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RESEARCH ARTICLE

3D finite element analysis of the influence of different soft lining materials with variable thicknesses on stress transmitted to underlying mucosa

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Abstract

The objective of the present study was to investigate the effect of thickness of different soft denture liner materials on load transmission to the underlining supporting structures by finite element analysis. 3D finite element models were developed from CT of the patient maxillary supporting structures and optically scanned maxillary denture. Denture lining material was created by a subtraction from denture fitting surface, with two customized thicknesses according to the different studied groups. Three dimensional finite elements analysis were used to calculate the stress distribution in the denture bearing mucosa beneath the soft denture liner. Two different soft lining materials were used, a silicone reliner and an acrylic reliner. Models were categorized into five, a control group, and four groups according to soft lining material and thickness. All the contacts between the structures were considered bonded. A load in the occlusal region of posterior teeth with an intensity of 60 N perpendicular to the alveolar ridge in the frontal plane was applied. The maximum principal (σmax) (tensile) and minimum principle (σmin) (compression) stresses were calculated for mucosa and supporting bones. Finally, all models were evaluated both quantitatively and qualitatively, and then the numerical and graphical data were recorded, evaluated and interpreted. The results showed that 2mm thickness of the silicone soft liner materials had the least amount of stress generated while the acrylic based liner with 1 mm thickness was the highest value. It was concluded that the use of silicone soft liner materials with a 2 mm thickness promoted the tendency to decrease the maximum and minimum principal stress in the mucosa and in the underlying bone than other studied groups.

Introduction

Many edentulous individuals have resorbed residual ridges with thin and non-resilient lining mucosa. So that, they are unable to tolerate occlusal forces and resulting in pain during mastication (Darbar et al. 1994). In order to resolve this condition, a permanent soft liner under hard acrylic denture bases was used. Because of the capability of soft liners to distribute and absorb loads, they act a role of cushion for insulted mucosa. They can decrease the amount of forces loaded on denture supporting structures, decrease pain during mastication, and enable the successful use of prosthesis.(Zarb et al 2003), (Chenga et al 2006) and (Kimoto et al 2010) No selective criteria for soft denture liner for individual patient have developed. Thus, (Hayakawa et al 2000) hypothesized that the properties of soft denture liner should be the same as that of mucosa.

Consequently, the modulus of elasticity must match that of mucosa to obtain the optimum conditioning effect of soft denture liner (Murata et al.2002). However, soft liner materials may change the magnitude and distribution of stress within the prostheses by their viscoelastic behavior. Dentures are subjected to functional loads and flexural fatigue, which may lead to fracture. Soft-lined complete dentures are more liable to fracture because of the reduced thickness of acrylic denture base to accommodate the soft liner (Murata et al 2008). Although, relining is the procedure used to re-surface the tissue side of the denture by a new base material, producing an accurate adaptation to the denture foundation area (Chenga et al 2006). Denture liners are classified as hard or soft, resin-based or silicone-based, and chemically or thermally polymerized and are indicated for temporary and permanent use (McCabe 1998), (Van Noort 1994), (Annusavice 1996) and (Craig and Powers 2002).

Clinical efficacy of soft liners has been reported in numerous studies. Controlled randomized clinical trials indicated that the use of silicone soft liners in dentures improves the masticatory efficacy of patients (Chenga et al 2006), (Kimoto et al 2010) and (Hayakawa et al 2000). Furthermore, utilization of acrylic soft liners under denture bases decreases complications during the first patient visit after delivery session and the patients' satisfaction is significantly higher in dentures with soft liners compared to hard acrylic bases (Kimoto et al 2007).

Despite the clinical efficacy of soft liners, there is insufficient information on soft liners' role in load distribution and absorption in denture supporting tissues because of limitations in study methods (McCabe 1998). Therefore, finite element analysis can be used to evaluate the destination of loads in underlying mucosa and bone.

In all the assessments with this method, elastic properties of soft liners under rapid mastication forces have been evaluated. On the other hand some finite element analysis findings have revealed that stress increased in bone following soft liner use (Murata et al 2002) and (Kasperski et al 2010). Therefore, the use of soft liners in patients suffering from bruxism and clenching could not be questionable.

(Shim& Watts 2000) conducted a Finite element analysis study to examine the stress distribution in a soft-lined acrylic resin mandibular complete denture. Their study showed that modulus of elasticity of soft liner should not be lower than that of the lining mucosa. In other words, for maximum cushioning effect, the modulus of elasticity of soft liner should be the same as that of mucosa, which seems logical because the soft liner compensates the lost thickness of lining mucosa. The findings also indicate that the thickness of soft tissue does not affect stress ratio. As a result, excessive thickness of soft liner is unnecessary and just weakens denture base. It seems that the above findings are contrary to positive clinical effects of soft liners.

