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COMPARISON OF TWO DIFFERENT BONE GRAFTS TO IMMEDIATE LOADING OF DENTAL IMPLANT WITH FINITE ELEMENT ANALYSIS METHOD

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Abstract

The aim of study, to evaluate the stresses on bovine sourced Cerabone graft materials with a new synthetic bone graft, TiO_2, by using a three dimensional (3D) finite element analysis method.

Methods: After the dental implant was placed in the maxilla, 2 separate defect models (2 mm vertical 2 mm horizontal defect and 3 mm vertical 3 mm horizontol defect) were supported with the above-mentioned bone grafts. Dental implants, abutments and bone grafts are used for modeling. In order to compare the stress distribution of two different grafts in a virtual environment, the maxilla model, implant model and bone graft model were created in three dimensions. Finite Element Analysis was performed on the models and their stress distribution properties were evaluated according to the results.

Results: There is no difference between the synthetic bone graft TiO_2 and bovine sourced Cerabone in terms of stress distribution according to the 3D Finite Element Analysis Method.

Conclusion: It has been found that the stress on the implant is reduced when the graft is not placed. If possible, applying implants directly without grafting is more advantageous in terms of stress distribution.

Keywords: Finite Element Analysis, TiO_2, Cerabone, Implant

1. Introduction

Dental implants have been successfully used for a long time in the treatment of missing teeth. The anterior maxilla is considered the region with the highest risk in these treatments. Thus this procedure is difficult to perform in this region, and meticulous planning is necessary for the denture to last longer (Bölükbaşı, Koçak, & Özdemir, 2012).

Load transfer from implants to the supporting tissue depends on the magnitude and direction of the force, bone implant interface, number, length, diameter and surface characteristics of the implants placed, type of denture material, and bone quality. Load transfer affects the long-term success of implants. Stress should be properly transferred to the supporting tissues (Steigenga, al-Shammari , Nociti, Misch , & Wang, 2003).

Many analysis methods have been used to examine the role of these factors in load transfer. Finite element analysis method, photoelastic method, and strain-gauge methods are the most commonly applied. In many studies on implant biomechanics, three-dimensional finite element analysis gives the closest results to those obtained in in vitro studies.

Moreover, the reproducibility of the study is a very significant advantage of the finite element analysis method compared with in vitro studies (Steigenga, al-Shammari , Nociti, Misch , & Wang, 2003)

Many studies have investigated prognosis of implants placed after the application of different graft materials. An autogenous graft is still considered the gold standard (Hammack & Enneking, 1960). TiO_2, a new synthetic graft material was found to be promising for bone regeneration. Studies have shown that this graft material has a high compressive strength and low toxicity (Fostad et al., 2009), (Sabetrasekh, Tiainen , Lyngstadaas, Reseland, & Haugen , 2011), (Tiainen, Wiedmer, & Haugen, 2013) . Another graft material analyzed in the present study, is bovine-derived Cerabone, a xenograft. Xenografts are obtained from a tissue derived from another species. It has more antigenicity than allografts. These grafts are not involved in osteogenesis alone, and they have a minimum effect on the stimulation of bone remodeling. Given their high antigenicity, they are chemically processed to prevent graft rejection. Compared with allografts do not require a second operation area and it can be provided in the desired amount (Büyükakyüz & Öztürk , 2012).

2. Materials and Methods

2.1 Geometric Definition:

Computed tomography (CT) images of the upper jaw were used in the finite element model analyzes. Images in the DICOM format were obtained using the ITK-Snap (University of Pennsylvania) program and surface geometries of the maxilla and teeth were in the STL format (Figure 1a). Solid models were provided using SolidWorks 2015 (SolidWorks Corp., Concord, MA, USA), and the 3D model was provided by separately defining each of the maxilla models and tooth geometries (Figure 1b).

