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Original Research

# Evaluation of Stress Distribution in Mandibular Donor Site After Harvesting Bone Grafts of Different Sizes from the Symphysis

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**ABSTRACT**

**Objective:** The purpose of this study is to investigate the stress distribution in the mandibular donor site after harvesting bone grafts of different sizes from the symphysis by applying three different occlusal loads.

**Methods:** First, we constructed 16 experimental mandible models after harvesting the block grafts. We harvested rectangular-shaped and cylindrical block grafts of different sizes, localizations, and depths from the symphysis region. Three different occlusal loads were applied on the models. After the application of three occlusal loads on the models, we analyzed the von Mises stress distribution in the surface of the donor sites in the symphysis.

**Results:** In all the mandible models, the highest von Mises stress values were detected under incisal loads. Under the ipsilateral load of 300 N, the maximum von Mises stress was similar between R1 (unilateral one cylindrical graft) and R2 (unilateral two cylindrical grafts) models, and also between R1+1 (bilateral two cylindrical grafts) and R2+2 (bilateral four cylindrical grafts) models. The maximum von Mises stress under incisal load in the models measuring 20×10×4 mm (width, height, and depth, respectively) and 20×10×6 mm were 2.46 and 2.79 MPa, respectively. Among the unilateral models, the lowest maximum von Mises stress value was found in the R4 model (cylindrical graft: diameter=10 mm, depth=4 mm), and the highest value was found in the model measuring 15×10×6 mm under all the loads.

**Conclusion:** The application of incisal load led to a higher stress as than that of the bilateral and ipsilateral loads. The stress distribution in the symphysis donor site varies according to the localization, shape, and dimensions of the harvested grafts. Cylindrical grafts led to lower stress than the rectangular grafts.

**Keywords:** Block graft, finite element analysis, stress, symphysis

## INTRODUCTION

The quantity of the dentoalveolar bone at the recipient site is a crucial factor for a successful insertion of endosteal implants and ensuring long-term survival rates. Trauma, tooth loss, and pathological entities such as cyst, tumor, and periodontal diseases may decrease the dimensions of the dentoalveolar bone. When the quantity of the dentoalveolar bone is insufficient in the dental implant surgery, several techniques can be used to increase the dimensions of the dentoalveolar bone for supporting the dental implants. These techniques include socket/dentoalveolar ridge preservation, distraction osteogenesis, bone splitting, on-lay graft, and guided bone regeneration (1). Previously, autologous bone graft was accepted as the gold standard for oral reconstruction, and intraoral and extraoral autologous bone grafts were used for the reconstruction of oral cavity defects. However, intraoral bone grafts are easily harvested in the present times for correcting limited and small defects. They provide various advantages such as the proximity between the donor and recipient sites. Intraoral donor sites include zygomatic arch, coronoid process, maxillary tuberosity, buccal aspect of the third molar region, anterior mandibular ramus, lateral aspect of the ramus, and symphysis (2-6).

Symphysis is an intraoral donor site that facilitates an easy and rapid surgical intervention. However, there may be some complications in the donor sites of symphysis during the intra- and/or post-operative period. These complications may include hemorrhage, infection, flap dehiscence, hematoma, pulp necrosis following damage to the dental root, hypoesthesia or anesthesia due to the injury of the mental nerve, insensitivity of the anterior teeth because of the proximity of the donor site to the roots of the teeth, pain, and swelling.

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After the harvesting of intraoral bone graft, biomechanical forces may lead to an increased risk of fracture. Although maxillofacial trauma is the primary cause of mandibular fractures, harvesting bone graft from the ramus increases the risk of mandibular fractures because of the weakness of the mandible (7, 8).

The assessment of stress distribution to the mandible is highly crucial for analyzing the risk of fracture after harvesting the autologous bone grafts. Finite element analysis (FEA) is a numerical method that provides solutions for the complicated mechanical problems by dividing the problem into smaller and basic components (9). Our study employed a three-dimensional (3D) FEA to analyze the stress distribution in the donor site of symphysis after harvesting different bone grafts of varying sizes from the symphysis under different occlusal loads.

