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To Evaluate the Favourable Distribution Pattern of Stress in Maxilla and Mandible during Maxillary Protraction Using Miniplates of Varying Diameters and Thread Pitches under Different Levels of Inter Maxillary Forces: A Study Using Finite Element Analysis

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Abstract:-

➢ ***Introduction***

The aim of the study is to compare the stress distribution pattern by three different diameters of miniplate (1.5 mm, 2 mm, 2.5 mm) of three different mini-implant thread pitches (0 .5 mm, 1 mm, 1.5 mm), in the maxilla and mandible during maxillary protraction using different inter-maxillary elastic force of (2 N,4N,6N,8 N).

➢ ***Materials and Methods***

Using Autocad software and plate geometry, a 3D finite element model of the maxilla was made with a miniplate at the infrazygomatic buttress and a mandibular miniplate at the mandibular parasymphysis. Stress distributions and displacements were analyzed in Von Mises stress form using Ansys software.

➢ ***Results***

In the implant study, the Von Mises stress in bone (Mpa) was 142 Mpa for the 1 mm diameter implant, which was the lowest compared to 170 Mpa for the 0.5 mm pitch and 233 Mpa for the 1.5 mm pitch. Whereas in skull study when 2N elastic force was applied for a 2 mm diameter minimplant, the maximum Von Mises stress at 0.5mm,1mm and 1.5mm thread pitch was (18.454 Mpa, 18.47 Mpa, and 18.344 Mpa. For elastic force of 4N was (18,465 Mpa, 18.492 Mpa and 18.244 Mpa), for 6N elastic force was 18.388 Mpa, 18.43 Mpa and 18.086 Mpa), and for 8N was (18.272 Mpa, 18.324 Mpa and 17.883 Mpa), which was similar compared from other two diameters.

➢ ***Conclusion***

When comparing 1.5 mm, 2 mm, and 2.5 mm diameter implants with 0.5 mm, 1 mm, and 1.5 mm pitch thread , the 2 mm diameter at 1 mm pitch thread shows the least strained bone in the implant study. Whereas,in the skull study, 2 mm diameter mini-implants had similar stress distribution in the maxilla and mandible,in all the thread pitches and elastic force which shows pitch variants and different force application is not a factor for stress distribution in the bone.

Keywords:- *Class III Skeletal Malocclusion, Finite Element Method, Miniplates.*

I. INTRODUCTION

The clinician faces a hurdle when treating Class III malocclusion. Skeletal anchoring has been used in the orthopedic treatment of Class III malocclusions since it was just introduced into the field of orthodontics. Intermaxillary Class III elastics have been worn full time to protract the maxilla[1] and prevent any dento-alveolar decompensations[2,3],following the placement of surgical plates in the maxilla and mandible recently. This allows the growing patient to retain their protraction for the entire duration without the need for the heavy extraoral headgearappliance.

Nowadays, because of their tiny size and ability to be loaded instantly, miniscrews and miniplates are more commonly utilized than endossous implants[4]. Miniscrew's primary stability can be compromised, usually within the first two weeks of treatment, which is a severe drawback.

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Primary stability describes the primary factors that impact the patient, including the surgical procedure (mandibular plane angle, torque, and force levels), the host bone properties (quantity and quality of the jawbone at the placement site), and the miniscrew's design properties (diameter, length, thread shape, thread pitch, and screw material)[4] .Thread pitch is one of the most important design parameters of a miniscrew because of its effect on anchorage surfaces; however, it appears that the changes in stresses resulting from pitch variants are not yet well understood because there hasn't been much research done because of data variation in published studies.

Thus, the purpose of this study was to investigate in greater detail how the mini-plates of varying dimensions (1.5, 2, and 2.5 mm) generate light orthopaedic forces to heavy orthopaedic forces (2N, 4 N, 6 N, and 8 N) and how these forces disperse within the maxilla and mandible.

II. A FINITE ELEMENT ANALYSIS- INTRODUCTION

An orthodontist's modern research tool is the finite element method (FEM), also known as finite element analysis (FEA).FEM is an engineering technique used to determine the stresses and strains in any material, including biological tissues[5].Clough coined the word and used it in dentistry in 1960[6].Weinstein first used it in implant dentistry in 1976.

A growth model utilizing FEM[7] was documented by MOSS in 1980. The orthodontist can gain a deeper understanding of the physiologic processes that take place inside the dentoalveolar complex by using the quantitative data that finite element analysis offers. An enhanced comprehension of the responses and interplay of distinct tissues could be achieved through the application of numerical approaches. A computer program simulates the item to be studied graphically as a mesh, which defines the geometry of the body being studied.

Because the FEM findings will depend on the characteristics of the modeling systems, the modeling process is crucial. One can ascertain how much distortion any section of the cube experiences when another component is pushed by a force by understanding the mechanical characteristics of the object, such as the modulus of elasticity and Poisson's ratio.

Pre-processing, which is arguably the most important stage, essentially entails modeling the structure under study. Representing geometry in terms of points, lines, areas, and volumes is the aim of the geometric modeling phase. Geometrically simple parts (Elements) can represent smooth or complex objects.3D-CT scanning can be used to accomplish this.