In order to minimize and prevent prostheses fracture the understanding of stress distribution within the prostheses is important (Kawano et al 1993). Several studies were conducted to examine the effect of a soft denture liner on the distribution of stresses beneath the denture supporting structures (Darbaret al 1994), (Katayoun et al 2012) and (Braden et al 1995).

The aim of this study was to determine the optimal thickness and type of soft liner material that provides the least amount of stress on mucosa and supporting bone in patients with complete removable dentures using a CT-based three-dimensional finite element analysis.

Materials & methods

A CT-based 3D finite element model of the maxillary arch of an edentulous patient was created. In addition, a complete replica of the prosthesis was produced with three-dimensional digitizer.

A 60-year old male patient with well-formed residual ridge was CT-scanned using standardized CT scanning procedures (Somatom Definition Flash, Siemens Ag, Germany). Dicom images were generated using the machine with resolution 500 x 500 pixel and high contrast for bone algorithm. Dicom images were stored then imported to Mimics v10.01 software (Materialise Software, Belgium) where images were masked and 3d model of the edentulous maxilla was created, the 3D model of the maxilla was exported as STL file., (fig. l).

The patient's maxillary denture was 3D scanned by 3D optical scanner (Kavo scanner pro, Kavo Dental, Germany) then registered to the bone model using 3-matic software v6; (Materialize Software, Belgium); keeping space for supporting mucosa. All STL files were refined and prepared for patching to be converted it to solid cad files. After virtual reconstruction, the 3D models were exported to CAD designing software (SolidWorks Corporation, Concord, MA, USA) to edit the denture model and creating soft liner layer. The soft liner model was designed to cover all fitting surface except that of primary stress bearing areas (horizontal part of the palate and crestal residual ridge. This layer created as a subtraction from denture fitting surface, with two customized thicknesses according to the different study groups, figure (2, E). The cad files then exported as IGS file format from the CAD software to the design modeler module of ANSYS v 14 finite element software (ANSYS Inc., Houston, PA, USA), (fig. 2).

Using the predefined material library, material properties were assigned to each solid component of the assembly according to Table 1. All material properties were assumed linear, homogenous, and isotropic to facilitate calculation process and reduce solving time. Accordingly, two values (Young's modulus and Poisson's ratio) were assigned for each part, Table 1.

Table 1: Material properties of different components used in the study (*including Young's Modulus and Poison's ratio*)

Material	Young's Modulus	Poisson's ratio	References
Compact bone	20 GPa	0.3	Lima et al 2013
Cancellous bone	2 GPa	0.4	Lima et al 2013
Prosthesis	2 GPa	0.3	Lima et al 2013
Mucosa	5 MPa	0.45	Lima et al 2013
Silicone reline material	5 MPa	0.45	Kasperski et al 2010
Acrylic reline material	1.5 MPa	0.35	Ikeda et al 2006

To analyze the behavior of soft liner materials with different thicknesses on the absorption of mastication forces from a complete removable denture within the mucosa, the models were categorized into the following five models:

- Model 1: (control) without soft liner material.
- Model 2: with a 1 mm thick silicone soft liner material.
- Model 3: with a 1 mm thick acrylic soft liner material.
- Model 4: with a 2 mm thick silicone soft liner material.
- Model 5: with a 2 mm thick acrylic soft liner material.

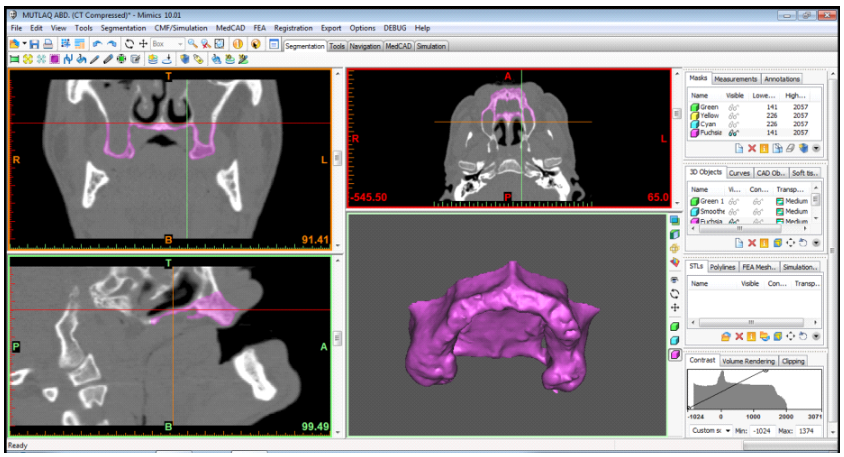

Fig. 1: Dicom images processed in Mimics software and converted both bone types to 3D STL file.