## METHODS

Ethics approval was not required for this *in vitro* study. We used a cone-beam computed tomography (CBCT) image of a patient with no tooth loss to form a 3D solid model of the mandible that comprised the dense trabecular and cortical bones. CBCT images of bones and teeth were taken in the DICOM format, and these images were combined layer by layer via the 3D Slicer® program to obtain a 3D mesh format (Figure 1). The mesh file obtained in the STL (stereolithography) format was converted into a solid model by Rhinoceros 4.0 software (Robert McNeel & Associates, Seattle, USA) (Figure 2). Cavity operations were performed on the solid model via Rhinoceros 4.0® and Solidworks® software, and then the models were prepared for analysis (Figures 3, 4). The models prepared for analysis were exported in the parasolid format and transferred to ANSYS 14.0 (ANSYS Inc., Canonsburg, PA, USA) software.

The thickness of the cortical bone in the lingual and vestibular/buccal surfaces was 2 mm at the interforaminal region and 2.5 mm at the site between the mental foramen and ramus. At the base of the mandible, the thickness of the cortical bone was 4 mm. Table 1 presents the elasticity modulus and Poisson's ratio of materials (10).

The boundaries of the block graft harvested from the symphysis were as follows:

- Superiorly 5 mm below from the apexes
- Inferiorly 4 mm superior to the inferior border of the mandible
- Laterally 5 mm anterior to the mental foramens
- Posteriorly at the lingual cortex of the mandible regeneration, (1)

**Main Points:**

- The highest stress values after harvesting the grafts from the symphysis were detected under the incisal loads.
- Harvested cylindrical grafts lead to a lower stress than the rectangular grafts in the symphysis.
- The fracture risk increases under the bilateral posterior loads because of the excessive depth of the harvested block graft from the midline symphysis.
- All of the drawings belong to us.

Figure 1. Mesh image of the mandible

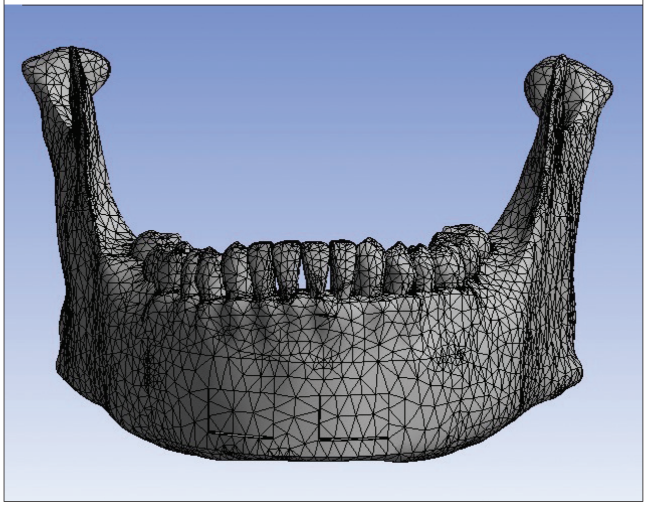


Figure 2. 3D solid model of the mandible

Figure 3. Mandible model with the harvested cylindrical grafts (diameter: 10 mm)

The grafts were harvested at the depths of 4 mm and 6 mm following the mandible external curvature, of which 4-mm-deep grafts included 2-mm cortical and 2-mm trabecular bone and 6-mm-deep grafts included 2-mm cortical and 4-mm trabecular bone. The block grafts were harvested from unilateral, bilateral, and midline symphysis, among which the unilateral grafts were harvested from the right side of the symphysis in all the models and bilateral bock grafts were harvested symmetrically from the midline of the mandible (Figures 3, 4). The dimensions of graft models were as follows:

- Cylindrical graft (R4: diameter=10 mm, depth=4 mm)
- Cylindrical graft (R6: diameter =10 mm, depth=6 mm)
- 15×10×4 mm
- 15×10×6 mm
- 20×10×4 mm
- 20×10×6 mm
- 30×10×4 mm
- 30×10×6 mm, (Figures 3, 4).