The technique of Discretization[8] involves breaking the structure up into multiple little components that are connected by nodes. It is necessary to number each element and node in order to create a matrix connectivity configuration. The elements could come in a variety of shapes and be one, two, or three dimensional. It is imperative that the components do not overlap and are only connected at critical points, also referred to as nodes. "Meshing" is the process of linking elements at nodes and removing duplicate nodes. The ANSYS software can assist in the development of the finite element model. Every element has the freedom to move in all three spatial planes. A set of global equations that model the characteristics of the entire system are constructed from equations created for each element in the FEM mesh.

➢ *The Minimal Attributes that must be Assigned are:*

- The elastic modulus and
- Poisson's Ratio.

The Young's modulus, or the modulus of elasticity[9], is one of the most crucial characteristics of solid materials is E, a material parameter that indicates rigidity. Energy is added to a material by mechanical deformation. Either plastic dissipation or elastic storage occurs with the energy. Stress-strain curves provide a concise representation of how a material stores this energy.

The Poisson effect, which occurs when a material has a tendency to expand perpendicular to the direction of compression, is quantified by Poisson's ratio. In contrast, the material typically tends to contract in directions transverse to the direction of stretching if it is stretched as opposed to compressed. A stable, isotropic, linear elastic material's Poisson's ratio will be greater than −1.0 or less than 0.5 due to the need for positive values for the bulk, shear, and Young's moduli[10].

A. Boundary Conditions

If an element is built on the computer and a force is applied, it will behave as though it is a hard body floating freely and will move in a translatory, rotatory, or a mix of the two directions without experiencing deformation. To study its deformation, some degrees of freedom (movement of the node in each direction x, y, and z) for some of the nodes must be restricted. Such constraints are termed boundary conditions[11].

B. Force Applied at Different Geometry and Configuration Positions

These can be aimed at any point in any of the three space planes and can take the form of force or moments. Hooke's law allows us to calculate the stresses based on the strains[12]. The numerical form is the predominant output format of the Finite Element Analysis. Typically, it consists of the derivatives and nodal values of the field variables. The majority of the output is provided as color-coded maps[13]. These maps are interpreted to determine the quantitative analysis.

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III. MATERIALS AND METHODS

A. Preparation for Geometric Model of the Skull(Figure 1)

Using a CT scan, the morphology of the teeth and bones was obtained. Bony elements' geometries are thought to be homogenous, isotropic, and linearly elastic.

B. Preparation for Geometric Model of Miniplates

Three distinct diameters of titanium miniplates were designed in accordance with the following dimensions: miniplate diameters of 1.5 mm, 2 mm, and 2.5 mm (thread pitch of 0.5 mm, 1 mm, and 1.5 mm) respectively in the maxilla (one in each infrazygomatic buttress) and mandible (one in each of the anterior segment of mandible between the left and right permanent lateral incisors and canine; figure 1C).

C. Modelling

The representation of the geometric model in terms of a limited number of elements and nodes, which serve as the foundation for the numerical representation of the model, is known as element modeling. This model includes information about the material and other properties, loading, boundary conditions, and an element that may consist of triangular or quadrilateral shapes (figure 1 A). It is a mathematical matrix of the collective interaction among degrees of freedom whose (displacements) and actions (forces) of structure under load or considered to exist.

D. Material Properties

Young's modulus, also known as the modulus of elasticity, and the Poisson ratio were the material qualities assigned (Table 1)

Finite element software can be used to study a structure for stress distributions during force application after it has been numerically constructed and given material parameters."ANSYS WORKBENCH" was the finite element program utilized in this investigation. Von Mises stresses, a measurement used to predict whether a specific material would yield or fracture, were used to evaluate the stresses and strains on the bone elements.

36 models in all were created and divided into 4 groups.

The miniplate diameters of 1.5 mm, 2 mm, and 2.5 mm are subjected to the following intermaxillary elastic forces: Group 1: 2N, Group 2: 4N, Group 3: 6N, and Group 4: 8N.Utilizing finite element software, the many models that were produced were examined in order to document the pattern of stress distribution inside the structure that von Mises stress represented. The SPSS software package (SPSS for Windows XP, version 17.0, Chicago) was used for all statistical analysis. A one-way ANOVA test was used to assess the significance of the stress distribution patterns in the maxilla and mandible using various intermaxillary elastics.

IV. RESULTS AND OBSERVATION

The study's objective is to compare, using varying intermaxillary elastic forces (2 N, 4 N, 6 N, 8 N), the stress distribution pattern in the maxilla and mandible during maxillary protraction of different miniplate diameters (1.5 mm, 2 mm, 2.5 mm) of different miniimplant thread pitches (0.5 mm, 1 mm, 1.5 mm).

- *Implant Study*

The values found in (Table 2) correspond to the Von Mises stress in bone. Figure 2 illustrates the least amount of stress in the bone when comparing the Von Mises stress of 1.5mm, 2mm, and 2.5mm diameter implants of 0.5mm, 1mm, and 1.5mm pitch.

- *Skull Study*

Table 3 displayed the obtained data. Using three distinct diameters, the current finite element study of the skull during maxillary protraction it was discovered that, despite variations in pitch and force application, the stress distribution pattern in the maxilla and mandible was identical for miniimplants with a 2 mm diameter (Figures 3 and 5).