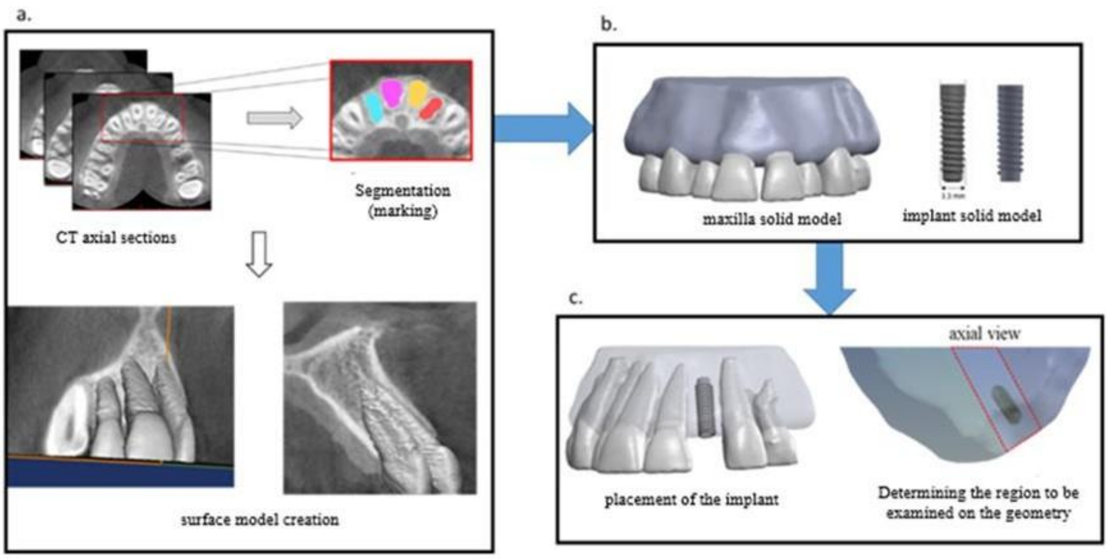

Figure 1. Providing solid models (a) Segmentation and surface modeling (b) Maxilla and implant modeling and (c) placing the implant and selecting the region to be studied in three-dimensional geometry (red dashed lines).

The implant design was based on the dimensions provided by the manufacturer (Bone Level Ø3.3 mm, SLA 10 mm Loxim, Roxolid, Straumann, Basel, Switzerland). The implant geometry was placed into the maxilla model by clearing the anterior right tooth, on the same axis as the tooth (Figure 1c). The analyses included a single implant and therefore a geometrically single tooth region. Thus, the geometric model was narrowed and transferred to the finite element software. (Figure 1 c).

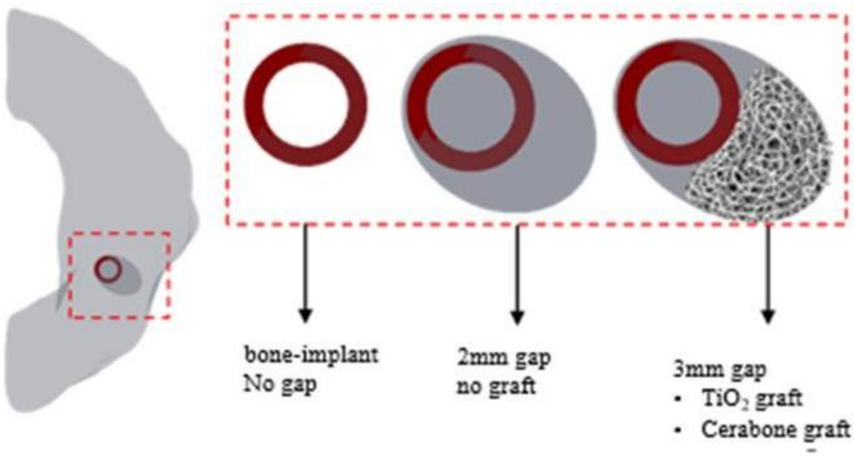

Figure 2. Definition of the study group.

In the first model, there is no gap between the bone and the implant (Control model). In the second model, a 2 mm gap is made between the bone and the implant. In the other two models, a 3 mm gap is made between the bone and the implant, whereas two grafts made of TiO_2 and Cerabone materials were used. Analyses were carried out on four different geometries in total.

