Purpose of the Study: The study was designed to evaluate and compare stress distribution in transcortical section of bone with normal abutment and platform switched abutment under vertical and oblique forces in posterior mandible region.

Materials and Methods: A three-dimensional finite element model was designed using ANSYS 13.0 software. The type of bone selection for the model was made of type II mandibular bone, having cortical bone thickness ranging from 0.595 mm to 1.515 mm with the crestal region measuring 1.5 mm surrounding dense trabecular bone. The implant will be modulated at 5 mm restorative platform and tapering down to 4.5 mm wide at the threads, 13 mm long with an abutment 3 mm in height. The models will be designed for two situations: (1) An implant with a 5 mm diameter abutment representing a standard platform in the posterior mandible region. (2) An implant with a 4.5 mm diameter abutment representing platform switching in the posterior mandible region. Force application was performed in both oblique and vertical conditions using 100 N as a representative masticatory force. For oblique loading, a force of 100 N was applied at 15° from the vertical axis. von Mises stress analysis was evaluated.

Results: The results of the study showed cortical stress in the conventional and platform switching model under oblique forces were 59.329 MPa and 39.952 MPa, respectively. Cortical stress in the conventional and platform switching model under vertical forces was 13.914 MPa and 12.793 MPa, respectively.

Conclusion: Results from this study showed the platform switched abutment led to relative decrease in von Mises stress in transcortical section of bone compared to normal abutment under vertical and oblique forces in posterior mandible region.

Key words: Finite element analysis implants, isotropic material, platform-switched model, von Mises stress

The dental implants have been used for the restoration of complete or partial edentulous ridges with the predictable outcome. The longevity of the implants primarily relies on the stability of the implant-bone interface.[3] It has been suggested that the factors of early implant loss are microgap if placed at or below the bone crest, implant crest module, occlusal overload, and the reformation of biologic width around dental implants. Therefore, to best avoid...
Platform switching design on an implant fixture shows benefits in controlling the early implant bone loss factors. In this study, the term platform switching refers to a reduced diameter abutment in relation to the fixture platform diameter. 

Several studies have described methods (photoelastic analysis, strain gauge placement, and finite element analysis [FEA]) for evaluating the biomechanical advantages of the platform switching. Strain gauge placement has the disadvantage of point measurement only. The photoelastic analysis must have visual access and limited temperature. Hence, in a computed tomography–based three-dimensional (3D) FEA demonstrated that the platform-switched designs can be considered a valid treatment option, equivalent to the conventional matching diameter abutment–implant configurations.

FEA is the suitable tool available for analyzing them. By FEA researchers predict stress distribution in the contact area between cortical bone and implant as well as around the apex of implants in the trabecular bone.

In a recently published review and meta-analysis showed that platform switching may preserve the inter-implant bone height and soft tissue levels. The degree of marginal bone resorption was inversely related to the extent of implant-abutment mismatch. Platform-switched implants are also known to preserve marginal bone from stress concentration, mostly localized in the proximal layer between implant and abutment. As FEA has been extensively and successfully employed in an attempt to predict the biomechanical performance of various dental implant designs.

Several hypotheses were posed to explain the rationale behind the concept of platform switching for crestal bone preservation. The biomechanical rationale proposed that by platform switching the stress concentration zone is directed from the crestal bone implant interface to the axis of the implant and so reduces the stress level in the cervical bone area. Jemt et al. proposed that, by placing the implant-abutment connection below the crestal bone level, may cause bone resorption to re-establish the biologic width. Following this theory, platform switching mediates the microgap and the dimension of the biologic width. Another hypothesis concerned the role of inflammatory cell infiltrate at the implant-abutment connection. Since, there is a lacunae of knowledge and very few research done with the 3D FEM analysis and also due to the absence of long-term data, the study was planned with aim to analyze the interaction phenomena of platform switching on the transcortical section of bone adjacent to an endosseous dental implant under vertical and oblique forces in posterior mandible region.