The localization of the cylindrical grafts was defined as follows:

- R1: Only one cylindrical graft on the right site of the symphysis (unilateral one cylindrical graft)
- R2: Two cylindrical grafts on the right site of the symphysis (unilateral two cylindrical grafts)
- R1+1: One cylindrical graft on the right and one cylindrical graft on the left site of the symphysis (bilateral two cylindrical grafts)
- R2+2: Two cylindrical grafts on the right and two cylindrical grafts on the left site of the symphysis (bilateral four cylindrical grafts) (Figure 3).

All the mandible models were termed according to the size of the harvested grafts. Table 2 enlists all the mandible models of this study. After harvesting the grafts, three loads were applied on the central fossa of the first molar teeth and on the midline of the incisal teeth.

The occlusal forces applied on the models were as follows:

1. Incisal load of 300 N (on the midline of the incisal teeth)
2. Ipsilateral load of 300 N (on the right first molar)
3. Bilateral (ipsilateral and contralateral) loads (on the right and left first molars) of 600 N.

We conducted the 3D FEA using the Rhinoceros 3-D modeling software with ANSYS 14.0 (ANSYS Inc., Canonsburg, PA, USA) analysis program. Moreover, we used von Mises stress, which is the initial value of deformation energy indicating the stress distribution in FEA, as the indicator of stress in the analysis (11). All the materials used in this study were assumed to be homogenous, isotropic, and linearly elastic. While establishing the limit conditions, the condyle of the mandible was fixed at the x, y, and z axes, and the other node points were allowed to move in all the axes. Vertical movement of the incisal and molar teeth on which the occlusal force was applied were fully constrained in the vertical direction by the displacement of boundary conditions (12).

After applying three occlusal loads on the models, we analyzed the von Mises stress distribution on the surface of the donor sites in the symphysis. In all the graft models, we only analyzed the stress distribution in the donor site and did not assess stress distribution on the other regions of the mandible (Figures 5, 6).

## RESULTS

All the harvested grafts had the depths of either 4 mm or 6 mm and were either cylindrical or rectangular in shape. All the grafts were harvested from the three different locations including unilateral, bilateral, and midline symphysis. After applying three different occlusal loads, we analyzed the von

Figure 4. Mandible model with the harvested rectangular-shaped grafts

Figure 5. Finite element analysis of the mandible model with harvested cylindrical grafts

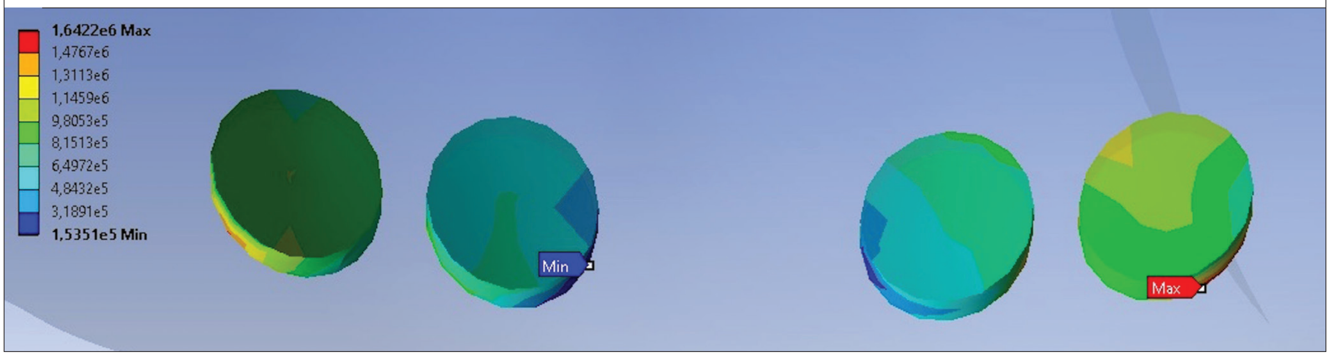


Figure 6. Finite element analysis of the mandible model with harvested rectangular-shaped grafts