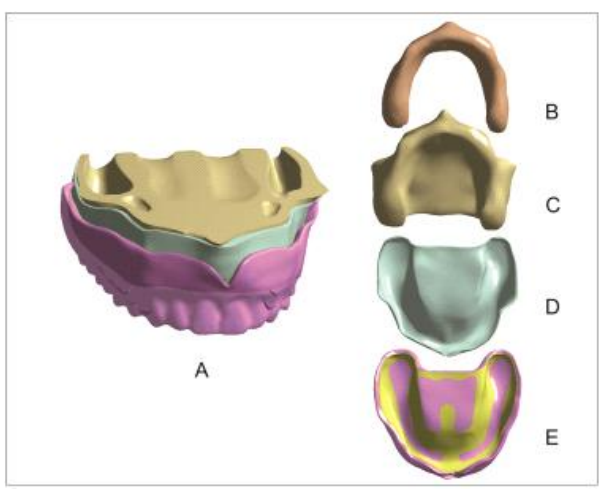

Fig. 2: The full design assembly imported to design modeler module of the finite element software, A. cancellous bone,B, compact bone,C, mucosa, D, and denture with liner (yellow color), E, respectively.

After material data assignment, the model was meshed using tetrahedron (four-sided) elements. Mesh refinement were applied at the areas of contacts and fine model details, (fig. 3). All the contacts between the structures were considered bonded. A load in the occlusal region of all artificial teeth with an intensity of 60 N, perpendicular to the alveolar ridge in the transversal plane, was applied. The load was localized on all posterior teeth.

The principal maximum (σmax) (tensile) and minimum (σmin) (compression) stresses were calculated for mucosa and supporting bones (Lima et al 2012). Finally, all models were evaluated both quantitatively and qualitatively, and then the numerical and graphical plotted data were recorded, evaluated and interpreted.

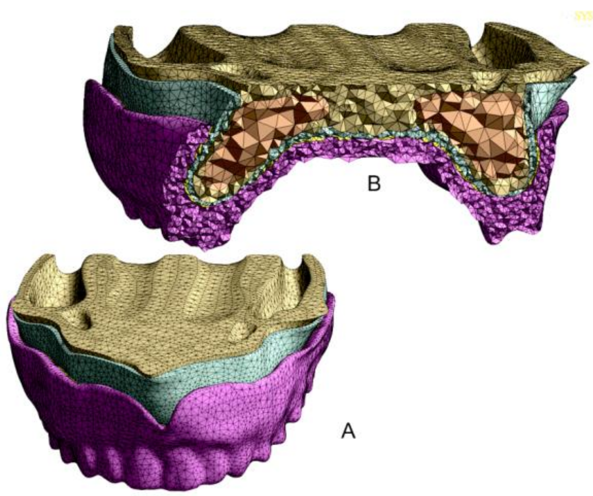

Fig. 3: Meshing of the model assembly using tetrahedron element type, A. A representative of cross-section at molar areas showing elements in 3D, seen in B.

Results

• Maximum principal stress

Superficial mucosa

The values of the maximum principal stress were tabulated in (Table 2) and shown in Fig. 4 and 5.

Model 1 (control) had the highest values. The lowest values were observed in model 4 that had 2mm thick silicone reline material. Table 2 indicated the tendency to decrease the maximum principal stresses when the thickness of the resilient material was increased. It was also shown that using silicone reline material decreased the maximal principal stress on the mucosa more than acrylic resin reline material did.

Underlying bone

Model 1 (control) had the highest values. In case of cancellous bone, the lowest values were observed in model 5 that had 2mm thick acrylic resin reline material. Table 2 indicated the tendency to decrease the maximum principal stresses when the thickness of the resin resilient material was increased. That was the opposite for silicone reline material.

In case of compact bone, the lowest values were shown in model 4. (Table 2) indicated the tendency to decrease the maximum principal stresses when the thickness of the resilient material was increased. It was also shown that using silicone reline material decreased the maximal principal stress on the mucosa more than acrylic reline material did.

Stress concentrated on the alveolar ridges, anteriorly at the incisive canal area.

Table 2: Values of maximum principal stress (MPS) in the superficial mucosa, compact and cancellous bones, and percentages in relation to the control group for both reline materials.