2.2 Material Properties:

The material properties of bone tissue were obtained from CT data. The density and elasticity modulus values of bone tissue can be determined using the Hounsfield units (HU) determined from the CT scans. HU-density and density-elasticity modulus equations were taken from the literature (Peng , Bai , Zeng, & Zhou, 2006). Defining the bone material properties heterogeneously for each element separately would give more realistic results in simulations. In Figure 3, the distribution of the region, in which the density [g/cm3] values were calculated, was reflected in a CT section.

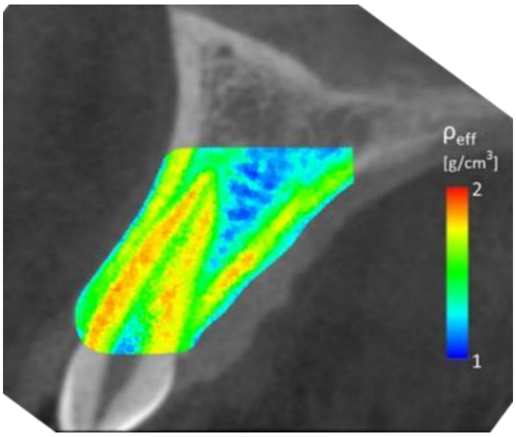

Figure 3. Determination of bone tissue material properties using CT scans and density distribution.

In the elasticity module values obtained, a maximum of 3569 MPA was detected. The gaps defined in the region were considered granulation tissue. Previous studies have defined the elasticity module of granulation tissue as 1 MPa (Lacroix, Prendergast , Li , & Marsh, 2002), (Isaksson, Wilson , Van Donkelaar, Huiskes, & Ito, 2006). For the implant, the material properties of the Ti-Zr alloy Roxolid were defined (E=100 GPa) (Cinel , Celik , Sagirkaya, & Sahin , 2018). The TiO_2 and Cerabone grafts used in the present study, had GPa values of 230 and 83 respectively, as determined previously (Ebrahimian-Hosseinabadi, Ashrafizadeh , Etemadifar, & Venkatraman, 2011), (Birmingham et al., 2015). All material properties are defined as linear isotropic and summarized in Table 1.

Table 1. Material Properties

Material	Elasticity module [MPa]	Poisson's ratio
Bone tissue	20 – 13569	0.3
Granulation Tissue	1	0.167
Roxolid Ti-Zr alloy	100000	0.3
TiO_2	230000	0.29
Cerabone	83000	0.28

2.3 Finite Element Analysis:

3D geometries were transferred to the ANSYS (ANSYS, Inc. Canonsburg, Pennsylvania, USA) software, in which the finite element analyses would be made, to create the meshwork. For bone tissue geometry (maxillary geometry), the meshing process was performed with an edge length of 0.5 mm. Graft structures were established using the mesh nodes of the tissue geometry covering the implant. A lattice structure was created by connecting the nodes of each element of the determined tissue region using the LINK180 element to simulate graft structures (Figure 4). As specified in a study, the pore diameters of TiO_2 and Cerabone grafts were approximately 300 µm, and the strut diameters were as 50.4 µm and 117.4 µm, respectively (Zhang X, 2019). Therefore, the mesh structure was developed for the implant and surrounding tissue with an edge length of 300 µm. For this tissue forming the graft, the lattice structure was established by defining the diameter values and material properties of the above-mentioned grafts. Thus, the pore diameters and strut thicknesses were determined based on the experimental study data. Four-node tetrahedral elements were used for all geometries. For each model, 97079 nodal points and 545504 elements were created, excluding the lattice elements (LINK182). The contact properties were defined as all geometries that were bonded. The gap surrounding the implant was defined as granulation tissue in the virtual environment.