**MATERIALS AND METHODS**

Implants with abutment were modeled using a computer with specifications. A finite element program, ANSYS version 13 (South of Pittsburgh, USA) was used for the study. ANSYS software offers an unparalleled breadth of solutions across a broad range of disciplines that can accurately address the fluid, structural, electromagnetic and thermal modeling of any product or process. These solutions are built within the ANSYS Workbench user environment – a single framework enabling us to undertake FEA simulations quickly and efficiently at both concept and validation stages of design. The implant was assumed to be placed in the region of molar of the mandible. The models were provided in close approximation to the \textit{in vivo} geometry. The steps involved in this study are as follows:

- Finite element modeling
  Construction of geometric model, mesh generation, specifying material properties, applying boundary conditions, and application of loads.
- Finite element analysis.

**Finite element modeling**

**Construction of geometric model**

**Bone design**

Initially, computerized tomography (CT scan) of a normal human mandible with no history of an implant placement or no history of any associated pathologies of the mandible was obtained using a CT scanner. The CT scans were taken extending up to the soft tissue plane over the inferior border of the mandible. The mandible was modeled as a sagittal cut of the mandible, including the residual alveolar process and the lingual bone from the CT scan to generate the model of the bone. The section of bone was traced on the graph paper and coordinates of the contouring points were extracted and joined to form partial volumes of both cortical and trabecular bone that together defined the final geometry. Then the section was extended mesially and distally in the z plane. Through this process, the CT scan data were converted into a 3D solid model of the posterior mandible region for analysis purpose using Ansys mixed approach.

**Implant design**

A 3D finite element model of endosseous implant simulating BIOMET 3i Implant System was generated using Catia Version 19 (Palm Beach Gardens, Florida). Biomet 3i Products are manufactured from biocompatible titanium, titanium alloy, gold, gold alloy, zirconium, vanadium, stainless steel, cobalt chromium alloy. The dimension of the implant designed was 5 mm in diameter and 13 mm in length. Around the prepared tapered implant, the bone was constructed with definitive differentiation of outer cortical and inner trabecular to form model 1. Thus, constructed...
a model of implant and bone was duplicated to one more model. The abutment of different diameters, the straight abutment, with 5 mm and 4.5 mm was constructed on these two models, thus, in total two models consisting of an implant, the bone around it and one type of abutment fixed to the implant were designed [Figures 1-4].

The bone-implant interface for both the models was bonded, simulating complete osseointegration and the dental implant, abutment was assumed to be connected as a single unit.

**Mesh generation**
When the geometry of model was complete, a specialized mesh generation procedure was used to discretize the model. The 3D finite element model corresponding to the geometric model was meshed using Hypermesh Software (ANSYS version 13 software). The type of meshing is free meshing because the model is not geometrically symmetric. The element size (SOLID 92) was selected according to default settings. The type of element suitable for this particular study was noded tetrahedron element which was assigned four degrees of freedom per node, namely, translation in the x, y, and z directions. The elements were constructed so that their size aspect ratio would yield reasonable solution accuracy. The coordinates were finally imported into the ANSYS 13 software as key points of the definitive image [Figures 5 and 6].

**Specifying material properties**
For the execution and accurate analysis of the program and interpretation of the results, two material properties were utilized, i.e., Young's modulus and Poisson's ratio. All the materials used in this study were considered isotropic, homogenous, and linearly elastic. The physical properties of different components used in this study were illustrated in Table 1.

| Material               | Elastic modulus (MPa) | Poisson’s ratio |
|------------------------|-----------------------|----------------|
| Ti alloy               | 1.17 E + 5            | 0.30           |
| Cortical Bone          | 2727                  | 0.30           |
| Trabecular Bone        | 1370                  | 0.31           |
Applying boundary conditions
Zero displacement constraints must be placed on boundaries of the model to ensure an equilibrium solution. In this study, a zero displacement constraint was placed on all nodes lying along the external lines of the cortical bone.

The final models [Table 2] had a total number of nodes 52,176 and elements 52,876 for the model with the 5 mm abutment and nodes 52,370 and elements 53,017 for the model with 4.5 mm abutment.

Application of loads
The magnitude of the force of 100 N was also within the range of mean values reported in the literature. After applying the static loads on each model, the stress generated in the bone and the implant was recorded.

