ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

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3D Finite Element Analysis of Stress Distribution Conical and Cylindrical Implants by Alveolar Ridge Splitting Technique: Analytical Study

Alveolar Kret Ayırma Tekniği ile Atrofik Çenelere Konik ve Silindirik İmplantların Yerleştirilmesinin 3B Sonlu Eleman Analizi ile Değerlendirilmesi: Analitik Çalışma

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ABSTRACT Objective: Alveolar ridge splitting technique (ARST) is a horizontal bone augmentation technique used in atrophic alveolar ridge. The present study aimed to evaluate the insertion of conical and cylindrical implants with the same surface structure in atrophic alveolar ridges augmented by ARST and to analyze the stress distributions on the implant and adjacent bone surfaces using three dimensional (3D) finite element analysis (FEA). **Material and Methods:** The thickness of the atrophic alveolar ridge was adjusted to 5 mm. The implants were inserted in the atrophic alveolar ridges that were augmented by ARST with a torque of resistance of 35 Newtons. Stress distributions were evaluated by using FEA. **Results:** The results indicated that the conical implants resulted in lower strain on the implant and adjacent bone surfaces compared to cylindrical implants. It was also revealed that conical implants had a homogeneous stress distribution on the implant surfaces while the stress in cylindrical implants was mostly concentrated on the neck region. As the diameter of the implants increased, the Von Mises stress values on the adjacent bone surfaces decreased. **Conclusion:** Although no definitive recommendations can be made regarding the design of the implants used in ARST, the results of the present study indicated that conical implants could be more advantageous than cylindrical implants with regard to stress distribution.

Keywords: Dental implants; finite element analysis; stress; alveolar ridge augmentation

ÖZET Amaç: Alveolar kret ayırma tekniği (AKAT), atrofik çenelerde yatay kemik büyütme yöntemlerinden bir tanesidir. Bu çalışmadaki amacımız, kret ayırma tekniği ile aynı yüzey yapısına sahip konik ve silindirik formdaki farklı çaptaki implantları yerleştirmek, 3 boyutlu sonlu eleman analizi ile komşu kemik yüzeyinde ve implant yüzeylerinde oluşan stres dağılımlarını değerlendirmektir. **Gereç ve Yöntemler:** Alveolar kretin kalınlığı 5 mm'ye ayarlandoı. Kret ayırma ile genişletilmesi sonucu atrofik alveolar kretlere 35 Newton tork kuvveti ile implantlar yerleştirildi. Stres dağılımları SEA ile değerlendirildi. **Bulgular:** Konik implantların, implant yüzeyinde ve komşu kemik yüzeyinde oluşturdukları stres değerlerinin silindirik implantlara göre daha az olduğu görüldü. Silindirik implantların boyun bölgesinde stres yoğunlaşırken, konik implantlarda implant yüzeyine homojen dağıldı. İmplantlarda çap arttıkça komşu kemik yüzeyinde oluşan Von Mises stres değeri azaldı. **Sonuç:** Kret ayırma tekniğinde kullanılacak implant tasarımı ile kesin bilgiler olmasa da çalışmamız bize konik formlu implantların stres dağılımı açısından silindirik formlu implantlara göre daha avantajlı olacağını göstermiştir.

Anahtar Kelimeler: Dental implantlar; sonlu elemanlar analizi; stres; alveolar kret ogmentasyonu

One of the most critical problems encountered in implant dentistry is the presence of insufficient bone width and height to allow for the appropriate implant placement according to standard protocols and to obtain appropriate, optimal, functional, and esthetic long-term outcomes.[1,2] Accordingly, for a fully functional and aesthetic prosthetic structure, a comprehensive examination is required before and after implant placement to ensure hard and soft tissue compatibility.[1]

To date, numerous techniques have been used for bone augmentation in cases with inadequate alve-

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olar bone width. Among these, onlay bone grafts, guided bone regeneration (GBR), and alveolar distraction osteogenesis are commonly used horizontal bone augmentation techniques for increasing the bone volume of alveolar crest.[3-5] Bone augmentation and implant placement with the edentulous ridge splitting and expansion technique can be an innovative technique as it eliminates the need for a second surgical site, which further increases the patient's discomfort.[6] The alveolar ridge splitting technique (ARST) was first described by Simion et al. and Scipioni et al. in early 1990s, which involved splitting the atrophic alveolar ridge longitudinally in 2 parts, provoking a greenstick fracture to create a self-space-making defect in both maxilla and mandible.[7,8]

