirson et al. study, which concluded that the highest values were found in the implant-abutment connections of the pterygoid implants (178).

According to the evaluation of stress and strain values obtained on the surrounding bone, this study was determined that under 150-N axial loading, the 75° monocortically placed model has the lowest stress value, and the lowest strain value under the same loading is shown in the same model. This is closely related to the findings of the Rodríguez X et al. study, which concluded that an implant at least 15 mm long should be used in the pterygomaxillary region. In order to optimize the utilization of superior bone quantity and quality in this specific area, it is recommended that implants be positioned at an approximate angulation of 74 degrees in the anteroposterior axis and 81 degrees in the buccopalatal axis, with reference to the Frankfort Horizontal Plane (7).

Furthermore, the evaluation of stress and strain values obtained on the surrounding bone was determined to be under 50-N lateral loading, the 65° bicortically placed model has the lowest stress value. The lowest strain value under the same loading is shown in the same model. It was found that the 75° monocortically placed model has the lowest stress value, under 150-N axial loading with simultaneous 50-N lateral loading. The lowest strain value under the same loading is shown in the 55° monocortically placed model. This is consistent with the assumption made in the study conducted by Wilkirson et al., where an angle of 55 degrees was employed. The authors described the use of pterygoid implants, which are angled implants placed in the maxillary tuberosity and extending upwards towards the pterygomaxillary fissure at an angle of approximately 55 degrees (178).

The present study's findings indicate that the PI implant, which is placed 75° monocortically, showed the lowest stress values on the surrounding bone, this finding proves that 75° monocortical placement results in the least risk of biomechanical complications on the bone. This makes it one of the optimal options for placing the PI implant. By comparing these results with a few previous studies written on the same topic, we can observe a similar consensus being obtained. Rodríguez X et al. study concluded that an implant at least 15 mm long should be used in the pterygomaxillary region. It is suggested that implants be placed so that they are about 74 degrees in the anteroposterior direction and 81 degrees in the buccopalatal direction, based on the Frankfort Horizontal Plane (7). The placement of pterygoid implants entails a thorough understanding of each patient's anatomy and individual needs. As for the least strain values on the surrounding bone, which means the least risk of distortion or deformation on the surrounding bone around the PI implant, the present study determined the same angle degree as in the least stress value on bone, which is 75° monocortical placement. This further confirms the assumption that this angle is one of the best angles for PI implant placement. This is consistent with the Rodriguez X et al. study, which found that the pterygomaxillary buttress axis was placed 72.5 ± 4.9 degrees distal and 81.3 ± 2.8 degrees palatal along the Frankfort Horizontal Plane (253).

Recent research done by Wilkerson et al. examined six models with varying implant positions and numbers designed to simulate various clinical scenarios for patients with complete maxillary edentulism. The maximum stress and strain in the pterygoid implants and surrounding bone under both loading scenarios were found in model 4, which had two pterygoid implants and two anterior implants. They concluded that pterygoid implants decreased the stress and strain levels in the surrounding bone in all cases studied (178). The present study revealed that the angle degrees of 65, 75, and 85 at which the pterygoid dental implant was placed monocortically in the pterygomaxillary region corresponded to the minimum stress and strain values observed on both the implant's titanium body and the surrounding bone.

After looking at the stress and strain values on the titanium implant body, it was found that under 150-N axial loading, the 85° monocortical placement model has the lowest stress value. The lowest strain value under the same loading is shown in the same model. These results agree with those of the Patturaja et al. Study (260). In contrast, it was found that under 50-N lateral loading, the 65° monocortical placement model has the lowest stress value. The lowest strain value under the same loading is shown in the 55° monocortical model. Also it was encountered that under 150-N axial loading with simultaneous 50-N lateral loading, the 75° monocortical placement model has the lowest stress value. The lowest strain value under the same loading is shown in the same model.

Based on the findings of this study, it has been concluded that placing a pterygoid dental implant at angles of 65, 75, and 85 degrees monocortically in the pterygomaxillary region, results in the least amount of stress and strain on the titanium implant. This suggests that there is a lower risk of biomechanical complications. The angles of 65, 75, and 85 degrees are among the optimal choices for positioning the PI implant. If these results are compared with what the Patturaja et al. study concluded, the current study is consistent with it. They found that the average angulation of the pterygomaxillary region, namely in the buccal-palatal direction, was 81.26 ± 2.71 degrees. The mean antero-posterior angulation of the pterygomaxillary area was 73.58 ± 3.85 degrees (260).

