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Evaluation of Stress Distribution in U-Shaped and V-Shaped Maxillary Edentulous Residual Alveolar Ridges by using Finite Element Analysis

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ABSTRACT

Background & Objectives: The rate and pattern of resorption of the alveolar process in edentulous patients are dependent on many factors like frequency, magnitude and direction of pressure on the edentulous ridges. So, this study is proposed to evaluate the stress distribution in U-shaped and V-shaped maxillary edentulous residual alveolar ridges.

Method: Finite element models of U-shaped and V-shaped were made using NISA software, Display 3, Version 16. A load of 40 N and 100 N was applied at an angulation of 60 degrees and 30 degrees in the incisor and premolar-molar region respectively.

Results: Stresses produced are maximum in second premolar and first molar region in both U-shaped and V-shaped residual alveolar ridges. Stresses on the palatal and buccal slopes are less in V-shaped residual alveolar ridges. Stresses exerted and linear displacement are minimal in the region of maxillary tuberosity area. Stresses are almost negligible in mid-palatal suture area. Linear displacement is more in anterior palatal region of V-shaped residual alveolar ridge.

Interpretation and Conclusion: There is the considerable difference between the stress distribution and linear displacement of V-shaped and U-shaped residual alveolar ridges. As denture stability, retention and support are interrelated to each other. Any of these deviating more towards abnormality may results in deleterious effect on residual ridges. So, all the principles and objectives of impression making should be kept in mind to prevent the resorption of the residual ridges.

Keywords: Finite element analysis, U-shaped maxillary edentulous ridge, V-shaped maxillary edentulous ridge.

INTRODUCTION

Various type of forces are exerted on the edentulous ridges during the functional and para-functional movements which are one of the etiological factor for bone resorption. Bone resorption is not symmetrical in all the area of edentulous ridges. The rate and pattern of resorption of the alveolar process in edentulous patients are dependent on many factors like frequency, magnitude and direction of pressure on the edentulous ridges. Fracture of dentures continues to be a challenge to the clinician and inconvenience to the patient and is reflected in the rising costs incurred annually in the repair of these appliances. In order to improve the resistance to fracture, it is important to have a knowledge of stress distribution and magnitude so that area of high stress concentration can be identified and steps can be taken to minimize these.

The ridge form definitely affects retention and stability. The most favorable form is U-shaped. Its height resists lateral displacement and the parallelism of its sides maintains the seal for a considerable distance to resist vertical displacement. V-shaped ridges provide little resistance to vertical displacement, as the seal may be broken in all area simultaneously. So, this study is proposed to evaluate the stress distribution in U-shaped and V-shaped maxillary edentulous residual alveolar ridges.

MATERIALS AND METHODS

Two ideal edentulous stone models, U-shaped and V-shaped were selected for the study. The models were duplicated in the agar hydrocolloid (Castogel, Bego, Germany) which was used as a duplicating material. After duplicating the models we got the duplicated mould of the edentulous models. Then Soft putty Polyvinylsiloxane elastomeric material (Aquasil, Dentsply, Germany) was taken and adapted in the duplicated mould. After the material was set, we retrieved it from the mould and we got the positive replica of the edentulous models in the Soft putty Polyvinylsiloxane elastomeric material (Aquasil, Dentsply, Germany). Duplicate models were sectioned transversely at the level of 3 mm in to 3 sections.

After sectioning, radial lines were drawn on the model. Then the physical model was discritized using extracting coordinates. Mechanical properties of the mucosa, cortical bone, cancellous bone and denture base used are mentioned as below:

	Young's modulus	**Poisson's ratio**
Mucosa	10Mpa	0.4
Cortical bone	10,000Mpa	0.3
Cancellous bone	1500Mpa	0.3
Denture Base	2000MPa	0.3

The CAD model obtained was misched using "Automated finite element generation" available in NISA package.

Model was represented by number of nodes and number of elements. Elements chosen was 3-D wedged type, 6 node element with 6 degrees of freedom at each node. After that, appropriate boundary conditions were applied. Then load was applied at the anterior (incisor) and the posterior(premolar-molar) region at an angulation of 60 and 30 degrees on both U-shaped and V-shaped finite element model.

Results obtained were viewed in Display 3 to visualize the stresses and linear displacement.

RESULTS

From the present study it was found that there is the considerable difference between the stress distribution and linear displacement of V-shaped and U-shaped edentulous ridges. When forces were exerted at an angulation of 60 degrees and 30 degrees, stresses produced are more in case of U-shaped ridge as compared to V-shaped ridge except on crest of the canine. In both U-shaped and V-shaped edentulous ridges, stresses are concentrated in second premolar and first molar region. Stresses in the maxillary tuberosity area are minimal in both U-shaped and V- shaped ridges. Stresses on the buccal and palatal slopes are less in V-shaped ridge as compared to U-shaped ridge, this is because of increase surface area provided by these inclines. Stresses exerted are almost negligible in the mid-palatal suture area.