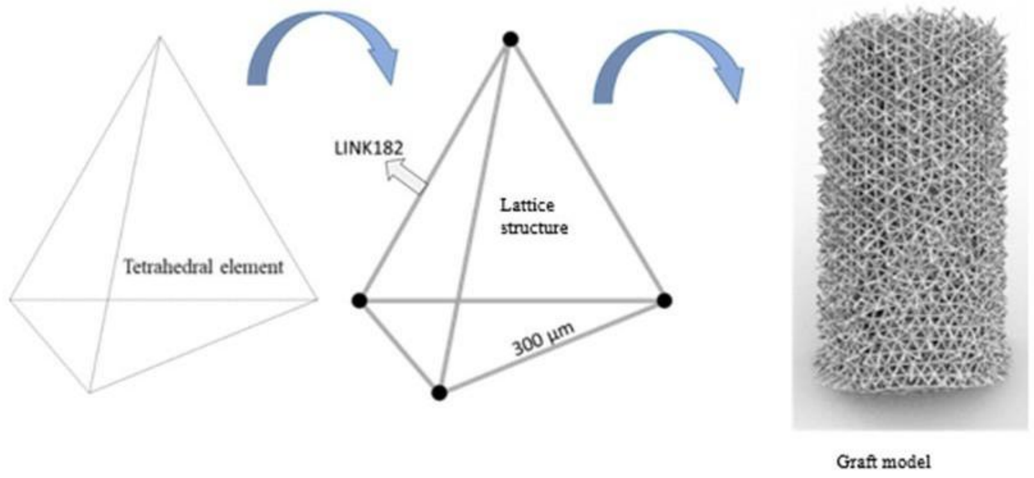

Figure 4. Graft modeling

The models were fully fixed from the upper part of the maxilla and loading conditions were applied to implant nodes. In finite element analysis, vertical and horizontal forces are applied and the results reported separately. As shown in Figure 5, the vertical force of 150 N parallel to the axis and horizontal force of 100 N vertical to the axis were applied to the implant top surface (Marcián et al., 2018). Totally, eight analyses were performed using four different geometries with two loading conditions. The assessments were performed by obtaining the maximum and minimum principal strain values in the bone tissue, the maximum von Mises stress in the implant geometry, and the maximum deformation values.

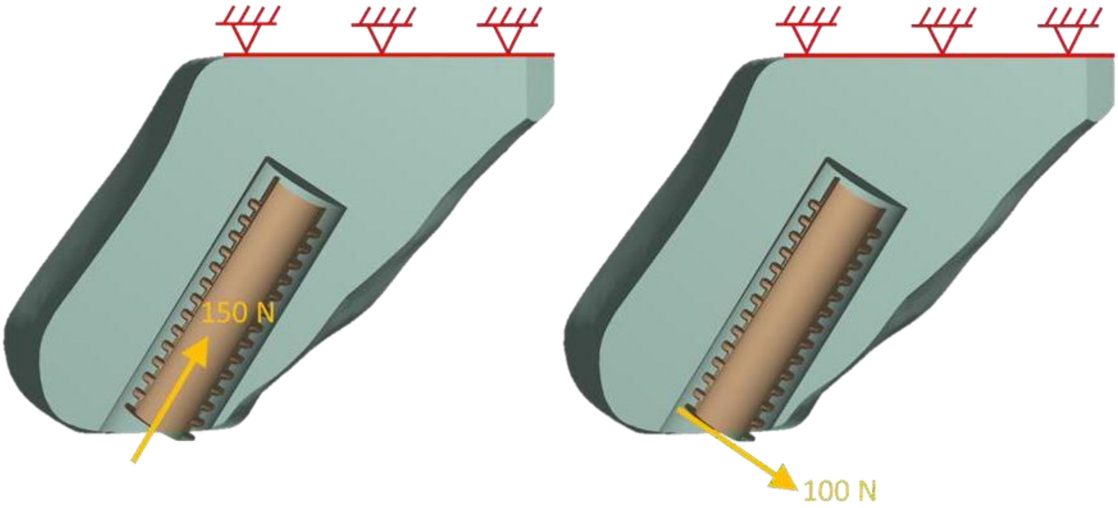

Figure 5. Boundary conditions

3. Results

The maximum and minimum principal strain distributions in the bone tissue under vertical and horizontal loading conditions, are shown in Figures 6 and 7, respectively. The peak minimum and maximum principal strain on the bone tissue, von-Mises stress and displacement values of the implant in the direction of the applied forces are presented in Table 2.

