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A Comparative Evaluation of Stress Distribution in Different Designs of Corticobasal Implants in Bone:

A 3-Dimensional Finite Element Analysis

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Abstract

Purpose: The purpose of this study is to use a three-dimensional finite element analysis to assess the stress distribution around bone for different corticobasal implant designs.

Materials and Methods: A three-dimensional model of a human mandibular bone was created using Finite Element Analysis (FEA) modeling software, based on measurements from a dried human edentulous mandible. This model was duplicated to evaluate stress distribution around the bone with different implant designs: KOS Implant (rough surface), KOS Implant (smooth and rough surface), KOS PLUS Implant (smooth and rough surface), and KOS MU Implant (rough surface). Each implant measured 12 mm in length and 3.7 mm in width. Axial and non-axial loads of 200 N and 20 N, respectively, were applied to the implant in these FEA models. The models were then analyzed using ANSYS software (version R18.1) for finite element analysis.

Results: For the group I implant models subjected to an axial load of 200 N, the overall stress (MPa) values for the KOS Classic implants were 257.515 MPa. Under a non-axial load of 20 N applied to the group II implant models, the KOS Classic implants exhibited overall stress values of 142.424 MPa.

Conclusion: This finite element comparative study found that the KOS Classic implant models exhibited the maximum Von Mises Stress distribution. Further research is necessary to comprehend the clinical implications of these findings.

Keywords

Basal implants, KOS implants, KOS Plus implants, Finite element analysis, Axial and non-axial load

INTRODUCTION

Restoring the edentulous maxilla or mandible with implants can be challenging when there are insufficient bone dimensions. For successful implant therapy, adequate bone dimensions of at least 13-15 mm in length and 5-7 mm in width are generally required. When these dimensions are not met, it becomes essential to restore the lost alveolar dimensions to achieve a predictable and successful outcome. This may involve treatments such as inlay or onlay alveolar grafts, nerve repositioning, sinus lifts, and even nasal lifts. Without these procedures, traditional implant therapy may not be effective.[1]

Basal implants are designed to utilize the basal cortical segment of the jawbone for retention. These implants are specifically engineered to anchor into the basal cortical bone and have been extensively modified over the years. Modern basal implants feature a prosthetic-friendly design that is both complex and simple, leading many practitioners worldwide to adopt basal implantology in their practices. This technique has consistently yielded satisfactory results.[2]

The primary advantage of using basal cortical bone for these implants, as opposed to alveolar bone, is the stress-bearing capability of the implant site, which allows for immediate prosthetic loading. Basal implants offer multicortical support, guaranteeing absolute primary stability in dense, native bone.[3]

Finite Element Analysis (FEA) was first applied to implant dentistry in 1976 by [4] Weinstein et al. Over the past two decades, FEA has become an increasingly valuable tool for predicting the impact of stress on both the implant and surrounding bone. Mastication generates vertical and transverse stresses, leading to axial forces and bending moments that create stress gradients within the implant and the surrounding bone. Success or failure of implant depends on how stresses are distributed to the surrounding bone. Factors influencing load transmission include the type of loading, the bone-implant interface, implant length and diameter, implant surface form and properties, prosthesis type, and the quality and quantity of the surrounding bone. Researchers use FEA to analyse stress distribution in the cortical bone at the implant contact area and around the implant's apex in trabecular bone. Implants that generate excessively high or low stresses can lead to pathologic bone resorption or atrophy.[5]

The aim of this study is to assess stress distribution in tapered corticobasal implant designs (KOS and KOS Plus), examining both smooth and rough surface configurations in one implant design and exclusively rough surfaces in another. This comparison aims to enhance our understanding of stress distribution patterns and their implications for implant stability and success.

MATERIALS AND METHODS

Finite Element Analysis (FEA) is a numerical method widely employed to anticipate engineering and biomechanical challenges. It involves creating a finite element model by subdividing solid objects into multiple interconnected components, each linked at a common node. These elements are assigned material properties corresponding to those of the modeled object. A mathematical matrix representing the interaction among degrees of freedom (displacements) and actions (forces) of the structure under load is formed, typically using triangular or quadrilateral elements. This model encompasses data on material properties, loads, boundary conditions, as well as details about elements and nodes.