Magnitude of displacement is more in anterior palatal region (from incisor-first premolar) in V-shaped ridges, because of steep palatal curvature in V-shaped ridges. Magnitude of displacement is more in posterior palatal region (from second premolar-second molar) in U-shaped ridges. Magnitude of linear displacement in crestal region is more in U-shaped ridges as compared to V-shaped ridges. Magnitude of displacement is least in the maxillary tuberosity area. Linear displacement on the buccal and palatal slopes are less in V-shaped ridge as compared to U-shaped ridge which provide resistance against horizontal forces. From the results of the present study it can be correlated that crest of ridge in relation to second premolar-first molar area and hard palate area can be taken as supporting structures. Maxillary tuberosity act as the stabilizing area. Mid-palatal suture and incisive papilla area should be considered as relief areas.

DISCUSSION

Bone resorption and apposition has a vital role in the growth and maintenance of the skeletal system. Residual alveolar ridge resorption is a chronic, progressive, irreversible, and disabling condition of multifactorial origin. Much is known about its pathology and pathophysiology, but a lot remains to know about its pathogenesis, epidemiology and etiology.

Due to the forces generated by complete dentures causes stresses in the supporting tissues, which by some unknown mechanism, initiate an irreversible loss of alveolar bone. Necessary steps can be undertaken to reduce its incidence, thereby preventing damage to the underlying tissues. Identification and knowledge about the magnitude, direction and distribution of the forces in different sizes and shapes of the residual alveolar ridges will be helpful to minimize the problems associated with the treatment of edentulous patients. Dentists can only apply the results of clinical findings to their treatment of edentulous patients in attempting to prevent the loss of the residual alveolar ridges.

In our study, two models of U-shaped and V-shaped edentulous ridges were taken and by discritizing the coordinates, finite element model were simulated for both type of ridges. The system is meshed into lots of points which have relationships to each other. Model was represented by number of nodes and number of elements. Then load was applied at the anterior (incisor) and the posterior (premolar-molar) region at an angulation of 60 and 30 degrees on both U-shaped and V-shaped finite element models.

More stresses are seen on the palatal region of U-shaped ridges, when forces are directed at an angulation of 60 degrees shaped and V-shaped ridges, This is because of less depth of palate, the stresses are acting directly on the U-shaped ridges. In case of V-shaped ridges, when forces are directed the stresses will distribute in to horizontal and vertical components due to increase in depth of anterior palatal region. So stresses are less in palatal region of V-shaped alveolar ridges.

Results showed that stresses are concentrated in second premolar and first molar region when forces are exerted on U-shaped and V-shaped residual alveolar ridges at an angulation of 60 degrees. As studies showed the second bicuspid to carry the heaviest load followed by the first molar and first bicuspid. As the stresses exerted are more in this area, it can be used as the stress bearing area or supporting area. For achieving proper support adequate bone thickness should be present in this region.

At 60 degrees angulation, stresses produced in the crestal region are more in U-shaped ridges when compared to V-shaped ridges except in the area of crest of canine. Because in case of V-shaped ridges the canine area is very much pronounced and there is an abrupt curvature in that region. When forces are applied at 60 degrees angulation on both U-shaped and V-shaped ridges, stresses produced are minimal on the maxillary tuberosity as compared to the other regions. This is because stress distribution depends on the (a).the force-surface area ratio (b).distance between the point of action of force and surface (c) elastic property of the underlying hard tissues. As in the tuberosity area, bone is of trabecular quality and having less modulus of elasticity. So it has got the ability to absorb the stresses. So stresses developed in the region of maxillary tuberosity are less as compared to other regions.

Stresses on the hard palate area are more in U-shaped ridges when compared to V-shaped ridges when forces are applied at an angulation of 60 degrees. This might be because of flat configuration in U-shaped ridges. On the other aspect, in V-shaped ridges the increase in the depth of palatal inclines will provide more surface area which reduces the amount of stress. Results of the study showed that the stresses are almost negligible in the mid-palatal suture and structures present in the midline of the palatal region when the forces are applied at an angulation of 60 degrees. So results are justifying the selective impression technique of impression making. As the nasopalatine nerves and vessels passes through the incisive foramen which is present slightly posterior to anterior alveolar ridge near the midline, so pressure should be avoided and relief should be given in incisive papilla in complete denture to prevent damage to these crucial structures.