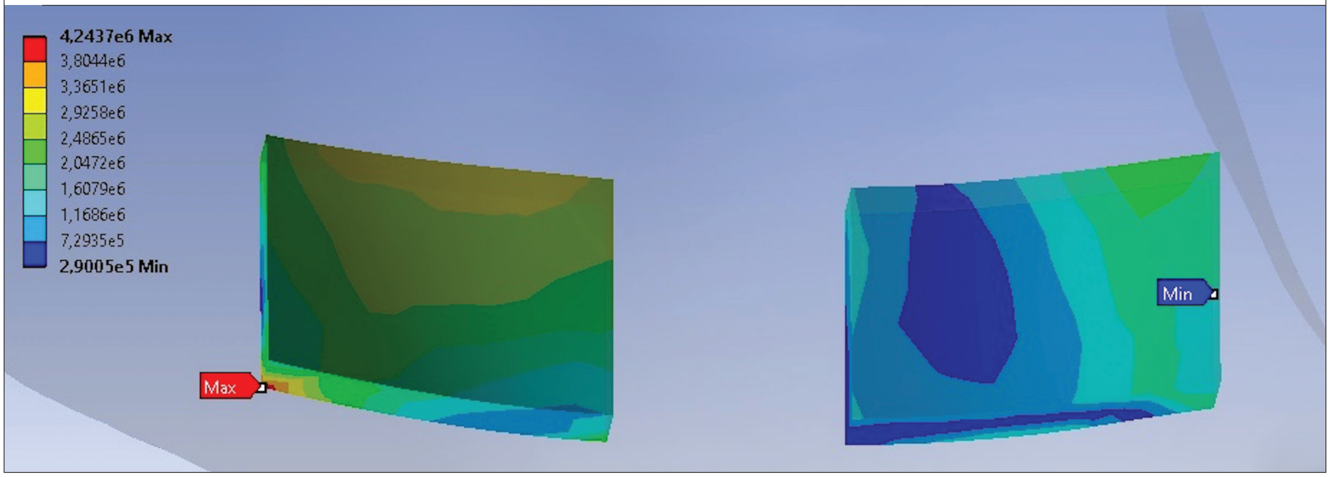



**Table 1.** Material properties

| Material | Elasticity modulus (Gpa) | Poisson's ratio |
|---|---|---|
| Cortical bone | 13.7 | 0.3 |
| Dense trabecular bone | 1.37 | 0.3 |

Mises stress distribution of each donor site. In all the mandible models, we detected the highest von Mises stress values under incisal loads (Figures 3, 4).

In the mandibular models with harvested cylindrical grafts, the highest von Mises stress was detected under incisal load. Under an ipsilateral load of 300 N, the maximum von Mises stress was similar between the R1 (unilateral one cylindrical graft) and R2 (unilateral two cylindrical grafts) models, and also between R1+1 (bilateral two cylindrical grafts) and R2+2 (bilateral four cylindrical grafts) models. However, the maximum von Mises stress in the R1+1 and R2+2 models was higher (approximately two times) than in the R1 and R2 models under ipsilateral load. Under the ipsilateral and contralateral loads of 600 N, the maximum von Mises stress was higher in the R2 and R2+2 models than in the R1 and R1+1 models. Under the ipsilateral load, the maximum von Mises stress was similar in the mandibular models with harvested 4- and 6-mm cylindrical grafts than under the incisal and bilateral loads (Figure 7, 8).