Here geometrical models were constructed using SolidEdge V19 software. Once a structure is digitally created and material properties are assigned, finite element software, such as 'ANSYS R 18.1', is utilized to analyze stress distributions during force application. Stresses are typically categorized as compressive (negative) or tensile (positive). Von Mises stresses are derived from the combined absolute values squared of all stresses in three dimensions (x, y, and z).

FEA divides a structure into finite elements interconnected at nodes with three degrees of freedom along the three dimensions (X, Y, and Z axes). Each element is assigned specific elastic properties (such as Poisson's ratio and modulus of elasticity), and its mechanical behaviour is described based on node displacement. Loading conditions are applied to these nodes, resulting in model behaviour analogous to the actual structure. Through the resolution of a system of simultaneous equations, the relationship between all forces and displacements at the nodes is determined during computer analysis. This process allows for the establishment of stress contours within each element and across the entire body. FEA is increasingly utilized in biomechanical fields like orthopedics, cardiology, and dental mechanics.

System Configuration

A computer with the following system configuration was used

1. INTEL CORE i5-PROCESSOR
2. 3 GHZ SPEED
3. 16 GB RAM
4. 1 TB HARD DISC DRIVE
5. Operation system: 16GB
6. Analysis software: Ansys R18.1
7. Meshing Software: HypermeshV11
8. Modelling software: SolidEdge V19
9. KEY BOARD
10. MOUSE.

Based on the dimensions of a dried human edentulous mandible, a geometric model of the mandibular body was created, and four different implant designs were created to be inserted in the body of the jaw at specified particular areas

Geometric Model of Mandible

The edentulous section of the mandible was modelled based on the measurements of a dried human edentulous mandible. (Fig. 1)

The dimensions of mandibular section are -

· Height - 15 mm

· Width - 9mm

Thickness of cortical bone

· Crestal - 2mm

· Buccal and lingual - 2mm

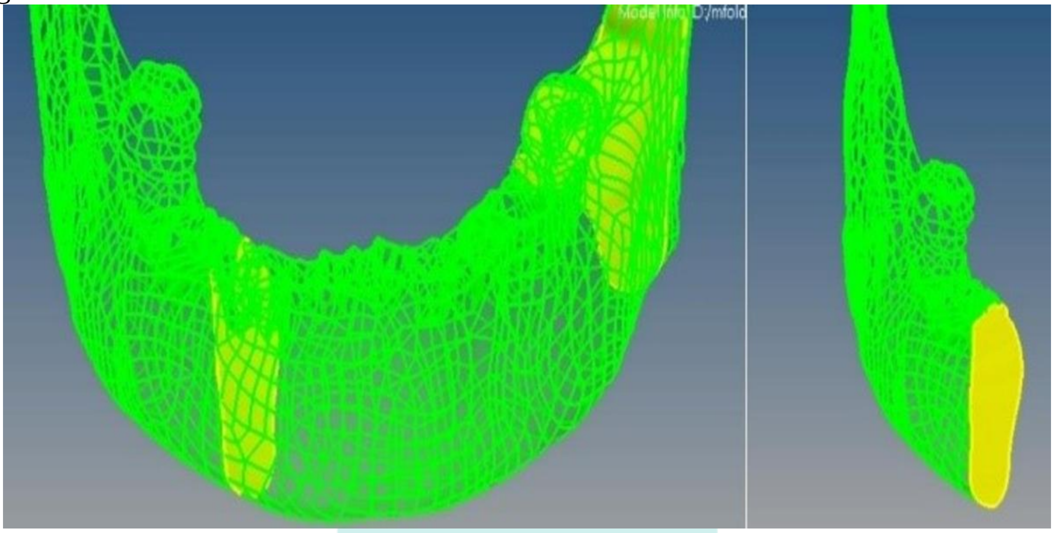

Fig. 1 Geometrical model of mandibular bone

Implants

Four different implant designs (Fig. 2) were designed according to the following dimensions:-

1) KOS Implant (Rough surface)
   Length of the implant: 12 mm
   Diameter of the implant: 3.7 mm

2) KOS Implant (Smooth and Rough surface)
   Length of the implant: 12 mm
   Diameter of the implant: 3.7 mm

3) KOS PLUS Implant (Smooth and Rough surface)
   Length of the implant: 12 mm
   Diameter of the implant: 3.7 mm

4) KOS MU Implant (Rough surface)
   Length of the implant: 12 mm
   Diameter of the implant: 3.7 mm