V. STATISTICAL ANALYSIS

For every group, descriptive statistics were computed, encompassing the mean, standard deviation, and the lowest and highest values presented in MEAN±SD.(Table 4). For statistical analysis, SPSS 16.0, the Statistical Package for Social Sciences, was utilized. ANOVA applied in one approach for analysis. At a 95% confidence interval, a P value of less than 0.05 ($P<0.05$) is deemed statistically significant.

Our hypothesis was that the stress is lowest for implants with a diameter of 2 mm, while the null hypothesis stated that the stress is not lowest for implants with a diameter of 2 mm.

Stress samples for all diameters under all load circumstances were subjected to a one-way ANOVA (Table 5). The mean is significantly different for at least one of the diameters, as indicated by the F statistic of $F=19.347$. (Table II).

The research is noteworthy because the p value is less than 0.05. As a result, the null hypothesis can be rejected.When comparing the relevance of the various implant diameters, the 2.0 mm diameter implant's p value is noteworthy.(Table 5).Thus, our theory is supported.

VI. DISCUSSION

Many attempts have been made in the field of orthodontics to demonstrate how teeth and the tissues that support them respond to the application of orthodontic forces. Modern tools for advancing 3-dimensional (3D) morphology from radiographic charts and stress distributions for intricate anatomic geometries, such bone14, include medical imaging, showing, and the finite element method (FEM).

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The model to be examined is represented graphically as a mesh in a computer, which depicts the anatomy of the subject under examination. Using a technique known as discretization, this mesh is divided into several subunits known as elements. These are connected at nodes, which are a finite set of points. Initially, 3-matic programming was used for the display. Using a computer-aided design (CAD) tool is typically the first step in creating the basic framework. Nevertheless, the necessity for a flexible tool to design STL-level modifications increases with proximity to the actual generation.

This is where 3-matic proves to be possibly the most important component. On an STL level, 3-matic provides plan modification, design modifications, 3D finishing, remeshing, forward building, and much more. After that, the display is finished and broken down using software. There are several FEA groups, such as Ansys, Universe, Diffpack, Lusas, Nastran, SAP2000, visual FEA, and so on, but Ansys will be a suitable programming for this test due to its extensive qualification in material characteristics and strength. Relationships are programmed using ANSYS to unquestionably predict their overall behavior.

The distinctive growth of the malocclusion consistently emphasizes that it is a non-self-correcting condition that will eventually deteriorate. Treatment options include camouflage orthodontics, dentofacial orthopedics, and a combined orthognathic and orthodontic methodology[14]. One of the therapeutic strategies for Class III malocclusion in its early stages has been upheld: protraction facemask with maxillary development[15,16,17].

Skeletal anchoring is being used in the orthopedic treatment of Class III malocclusions because of its application in orthodontics. According to B H Kircellia et al.[18], an 11-year-old girl's midface significantly improved when an orthopedic force was applied from miniplates using elastics, specifically on the anterior maxillary bone. Similarly, using 200 miniplates for 97 patients, M A Cornelis et al.[19] concluded that miniplates were simple to use, safe, and an effective complement for difficult orthodontic procedures.

Miniplates are therefore the best option in this study for improved anchoring when treating skeletal class III patients.In order to lengthen the maxilla, miniplates have recently been inserted into the mandible and maxilla, and intermaxillary Class III elastics have been worn all the time. As a result, the cumbersome extraoral headgear is no longer necessary, and the protraction is maintained continuously.

Using intermaxillary elastics made of titanium miniplates for better skeletal anchorage without having any negative dentoalveolar effects, Gavin C. Heymann et al.[12] discovered an alternative method for maxillary protraction in six patients that outperformed the conventional method and resulted in minimal dentoalveolar changes and better improvement in the skeletal relationships of maxillary protraction.

Miniplates were positioned in the parasymphyseal and infrazygomatic buttresses of the jaw, and elastics were used to provide intermaxillary strains.

In their study of ten patients, Ola Mohamed Eid et al[20] also reported a noteworthy advancement in orthopedic maxillary care. In each treated patient, four miniplates were inserted between the lower right and left lateral incisor and canine of the mandible and on the left and right infrazygomatic crest of the maxillary buttress. Intermaxillary elastics of class III were used. Force was applied at a rate of 300 g per side at first, then 350 g after a month, and 450 g per side after two months. While the SNB angle dropped to 0.20°, the SNA angle rose to 2.80°. The N A-Pog angle rose to 4.70°, whereas the ANB angle grew to 3.40°.

In the current investigation, we examined the distribution of stress and displacement under varied orthopaedic forces of 2N, 4N, 6N, and 8N during maxillary protraction of three distinct miniplate diameters. The application of high orthopaedic forces examined from a work by Lucilla Zimmermann et al.[21], in which he evaluated the distribution of stresses and strains on the bone tissue next to the miniplate loaded with 2,5, and 15 N using the finite element method. The miniplate with the screw anchorage system was able to sustain orthopaedic forces without compromising its strength and remaining within physiological bounds.

The design characteristics of the miniimplant, such as diameter, length, thread pitch, thread form, and screw material, determine the primary stability of the minimplants. Given its impact on anchorage surfaces, thread pitch is one of the most significant factors among them. Using 26 models loaded with 2 N, Ramzi Duabis et al.[22] measured several forms of stress in the cortical bone around miniscrew implants. They came to the conclusion that the diameter, head length, thread size, and elastic modulus of cancellous bone of miniscrew implants influence the stresses in the cortical bone layer around the implant, which may consequently have an impact on its stability.