MAXIMUM PRINCIPLE STRESS IN MPa						
	Compact	**Cancellous**	**Mucosa**	**Percentage**		
Control	1.7064	0.1379	0.1756	100%	100%	100%
1mm Silicone	1.6697	0.1186	0.1675	98%	86%	95%
1mm Resin	1.6745	0.1293	0.1728	98%	94%	98%
2mm Silicone	0.6587	0.1257	0.1237	39%	91%	70%
2mm Resin	0.7662	0.1159	0.1535	45%	84%	87%

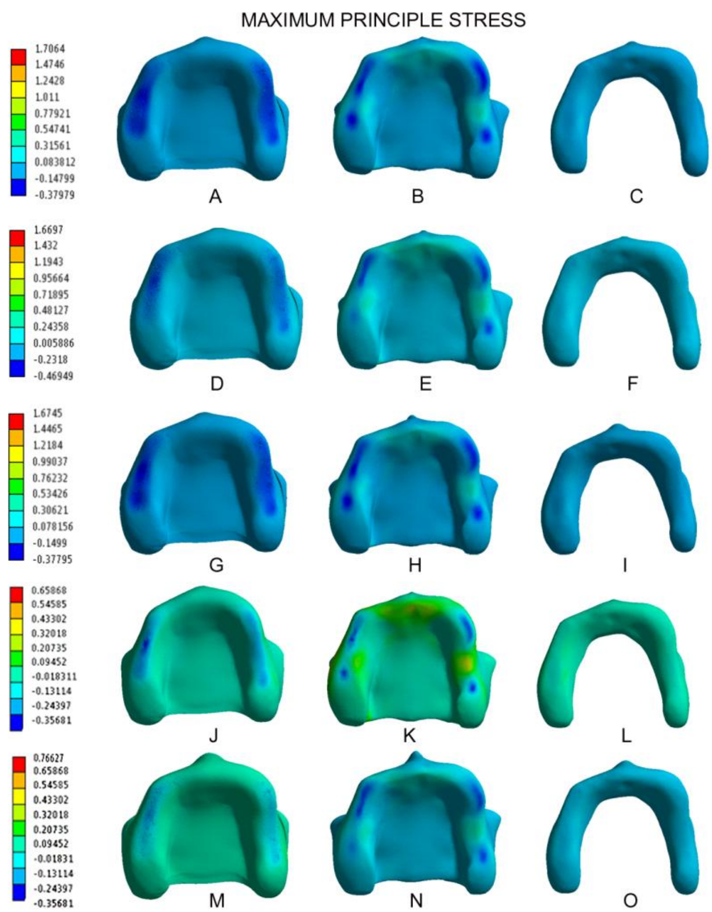

Fig. 4: values of maximum principal stresses of the superficial mucosa and underlying bone (MPa) (A,B and C. control, D,E and F. 1-mm-thick silicone soft liner material, G,H and I 1-mm-thick acrylic resin soft liner material, J,K and L. 2-mm-thick silicone soft liner material and M, N and O. 2-mm-thick acrylic resin soft liner material).

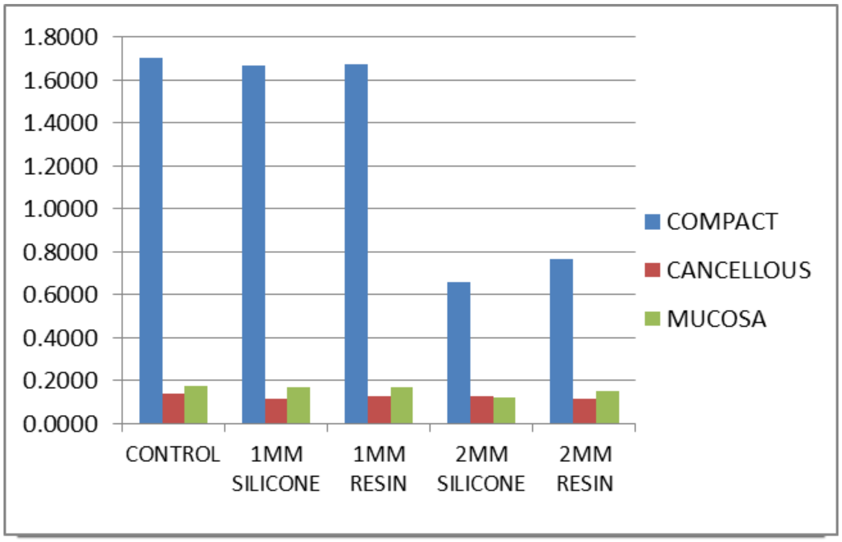

Fig. 5: values of maximum principal stresses of the superficial mucosa and underlying bone (MPa)

• Minimum principal stress

Superficial mucosa

The values of the minimum principal stress were tabulated in (Table 3) and shown in Fig. 6 and 7.