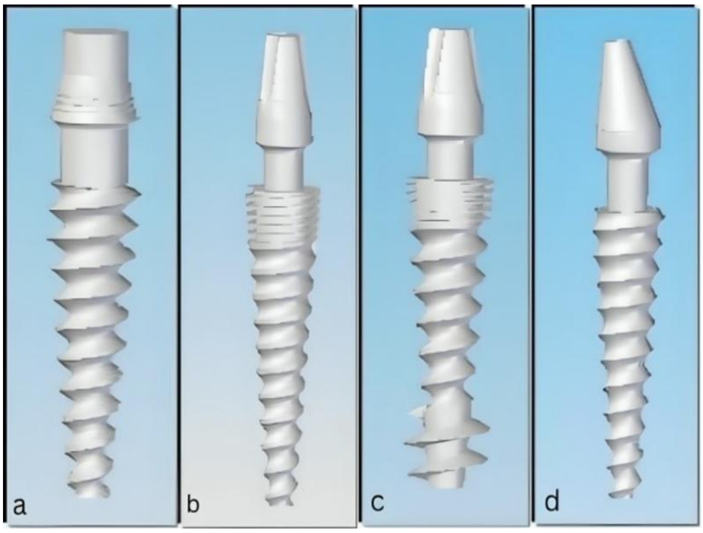

Fig. 2 Geometric implant model **a)** KOS Classic implant **b)** KOS MICRO implant **c)** KOS PLUS implant **d)** KOS MU implant

Material Properties

The properties corresponding to various materials used in the study are given in (Table 1)

Table 1 Mechanical properties of materials

	Materials	YOUNG' MODULUS (Mpa)	POISSONS RATIO
1	Titanium implant	110000	0.35
2	Cancellous bone	1370	0.30
3	Cortical bone	13700	0.30

The program used implied several assumptions with regard to the mechanical properties of the simulated structures.

1. Homogeneity: The mechanical properties of a material are thought to be the same in the entire structure.
2. Isotropy: The material properties are same in all directions
3. Linear elasticity: The deformation or strain of the structure varies directly with the applied force and remains unaffected by the strain rate.

Bone Implant Interface

The study assumed a fully continuous connection between the bone and implant throughout the entire contact area, leading to no relative movement between them when subjected to stress. This was considered as the clinical scenario if the implant was entirely Osseo integrated.

Loads applied

Axial loads of magnitudes 200N is applied as during uniform bilateral biting which are directed downwards parallel to long axis of the implant (Fig. 3a). Non-Axial loads of magnitudes 20N are given at an angle of 15° from the long axis of the implant as during lateral movements (Fig. 3b).