Finite element analysis
These different models were analyzed by Processor, i.e., solver, and the results were displayed by postprocessor of the Finite Element Software (ANSYS version 13) in the form of color-coded maps using von Mises Stress Analysis. von Mises stress values are defined as the beginning of deformation for ductile materials. Metallic implant failure occurs when von Mises stress values exceed the yield strength of an implant material. von Mises stresses are most commonly reported in FEA studies to summarize the overall stress state at a point. The von Mises stresses were generated in cortical, trabecular, and implant regions after application of loads. Therefore, they are important for interpreting the stresses occurring within the implant.

RESULTS
Stress distribution pattern generated in the finite element models comes in numerical values and color coding. Maximum values of von Mises stress is denoted by red color and minimum value by blue color. In between the values are represented by bluish green, green, greenish yellow and yellowish red in the ascending order of stress distribution. The two models of different abutment diameters were studied under a load of 100 N. The color plots obtained were studied, and the maximum von Mises stresses were noted and tabulated for each condition.

Tables 3 and 4 show the values of von Mises stress in implant, cortical, and trabecular bone in a model with 5 mm abutment model and 4.5 mm abutment model, after application of 100 N loads under vertical and oblique forces.

Figures 7 and 8 show the stress distribution after application of load in 5 mm abutment model and 4.5 mm abutment model under the oblique force of 100 N. Cortical von Mises stresses were found to be maximum in the cervical region of bone measuring 59.329 MPa and 39.52 MPa, respectively.

Figures 9 and 10 show the stress distribution after application of load in 5 mm abutment model and 4.5 mm abutment model under the vertical force of 100 N. Cortical von Mises stresses were found to be maximum in the cervical region of bone measuring 13.914 MPa and 12.793 MPa, respectively.

The comparison values of von Mises stress on the bone and implant were summarized in Figures 11 and 12 when a load of 100 N was applied to the 4.5 mm abutment and 5 mm abutments. This study states that the von Mises stress changed considerably with abutment diameters. The stress was minimal in 4.5 mm abutment model and increased progressively in 5 mm abutment models. Furthermore, the stress was minimal in cortical bone than in cancellous bone, and the stress was highest in the implant-abutment.

DISCUSSION
The concept of “platform switching” refers to the use of a smaller-diameter abutment on a larger-diameter...
implant collar. This connection shifts the perimeter of the implant-abutment junction (IAJ) inward toward the central axis (i.e., the middle) of the implant.

Baumgarten et al.\textsuperscript{[11]} stated that sufficient tissue depth (approximately 3 mm or more) is required to have an adequate biologic width. They concluded that platform switching helps in preventing the bone loss and also preserve crestal bone. The inflammatory cell infiltrate, which surrounds the IAJ in a collar like fashion, is contained within the angle formed at the interface and thus prevented from spreading further apically along the implant.\textsuperscript{[12]}

Krishna Prasad et al.\textsuperscript{[12]} compared crestal bone loss around platform-switched and nonplatform-switched implants. They found the mean crestal bone loss was 2.02 mm in nonplatform-switched implants and 0.22 mm in platform-switched implants. They also concluded that
reduction of the abutment diameter of 0.45 mm on each side is sufficient to avoid peri-implant bone loss.\textsuperscript{[11]}

Stress concentration around the implant can lead to a bone loss because of bone microdamage and crater-like bone defects creation around the implant. The correct reasons for bone preservation with the platform switching technique include inward shifting of the location of the IAJ or the stress concentration area between the abutment and implant.\textsuperscript{[13]}

Many claims have been made as to the benefit of platform switching. Hence, it is the purpose of this computer model to analyze the effect of platform switching upon an adjacent bone level as well as stress that is transferred from the implant fixture to the transcortical aspect. Analysis of these stresses was performed using FEA technology. The results demonstrate the translation of simulated masticatory forces through the abutment to the implant and onto the surrounding bony structures in a 3D cross-section of the mandible.