In the mid-palatal suture, the submucosa is extremely thin and the mucosal layer is almost in contact with the bone and because of that soft tissue covering in this area is non resilient and should be relieved to avoid trauma from the denture base. When force is applied at an angulation of 60 degrees on both the U-shaped and V-shaped residual alveolar ridges, it was found that linear displacement is more in anterior palatal region of V-shaped ridges. This is because the inner plate in the anterior region is steep and there is a sharp angle between the alveolar process and roof of mouth, due to this configuration horizontal component of forces tends to displace the denture which decreases the stability. When forces are applied at an angulation of 60 degrees and 30 degrees, magnitude of displacement decreases from anterior palatal region to posterior palatal region in V-shaped edentulous ridges. This is because of the horizontal or lateral component of force which is responsible for destabilization going to be reduced when we observe stress distribution from anterior palatal region to posterior palatal region. When forces are applied at an angulation of 60 degrees and 30 degrees, magnitude of displacement increases from anterior palatal region to posterior palatal region in U-shaped edentulous ridges which is directly dependent on amount of stress produced in that region. More the amount of stresses, more will be the displacement.

Magnitude of linear displacement is also less in the tuberosity area when forces are applied at an angulation of 60 degrees and 30 degrees. As the stresses distributed in tuberosity area are less, displacement also is going be less. It means maxillary tuberosity provides stability to the denture against the horizontal and torquing forces. So it acts as the denture stabilizing area.

Stresses and linear displacement on the facial and palatal slopes of V- shaped ridges are less as compared to U-shaped ridges when forces are applied at an angulation of 60 degrees and 30 degrees. This is because of long inclines of V-shaped ridges which will prevent the lateral or horizontal displacement of the denture and enhances the stability of complete denture.

Although the stresses produced by contacting of artificial teeth in complete denture is directed to the crest of residual alveolar ridge, but other areas can be used to help minimize the stresses. Therefore hard palate and maxillary tuberosity should be covered to minimize the stresses and provide adequate support.

So while fabricating the denture all the concepts should be kept in mind to achieve the objectives of impression making. For that dentures should take support from stress bearing areas or supporting areas. Adequate relief should be provided in the relief areas such as incisive papilla and the midpalatine raphe areas. Denture extension should be restricted up to the limiting or the peripheral structures to attain the proper border seal. The lack of stability in denture will lead to loss of retention and support. A denture that shifts easily in response to laterally applied forces can cause disruption in the border seal or prevent the denture base from correctly relating to supporting tissues.

The basic snow-shoe principle of maximum denture base extension should be followed to distribute the stresses more evenly and on a broad surface area that distributes occlusal forces. Broad denture bearing area reduces stress per unit area under denture base, also reduces tissue displacement and denture base movement. By following the principle of selective impression technique, the foremost objective of preservation of underlying tissues can be achieved and the oral as well as physical health of the complete denture patient can be maintained better.

CONCLUSION

Within the limitations of this in-vitro study and from the results obtained the following conclusions can be drawn:

1. Stress distribution is more at the crestal region in U-shaped residual alveolar ridge when compared to V-shaped residual alveolar ridge except on the crest of canine.
2. Magnitude of stresses are maximum in second premolar and first molar region in both U-shaped and V-shaped residual alveolar ridges.
3. Stresses on the palatal and buccal slopes are less in V-shaped residual alveolar ridges when it compared to U-shaped residual alveolar ridges.
4. Stresses exerted and linear displacement are minimal in the region of maxillary tuberosity area.
5. Stresses are almost negligible in mid-palatal suture area.
6. Linear displacement is more in anterior palatal region of V-shaped residual alveolar ridge when compared to U-shaped residual alveolar ridge..
7. Linear displacement is more in posterior palatal region of U-shaped residual alveolar ridge when compared to V-shaped residual alveolar ridge.
8. Linear displacement on buccal and palatal slopes are less in V-shaped residual alveolar ridges when compared to U-shaped residual alveolar ridges.

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TABLE 1: showing stress distribution (MPa) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on U-shaped edentulous ridge finite element model at an angulation of 60 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	2.516-2.013	2.013	2.516-7.044	7.044	5.535	1.007	0.5040
Buccal slopes	0.5040	0.5040	0.5040	1.007-0.5040	1.007-0.5040	0.5040	0.5040
Palatal slopes	1.510-2.013	2.516-2.013	2.516	2.516-2.013	2.013-1.007	1.007	0.5040
Palate	1.007-0.5040	1.007-0.5040	1.510-0.5040	2.013-0.5040	1.510-0.5040	1.007-0.5040	0.5040

Unit of stress- MegaPascal(MPa)

