Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 4, 2021, Pages. 2211 – 2217
Received 05 March 2021; Accepted 01 April 2021.

Evaluation of Stress Distribution Pattern of Square Head One-Piece Mini-Implant and Newly Designed Mini-Implant (Pedoplant) as Anterior Tooth Prosthesis in Children: Protocol for Finite Element Analysis Study.

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ABSTRACT

Background: Mini-implants as anterior tooth prosthesis in children have shown promising results. However, improvisation in their design to create lifelike restorations that is aesthetically pleasing is a necessity.
Objective: To determine the stress distributing propertyof commercially available square-head one-piece mini-implant and a newly designed mini-implant named 'Pedoplant' as anterior tooth prosthesis in children using finite element analysis (FEA).
Methods:A FEA of square head one-piece mini-implant used as maxillary anterior prosthesis in growing children will be performed to determine its stress distribution pattern. A novel mini-implant is designed, taking into account the aesthetic consideration like the ability to create a good emergence profile along with other favourable mechanical properties. A finite element analysis of this virtually designed mini-implant named 'Pedoplant' will be performed to evaluate its stress distribution pattern.
Expected Results:The results obtained after performing finite element analysis of square-head one-piece mini-implant and Pedoplant mini-implant will be compared for evaluating the most efficacious mini-implant in terms of its stress distributing property.
Conclusions:The new mini-implant designed to create good emergence profile will be evaluated for its stress distribution property. The study will thus, provide insights regarding the use of most appropriate type of mini-implant in children.

Keywords
Mini-implant; Children; Maxilla; Missing anterior teeth

Introduction

Missing permanent anterior teeth in children, especially during the years of their transition into adolescence is a matter of concern as it may jeopardize the aesthetic appearance, speech and have a negative impact on their psychological development (Prakash et al., 2011).It is most commonly attributed to congenital absence of teeth or traumatic injuries commonly witnessed in children.Prosthodontic rehabilitation treatment modalities in growing children proposed to replace the missing teeth include removable partial dentures, fixed conventional bridges and cantilever bridges (AlNuaimi & Mansoor, 2019).
However, each of these treatment modalities come at a cost of their own disadvantages which prevail over the advantages.For instance, fixed prosthetic devices require the grinding of adjacent healthy teeth and hence are generally not advised in growing age group (Bilgin & Kaya, 2018). Thus, to replace a tooth missing in children, removable partial denture has been the treatment of choice.Nevertheless, this technique of prosthetic rehabilitation is also associated with certain drawbacks which include increased ridge resorption, dental caries incidences, periodontal problems and the fact that this treatment method largely depends upon patient compliance for successful results, turns out to be its major disadvantage (Dula et al., 2015).
To overcome these drawbacks, the concept of prosthetic rehabilitation using implants was brought forth. Conventional implants usually present with a larger diameter which can produce fenestrations in growing children due to loss of labial bone (Op Heij et al., 2000).Also, their use as provisional prosthesis is a matter of concern considering the larger size. Thus, in such clinical situations, mini-implants can be considered as an apt substitute to traditional dental implants accounting to the smaller size they come with.
Mini implants are the dental implants with a smaller diameter (Upendran et al., 2020). They are mostly made up of biocompatible titanium material. These mini-implants comparatively require less surgical intervention and can be placed when the labio-lingual width of the bone is insufficient which is commonly seen in the anterior maxilla (Balaji et al., 2010).Furthermore, these implants have the advantage of immediate stability, reduced marginal bone loss and minimum post-operative discomfort thus making them a reliable alternative for anterior prosthetic rehabilitation in children (Preoteasa et al. 2015). These mini-implants are available in different diameters. The prosthetic head of these mini-implants are mostly available as O-ball head and square head types. The O-ball head is used in cases of overdentures whereas the square prosthetic head is used for anterior prosthesis (Upendran et al.,