The numerical methods solutions must always be carefully evaluated in the light of experimental testing, it seems reasonable to apply this approach for the possibility of evaluating data that are experimentally not measurable, such as stress or strain in the bone tissue, thus completing and extending information obtained from \textit{in vivo} and \textit{in vitro} tests. The development of numerical models makes it possible to evaluate the mechanical behavior of the bone-implant compound by estimating fundamental variables, such as stress and strain in the bone tissue, and also to investigate a large number of operational conditions.\textsuperscript{[14]}

The border between the mechanical environment causing implant failure and under which bone adapts through bone resorption is not yet clearly drawn.\textsuperscript{[15]} However, the models are definitely useful for a preliminary interpretation of implant-abutment interaction.\textsuperscript{[16]}

Platform switching has some benefits such as improved bone support for short implants and optimal management of the prosthetic space. The amount of restorative volume available for an optimally contoured, physiological implant restoration is a critical factor. Support is retained for the interdental papillae with the crestal bone preservation both horizontally and vertically. Maintenance of midfacial bone height helps to maintain facial gingival tissues.\textsuperscript{[17]}

There appears to be one major consequence of the horizontal inward repositioning of the implant-abutment interface. As it has been reported, the IAJ is always encircled by an inflammatory cell infiltrate (0.75 mm above and below the IAJ).\textsuperscript{[12]} One millimeter of healthy connective tissue is needed to establish a biologic seal comparable to natural teeth to protect the underlying bone from this inflammatory infiltrate and microbiologic invasion.\textsuperscript{[12]} Thus, a close proximity of the IAJ to the bone, which is always established when implants are placed epicrestally, is eliminated by bone resorption and establishment of the mentioned biologic seal. As described by Ericsson \textit{et al.},\textsuperscript{[18]} by repositioning the IAJ inward and away from the outer edge of the implant and adjacent bone (platform switching), the overall effect of the inflammatory cell infiltrate on the surrounding tissue, may be reduced, thus decreasing the resorptive effect of the inflammatory cell infiltrate on crestal bone. This can be explained by the enhanced distance, which is generated between bone and the inflammatory cell infiltrate by shifting the platform inwardly. Furthermore, by the inward positioning of the abutment, an approximately 90° step will be created compared with a 180° step when using the traditional abutment design. The resulting confined area may have the consequence of restricting the inflammatory infiltrate to this restrained region and limiting the consequence to the adjacent tissues as it is mostly surrounded by nonbiologic material. This may result in a reduced inflammatory effect within the surrounding soft tissue and crestal bone.\textsuperscript{[19]}

The use of 3D modeling in this study for analysis with isotropic characteristics will increase the clinical relevance, when compared to the two-dimensional modeling and analysis as it is assumed to be infinitely thick, disregarding the cylindrical shape of the implant, and its contact with the bone around it. Therefore, the axial forces that would have been absorbed by the bone surrounding the implant

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure11.png}
\caption{Comparisons of two abutments with cortical stress under oblique load of 100 N}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure12.png}
\caption{Comparisons of two abutments with cortical stress under vertical load of 100 N}
\end{figure}
will not be considered, and the maximum strains would be higher than a 3D model.

The FE model was used to calculate the von Mises stress. However, the bone sometimes can be classified as brittle material, so the principal stress is also implemented to evaluate the situation of compact bone surrounding the implants. In addition, stress distributions in the FE models were illustrated to compare the biomechanical effect between the conventional model and platform switching model.

Role of platform switching in minimizing crestal bone loss remains debatable. Bone loss around implants seems to be governed by several factors, such as the cervical features of the implant design, 3D-implant positioning, prosthetic concept and the implant-abutment connection, width of alveolar ridge, and prevention of micromotion at the implant-abutment interface and not merely placing implants according to the platform switching concept.\(^{[20,21]}\)

Data from this study showed in oblique loading, 100 N resulted in 59.329 MPa von Mises stresses whereas a 10% reduction of abutment diameter led to a 2.3% decrease in von Mises shear stress. For vertical loading, the effect was less than that noted in oblique loading. For the standard (control) abutment diameter, a crestal von Mises shear stress of 13.914 MPa was seen compared with 0.9% decrease in von Mises shear stress where abutment diameter was reduced 10%. In a study done by Akagawa et al.,\(^{[22]}\) the trabecular bone was modeled both as a solid substance and a more natural porous substance.