Four different block grafts with the dimensions of 20×10×4 mm, 20×10×6 mm, 30×10×4 mm, and 30×10×6 mm were harvested from the midline symphysis. The maximum von Mises stress under incisal load in the models measuring 20×10×4 mm and 20×10×6 mm were 2.46 and 2.79 MPa, respectively. The maximum von Mises stress in the model measuring 20×10×6 mm was higher than in the models measuring 20×10×4 mm, 30×10×4 mm, and 30×10×6 mm under incisal loads. However, the maximum von Mises stress under ipsilateral load was lowest in the model measuring 20×10×4 mm (1.72 MPa) and highest in the model measuring 30×10×6 mm (2.38 MPa). Under bilateral loads, the von Mises stress values were similar in the models measuring 30×10×4 mm (1.52 MPa) and 30×10×6 mm (1.50 MPa). The lowest maximum von Mises stress under bilateral load (600 N) was in the model measuring 20×10×4 mm (0.92 MPa) (Figure 9).

Among unilateral models, the lowest and highest maximum von Mises stress values under incisal load were in the R4 model (2.30 MPa) and in the model measuring 15×10×6 mm (3.03 MPa), respectively. Under ipsilateral load, the maximum von Mises stress values were similar in all the models. In both the R4 and R6 models, the maximum von Mises stress distribution under the bilateral load were similar to the values under incisal load; however, they were lower than those under the incisal load (Table 6). The maximum von Mises stress values were higher under the incisal loads than under the ipsilateral and bilateral loads in all the harvested grafts. The lowest maximum von Mises stress value was in the R4 model, and the highest value was in the model measuring 15×10×6 mm under all the loads (Figure 10).

The maximum von Mises stress values were detected in the bilateral models measuring 15×10×4 mm, and the lowest maximum von Mises stress values were detected in the unilateral models measuring 15×10×4 mm and 15×10×6 mm under all the three loads (Figure 11).

## DISCUSSION

The clinical investigation and analysis of stress distribution after harvesting the bone graft is not possible. Therefore, numerical methods such as FEA can facilitate the analysis of the stress distribution after harvesting the grafts from the mandibular symphysis. A previous theoretical and biomechanical study used various materials (cortical, trabecular bone and teeth) that were assumed to be isotropic, homogenous, and linearly elastic to standardize the harvested mandible models and accurately compare the models; however, the cortical and trabecular bones of the mandible does not have a clinically homogenous and isotropic structure (10).

**Table 2.** Experimental groups and conditions

| | | Maximum von Mises values (MPa) | | | | |
|---|---|---|---|---|---|---|
| | | Load localization and magnitude (N) | | | | |
| Analysis model | Depth (mm) | Incisal 300 N | Unilateral 300 N | Bilateral 600 N | Cycle time (s) | Load direction (deg.) |
| R1 | 4 | 2.30 | 1.06 | 1.32 | 1.80 | 90°-Vertical |
| | 6 | 2.45 | 1.08 | 1.49 | | |
| R2 | 4 | 2.65 | 1.08 | 1.67 | 1.80 | 90°-Vertical |
| | 6 | 2.82 | 1.07 | 1.75 | | |
| R1+1 | 4 | 2.67 | 2.00 | 1.32 | 1.80 | 90°-Vertical |
| | 6 | 2.74 | 1.98 | 1.47 | | |
| R2+2 | 4 | 2.62 | 1.98 | 1.64 | 1.80 | 90°-Vertical |
| | 6 | 2.98 | 2.16 | 1.88 | | |
| 15×10×4 unilateral | | 2.49 | 1.15 | 1.63 | 1.80 | 90°-Vertical |
| 15×10×4 bilateral | | 4.24 | 3.55 | 3.68 | 1.80 | 90°-Vertical |
| 15×10×6 unilateral | | 3.03 | 1.20 | 1.83 | 1.80 | 90°-Vertical |
| 15×10×6 bilateral | | 3.28 | 2.71 | 2.21 | 1.80 | 90°-Vertical |
| 20×10×4 | | 2.46 | 1.72 | 0.92 | 1.80 | 90°-Vertical |
| 20×10×6 | | 2.79 | 1.98 | 1.26 | 1.80 | 90°-Vertical |
| 30×10×4 | | 2.63 | 2.21 | 1.52 | 1.80 | 90°-Vertical |
| 30×10×6 | | 2.45 | 2.38 | 1.50 | 1.80 | 90°-Vertical |