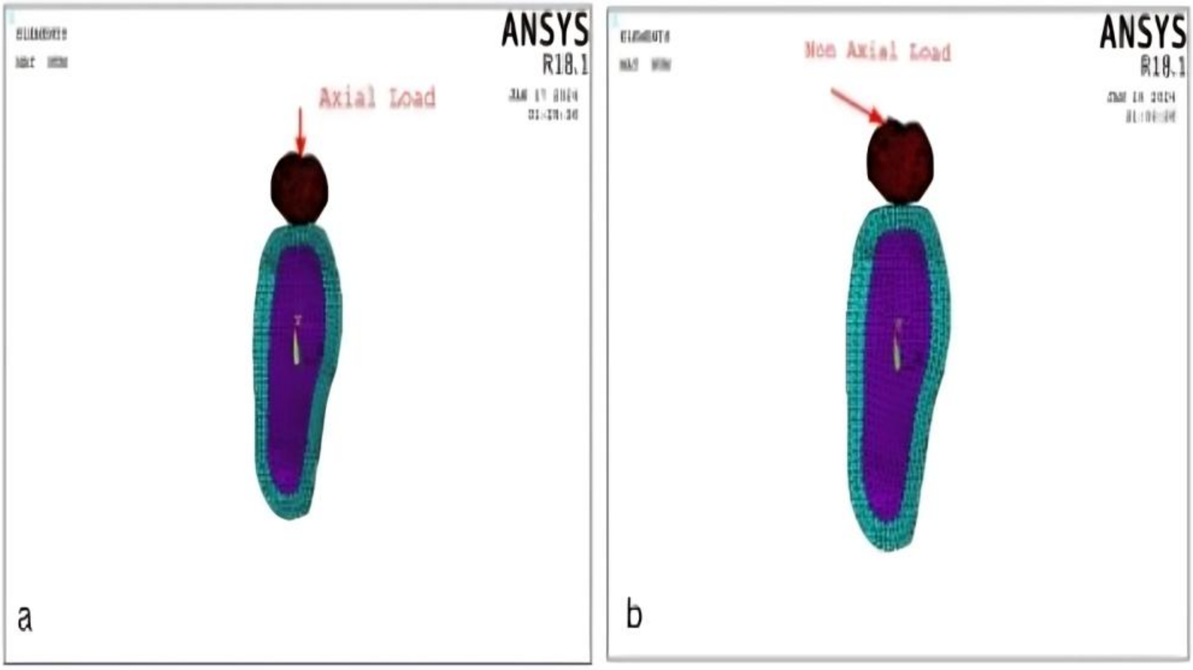

Fig. 3 a) Axial load b) Non axial load

Analysis

For ease of analysis, total of eight models were formed and grouped into two. Group 1 consisted of four models on which axial loads were applied, Group II consisted of four models on which non-axial loads were applied.

Model 1 consisted of mandibular section with KOS Implant (Rough surface) placed in the molar region.

Model 2 consisted of mandibular section with KOS Implant (Smooth and Rough surface) placed in the molar region.

Model 3 consisted of mandibular section with KOS PLUS Implant (smooth and rough surface) placed in the molar region.

Model 4 consisted of mandibular section with KOS MU Implant (Rough surface) placed in the molar region. The different models, as previously described, were examined using the linear static module of the finite element software to acquire both the deformation pattern and stress distribution within the structure

Stresses

The stress distribution in the structure is shown as contour plots for different types of the model analysed. To provide a good image of the stress state, contour plots were created separately for areas of special interest, namely the implant and the bone around it. To compare the magnitude of stress in each model, the peak Von Mises Stresses in the areas of special concern were tabulated.

RESULTS

The current study assessed the distribution of stress of eight finite element models which were grouped into two, Group I consisted of models on which axial loads of magnitudes 200 N and Group II consisted of models on which non-axial loads of magnitudes 20 N were applied (Table 2).

Table 2 Description of groups

Groups	Models
GROUP I AXIAL LOADING (200 N)	KOS Implant (Rough surface) KOS Implant (Smooth and Rough surface) KOS PLUS Implant (smooth and rough surface) KOS MU Implant (Rough surface)
GROUP II NON AXIAL LOADING (20 N)	KOS Implant (Rough surface) KOS Implant (Smooth and Rough surface) KOS PLUS Implant (smooth and rough surface) KOS MU Implant (Rough surface)

For all the models Overall Deformation(mm), Overall Stress (MPa), Cortical Stress (MPa), Cancellous Stress (MPa), Implant Stress (MPa), Crown Stress (MPa) were studied. Results of group I models illustrated in Table 3, and group II models in Table 4.

Table 3 Values of groups- I models

Axial load	Classic	Micro	Plus	MU
Overall deformation(mm)	0.028228	0.0406	0.041508	0.053198
Overall stress (Mpa)	257.515	413.491	402.932	400.417
Cortical stress (Mpa)	61.1231	23.8835	23.8645	107.992
Cancellous stress (Mpa)	5.49032	2.63288	4.28114	2.52082
Implant stress (Mpa)	286.422	413.491	402.932	360.241
Crown stress (Mpa)	131.121	214.418	257.918	255.651

Table 4 Values of groups- II models

Non axial Load	Classic	Micro	Plus	MU
Overall deformation (mm)	0.022038	0.033211	0.033961	0.047088
Overall Stress (Mpa)	142.424	281.073	276.703	285.878
Cortical Stress (Mpa)	32.0619	13.2008	14.4924	75.9381
Cancellous Stress (Mpa)	2.71977	0.727468	1.28905	0.760397
Implant Stress (Mpa)	143.387	281.073	274.458	259.02
Crown Stress (Mpa)	81.921	133.861	139.652	150.809

DISCUSSION

Prosthodontics has addressed issues with either partial or total edentulism. Because implants provide better esthetics, comfort, speech, and protection of the oral cavity's soft and hard tissues, they present a more promising future. Previous reports have compared implant prosthetic designs or varying implant angles using comparative FEM stress evaluations under identical settings. These reports frequently compare novel implant geometries to traditional implant shapes. While they can be used as a guide, comparisons made under various modelling scenarios cannot prove anything definitively. Therefore, it is essential that clinicians understand how stress factors correlate with different implant designs in order to aid them in selecting the appropriate implant.