Table 2: showing stress distribution (MPa) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on V-shaped edentulous ridge finite element model at an angulation of 60 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	2.162-1.730	2.62-1.730	1.297-6.053	6.053	3.459-3.027	1.730-0.8649	0.4325
Buccal slopes	0.4325	0.8649-0.4325	0.8649-0.4325	0.8649-0.4325	0.8649-0.4325	0.4325	0.4325
Palatal slopes	1.297	1.730	1.297-0.8649	2.162-1.730	1.730	1.297-0.8649	0.4325
Palate	0.8649-0.4325	0.8649-0.4325	0.8649-0.4325	0.8649-0.4325	0.8649-0.4325	0.8649-0-4325	0.4325

Unit of stress- MegaPascal(MPa)

Table 3: showing linear displacement (10^{-3} m/second) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on U-shaped edentulous ridge finite element model at an angulation of 60 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	23.47	20.12	23.47-26.82	46.94	46.94	36.88-26.82	23.47
Buccal slopes	13.41	13.41	13.41-16.76	20.12	20.12	20.12	10.06
Palatal slopes	20.12	20.12	23.47	26.82-33.53	33.53	26.82	23.47
Palate	13.12-6.706	13.12-6.706	13.41-6.706	16.76-10.06	16.76-6.706	16.76-10.06	13.41-10.06

Unit of linear displacement- Meter per second(m/sec)

Table 4: showing linear displacement (10^{-3} m/second) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on V-shaped edentulous ridge finite element model at an angulation of 60 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	28.96	26.33-23.70	26.33-31.59	36.86	34.23-31.59	15.80-13.16	13.16
Buccal slopes	15.80-10.53	10.53-7.898	7.898	7.898	5.266-2.633	2.633	2.633
Palatal slopes	21.06	21.06	21.66	26.33	21.06	13.16	13.16
Palate	15.80-5.266	15.80-5.266	15.80-7.898	15.80-5.266	15.80-5.266	13.16-5.266	13.16-5.266

Unit of linear displacement- Meter per second(m/sec)

Table 5: showing stress distribution (MPa) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on U-shaped edentulous ridge finite element model at an angulation of 30 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	2.868-2.049	1.639	2-868-5-736	5.736-4.096	3.688-2.049	0.8198	0.4101
Buccal slopes	0.4101	0.4101	0.4101	0.8198-0.4101	0.4101	0.4101	0.4101
Palatal slopes	1.230-0.8198	1.639	2.459	2.049-1.230	1.230-0.8198	0.8198	0.4101
Palate	0.8198-0.4101	0.8198-0.4101	0.8198-0.4101	0.8198-0.4101	0.8198-0.4101	0.8198-0.4101	0.4101

Unit of stress- MegaPascal(MPa)

Table 6: showing stress distribution (MPa) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on V-shaped edentulous ridge finite element model at an angulation of 30 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	1.260-1.889	1.889	2.519- 4.093	3.778-4.408	3.778-2.519	0.6300	0.3152
Buccal slopes	0.6300	0.6300	1.260	1.260	1.260	0.6300	0.3152
Palatal slopes	1.260	1.889	1.889	1.889	1.889	0.6300	0.6300
Palate	0.6300-0.3152	0.6300-0.3152	0.6300-0.3152	0.6300-0.3152	0.6300-0.3152	0.6300-0.3152	0.6300-0.3152

Unit of stress- MegaPascal(MPa)

Table 7: showing linear displacement (10^{-3} m/second) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on U-shaped edentulous ridge finite element model at an angulation of 30 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	25.36	18.45	18.45	32.28	32.28	23.06	13.83
Buccal slopes	16.14	11.53	11.53	18.45-11.53	18.45-11.53	11.53	6.917-4.612
Palatal slopes	18.45	18.45	16.14	23.06	23.06-18.45	18.45	13.83
Palate	16.14-4.612	11.53-4.612	6.917	11.53-6.97	11.53-6.917	11.53-6.917	11.53-9.223

Unit of linear displacement- Meter per second(m/sec)

Table 8: showing linear displacement (10^{-3} m/second) when 40 N of force was applied in the incisor area and 100N of force was applied in the premolar-molar area on V-shaped edentulous ridge finite element model at an angulation of 30 degrees.

	Incisors	Canine	First premolar	Second premolar	First molar	Second molar	Maxillary tuberosity
Crest	12.09	9.673	16.93- 24.18	33.86	33.86	21.76-16.93	14.51-12.09
Buccal slopes	7.255-4.837	4.837	7.255	14.51-9.673	7.255	4.837	2.418
Palatal slopes	9.673-7.255	9.673-7.255	4.837-7.255	24.18	21.76-19.35	16.93	12.09
Palate	4.837	4.837	4.837	9.673-7.255	9.673-4.837	7.255-4.837	7.255-4.837

Unit of linear displacement- Meter per second(m/sec)