Figure 7. Four different cylindrical grafts with a depth of 4 mm harvested from the symphysis and distribution of the maximum von Mises stress values (MPa)

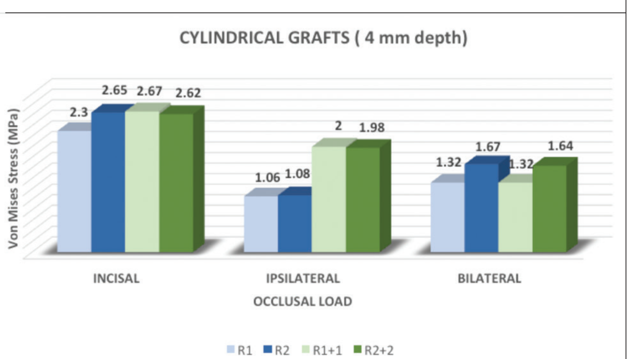
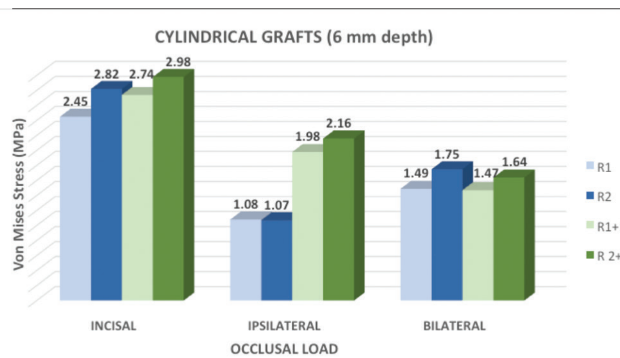



Figure 8. Four different cylindrical grafts with a depth of 6 mm harvested from the symphysis and the distribution of the maximum von Mises stress values (MPa)




Möhlhenrich et al. (8) investigated the stress distribution of bone grafts of various sizes harvested from the ascending ramus of a dentate mandible using FEA. The authors reported that the location of the force application significantly affected the resulting stress within the donor site and also noted that the lowest stress was detected under the incisal load, whereas the occlusal load in the molar region particularly increased the stress under the contralateral load (8). However, Möhlhenrich et al. (8) only analyzed the donor sites of the bone grafts harvested from the ascending ramus and did not evaluate the curved osteotomies or cylindrical grafts. In other study, Ertem et al. (13) investigated the stress distribution of two different osteotomies in the mandibles, which had a rectangular shape with angled borders and an elliptical shape with curved design osteotomies. The authors indicated that the curved osteotomy model had lower stress and a wider stress distribution than the angled model (13). In

Figure 9. Two harvested grafts of different dimensions with the depths of 4 mm and 6 mm in the midline of the symphysis and the distribution of the maximum von Mises stress values (MPa)

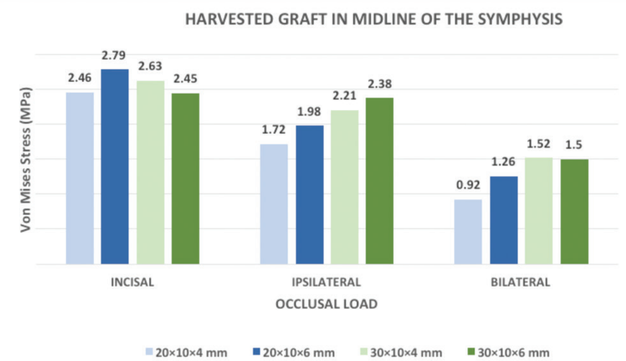



Figure 10. Stress distribution and maximum von Mises stress values when the unilateral block grafts were harvested (MPa)