ARST provides successful outcomes similar to those of onlay bone grafts in the restructuring of alveolar bones with an adequate height and inadequate width. In this technique, one horizontal and two vertical relieving incisions are made on the alveolar bone to distract the buccal segment with well-defined borders, ultimately to allow for alveolar ridge augmentation through implant placement.[9,10] In severely atrophic cases, the absorption of a significant portion of strain by the buccal plate during augmentation and its breakage risk due to its fragile structure are serious risk factors for the success of ARST.[8,11]

Clinical assessment of the stress distribution in an implant and bone caused by the strain on dental implants is highly difficult. Therefore, quantitative techniques such as finite element analysis (FEA) are used for the quantification of the stress in the peri-implant region and surrounding structures. Additionally, FEA also allows the assessment of the strain and the changes in structure shape in each element as well as in the entire structure formed by the elements.[12,13]

Literature indicates that no definitive recommendations can be made regarding the design of the implants used in ARST.[14,15] The present study aimed to evaluate the Von Mises stress distributions on the conical and cylindrical implants that were inserted in atrophic alveolar ridges augmented by ARST with a torque of resistance of 35 Newtons (N).

MATERIAL AND METHODS

IMPLANT MATERIAL PROPERTIES

Two different cylindrical bone-level (BL) implants (∅ 3.3, 4.1 mm in diameter and 10 mm in length) (Roxolid®, Institute Straumann AG, Basel, Switzerland) and two distinct conical bone-level tapered (BLT) implants (∅ 3.3, 4.1 mm in diameter and 10 mm in length) (Roxolid®, Institute Straumann AG, Basel, Switzerland) were used in the study (Figure 1).

MODELING

This study we conducted on implant placement using the alveolar crest separation technique is a continuation of our work on fracturing the buccal lamella with the crest separation technique.[16]

Cone-beam computed tomography (CBCT) images were used for creating 3-dimensional (3D) solid models of maxilla and mandible using Rhinoceros 4.0 software (Mc Neel&Associates, Seattle, USA). The maxillary model had a height of 13 mm, mesiodistal length of 80 mm, and buccolingual width of 9 mm. In contrast, the mandibular model had a height of 30 mm, mesiodistal length of 130 mm, and buccolingual width of 9 mm, with the width gradually increasing between the coronal and apical aspects. In both models, the bone thickness in the right first molar region was adjusted to 5 mm in the buccolingual direction and 8 mm in the mesiodistal direction and the resulting cortical bone thickness was 2 mm in the mandible and 1 mm in the maxilla. The inner surface of the cor-

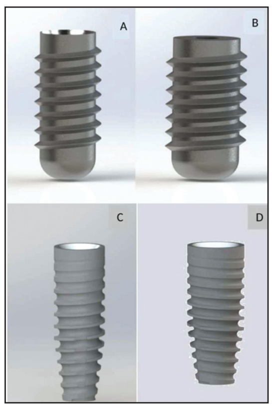

FIGURE 1: (A) Bone level implant 3.3 mm/10 mm; **(B)** bone level implant 4.1 mm/10 mm; **(C)** Bone level tapered implant 3.3 mm/10 mm; **(D)** Bone level tapered implant 4.1 mm/10 mm.

tical bone was composed of cancellous bone. Subsequently, both models were scanned by a NextEngine 3D laser scanner (NextEngine Inc., Santa Monica, California, USA) and then transformed to 3D solid models using a 3D modeling software (Rhinoceros 4.0, McNeel & Associates, Seattle, USA). Two vertical incisions with a depth of 8 mm were made on the right and left edges of the atrophic ridge to form an osteotomy that could support the horizontal incision. By using ARST, the buccal plate was distracted without causing any fractures and the buccolingual alveolar bone thickness increased from 5 mm to 7 mm. To obtain optimum outcomes, the elasticity modules and Poisson's ratios of the implants, compacts, and cancellous bones were transferred to computer environment (Table 1).

BOUNDARY AND LOADING CONDITIONS

The BLT and BL implants were placed on the alveolar ridge formed by ARST by applying a torque of resistance of 35 N (Figure 2, Figure 3).

STATISTICAL ANALYSIS

The FEA results were analyzed using ANSYS 14.0 software (ANSYS Inc., Canonsburg). All the values were expressed in Megapascal (Mpa) and the stress distributions were color-coded and compared between the implants.