As a result, thread pitch serves to stabilize the miniscrew. However, it appears that the variations in pitch that induce changes in stresses have not yet been adequately investigated because of discrepancies in the data from published studies. Therefore, for three distinct diameters (1.5, 2, and 2.5 mm), three pitch variants (0.5, 1 mm, and 1.5 mm) are used in the current investigation.

A three-dimensional model of the bone with the implant is made in order to ascertain the distribution of stress in the bone. Compared to 0.5mm (170 Mpa) and 1.5mm (233 Mpa) pitch, it was discovered that a 2mm diameter implant with a 1 mm pitch exhibits the least Von Mises stress in bone (142 Mpa). This finding is consistent with a research by Motaghi et al[23], which demonstrated that stresses rise with decreasing thread pitch but decrease with decreasing thread pitch below a specific threshold. As the stresses grew, the pattern of stress distribution changed. In this study, the stress distributions steadily increase and decrease with increasing pitch when

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three diameters and three pitch variants are compared. In light of this, 1 mm pitch exhibits the least and most significant stress dispersion of all.

In contrast, Motoyoshi et al[24] study, examined the more advantageous stress distribution of shorter screw pitches in comparison to longer ones. Abuhussein et al[25] also looked at these variables that could impact implant stability. They came to the conclusion that implant stability would benefit from a lower thread pitch.

A number of researchers, including Amanda et al.[26], assessed how pitch distance affected the main stability of 20 minimplants. They concluded that, in comparison to longer pitch implants and an insertion angle of 450, shorter pitch miniimplants with an insertion angle of 30° (G1) demonstrated superior stability.

Using the finite element method, Handa et al[27] also assessed the effect of thread pitch on orthodontic mini-implants. Mini-implants with 0.5 mm, 1.0 mm, and 1.5 mm thread pitches were used in the creation of three models. When compared to implants with thread pitches of 1.0 and 1.5 mm, mini-implants with a thread pitch of 0.5 mm revealed the least amount of bone stress; thus, as the thread pitch of the orthodontic mini-implant grows, so do the stresses in the bone.But in this study, compared to 0.5mm and 1.5mm pitches (170 Mpa and 233 Mpa, respectively), a 2mm diameter implant with a 1 mm pitch exhibits the lowest Von Mises stress in bone (142 Mpa).

The current study examined the patterns of stress distribution in the maxilla and mandible using a three-dimensional model of the skull. It was discovered that the cortical bone has a more significantly spread stress distribution pattern than the cancellous bone. In their investigation of two different types of miniplates, Lee et al.[28] determined that an orthopedic force of 4 N produced the highest von Mises stress in the cortical bone as opposed to the cancellous segment. It was discovered that stress distribution rises with an increase in force application and miniimplant pitch when comparing Von Mises stresses of 1.5mm implant diameter during the application of orthodontic and orthopedic pressures.

Byoun N Y et al[29] discovered that when the diameter increases from 1.2 mm to 2.0 mm, there was no correlation between the insertion angle and the reduction of von Mises stresses in the miniimplant and cortical and cancellous bone. He came to the conclusion that, rather than the insertion angle, the minimplant's success was closely tied to its diameter and point of contact with the cortical bone surface. In this study, it was discovered that stress distribution does not change despite an increase in force application and miniimplant pitch when comparing Von Mises stresses of a 2 mm implant diameter during the application of orthodontic and orthopedic forces. It was discovered that the Von Mises stresses of a 2.5 mm implant diameter increased as orthodontic and orthopedic forces were applied. However, the 1.5 mm pitch showed greater stress distribution than the 0.5 mm and 1 mm pitches, which were found to be equal.

The modeling system, the most important stage in conducting a FEA study, is the foundation of the FEA result. An experienced operator is needed for this. The material's qualities, the load being applied, and the boundary condition must also be understood. As a result, the results need to be carefully considered.

VII. CONCLUSION

The study's goal is to compare, using finite element modeling (FEM), the stress distribution patterns in the maxilla and mandible during maxillary protraction of various miniplate diameters with various miniimplant thread pitches.

➢ *Within the Parameters of the Research, the Subsequent Deductions were Made:*

- The strength of the miniplate was unaffected by the orthopedic forces that the miniplate and screws anchorage system could endure.
- The thread pitch is one of the key design characteristics of the miniimplant that affects primary stability, along with thread shape, diameter, and length.
- When comparing three miniimplant diameters (1.5 mm, 2 mm, and 2.5 mm) with three different pitch versions (0.5 mm, 1 mm, and 1.5 mm), the stress distributions gradually rise as pitch increases.In comparison to 0.5mm and 1.5mm pitches (170 and 233 MPa), the Von Mises stress in bone is 142 MPa for a 2mm diameter implant with a 1 mm pitch.
- The current finite element analysis of the skull during maxillary protraction found that, despite variations in pitch and force application, the stress distribution pattern in the maxilla and mandible was identical for 2 mm diameter miniimplants.
- Because the finite element method is precise, noninvasive, controls the research variables, and yields quantitative data regarding the interior structures of the skull, it can overcome the drawbacks of other experimental techniques.