As stated by the evaluation of stress and strain values obtained on the surrounding bone, it was determined that under 150-N axial loading, a 45° bicortically placed implant has the maximum stress value. The maximum strain value under the same loading is shown in the same model. Furthermore, it was determined that under 50-N lateral loading, a 45° bicortically placed implant has the maximum stress value. The maximum strain value under the same loading is shown in the same model. By comparing these results with the Rodríguez X et al. study that stated, a 45° bicortical placement of the PI implant is not preferable, and the highest stress values are on the bone, which means more risk of biomechanical complications in the surrounding bone around the PI implant. It is consistent with the Rodríguez X et al. study (253).

However, it was found that a 75° bicortically placed implant under 150-N axial loading with simultaneous 50-N lateral loading has the maximum stress value. The maximum strain value under the same loading is shown in an 85° monocortically placed implant. Therefore, an angulation of 70 degrees relative to the Frankfort Horizontal Plane can reduce potential horizontal forces during implant rehabilitation. The outcomes of the present study are consistent with the findings of Rodríguez X et al. (7, 253).

Conversely, Graves et al. and other research have suggested using a 45° angle to position a PI implant in that location (259). The current research has determined that a 45° bicortically placed implant exhibits the highest stress and strain levels, indicating a less desirable implant stability degree. The present study and most recent research on this subject have found that the 45° angle is not the best or most suitable one (7,178, 253, 260).

This study identified the highest strain values on the bone at a 45° angle bicortically, indicating a greater risk of distortion and deformation on the surrounding bone. This further confirms the assumption that this angle is risky for PI implant insertion. In contrast to the Venturelli A et al. study, which advised an implant angulation of 45 degrees (258), nevertheless, investigations reveal that implants placed at 45 degrees have poorer load-bearing capability than implants placed at greater angulations (253).

Based on the evaluation of stress and strain values determined on the implant's titanium body, it was found that under 150-N axial loading, the model with a 45 angle degree bicortically placed implant has the maximum stress value. The maximum strain value under the same loading is shown in the same model. Furthermore, it was encountered that under 50-N lateral loading, a 45 angle degree bicortically placed implant has the maximum stress value. The maximum strain value under the same loading is shown in the same model. Finally, it was encountered that under 150-N axial loading with simultaneous 50-N lateral loading, a 45 angle degree bicortically placed implant has the maximum stress value. The maximum strain value under the same loading is shown in the same model. The present study found that the implant's titanium body has the highest stress value, which means more risk of biomechanical complications. This was observed on the bicortical 45 degree placement model, and this makes us exclude the placement of the PI implant in this particular degree. The outcomes of this study are consistent when compared to past studies conducted by Rodriguez X et al. and Patturaja et al. (253, 260).

Despite the fact that there are varied stresses and strains in the surrounding cortical bone due to the different angles of the pterygoid implant and different forms of loading, Sugiura et al. used in vivo FEA techniques to evaluate the critical bone resorption stress value. According to their findings, the essential threshold for bone resorption is around 50 MPa and 3,600 microstrains (254). These findings are consistent to the ones that we obtained.

As for the highest strain values on the implant's titanium body, which means more risk of disortion or deformation on the implant, it is found at the same angle degree as the highest strain value on the surrounding bone, which is 45 angle degree bicortical placement. This further confirms the assumption that this angle is risky for PI implant placement. The investigation conducted by Wilkirson et al. suggests that the decrease in stress and strain on the adjacent bone is likely due to a more even distribution of the applied load, while the order of increasing stress and strain did not precisely align (178). There is a high degree of consistency between Wilkirson et al. study and the results of our investigation.

A new study by Curi et al. investigated people who had atrophic posterior maxilla and had pterygoid implants placed in between 1999 and 2010. The patients were then followed up on for at least 36 months after the implants were loaded into the maxilla. They concluded that the placement of implants in the pterygoid region is a viable alternative treatment modality for the rehabilitation of patients with an atrophic posterior maxilla (206). Based on both the surrounding bone and the implant's titanium body, our study supports success with a pterygoid dental implant placed angled at 75,85 degrees monocortically or bicortically in the pterygomaxillary region. As a result, a pterygoid implant is an appropriate treatment option for patients suffering from severe posterior maxillary atrophy. This high likelihood of success is consistent with the Bidra et al. study and the Valeron et al. study and their findings reported in the clinical scenarios examined (255, 256).

In a recent study done by Ren et al., it was found that pterygoid implants have been effectively utilized in combination with the all-on-4 approach to avoid the need for a cantilevered prosthetic design. The study indicated positive long-term outcomes. The authors examine the clinical care and positive short-term results of treating severe maxillary atrophy using a distinctive 'VIV' design. This approach comprises the implantation of three implants in the anterior region and two implants in the pterygoid region (196). On the other hand, this study looked into the optimal placement of the pterygoid implant in greater detail.