RESULTS

In the 3.3-mm and 4.1-mm BLT implants, the maximum Von Mises stress values on the implant surfaces were 6.28 and 3.52 MPa for the maxillary models and 4.24 and 3.29 MPa for mandibular models, respectively (Figure 4). In contrast, in the 3.3-mm and 4.1-mm BL implants, the maximum Von Mises stress values on the implant surfaces of were 10.07 and 5.47 MPa for the maxillary models and were 11.47 and 5.31 MPa for mandibular models, respectively (Figure 4). Moreover, the 3.3-mm maxillary models of both BLT and BL implants had the maximum Von Mises stress values on the bone surfaces (1.98 and 6.76 MPa, respectively) (Figure 5). It was also revealed that as the diameter of the BLT and BL implants increased, the Von Mises stress values on the adjacent bone surfaces decreased (Figure 6).

TABLE 1: Material properties.

Material	Elasticity modulus (Gpa)	Poisson's ratio
Titanium	113.8	0.34
Cortical bone	13.7	0.3
Trabeculer bone	1.37	0.3

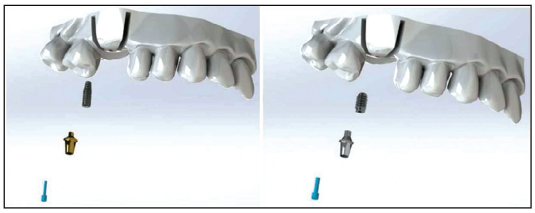

FIGURE 2: Insertion of bone-level tapered and bone-level implants by alveolar ridge splitting technique.

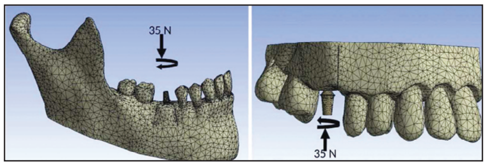

FIGURE 3: Insertion of the implants with a torque of resistance of 35 N.

DISCUSSION

The use of autogenous and guided bone grafts with osteoinductive and osteoconductive properties for an atrophic alveolar ridge provides various advantages such as achieving adequate bone volume. However, these techniques may also have several disadvantages such as morbidity caused by the formation of a second surgical site and the requirement of a minimum of 4-6 months for implant placement. For these reasons, the use of ARST for dental implant placement in atrophic ridges can be relatively more advantageous.[17]

FEA is a numerical technique used for the assessment of stress in complicated structures. Given that the clinical visualization of load-induced stress is almost impossible, 3D FEA allows a 3D examination of biomaterials and tissues, and provides information on the mechanical resistance under loading conditions.[18-20]

Demetriades et al. reported that ARST was a suitable technique for dental implants that were inserted in alveolar crests with a buccolingual bone di-

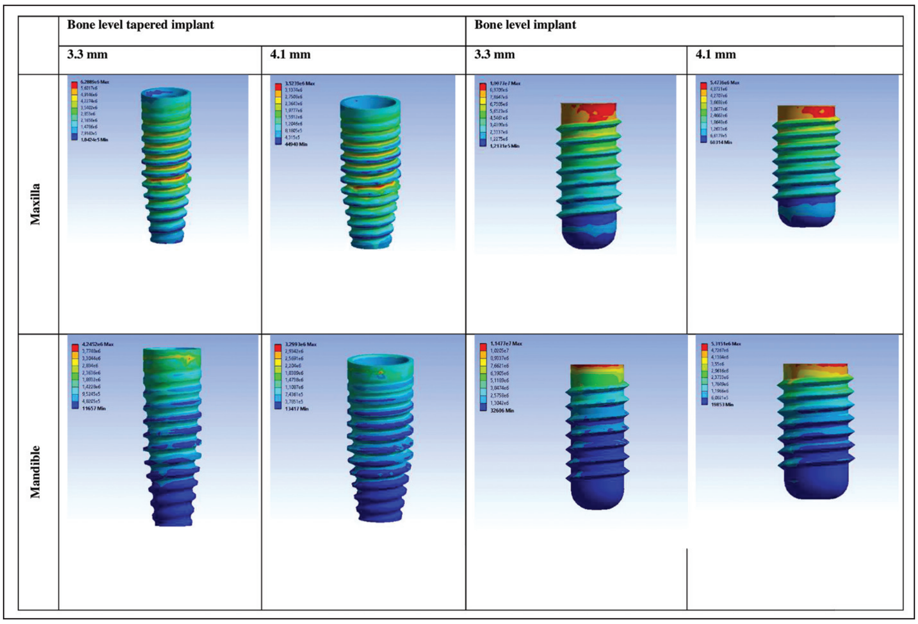

FIGURE 4: Distribution of Von Mises stress on the surfaces of bone-level tapered and bone-level implants.