FEM is a potent modern research instrument, and a wealth of literature exists on the distribution of stress and deformation of nonliving objects, as well as natural and restored craniofacial structures impacted by three-dimensional stress fields that are challenging to evaluate in any other way. However, the aim of any simulation study should be the experimental or clinical confirmation of the theoretical prediction.

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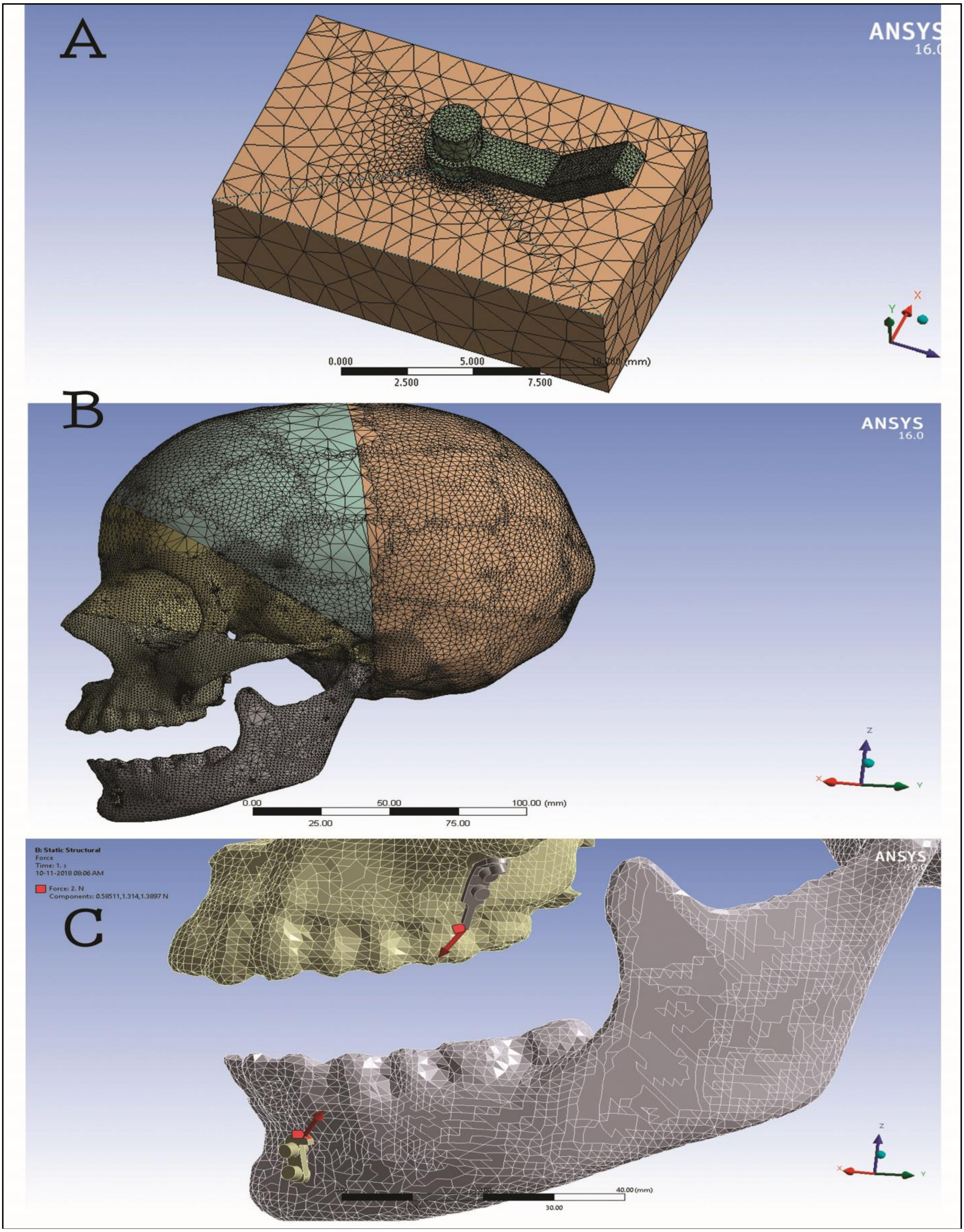

Fig 1: A)Mesh Diagram of Implant, B)Skull Geometry after Meshing and C) Direction of Force Applied