Model 1 (control) had the highest values. The lowest values were observed in model 4 that had 2mm thick silicone reline material. Table 2 indicated the tendency to decrease the minimum principal stresses when the thickness of the resilient material was increased. It was also shown that using 2mm silicone reline material decreased the minimal principal stress on the mucosa more than acrylic resin reline material did. Moreover, model 3 presented lesser minimal principal stresses than did model 2.

Underlying bone

The values of the minimum principal stress were tabulated in (Table 3) and shown in Fig. 6 and 7.

Model 1 (control) had the highest values. In case of cancellous bone, the lowest values were observed in model 4 that had 2mm thick silicone reline material. Table 3 indicated the tendency to decrease the minimum principal stresses when the thickness of the resilient material was increased.

In case of compact bone, the results indicated The increase in the thickness in reline material promoted a decrease in minimum principal stress (Fig. 6 and 7), with model 1 resulting in the highest compression stress and model 4 is the lowest (Table 3). It was also shown that using silicone reline material decreased the minimal principal stress on the bone more than acrylic resin reline material did. The zones that concentrated the highest compression stress values without the soft liner material were the midline area, the alveolar crest, and the occlusal gingival region.

Table 3: Minimum principal stress values in in the superficial mucosa, compact and cancellous bones, and percentages in relation to the control group for both reline materials.

MINIMUM PRINCIPLE STRESS IN MPa						
	Compact	**Cancellous**	**Mucosa**	**Percentage**		
Control	0.3609	0.0047	0.0143	100%	100%	100%
1mm Silicone	0.3542	0.0039	0.0140	98%	83%	98%
1mm Resin	0.3537	0.0037	0.0135	98%	79%	94%
2mm Silicone	0.0881	0.0034	0.0110	24%	72%	77%
2mm Resin	0.1522	0.0036	0.0119	42%	77%	83%

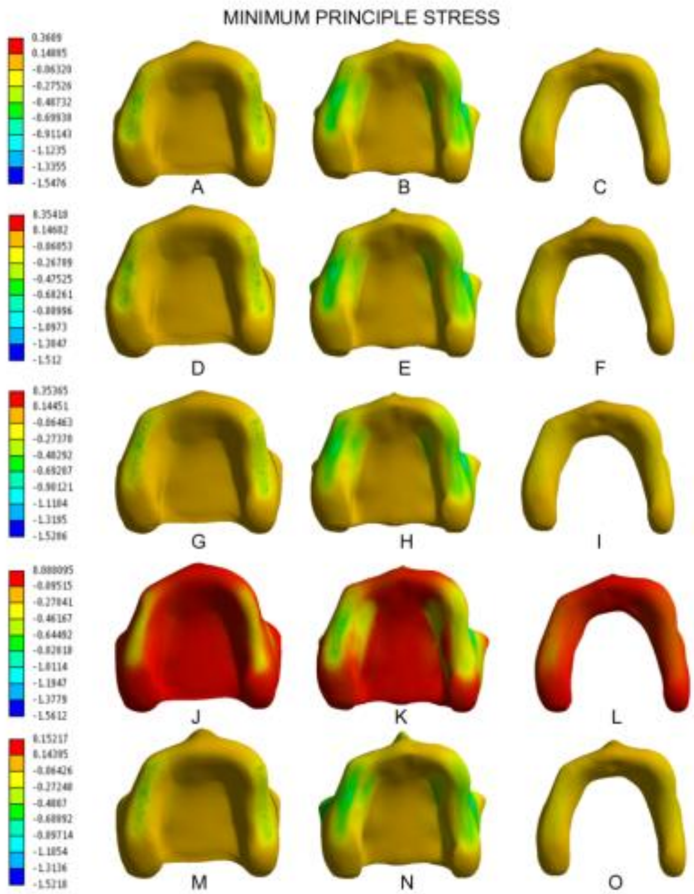

Fig. 6: Compression stress areas (MPa) in the superficial mucosa and underlying bone (A,B and C. control, D,E and F. 1-mm-thick silicone soft liner material, G,H and I 1-mm-thick acrylic soft liner material, J,K and L. 2-mm-thick silicone soft liner material and M, N and O. 2-mm-thick acrylic soft liner material).

