***ISSN:* 1812–1217**

Finite Element Analysis of Acrylic Denture Produced From Visible Light Custom Tray

Nadira A Hatim
BDS, MSc (Assist Prof)
Department of Prosthetic Dentistry
College of Dentistry, University of Mosul

Ayad A Abdul-Razaq
BSC, MSc, PhD (Assist Prof)
Department of Civil engineering
College of Engineering, University of Mosul

Ibtehal H Al-Zubaidy
BDS, MSc (Assist Lect)
Department of Prosthetic Dentistry
College of Dentistry, University of Mosul

ABSTRACT

Aim: To determine stress analysis exerted by denture on the edentulous alveolar bone in the premolar region represented by stone cast produced from visible light custom tray using linear finite element method. **Material and Method**: Visible light custom tray (spaced and close fit) was used to produce stone cast that represent the denture base and the underlying bone using silicone impression material. The dimension of the cross section of the stone cast was measured using Dimax program, then the data collected was entering Excel program for making the figures. The dimension of the cross section of the stone cast entering finite element program and other new auxiliary program prepared specially for this study for finite element analysis of vertical load of 100 Newton applied on the buccal cup (supporting cusp) of the second premolar tooth. **Result**: After the data was analyzed, the results were drawn in figures using surfer 7 program. High compressive, tensile, deflection, shear and maximum principal stress values were observed below the point of force application and in the underlying structure with different values and locations according to the analysis in the mucous membrane and in the underlying bone in the X and Y axes. **Conclusion**: By using finite element analysis, the more stress concentration and deflection were found below the point of force application, in the mucous membrane, at the beginning of the cortical bone and along the buccal vestibule. The less stress concentration, deflection and less value of shear and maximum principle stress that distributed over large distance was found by using visible light cure spaced custom tray.

Key words: finite element, alveolar bone, custom tray, visible light cure.

Hatim NA, Abdul-Razaq AA, Al-Zubaidy IA. Finite Element Analysis of Acrylic Denture Produced From Visible Light Custom Tray. *Al–Rafidain Dent J.* 2009; 9(1):9-16

Received: 4/9/2007 ***Sent to Referees:***4/9/2007 ***Accepted for Publication: :***25/11/2007

INTRODUCTION

Custom made trays are designed to allow more uniform thickness of impression material, and the dimensional stability of custom impression trays is an important factor in determining the degree of accuracy achieved in forming a master cast, visible light cure resin material has accurate fit, superior strength, and acceptable bond strength compared with heat – processed resin [1,2]. The finite element stress analysis technique models are actual continuous structures with discrete – element mathematical representation. This approach transforms the problem into one of matrix algebra, which may be solved with the aid of a digital computer [3].

Hirabayashi *et al.*, [4] investigated biomechanical aspects of the action of the biting force during mastication upon the mandibular bone in the lower first molar area, they suggested that there may be relationship between masticatory force and cortical bone hypertrophy, while the other [5] stated that to improve the quality of the complete denture prosthesis, the bucco – lingual position of the artificial posterior teeth must be determined with consideration of the shape of the maxillary and mandibular residual ridges, and the relationship between them.

MATERIALS AND METHODS

Visible light custom tray of two design

(close fit and spaced) was constructed on the master model, which is completely edentulous mandibular metal arch form using visible light curing unit (Megatray, MegaDenta-Germany), visible light custom tray was used to take impression using silicone impression material to produce stone cast.

For the finite element method, the stone cast produced from visible light custom tray that represent the denture base and the underlying bone was section in the horizontal direction in the premolar region by using fine saw, the dimension of the cross section of stone cast was measured by using Dimax program.

A stand held digital camera was placed (60cm) away from the dental surveyor in zero plane that contain the cross section of stone cast produced from metal perforated stock tray, then the picture analyzed by entering Dimax program, a ruler was used to detect the accuracy of the measurements, the measurements were done each (2mm) in two dimension.