This study assumes both cortical and trabecular bone to be of an isotropic nature. The trabecular model in this study was modeled as a solid, isotropic material with no porosities that was found with in vivo trabecular bone.

For the analysis portion of this study, it was determined that both a vertical and oblique loading model should be tested. The angle of 15° and loading force of 100 N were chosen as it has been shown in other studies\(^{[4,23]}\) to be more comparative to in vivo mastication. To augment the oblique condition, an additional model with the vertical loading of 100 N was done. Although these forces and angle represented possible applications of force to a dental implant, the actual vector of force can vary from individual to individual.\(^{[24]}\)

The control abutment diameter of 5 mm was selected, as it is a feasible size implant in this area of the mandible. A decrease of 10% led to abutment diameter and 4.5 mm. The purpose of the under-extended abutment was to demonstrate the concept of platform switching. The implant length (13 mm) was chosen as an average length in similarity to another FEA study.\(^{[25]}\) It is also an appropriate length as it is a commercially available size for implants that are often placed in edentulous premolar areas. With a wider implant in the platform switching, a lower incidence of stress was found that was also concentrated away from the peri-implant bone surface that would cause less microdamage in the bone tissue, resulting in a minimal crestal bone loss.

In addition, present data also suggested that when the abutment diameter were reduced by either 10% or 20%, it resulted in less stress transferred to the crestal bone regardless the direction of force (vertical or oblique). This is in support of the hypothesis that suggests platform switching may increase the distance between the abutment inflammatory cell infiltrate and the alveolar crest, thus reducing its bone resorptive effect.\(^{[26]}\) Furthermore, our results also confirmed the speculation made by Schrotenboer J\(^{[27]}\) who found that repositioning of implant-abutment interface away from the crestal bone into a more confined area reduces bone resorption at crestal bone level.\(^{[27]}\)

Another possible reason to explain the efficacy of the platform switching configuration is based on the distance between the bone surface and the stress-concentrated area on the implant surface.\(^{[28]}\) As microorganisms are likely to move toward the high-energy area or by the mechanism such as interface micromovements that allow the microorganisms to move that area, it is advantageous to have a large distance between the stress concentration area and the bone surface.\(^{[29]}\)

**CONCLUSION**

Within the limitations of this study and on the basis of results obtained, it can be concluded that:

- The cortical von Mises stresses in 5 mm diameter abutment model were found to be maximum as compared to 4.5 mm reduced diameter. The stress was concentrated in the cervical region of bone.
- The implant von Mises stresses in 4.5 mm diameter abutment model were found to be maximum as compared to 5 mm diameter abutment. The stress was concentrated in the implant-abutment joint area.
- The overall stresses in 4.5 mm diameter abutment model were found to be maximum as compared to 5 mm diameter abutment.
- The magnitude of stresses decreased as the diameter decreased.
- Maximum von Mises stress, compressive, and tensile stresses in cortical bone were lower in the platform switching model than in the conventional model.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.
REFERENCES