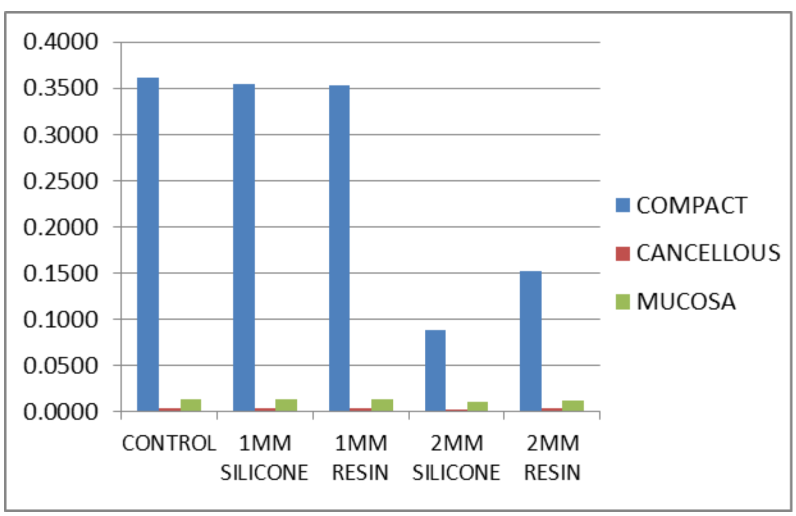

Fig. 7: values of minimum principal stresses of the superficial mucosa and underlying bone (MPa)

Discussion

Bone requires stresses within a physiological range to maintain the bone level. In contrast, excessive stresses above the physiologic limit accelerate bone resorption (Lima et al 2012). An excessive increase in stress may create an imbalance, favoring osteoclast activity resulting in significant bone loss (Lima et al 2012).

The results of the present study revealed that stress was concentrated mostly on the mucosa and on the alveolar ridges beneath areas of load application. Stress was also concentrated on the anterior portion at the incisive canal area of bone and its covering mucosa. The use of the soft liner material considerably minimized the stress in the alveolar bone and mucosa, compared to the non-relined control group. The maximum and minimum principal stress of both the mucosa and bone decreased, whereas the thickness of the soft liner material increased (2 mm).

Soft liner material plays an important role in absorption and uniform distribution of the functional load applied to the supporting structures, thereby reducing the influence of these forces. As this material may affect the perception and force distribution during chewing, it is important to determine an appropriate thickness for better clinical performance.

These findings were in agreement with (Lima et al 2012). They used a three-dimensional finite element analysis to determine the optimal thickness of soft liner material that provides the least amount of stress on thin mucosa and supporting bone in patients with complete removable dentures. The model was obtained from two CT scans of edentulous mandibles and overlying dentures. They observed that the maximum and minimum principal stress in mucosa and bone decreased when the thickness of the soft liner material increased up till 2 mm liner thickness. Soft liner materials with a thickness of 2.5 mm showed higher stress values than those with a thickness of 2 mm. They concluded that soft liner material with a thickness of 2 mm transmitted the lowest amount of stress to the mucosa and bone overlying 1 mm of mucosal thickness.

This coincides with (El-Anwar et al 2014). They evaluated the influence of different gingival thickness on stress to implant-supported overdenture and bone. They concluded that 2mm gingival thickness might enable the longer overdenture lifetime.

In addition, a study done by (Bacchi et al 2012) confirmed the use of 2mm soft liner thickness. They conducted a three-dimensional finite element analysis to evaluate the influence of different mucosal resiliency and denture reline on stress distribution in peri-implant bone tissue during osseointegration. The results showed inconsistent stress distribution in bone rather than in the mucosa. Moreover, they suggested the use of 2mm thickness liner to reduce stress of mucosa and underlying supporting bones.

The results of the current study were in harmony with (Kawano et al 1999). They conducted a study to compare the influence of lining design of three processed soft denture liners on their damping effect. They concluded that soft liner material thicker or thinner than 2 mm resulting in an increase in the maximum stress values, considering the elasticity of the soft liner material is similar to mucosa.

Moreover, (Parr and Rueggeberg 2002) conducted an in vitro study to compare between the thermally polymerized and chemically polymerized long-term resilient denture liners over one year of water storage. They concluded that the soft liner material should have a minimum thickness of 2mm; however, a thickness of more than 2mm resulted in slightly higher level of stress. They referred that to the instability of the prosthesis that could be created over the thick soft liner material.

On the other hand, contradicting results reported by (Dos Santos et al 2011). They analyzed the stress distribution in peri-implant bone with relined dentures and different heights of healing caps using three-dimensional finite element method. They stated that 3 mm was the minimum thickness for satisfactory results. (Barao et al 2008) compared the mucosal thickness and the maximum stress distribution, a mucosal thickness of 3 mm resulted in the least amount of stress, while thinner (1 mm) or thicker (5 mm) mucosa increased the stress.

It was clearly shown in the results of the current study that using silicone soft liner material was better than using acrylic resin soft liner material under the maxillary complete denture base. The maximum and minimum stresses in the mucosa and bone were the least among all models except for cancellous bone. This could be attributed to the same elastic modulus of both mucosa and silicone soft liner material. If a denture soft liner had a lower elastic modulus than the mucosa, it will distribute the applied stress adversely.