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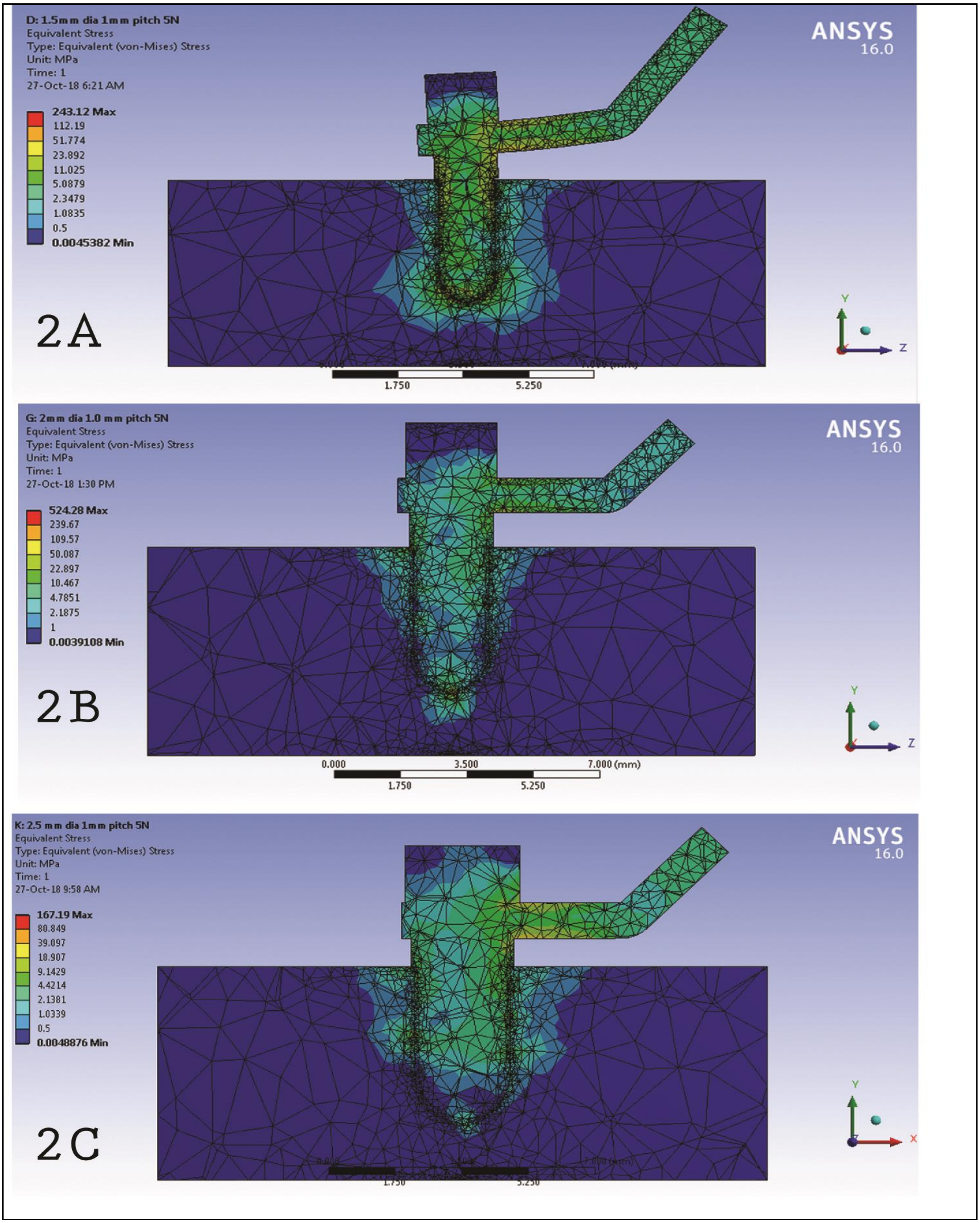

Fig 2: Implant Study

- 2A)Von Mises stress of 1.5mm implant diameter with 1 mm pitch ,
- 2B)Von Mises stress of 2mm implant diameter with 1 mm pitch and
- 2C) Von Mises stress of 2.5mm diameter implant with 1 mm pitch

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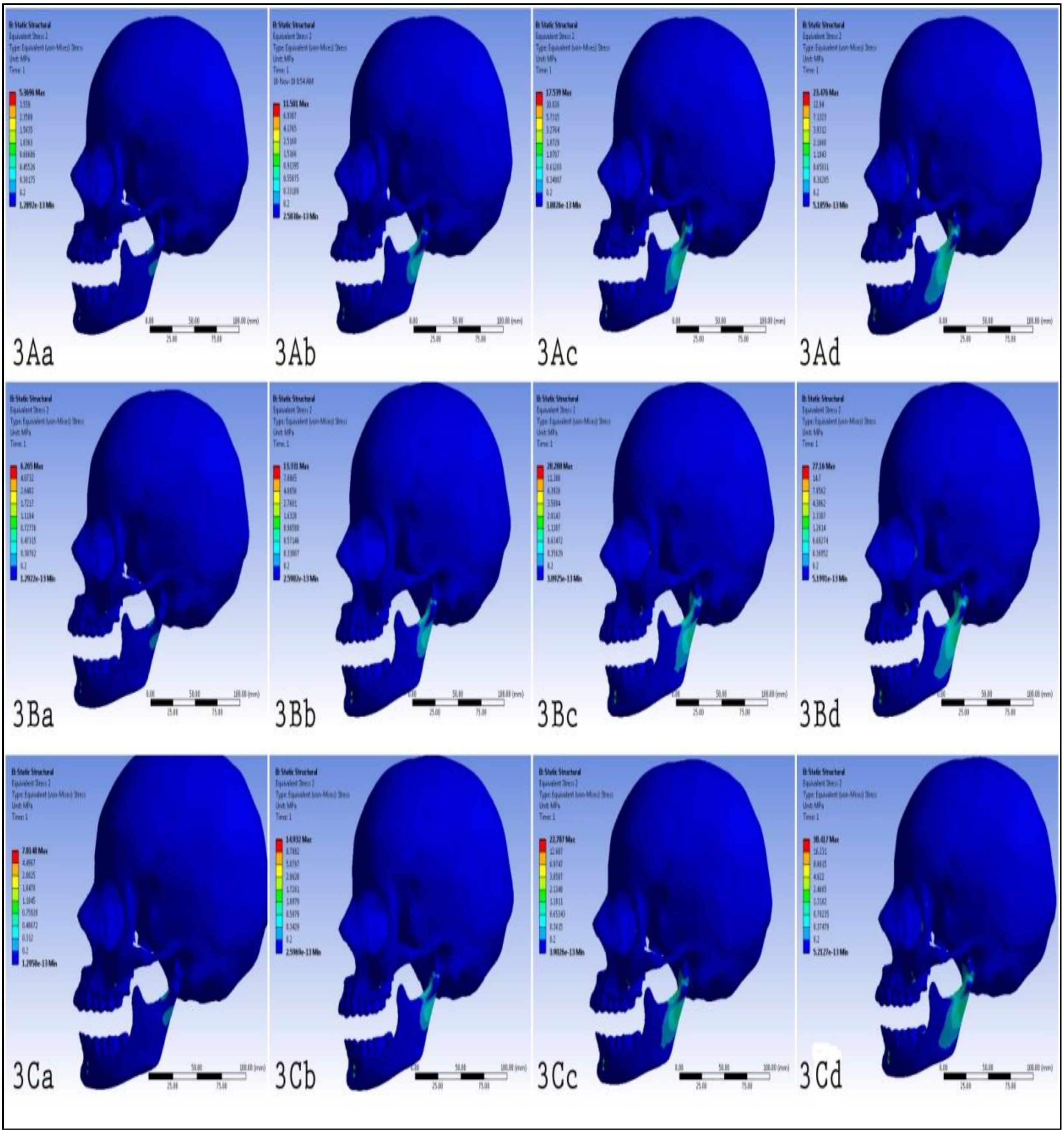