1. Albrektsson T, Worthington P. The long term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implant 1986;6:11-25.
2. Adell R, Lekholm U, Rockler B, Bränemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387-416.
3. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11-25.
4. Oh TJ, Yoon J, Misch CE, Wang HL. The causes of early implant bone loss: Myth or science? J Periodontol 2002;73:322-33.
5. Atieh MA, Ibrahim HM, Atieh AH. Platform switching for marginal bone preservation around dental implants: Initial observations and prospective study. J Oral Maxillofac Surg 2007;65 7 Suppl 1:33-9.
6. Canullo L, Fedele GR, Iannello G, Jepsen S. Platform switching and marginal bone-level alterations: The results of a randomized-controlled trial. Clin Oral Implants Res 2010;21:115-21.
7. Hermann F, Lerner H, Palti A. Factors influencing the preservation of the periimplant marginal bone. Implant Dent 2007;16:165-75.
8. Jemt T, Lekholm U, Gröndahl K. 3-year followup study of early single implant restorations ad modum Brånemark. Int J Periodontics Restorative Dent 1990;10:340-9.
9. Telleman G, Raghoebar GM, Vissink A, Meijer HJ. Impact of platform switching on peri-implant bone remodeling around short implants in the posterior region, 1-year results from a split-mouth clinical trial. Clin Implant Dent Relat Res 2014;16:70-80.
10. Hürzeler M, Pick S, Zühr O, Wachtel HC. Peri-implant bone level around implants with platform-switched abutments: Preliminary data from a prospective study. J Oral Maxillofac Surg 2007;65 7 Suppl 1:33-9.
11. Baumgarten H, Cocchirotto R, Testori T, Meltzer A, Porter S. A new implant design for crestal bone preservation: Initial observations and case report. Pract Proced Aesthet Dent 2005;17:73-40.
12. Prasad DK, Shetty M, Bansal N, Hegde C. Platform switching: An answer to crestal bone loss. J Dent Implants 2011;1:13-17.
13. Sahabi M, Adibrad M, Mirhashemi FS, Habibzadeh S. Biomechanical effects of platform switching in two different implant systems: A three-dimensional finite element analysis. J Dent (Tehran) 2013;10:338-50.
14. Tabata LF, Assunção WG, Adelino Ricardo Barão V, de Sousa EA, Gomes EA, Delben JA. Implant platform switching: Biomechanical approach using two-dimensional finite element analysis. J Craniofac Surg 2010;21:182-7.
15. Kitamura F, Stegaroiu R, Nomura S, Miyakawa O. Biomechanical aspects of marginal bone resorption around osseointegrated implants: Considerations based on a three-dimensional finite element analysis. Clin Oral Implants Res 2004;15:401-12.
16. Natali AN, Pavan PG, Ruggero AL. Analysis of bone-implant interaction phenomena by using a numerical approach. Clin Implant Oral Surg Relat Res 2006;17:67-74.
17. Deshpande SS, Sarin SP, Parkhedkar RD. Platform switching of dental implants: Panacea for crestal bone loss? J Clin Diagn Res 2009;3:1348-52.
18. Ericson I, Persson LG, Berglundh T, Marinello CP, Lindhe J, Klinge B. Different types of inflammatory reactions in peri-implant soft tissues. J Clin Periodontol 1995;22:255-61.
19. Ibrahim AM. Influence of platform-switching on crestal bone changes at non-submerged straight and inclined implants retaining mandibular overdentures. Cairo Dent J 2009;25:205-18.
20. Romanos GE, Javed F. Platform switching minimises crestal bone loss around dental implants: Truth or myth? J Oral Rehabil 2014;41:700-8.
21. Prosper L, Redaelli S, Pasi M, Zarone F, Radaelli G, Gherlone EF. A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of postrestorative crestal bone loss. Int J Oral Maxillofac Implants 2009;24:299-308.
22. Akagawa Y, Sato Y, Teixeira ER, Shindoi N, Wadamoto M. A mimic osseointegrated implant model for three-dimensional finite element analysis. J Oral Rehabil 2003;30:41-5.
23. Schrotenboer J, Tsao YP, Kinarwala V, Wang HL. Effect of platform switching on implant crest bone stress: A finite element analysis. Implant Dent 2009;18:260-9.
24. Vaillancourt H, Pillar RM, McCammond D. Factors affecting crestal bone loss with dental implants partially covered with a porous coating: A finite element analysis. Int J Oral Maxillofac Implants 1996;11:351-9.
25. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: A three-dimensional finite element analysis. J Prostheth Dent 2008;100:422-31.
26. Carinci F, Brunelli G, Danza M. Platform switching and bone platform switching. J Oral Implantol 2009;35:245-50.
27. Schrotenboer J, Tsao YP, Kinarwala V, Wang HL. Effect of microthreads and platform switching on crestal bone stress levels: A finite element analysis. J Peridontol 2008;79:2166-72.
28. Gardner DM. Platform switching as a means to achieving implant esthetics. N Y State Dent J 2005;71:34-7.
29. Maeda Y, Miura J, Taki I, Sogo M. Biomechanical analysis on platform switching: Is there any biomechanical rationale? Clin Oral Implants Res 2007;18:581-4.