(Sato et al 2000) also concluded this finding. They added that the inappropriate use of these materials might result in bone loss. Many other investigators supported the use of silicone soft liner material under complete denture base (Kasperski et al 2010), (Mudzki et al 2008) and (Inoue et al 1985)

On the other hand, there were opponents to the use of silicone soft liner material. (Elias and Henriques 2007), (Akin et al 2014) and (Ikeda et al 2006) recommended the use of acrylic resin reline material under the denture base. Their studies concluded that acrylic resin reline material had better interfacial bond strength with acrylic resin denture base material. The bonding properties sustained in different oral environmental conditions.

(Yoshikazu et al 2010) used two different lining materials with 1mm and 2 mm thickness. They concluded that acrylic lining materials should be used for difficult cases of mandibular edentulous patients when sufficient lining space is not available.

In the current study, three-dimensional finite element analysis enabled the assessment of stress distribution in the mucosa and underlying bone. Although the FE analysis is considered a useful tool (Kawano et al 1993) and (Katayoun et al 2012), it has certain limitations. Some limitations of this study were the applied force and the contacts between the materials. The force was considered uniform in all prosthetic teeth, and the contacts between the structures were considered bonded or perfect unions, which is not the case during chewing. Nevertheless, the loss in elasticity or material destruction of the soft liner was not evaluated. In addition, the structures were considered isotropic, homogeneous, and linearly elastic (Braden et al 1995). However, this study may be used as a base to conduct clinical trials to confirm its findings.

Recommendations

In order to confirm the above-mentioned resulted findings, clinical comparison and evaluation of stresses developed in denture supporting tissues following the use of acrylic and silicon soft liners should carried out. In addition, clinical effects of using different thicknesses of elastic soft liners in denture supporting tissues should be evaluated.

Conclusions

Within the limitations of the study, the following conclusion could be drawn:

1. The use of silicone soft liner materials showed the lower amount of stresses on a mucosa and bone than acrylic based liner.
2. The use of 2 mm thick soft liner material promoted the tendency to decrease the maximum and minimum principal stress in the mucosa and in the underlying bone.
3. Stress concentration was observed in the anterior portion of the maxilla at the incisive canal area and on the alveolar ridges at site of load application in both the mucosa and underlying bone.

References

Akin H., Tugut F., Mutaf B. and Guney U. (2014). Investigation of bonding properties of denture bases to silicone-based soft denture liner immersed in isobutyl methacrylate and 2-hydroxyethyl methacrylate. J Adv Prosthodont. ; 6: 121-5

Annusavice KJ. (1996). Science of dental materials. 10 ed. Philadelphia: W. B. Saunders Co.,. p. 237-69.

Bacchi A, Consani RL, Mesquita MF and dos Santos MB. (2012). Influence of different mucosal resiliency and denture reline on stress distribution in peri-implant bone tissue during osseointegration. A three-dimensional finite element analysis. Gerodontology.;29:e833–e837.

Barao VA, Assuncao WG, Tabata LF, de Sousa EA and Rocha EP. (2008). Effect of different mucosa thickness and resiliency on stress distribution of implant-retained overdentures-2D FEA. Comput Methods Programs Biomed.;92:213–223.

Braden M, Wright PS and Parker S. (1995). Soft lining materials. A review. Finite Element Analysis of Soft lined Mandibular Complete Denture and its Supporting Structures. Eur J Prosthodont Restorative Dent.; 3: 163–174.

Chenga Y.Y., Lib J.Y., Fokb S.L., Cheungc W.L. and Chowa T.W. (2 0 1 0). 3D FEA of high-performance polyethylene fiber reinforced maxillary dentures. dental materials; 2 6: 211–219

Craig R G and Powers J M. (2002). Restorative Dental Materials. 11th Edition St. Louis: Mosby: 666-672.

Darbar U.R., Huggett R. and Harrison A. (1994). Denture fracture a survey. Br Dent J; 176: 342–5.

Dos Santos MB, Da Silva Neto JP, Consani RL and Mesquita MF. (2011). Three-dimensional finite element analysis of stress distribution in peri-implant bone with relined dentures and different heights of healing caps. J Oral Rehabil.;38:691–696.

El-Anwar M., El-Mofty M. and Fawzy U. M. (2014). The Influence of Different Gingival Thickness on Stress to Implant-Supported Overdenture and Bone. IOSR Journal of Dental and Medical Sciences (IOSR-JDMS) e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 13, Issue 3 Ver. III. , PP 17-23.