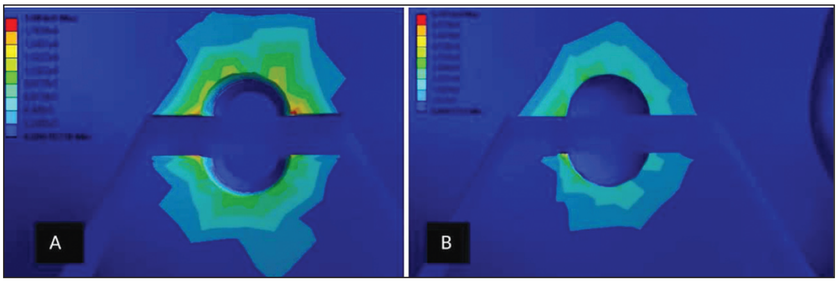

FIGURE 5: (A) Distribution of Von Mises stress on the adjacent bone surface after the insertion of a 3.3 mm bone-level tapered implant in the maxilla; **(B)** Distribution of Von Mises stress on the adjacent bone surface after the insertion of a 3.3 mm bone-level implant in the maxilla.

mension of 3-5 mm with a torque of resistance of 35 N.[21] The authors suggested that implementing ARST on atrophic ridges with a diameter of less than 3.0 mm may result in undesirable bone fractures that lead to bone resorption.[22] For these reasons, some other techniques could be more suitable for alveolar ridges with a diameter of less than 3.0 mm.[23,24] In the present study, the bone thickness in the right first molar region was adjusted to 5 mm in the buccolingual direction so as to avoid the risk of buccal plate fracture.

The mandible has a greater bone mineral density when compared to the maxilla. Accordingly, the posterior mandible is the most challenging region for reconstruction and for early single-implant placement in cases of severe alveolar resorption.[25] In ARST, distracting the buccal plate without causing fractures is

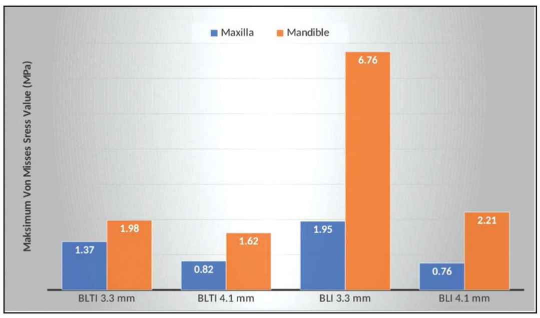

FIGURE 6: Distribution of Von Mises stress on the bone surfaces adjacent to BLT and BL implants. **BL:** Bone-level; **BLT:** Bone-level tapered.

more difficult to achieve in the mandibular bone compared to the maxillary bone.[26,27] In our study, the conical BLT implants resulted in lower stress values on the adjacent bone surfaces compared to the BL implants. Accordingly, we suggest that the use of conical implants could be relatively more suitable for the mandibular bone during the implementation of ARST due to its cortical structure.

ARST allows foreseeable treatment of clinical conditions that would otherwise not be treated. Nevertheless, this technique has no definitive recommendations that can be made regarding the best tools and implant designs to be used in the treatment.[14] In the present study, we used implants with the same surface structure and varying tapered angles and we found that conical implants could be more advantageous than cylindrical implants in ARST with regard to stress distribution. Moreover, we also found that the maximum Von Mises stress values on both implant and adjacent bone surfaces were lower in BLT implants compared to BL implants, which implicates that BLT implants are likely to have a longer survival period compared to BL implants when used in clinical settings.

The success of dental implant depends on marginal bone loss per year. Numerous studies investigating this issue indicated that the marginal bone loss around the dental implants in which the bone volume was augmented by ARST was similar to the bone loss around the dental implants in which no augmentation was performed.[21,28-30] In our study, the BLT implants had a homogeneous stress distribution on the implant surfaces while the stress in BL implants was mostly concentrated on the neck region.

Our findings also revealed that as the diameter of BLT and BL implants increased, the Von Mises stress values on the adjacent bone surfaces decreased. This finding was consistent with most FEA studies.[31,32]

Further studies involving a comprehensive evaluation of ARST performance with carefully selected patient populations, control groups, and well-documented methodologies are needed to adequately assess the performance of the ARST. Additionally, further studies should also include novel implant designs that could improve the performance of this technique.

CONCLUSION

Considering the inherent limitations of the study, the following results can be drawn:

1. BLT implants were found to be more advantageous than BL implants in ARST,

2. The increase in implant diameter led to decreased Von Mises stress values,

3. The BLT implants had a homogeneous stress distribution on the implant surfaces while the stress in BL implants was mostly concentrated on the neck region.

Source of Finance

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

This study is entirely author's own work and no other author contribution.

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