Fig 3: SKULL STUDY: Von Mises Stresses of 1.5mm diameter miniimplant

- 3Aa-d) Von Mises Stresses of 1.5mm diameter miniimplant with 0.5mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 3Ba-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 3Ca-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1.5mm pitch when 2N,4N,6N and 8N force is applied respectively.

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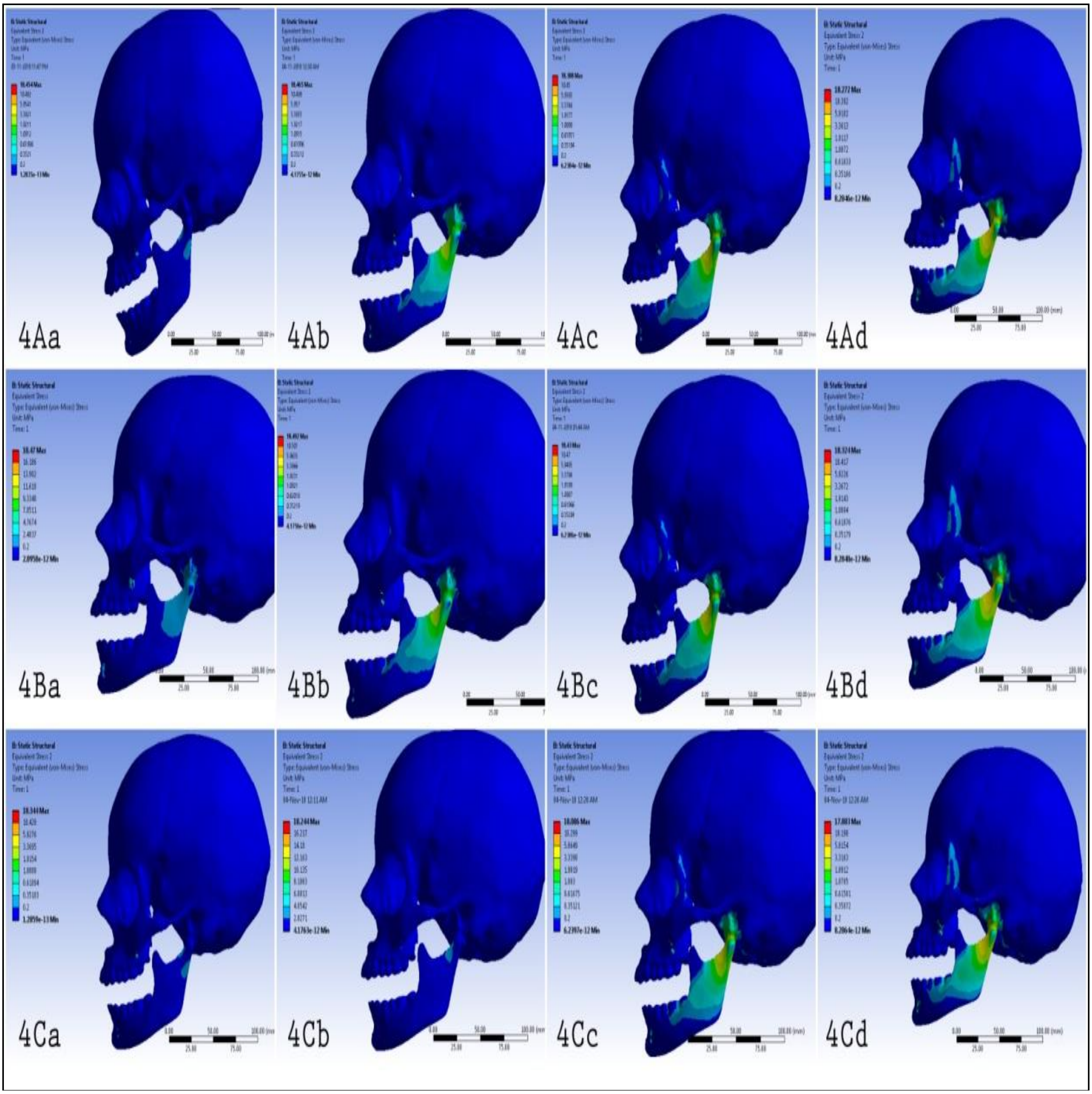