Elias C. N. and Henriques F. Q. (2007). Effect of thermocycling on the tensile and shear bond strengths of three soft liners to a denture base resin. J Appl Oral Sci.; 15(1): 18-23

Hayakawa I, Hirano S, Takahashi Y and Keh ES. (2000). Changes in the masticatory function of complete denture wearers after relining the mandibular denture with a soft denture liner. Int. J. Prosthodont ; 13: 227-231.

Ikeda T., Wakabayashi N., Ona M. and Ohyama T. (2006). Effects of polymerization shrinkage on the interfacial stressat resin metal joint in denture base: a non-linear F E stress analysis. Dent. Mater.; 22: 413–9.

Inoue K., Arikawa H., Fujii K., Shinohara N. and Kawahata N. (1985). Viscoelastic properties of oral soft tissue, A method of determining elastic modulus of oral soft tissue. Dental Material Journal ; (4): 47-53.

Katayoun Sadr, Jahangir Alipour and Fateme Heidary. (2012). Finite Element Analysis of Soft-lined Mandibular Complete Denture and its Supporting Structures**.** JODDD, Vol. 6, No. 2

Kasperski J, Żmudzki J and Chladek G. (2010). Denture foundation tissues loading criteria in evaluation of dentures wearing characteristics. Journal of Achievements in Materials and Manufacturing Engineering; 43: 324-32.

Kawano F, Koran A, Asaoka K and Matsumoto N. (1993). Effect of soft denture liner on stress distribution in supporting structures under a denture. Int J Prosthodont. ; 6: 43-9.

Kawano F, Ohguri T, Koran IA, Matsumoto N and Ichikawa T. (1999). Influence of lining design of three processed soft denture liners on cushioning effect. J Oral Rehabil.;26:962–968.

Kimoto S, Kimoto K, Gunji A, Kawai Y, Murakami H and Ta-naka K. (2007). Clinical effects of acrylic resilient denture liners applied to mandibular complete dentures on the alveolar ridge. J Oral Rehabil .; 34: 862-9.

Kimoto S, So K, Yamamoto S, Ohno Y, Shinomiya M and Ogura K. (2006). Randomized controlled clinical trial for verifying the effect of silicone-based resilient denture liner on the masticatory function of complete denture wearers. Int. J. Prosthodont ; 19: 593-600.

Lima J. B. G., Orsi I. A., Borie E., Jlima. H. F. & Noritomi P. Y. (2013). Analysis of stress on mucosa and basal bone underlying complete dentures with different softliner material thicknesses: a three-dimensional finite element study. Journal of Oral Rehabilitation. ; 40; 767-773

McCabe JF. (1985). Anderson's applied dental material. 6 ed. London: Blackwell Scientific Publications. 92-98.

Mudzki A J., Chladek A W. and Krukowska J. (2008). Estimation of stresses in layers of dentures' relining materials Archives of Materials Science and Engineering. Volume 30(1) March; 21-24

Mudzki A J., Chladek A W. and Krukowska J. (2008). Effort changes of lower complete denture material caused by relining. Archives of Materials Science and Engineering. Volume 31(2) June; 79-82.

Murata H, Hamada T and Shinsuke S. (2008). Relationship between Viscoelastic properties of soft denture liners and clinical ef-ficacy. Japanese Dental Science Review;44:128-32.

Murata H, Taguchi1 N, Hamada T, Kawamura M and McCabe JF. (2002). Dynamic viscoelasticity of soft liners and masticatory function. . J Dent Res; 81:123-28.

Parr GR and Rueggeberg FA.(2002). In-vitro hardness, water sorption, and resin solubility of laboratory-processed and autopolymerized long-term resilient denture liners over one year of water storage. J Prosthet Dent. 88:139–144.

Sato Y, Abe Y, Okane H, Tsuga K. (2000). Finite element analysis of stress relaxation in soft denture liner. J oral Rehabil. 27: 660-663.

Shim JS and Watts DC. (2000). An examination of the stress distribution in a soft-lined acrylic resin mandibular complete denture by finite element analysis. Int J Prosthodont. ; Jan-Feb: 13 (1): 19-24.

Thikra M. and Hachim. J. (2012). Evaluation of shear bond strength of silicon-based soft liner to the acrylic resin denture base using different polymerization technique with different storage periods in distilled water. Bagh College Dentistry; Vol. 24(3).

Van Noort R (1994). Introduction to dental materials. Mosby, London, 188-191.

Yoshikazu Y, Toshiako T, Chikahiro O and Toshio H. (2010). Pressure distribution of mandibular complete denture using soft lining materials. Int Chin J Dent; 10: 17-21.

Zarb GA, Bolender CL, Eckert S, Jacob R, Fenton A and Mericske-Stern R. (2003). Prosthodontic treatment for Edentulous Patients: Complete Dentures and Implant-Supported Prostheses. 12th ed. Mosby, 198-202.