Table 2. Analysis results obtained as a result of vertical and horizontal loading

Vertical loading					
Models (Gap distance)	Max. principal strain (μ-strain)	Min. principal strain (μ-strain)	Eq. von-Mises strain (μ-strain)	Implant Eq. von-Mises stress (MPa)	Implant deformation (μm)
Control group	1452	2844	2483	136	70
2 mm	2039	5350	4621	127	80
3 mm - TiO_2 Graft	2033	5619	4787	134	80
3mm-Cerabone	2021	5558	4735	131	80
Horizontal loading					
Models (Gap distance)	Max. principal strain (μ-strain)	Min. principal strain (μ-strain)	Eq. von-Mises Strain (μ-strain)	Implant Eq. von-Mises stress (MPa)	Implant deformation (μm)
Control group	1554	1485	1496	118	150
2 mm	1470	1449	1556	112	212
3 mm - TiO_2 Graft	1566	1584	1788	123	172
3mm - Cerabone	1607	1580	1767	126	202

The minimum and maximum principal strains (1452 and 2844 μ-strain) of the bone tissue under vertical loading were found lower in the model with no gap between the implant and the bone tissue (control group) than in the other models. In the 2 mm gap

and 3 mm gap models, the graft used provided comparable results under vertical force loading. The highest stress on the implant were obtained in the control group (136 MPa). While the lowest stress value was observed in the 2 mm gap model without graft (127 MPa), the stresses were found close to each other in graft models. While the maximum stress value of the implant with TiO_2 graft was 134 MPa, it was 131 MPa with Cerabone graft.

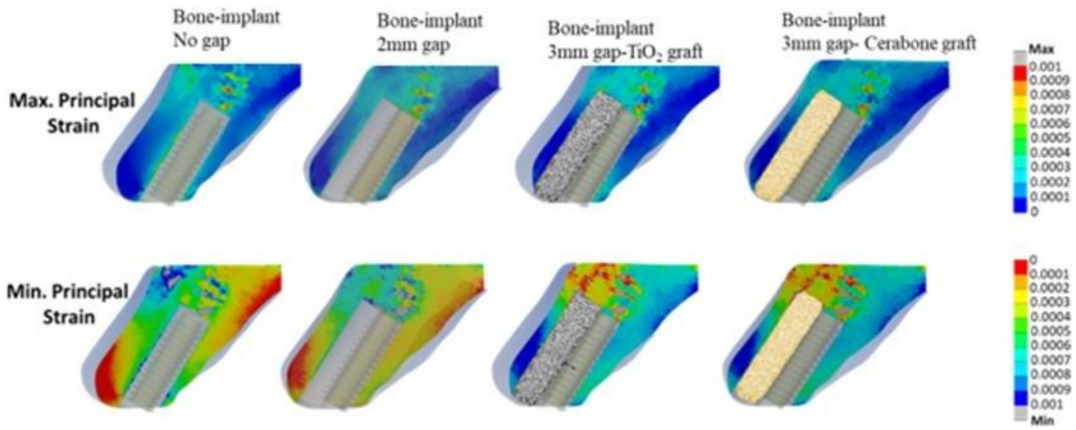

Figure 6. Maximum and minimum principal strain distributions in models under vertical load

The peak minimum and maximum principal strains (1470 and 1449 μ-strains) on bone tissue due to horizontal loading were lower in the 2-mm gap model than those in other models. Stress were lower in the control group than models with grafts. The highest value were observed in the Cerabone graft model. Regarding the maximum von-Mises stress on the implant, the highest value was observed in the Cerabone graft model (126 MPa). The lowest stress value was observed in the 2 mm gap model without graft (112 MPa), whereas the values were close to each other in the models with graft. The maximum stress values of the implant were 123 MPa and 118 MPa TiO_2 graft and model without gap, respectively. Although no difference was found between the movement values of the implant under vertical loading, differences were noted under horizontal loading. The control model had the lowest deformation at 150 μm whereas the 2 mm gap model without graft had the highest deformation at 212 μm. When comparing the graft materials, the TiO_2 graft model was more stable at 172 μm, than the Cerabone-graft model at 202 μm.