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2020). However, the regularly placed mini-implants with square prosthetic head do lack the proficiency of incorporating emergence profile which is an important key factor for gingival aesthetic to create a lifelike restoration. Till date no finite element analysis (FEA) has been conducted regarding stress distribution pattern of one-piece mini-implant (square head) in children as an anterior tooth prosthesis. Considering this disadvantage of square head one-piece mini-implants we will be designing a virtual novel mini-implant named 'Pedoplant' which will have the ability to execute an emergence profile along with other superior qualities. Thus, the present FEA is planned to evaluate square head one-piece mini-implant and Pedoplant mini-implant for their stress distribution pattern along the mini-implant and underlying alveolar bone in growing children.
Aim of the study is to evaluate the efficacy of square head one-piece mini-implant and Pedoplant mini-implant in terms of their stress distribution pattern along the mini-implant and underlying maxillary anterior region alveolar bone in growing children.

Materials and Methodology

Study design - An in-vitro study.
Participants and setting - The target population considered in the study is growing age children. Hence the maxillary jaw model in the finite element analysis mimics that of a growing child (10-16 year). All the material properties incorporated in the model are taken considering the concerned age group.
Screening - Not applicable
Randomization **-** Not applicable
Blinding **-** Not applicable
Study objective and outcome – The primary objectives of the study are: 1. To evaluate the stress distribution pattern in square head one-piece mini-implant and Pedoplant mini-implant. 2. To predict the areas of obvious fracture in the mini-implants (square head one-piece and Pedoplant). 3. To predict the areas in the underlying alveolar bone showing maximum resorption.
Sample size - One sample each of square head one-piece mini-implant of diameter 2.1 mm and newly designed mini-implant 'Pedoplant' of the same diameter.
Armamentarium required -

1. Computer Aided Design (CAD) software - It a technology that designs a product and documents the design process (Najy, 2013). At first two dimensional sketches of cortical and cancellous bones and square head one-piece mini-implant of 2.1 mm diameter will be developed. Then they will be converted into 3D models by using Rib features in Computer-Aided Three-dimensional Interactive Application (CATIA) software. All the three-dimensional components are assembled together to form the final structure ready for FEA. While exporting the file, it will be saved in the format which is compatible with FEA software. In the current study it will be used for designing of models of anterior maxilla and the mini-implant.
2. FEA software – Analysis System (ANSYS)
   ANSYS provides the ability to automate and customize simulations and even parameterize them for design scenarios. It executes equations regarding components and solves them thereby making a thorough illustration of how the framework acts overall (Sharma et al., 2020). In our study the software will be used for analysis of stresses on the mentioned model.

3D models of a square head one-piece mini-implant and maxillary anterior jaw will be constructed using CATIA software. The 3D models of mini-implant will be assembled in 3D models of maxillary anterior jaw in CATIA software in a way similar to how a mini-implant is clinically placed in the bone. After proper placement of the mini-implant the 3D designed models then will be transferred to ANSYS software for stress analysis.
Selection and specifying the material and its properties-
In the current study for FEA; maxillary cortical bone, cancellous bone and titanium mini-implants are considered. The FEA will require mechanical properties of the mentioned entities like density, Young's modulus, and Poisson's ratio. These properties will be incorporated into the software so that they mimic the biological system.
Meshing of 3D Model –
For FEA analysis the whole assembly of mini-implant and bone structure gets divided into a number of well distanced points called nodes (Chatzigianni et al., 2011). These nodes are further joined to each other to form finite elements. The process of joining these nodes is called meshing. Any continuous object which is considered for analysis has an infinite number of points, Hence, the preliminary step in finite element analysis is to perform the basic calculations for a problem with finite number of points and then interpolate the obtained results for the entire domain (Nikishkov, 2004). The finite element method reduces the number of nodes/points from infinite into a finite