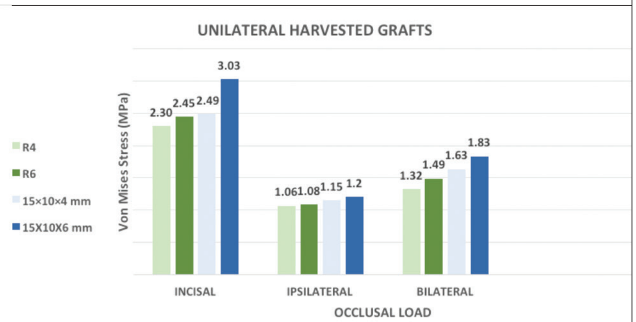
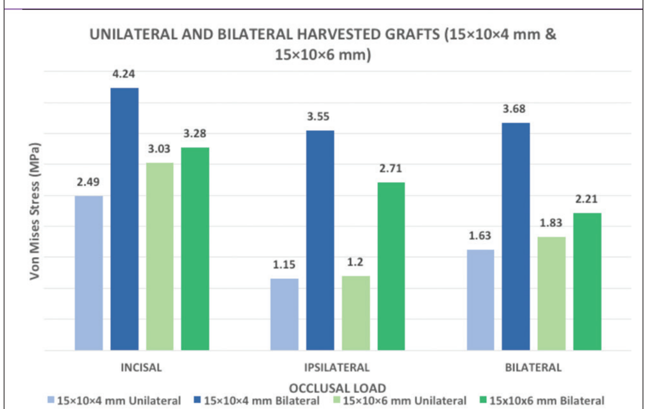



Figure 11. Comparison of the unilateral and bilateral harvested grafts with the depths of 4 and 6 mm




our study, the maximum von Mises stress values were higher under the incisal load than under the ipsilateral and bilateral loads, mainly because the incisal load was closer to the donor site. In block grafts that were harvested from the midline symphysis models, the maximum von Mises stress was 37% higher in the model measuring 20×10×6 mm than in the model measuring 20×10×4 mm under the bilateral load. The mandibular model harvested a graft measuring 20×10×4 mm from the midline symphysis, wherein the fracture risk increased under bilateral posterior loads with the increase in the depth of the harvested block graft (Figure 9). Cylindrical grafts had lower stress than the rectangular grafts with angled borders, and these findings were similar to the findings of Möhlhenrich et al. and Ertem et al. (13) (Figure 10). Furthermore, the location, dimension, and laterality (unilateral or bilateral) of the models affected the resultant stress in the grafts. Based on these findings, we consider that cylindrical grafts reduce the stress and if the rectangular grafts need to be harvested in the symphysis, then the localization of the grafts and the pattern of the occlusal load should be considered in terms of stress levels.

## CONCLUSION

The application of incisal load led to a higher stress than that of bilateral and ipsilateral loads. The stress distribution in the symphysis donor site varies according to the localization, shape, and dimensions of the harvested grafts. Cylindrical grafts lead to a lower stress than rectangular grafts.

**Ethics Committee Approval:** Ethics approval was not required for this in vitro study.

**Informed Consent:** Due to the study was experimental, informed consent was not taken.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept - M.Y.; Design - M.Y., E.A.; Supervision - M.Y., E.A; Materials - E.A.; Data Collection and/or Processing - E.A.; Analysis and/or Interpretation - E.A.; Literature Search - M.Y.; Writing Manuscript - M.Y.; Critical Review - M.Y., E.A.

**Conflict of Interest:** The authors have no conflicts of interest to declare.

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