Fig 4: Von Mises Stresses of 1.5mm Diameter Miniimplant

- 4Aa-d) Von Mises Stresses of 1.5mm diameter miniimplant with 0.5mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 4Ba-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 4Ca-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1.5mm pitch when 2N,4N,6N and 8N force is applied respectively.

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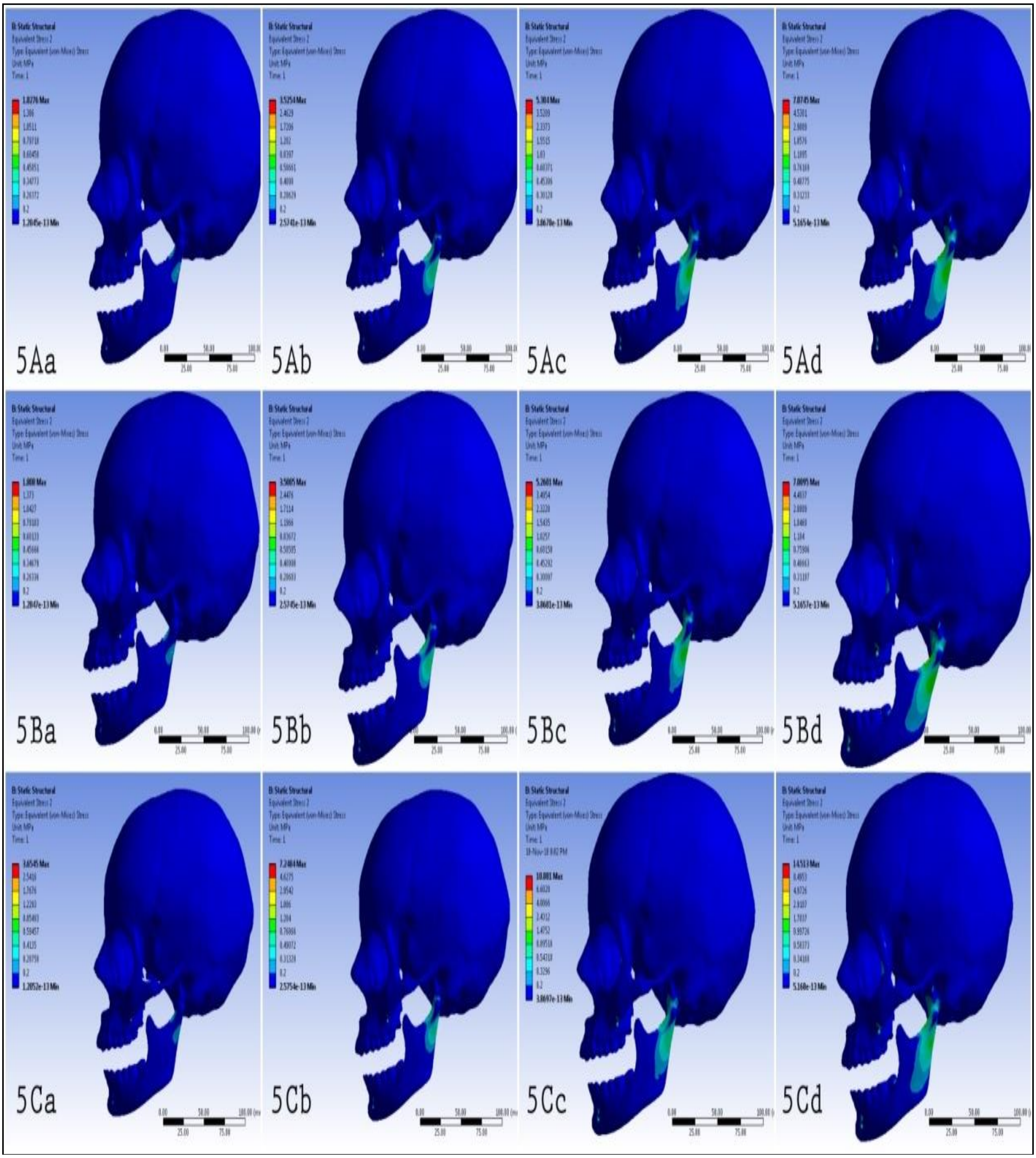

Fig 5: Von Mises Stresses of 1.5mm Diameter Miniimplant

- 5Aa-d) Von Mises Stresses of 1.5mm diameter miniimplant with 0.5mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 5Ba-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1mm pitch when 2N,4N,6N and 8N force is applied respectively.
- 5Ca-d) Von Mises Stresses of 1.5mm diameter miniimplant with 1.5mm pitch when 2N,4N,6N and 8N force is applied respectively.