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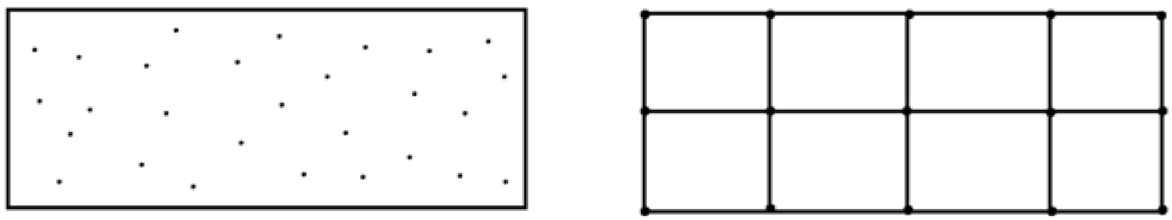
number with the help of meshing {Fig 1}.

Fig 1. The number of equations before and after meshing



No. of points = ∞
Total equation = ∞

No. of nodes = 15
Total equation = 90

There are various types of mesh such as triangular, quadrilateral, pyramid, triangular prism, hexahedron, and polyhedron (Shimada, 2006). For this research work hex dominant method is selected for meshing and mesh type is hexahedron. It is selected because it gives a fine quality of mesh and structure sustains its actual mechanical stiffness. The meshing elements size is chosen such that the difference between two nodes of an element will be minimum. This selection also provides accurate results and for more enhancement meshing is done without defeaturing with capturing all the curvatures and proximity.

Application of fixed and forced constraint -

In fixed constraint, bone assemblies (cortical and cancellous bone) will be fixed so that they remain static during the application of forces.A dummy crown resembling the properties of the zirconia {Table 1} will be used over the mini-implants.The bone assemblies (cortical and cancellous bone) will be fixed so that they remain static during the application of forces.Using FEM software, different compressive forces on the implant will be applied. The stress distribution pattern along the mini-implant and bone will be calculated in ANSYS. Stresses in the mini-implant and the bone will be evaluated by von mises stress analysis test.

Table 1. Material properties of zirconia

Properties	Young's modulus (Pa)	Poisson's ratio
Zirconia	$2.1 * 10^{11}$	0.3

Studying the pattern of stress distribution in the square head one-piece mini-implant and considering the shortcomings it possesses, we will be designing a virtual novel mini-implant (Pedoplant) which will create a better emergence profile, thus improving the aesthetics along with other superior properties. Major modifications will be done in the crest module of the mini-implant. All the changes will be done considering the biomechanical deliberations stated to improve the design of implant system.

The final design will be considered after performing a number of trials using different design inputs. 1. Increasing the diameter of the crest module. 2. Making the crest module divergent. 3. Scalloped collar. Parameters like screw diameter, length, thread form, pitch and size of thread will be similar to square head one-piece mini-implant. The 3D model of new design will be constructed using CATIA software. The 3D model of this Pedoplant mini-implant will be assembled with the 3D model of the anterior maxillary jaw. The design then will be transferred to ANSYS software for stress analysis.The Von Mises stresses for the models and the mini-implants once obtained, will be tabulated, illustrated and graphically represented.

The exact methodology used throughout the research study is briefed below {Figure 2}

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Figure 2. Methodology used to obtain stress distribution pattern using FEA

Developing 3D model of mini-implant and anterior maxillary jaw in CAD

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Importing 3D model into FEA software

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Specification of materials used

↓

Converting the model into finite elements through meshing

↓

Specifying the analysis setting

↓

Applying the fixed and forced constraints

↓

Evaluation of obtained results from the analysis

Ethical consideration –
As the study is a finite element analysis which is an in-vitro experimental study, ethical consideration is not necessarily required.

Patient Confidentiality and Involvement and Data access -
As the study is under in-vitro setting no patient confidentiality and involvement is required.
Directly involved persons in the study such as researchers will have access to data essential for the study and they can modify it as and when required.

Expected Results

The stress values are obtained through numerically calculated finite element analysis and mini-implant life is dependent on the magnitude of stresses induced.
Frequently, different colour figures are used according to the amount of stress around mini-implant regions and prosthetic structures. Stresses on each model are evaluated according to the stress values from low to high. The most favourable model has the lowest stress values, and in contrast, the most deleterious model has the highest stress values {Figure 3}.