Regarding pterygoid implants, the stress and strain levels in the surrounding bone for all cases are decreased in comparison to the standard cases (including those consisting of only traditionally placed implants), as conducted by Wilkirson et al. (178). According to the Patturaja et al. study, the average antero-posterior and buccopalatal angulation of the pterygomaxillary region is 81.26 degrees and 73.58 degrees, respectively (260). This is consistent with this research showing that an 85 angle minimizes bone tissue damage and implant structural integrity.

Based on the reports, these implants are considered an effective treatment for rehabilitating patients with severe posterior maxilla atrophy. However, there is not enough data available regarding the failures, particularly those that occurred after the specified follow-up periods in each trial. This biomechanical study of pterygoid implants enables the development of improved treatment plans and facilitates future research studies.



6. Conclusion

- The best angles (in terms of stress effect on the surrounding bone) for placement of a pterygoid implant, according to the Frankfort Horizontal Plane , are 65 angle degree bicortical placement , 75 angle degree monocortical placement , and 85 angle degree bicortical placement.

- The best angles (in terms of stress effect on the implant's titanium body) for placement of a pterygoid implant, according to the Frankfort Horizontal Plane, are 75 angle degree monocortical placement , 75 angle degree bicortical placement , and 85 angle degree monocortical placement.

- The best angles (in terms of distortion effect on the surrounding bone) for placement of a pterygoid implant, according to the Frankfort Horizontal Plane, are 75 angle degree monocortical placement , and 85 angle degree bicortical placement .

- The best angles (in terms of distortion effect on the implant's titanium body) for placement of a pterygoid implant, according to the Frankfort Horizontal Plane, are 85 angle degree monocortical placement , and 85 angle degree bicortical placement .

- According to this study, it is clear to us that an 85 angle degree pterygoid implant is the least harmful to the surrounding bone tissue and to the implant's body itself.

-This study provides an evidence that an angle of 85 degree offers the most favorable benefits in terms of minimizing injury to the surrounding bone tissue and the implant's structural integrity .

-This study found that the worst angle position of the pterygoid implant, according to the Frankfort Horizontal Plane, is 45 angle degree bicortical placement.

-This study showed that it is not recommended to place the pterygoid implant at 45, 55 angle degrees monocortical or bicortical placement , according to the Frankfort Horizontal Plane, this will lead to bone loss , distortion of the surrounding tissues , and implant failure .

7. References

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8. APPENDIX

8.1. Ethics Committee Approval Form



T.C.
YEDİTEPE ÜNİVERSİTESİ REKTÖRLÜĞÜ
Girişimsel Olmayan Klinik Araştırmalar Etik Kurulu



Sayı : E.83321821-805.02.03-408
Konu : Non Interventional Clinical Research
Ethics Board Decision

Sayın Prof. Dr. Ahmet Hamdi ARSLAN

Yeditepe University Non-Interventional Clinical Research Ethics Board has reviewed the research proposal placed upon ethical approval for the project as the research title, the researchers, the application number, the ethics board meeting details, and the provided documents have been outlined below. This research proposal has been evaluated by the members of the ethics board and full ethical **APPROVAL** has been granted.

Research Title:	Evaluation of lateral and axial forces in atrophic maxilla with angled pterygoid implant using three-dimensional finite element analysis
Researchers:	Thair MAHROQ, Prof. Dr. Ahmet Hamdi ARSLAN
Application Number:	202304Y0599

ETHICS BOARD MEETING DETAILS			
Meeting Date:	19 April 2024	Meeting Place:	Online (Google Meet)

PROVIDED DOCUMENTS	
Wet signed application file, file uploaded to a CD or USB media, and electronic submission	
Title of research and the names of the researchers	
Letter of application	
Application Form	
Nature of the Research;	
• Type	
• Significance and distinctive value	
• Aims and objectives	
• Method	
• Management of the research	
• Widespread impact	
• Pertinence of the budget and reason (if applicable)	
• Timeframe and convenience	
• References	
Informed consent form (uniquely prepared for the research)	

Bu belge, güvenli elektronik imza ile onaylanmıştır.

Belge Doğrulama Adresi : <http://belgedogrulama.yeditepe.edu.tr/bd.aspx?id=746674C5-90CC-4A0C-BFF0-BD850A598197>

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9. BIOGRAPHY

Personal Information

Name	Thair	Surname	MAHROQ
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Educational Status

Degree	Field	Name of Institution of Graduation	Year of Graduation
Doctoral	Oral and Maxillofacial Surgery	Yeditepe University	2024
Graduate	Faculty of Dentistry	Alquds University	2014
High School	Science	Alsamou High School	2007