Sigmar Kopp[6] concluded that in the immediate loaded scenario, the deformation energy is 30% greater compared to the loaded healed bone. Irrespective of the bone's healing state, deformation energy is absorbed by the bone is around 90%. In the present study a complete continuous link between bone and implant was assumed over the whole contact, resulting in no relative movement between the bone and implant (complete osseointegration) under stress, as the peak Von Mises Stresses (190.9 MPa) was observed in extremely soft type of bone compared to hard (complete osseointegration) when a model is designed which represents the interface between basal implants and bone through healing phase.[3]

On comparison immediately crestal versus basal Implant in central incisor region of maxillary bone, Von Mises Stresses in crestal implant supporting maxillary central incisor showed less stress concentration around the implant, cortical bone and cancellous bone,[7] highest Von Mises stresses are observed in the basal implant body when comparing stress distributions between osseointegrated crestal and basal implants in the zygomatic region of the maxilla under axial and oblique loading conditions,[8] and micromotion was observed with basal osseointegrated implants when compared to crestal osseointegrated implants,[9] where as in this study only basal implants are compared. Anip Kumar Roy,[10] observed stress distribution in cortical bone around the basal implants and found that maximum Von Mises Stress at implant neck (only implant considered), at implant and cortical bone interface (only cortical bone considered). Surface treatment significantly affects the stress distribution in immediately loaded implants, the superior stress distribution was observed in two part surface treatment when compared to single uniform treatment, [11] Porous surface implants exhibited even distribution of stress when compared to smooth surface implant, [12] and in study conducted by Satyanarayana TSV et al, [13] it was observed that similar stress distribution observed among surface coated and non surface coated implants.

In the present study maximum Von Mises Stress was observed in KOS MICRO under axial load and KOS MU under non axial load and minimum Von Mises stress and overall deformation, implant stress and crown stress was observed in KOS CLASSIC (Rough surface) implants under both axial and non axial loads. Cortical stress was almost equal for KOS MICRO (23.8835, 13.2008) and KOS PLUS (23.8645, 14.4924) and more for KOS CLASSIC (61.1231, 32.0619) and KOS MU (107.992, 75.9381) under both axial load and non axial load respectively.
From the values attained it was observed that the overall deformation (Fig. 4a & 4b).
Under axial load: kos classic < kos micro < kos plus < kos mu
Under non axial load: kos classic < kos micro < kos plus < kos mu