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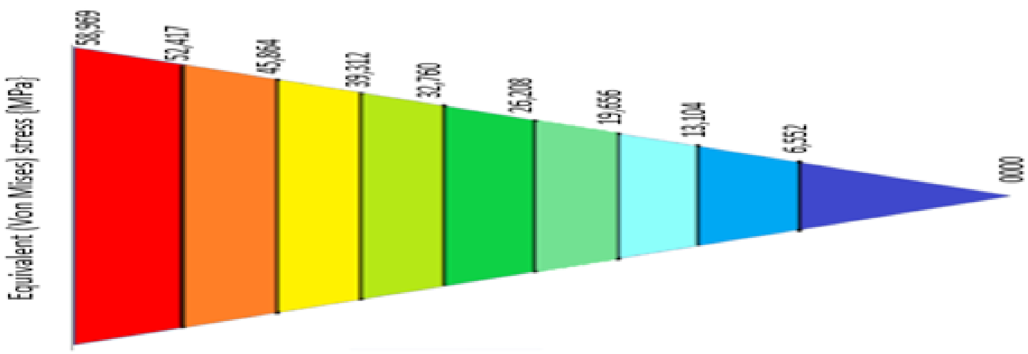
Figure 3. Colour indication for the amount of stress around the peri-implant region and prosthetic structure



Once the FEA of both the mini-implants are obtained, they are compared for their efficacy in terms of stress distribution pattern. The FEA will distinctly demonstrate areas with high stress concentrations. Thereby, we can conclude which of these mini-implants is more efficacious as an anterior tooth prosthesis.

Discussion

Branemark discovered implants in 1960s and since then they have been a vital treatment option for missing teeth in dental practice (Abraham, 2016). Moreover, in recent years many people favoured implant as a treatment modality in children to replace the missing tooth. However, the larger diameter proved a major trouble in areas with smaller labio-lingual width (Elsayed, 2019). Thus, mini-implants were introduced as prosthesis to replace the missing tooth especially in children. Various advances in technology evolved for successful placement of the implant, however the survival of implants also depends upon various factors like length and diameter of the implant, quality of the bone and biting forces (Bataineh & Al-Dakes, 2017). Even though the success rates of mini-implants are high, chances of failure cannot be ignored. The various forces which act on the mini-implants vary in their magnitude, direction, and type of stress they may induce. It is necessary to analyse the impact of these forces on mini-implant life. In order to predict the behaviour of the mini-implant to applied force along with stresses and deformation induced, FEA serves as the most reliable and cost-effective technique (Reddy et al., 2019). It also gives an approximate prediction of the mini-implant life which can be further used to improve the implant design thereby increasing its overall life. FEA is the process of simulation of physical models through numerical techniques for determining how the model will behave when put to use in a real-life environment. Through the application of FEA, the number of physical prototypes and experiments can be reduced (Al-Momani & Rawabdeh, 2008). This method is used in the design phase to optimize the products and to increase their functionality.

For the prevention of mini-implant failure caused by mechanical parameters, they should be evaluated well in advance. Application of FEA in implant dentistry includes in depth qualitative examination of the implant and its relation with the tooth, cortical, and cancellous bone. From the FEA analysis report, stress distribution and deformation in implants and bone can be calculated which correspond to results obtained from traditional methods.

Conclusion

Finite Element Analysis is a helpful tool to determine the mechanical properties of mini-implants and predicting the life of mini-implant on application of different forces. Simplifications and assumptions are the limitations of FEA studies. However, with more advancement even these drawbacks can be overlooked. FEA studies are considered helpful for clinical trials but the results achieved from these studies are not as valuable as clinical study results. Yet, it is advisable to refer to FEA studies before beginning of biomechanical clinical trials.

Acknowledgement

The authors would like to appreciate the design and software team for their contribution in the execution of this study.

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