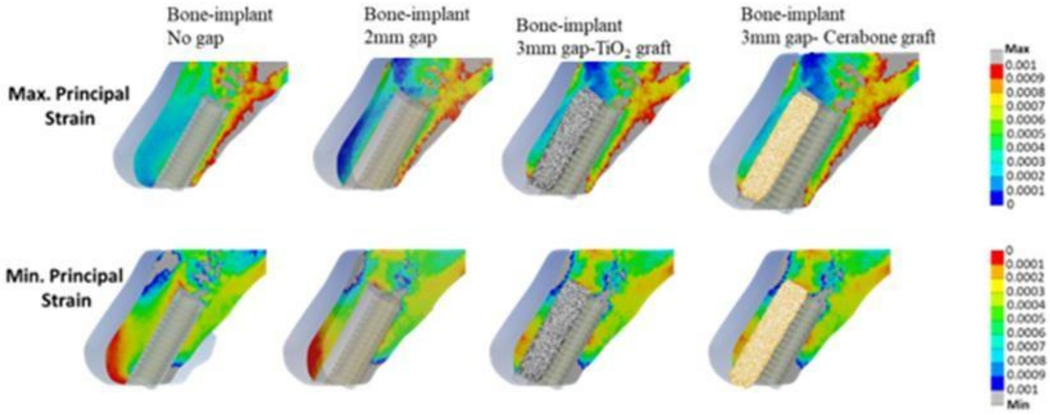

Figure 7. Maximum and minimum principal strain distributions in models under horizontal loading

The finite element method is a numerical method. With any numerical analysis method, errors can occur in the solution obtained. The accuracy of the finite element model affects the analysis results. Statistical analysis of the values obtained by finite element analysis cannot be performed, since these results are obtained by mathematical calculations without variance (2.65).

4. Discussion

Load transfer affects the long-term success of implants. Stress should be properly transferred to the supporting tissues (Steigenga, al-Shammari , Nociti, Misch , & Wang, 2003). Many analysis methods have been used to examine the role of these factors in load transfer. Finite element analysis method gives the closest results to those obtained in in vitro studies. Moreover, the reproducibility of the study is a very significant advantage of the finite element analysis method compared to in vitro studies (Steigenga, al-Shammari , Nociti, Misch , & Wang, 2003).

CT scans are frequently used to provide realistic images and models in finite element analysis studies. Bölükbaşı et al. used a CT scan with a millimetric section obtained from the maxilla of a person with full teeth to fully reflect the maxilla on the study model. Considering the resorptions following tooth loss in their studies, the angle of the implants to the frontal plane was determined as 10° in canines, 20° in the lateral incisors and 30° in the middle incisors (1.75). The surface geometries of the maxilla and teeth in STL format were obtained using the ITK-Snap (University of Pennsylvania) program with the images in DICOM format with 1 mm intervals. The implant design was based on the dimensions provided by the manufacturer (Bone Level Ø3.3 mm, SLA 10 mm Loxim, Roxolid, Straumann). The implant geometry was placed into the maxilla model by clearing the anterior right tooth, on the same axis as the tooth. It was performed in this way to obtain more realistic results if it is on the same axis with the tooth cleared. The analyses included a single implant and therefore a geometrically single tooth region.

In the analysis, implant + abutment and bone grafts were used in the modeling to enable immediate loading. This would give more realistic and sensitive results. Moreover, a study showed that loading the forces on the crowns gives more precise results (Hsu, Chen , Kao , & Cheng , 2007).

In the present study, four different geometries were provided. In the first model, there is no gap between the bone and the implant (control model). In the second model, a 2 mm gap is made between the bone and the implant. In the other two models, a 3 mm gap is made between the bone and the implant, whereas two grafts made of TiO_2 and Cerabone materials were used.