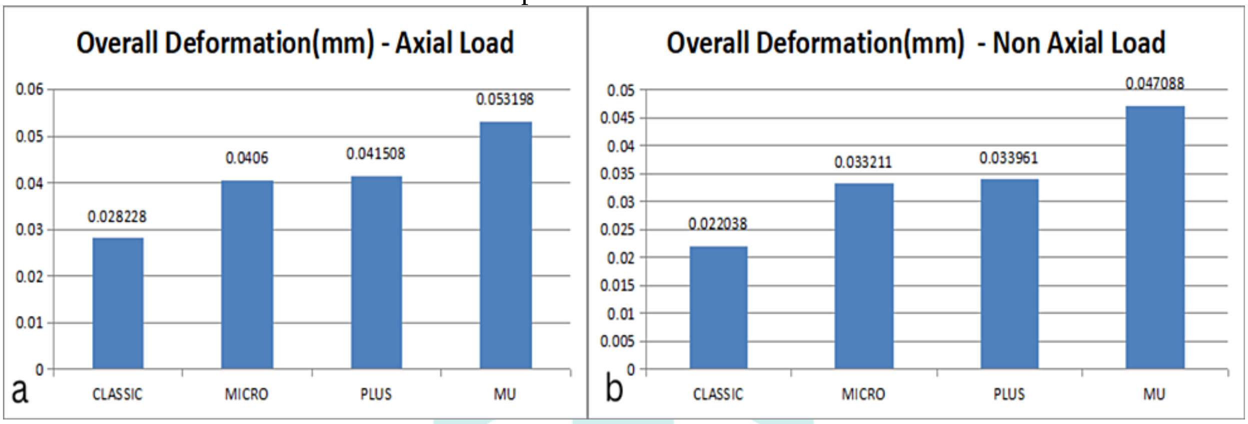

Fig. 4 Overall deformation a) Axial load b) Non axial load

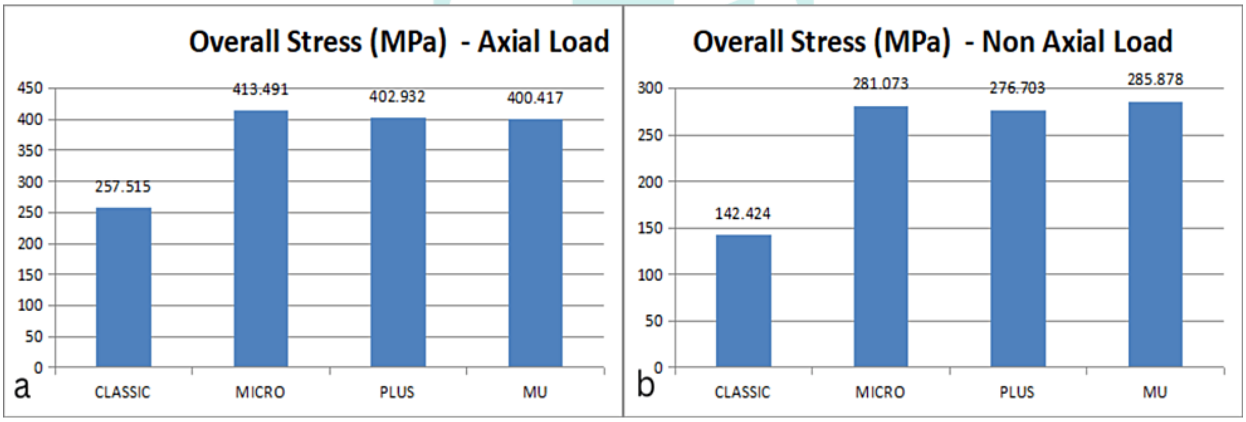

Fig. 5 Overall stress a) Axial load b) Non axial load

From the values attained it was also observed that the overall deformation and overall stress values of kos classic implants were the least.

Finite element analysis and statistical analysis

In Finite Element Analysis, since the computer may be manipulated variables with precision, from sampling error chance variation is eliminated. Repeating the Finite Element Analysis any number of times will consistently yield identical results. Therefore it's certain that manipulation of variables is always responsible for the observed results, not chance. Hence conventional interferential statistical analysis isn't typically included in a Finite Element Analysis study. However, there are other causes of possible inaccuracy. Inaccurately representing crucial elements of the real system, such as material qualities, geometry, interface status, boundary conditions, or loads, can lead to a deficient or wrong model.

Limitations of study

Finite Element Analysis is an accurate and exact approach for analysing structures. However, living structures are more than just things. Finite Element Analysis uses mathematical computations to simulate structures in their surroundings. But, Biology is not a computable thing, as live tissues cannot be reduced to fixed parameters or values. Finite Element Analysis offers a strong theoretical foundation for understanding a structure's behaviour in a particular environment, but it should not be solely relied upon. To establish the true nature of biologic system actual experimental techniques and finite element analysis should be followed by clinical trials.

CONCLUSION

The current research utilized a three-dimensional finite element method to analyze the stress distribution around four different implant designs placed in mandibular molar region under axial and non-axial loads.

A 3-dimensional finite element model of the mandible with four different implant designs were modelled using modelling software 'SolidEdge V19' and was analyzed for stresses produced in the bone following axial and non axial biting loads of different magnitude using analyzing software 'ANSYS R18.1'.

The results of the study indicated that implants with both smooth and rough surface (KOS CLASSIC) implants shows more favourable stress distribution, overall deformation energy, implant and crown stress.

Within the parameters of the current study, the following conclusions may be drawn:

1. Different implant designs lead to significant variations in stress distributions in thebone.
2. Overall deformation and Von Mises stress of kos classic (Rough surface) is less both under axial and non axial load.

To conclude kos classic (Rough surface) has maximum von mises stress distribution when entire assembly (implants and bone are assembled with the crowns) compared, and kos classic (Rough surface) has maximum implant and crown stress distribution. When only bone is compared kos plus (smooth and rough surface) has least cortical stress, kos mu (rough surface) has least cancellous bone under axial load and kos micro (Smooth and rough surface) has least cortical and cancellous bone under non axial load.

LIST OF ABBREVIATIONS

FEA	Finite Element Analysis
N	Newton
mm	Millimetre
Mpa	Megapascal
KOS Implant	King of Single Piece implant
FEM	Finite element method

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DECLARATION OF CONFLICT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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