Many studies have investigated the prognosis of implants placed after the application of different graft materials. An autogenous graft is still considered the gold standard (Hammack & Enneking, 1960). However, autogenous bone requires a second surgery that can be considered a disadvantage. In addition, graft resorption is high in the prognosis of cases with autogenous bone, and this may adversely affect long-term implant survival (Dursun et al., 2016). TiO_2, a new synthetic graft material was found to be promising for bone regeneration. Studies have shown that this graft has high compressive strength and low toxicity (Fostad et al., 2009), (Sabetrasekh, Tiainen , Lyngstadaas, Reseland, & Haugen , 2011), (Tiainen, Wiedmer, & Haugen, 2013). In an experimental study, TiO_2 graft material stimulates bone formation around the implant (Haugen et al., 2013).

Another graft material analyzed in this study, is bovine-derived Cerabone, a xenograft. Xenografts are obtained from a tissue derived from another species. It has more antigenicity than allografts. These grafts are not involved in osteogenesis alone, and they have a minimum effect on the stimulation of bone remodeling. Given their high antigenicity, they are chemically processed to prevent graft rejection. Xenografts without any chemical process cause severe a inflammatory reaction, and they are resorbed within 2 weeks. Compared with allografts, xenografts do not require a second operation area and it can be provided in the desired amount (Büyükakyüz & Öztürk , 2012).

In a clinical study 12 patients having immediate implant loading, Juodzbalys et al used bovine derived graft material, resorbable collagen membrane and absorbable pins for the treatment of defects arising around the implant. In the follow-up after a year, the implant showed 100% success, and the thickness of the keratinized mucosa, which is esthetically important, measured 13 mm on average. The thickness of the keratinized mucosa, which should be at least 2 mm, measured 1 mm only in a single patient (Juodzbalys & Wang, 2007).

In the studies conducted with finite element analysis, there is no universally accepted table for material properties. CT was used instead of assigning fixed material properties for the entire bone tissue to obtain more accurate results for the stress distribution in the bone tissue around the implant. In the literature, density and elasticity modulus values have been determined using the equations determined by experimental studies. In the elasticity module values obtained, a maximum of 13569 MPa was detected. The gaps defined in the region were considered granulation tissue. Previous study have defined the elasticity module of granulation tissue as 1 MPa (Lacroix, Prendergast , Li , & Marsh, 2002), (Isaksson, Wilson , Van Donkelaar, Huiskes, & Ito, 2006). For the implant, the material properties of the Ti-Zr alloy Roxolid were defined (E=100 GPa) (Cinel , Celik , Sagirkaya, & Sahin , 2018). The TiO_2 and Cerabone grafts used in the present study, had GPa values of 230 and 83, respectively.

Modeling the geometry in detail based on 3D finite element analysis is significant because this will affect the precision of the study. The meshwork were created by transferring 3D to be used in the study to the ANSYS (ANSYS, Inc. Canonsburg, Pennsylvania, USA) program, in which the finite element analyses would be made. Graft structures were established using the nodal points of the meshwork from the tissue geometry covering the implant. A lattice structure was established using the LINK element with two nodes on the edges of each element. The pore diameters of TiO_2 and Cerabone grafts were determined based on similar studies (Zhang X, 2019). Four-node tetrahedral elements were used for all geometries.

Meijer et al evaluated that a higher number of elements and nodes while creating the model makes the results to be more sensitive and accurate in their study performed with 3D finite element analysis (Meijer, Starmans, Steen, & Bosman , 1996). In the present study, 97079 nodal points and 545504 elements were created for each model, excluding the lattice elements (LINK182) to obtain realistic analysis results. The contact properties were defined as all geometries that are completely dependent on each other. While bone tissue covers the implant in the model with no gap, granulation tissue was defined to cover the gap in other models.

The aim was to examine the results in two different conditions by applying the parallel and vertical forces to the implant axis separately. The vertical force of 150 N parallel to the axis and horizontal force of 100 N vertical to the axis were applied to the implant end surface (Marcián et al., 2018). In total, eight analyzes were performed with four different geometries and two different force applications. As a result, evaluations were made by obtaining the maximum and minimum principal strain values in bone tissue, and the maximum von-Mises stress and maximum deformation values from the implant geometry.

Kwon et al used the finite element analysis method and evaluated the stress distribution in the evaluation of implant and graft stability before graft stabilization following the dental implant placement. For this purpose, Dembone, Bio-Oss, particle dentin and plaster of Paris were used to fill bone defects. Kwon et al compared the distribution of stress in the mandible and maxilla between the vertically applied force and the force applied at an angle of 30° and by time with three different graft materials. Accordingly, stress levels were higher when applied at an angle rather than vertically. Stress levels were higher immediately after implant placement. The greatest stress distribution was observed when using demineralized freeze-dried bone. The stress distribution pattern was found to be different according to the mechanical properties of implants (Kwon & Kim , 2006).

Verket et al used the finite element analysis method, to evaluate the osseointegration of the implants and bone defects grafted with TiO_2 and the performance of the graft in terms of mechanical stability and bone filling. The implants were placed after the bone was supported by the graft. Accordingly within the limitations of the study, TiO_2, the new synthetic graft material, worked similarly to the autologous bone block control when comparing implant osseointegration. The mechanical properties of the graft were found sufficient to resist the clinical load in the current experimental model (Verket et al., 2016).

The minimum and maximum principal strain peaks on bone tissue due to vertical loading were lower, in the control model than in other models. The 2 mm gap and 3 mm gap models obtained comparable results under vertical force loading. The highest peak stress values on the implant, were obtained in the control group. While the lowest stress value was in the 2 mm gap model without graft, the values were close to each other in the models with graft. The minimum and maximum principal strain peaks on bone tissue due to horizontal loading were lower in the 2mm gap model than in other models. The stress values were lower in the control group than in the models with grafts and the Cerabone graft model had the highest stress values. Regarding the maximum stress values on the implant, the highest value was observed in the Cerabone graft model. The 2 mm gap model without graft had the lowest stress value, whereas the values were close to each other in the models with graft. Although no difference was found between the movement values of the implant under vertical loading, differences were found under horizontal load. The control model had the lowest deformation at 150 μm, whereas the 2 mm gap model without graft had the highest deformation at 212 μm. When comparing the graft materials, the TiO_2 graft model was more stable at 172 μm than the Cerabone graft model at 202 μm.

The finite element analysis method has been used for a long time in the field of dental implantology, and is superior to clinical studies in terms of repeatability. Many studies have provided results similar to in vitro data (Geng , Tan, & Liu, 2001). As a limitation of the present study, it is not possible to fully transfer all the details and dynamics of biological tissues to the model using today's technology. Therefore, the studies conducted with this method should be confirmed by clinical studies until superior computer systems are developed in the future.

5. Conclusion

In summary, CT-based finite element analyses were conducted to determine which of the TiO_2 and Cerabone grafts are more stable and closer to the ideal condition (no-gap model) when used. Strain, implant stress and deformation values under vertical and horizontal loading were compared for the no gap model (control model) and the two graft materials used for the 2 mm and 3 mm gap modes.

In conclusion, the models supported with bone grafts following dental implant placement in the maxilla showed similar stress distributions.

Stress distribution is lower in implant surgery without graft placement. If possible, for immediate implant loading, direct implantation without graft placement is more advantageous in terms of stress distribution. However, there is not a great difference between the two graft materials.

There is not a great difference between the graft materials in terms of stress distribution under vertical and horizontal loading. Lower stress accumulation was obtained in the group with no graft. In vertical loading, the lowest stress accumulation was observed in the control group, whereas in horizontal loading, it was obtained in the 2-mm model without graft. Moreover, no differences was found between TiO_2 and Cerabone in terms of stress distribution in the bone tissue surrounding the implant according to the finite element analysis method. However, the TiO_2 graft provides a more stable structure than the Cerabone graft according to the results of implant micromovement.

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CONFLICT OF INTEREST

The authors have no affiliations with or involvement in any organization or entity with any financial interest or non-financial in the subject matter or materials discussed in this manuscript.

AUTHOR STATEMENT

This study did not require ethical approval, and no informed consent or custom software was applicable.

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