The tooth model was designed according to the average anatomic dimensions of selected set of teeth that were used for previous arrangement, (Cervico – incisal crown length 8 mm, Mesio – distal crown diameter 7 mm), the denture base thickness 2.5 mm [6]. The mucous – membrane thickness 2 mm [7], the cortical bone 2 mm thickness [8], the bone height was 22.5 mm according to the master model used.

***Materials Properties**:* Acrylic Resin**:** **{**Modulus of Elasticity (MPa)-2000, Poisson's ratio 0.3} [9, 10,11], Mucosa: { Modulus of Elasticity (MPa)- 3.45, Poisson's ratio 0.45 } [9,10,11]**,** Cortical Bone: { Modulus of Elasticity (MPa)- 13700, Poisson's ratio 0.3 } [12]**,** and Cancellous Bone: { Modulus of Elasticity (MPa)- 1370, Poisson's ratio 0.3 } [12].

Boundary Conditions: The lower border of the mandible was considered to be fixed in all directions to avoid the FE model from sinking when load is applied [12,13].

Load Application: A vertical load of 100 Newton was applied on the buccal cup (supporting cusp) of the second premolar tooth, this value is less than the actual maximum load in the oral cavity during normal mastication, but it is within the measured values in many previous studies in this area of oral cavity [14].

Finite Element Method

The finite element method is a general method of structural analysis in which a continuum is replaced by finite number of element interconnected at finite number of nodal points.

Shape Function: Eight – node element considered from high order – elements, in general, higher order element shape function can be developed by adding additional nodes to the sides of the linear element.

In this study, the cross section of the model is represented by 8 – nodes isoparametric plane strain element using standard shape function with two degrees of freedom at each node. Formulation of this element is formed by natural coordinate system (ξ, η) in place of cartesian coordinates Figure (1).

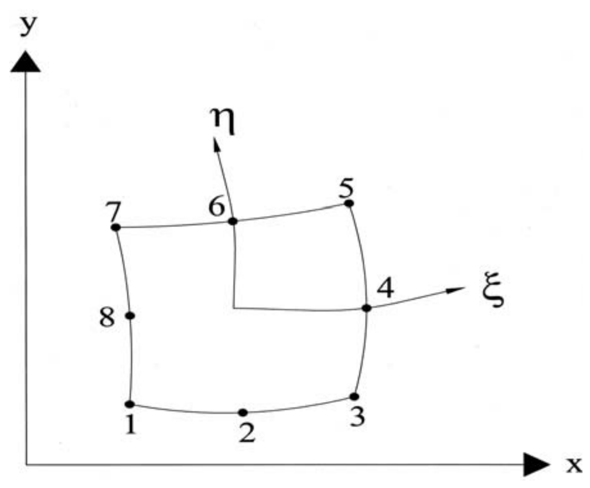


Figure (1) Eight nodes two-dimensional element

The nodal displacement vectors for these elements are:

$$\{d\} = [u_1, v_1, u_2, v_2, ..., u_8, v_8]^T$$

………. (1)

Where u and v are the translation in the X and Y directions respectively. The displacement field for two – dimensional element is given by:

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = [N] \begin{Bmatrix} u_1 \\ v_1 \\ . \\ . \\ u_8 \\ v_8 \end{Bmatrix} \quad ...(2)$$

Where

$$[N] = \begin{bmatrix} N_1 & 0 & N_2 & 0 & ..... & N_8 & 0 \\ 0 & N_1 & 0 & N_2 & ..... & 0 & N_8 \end{bmatrix}$$

…(3)

Where: N_i is the shape function and,

$$N_1 = -\frac{1}{4}(1-\xi)(1-\eta)(1+\xi+\eta)$$

$$N_2 = \frac{1}{2}(1-\xi^2)(1-\eta)$$

$$N_3 = \frac{1}{4}(1+\xi)(1-\eta)(\xi-\eta-1)$$

$$N_4 = \frac{1}{2}(1+\xi)(1-\eta^2)$$

$$N_5 = \frac{1}{4}(1+\xi)(1+\eta)(\xi+\eta+1)$$

$$N_6 = \frac{1}{4}(1-\xi^2)(1+\eta)$$

$$N_7 = \frac{1}{4}(1-\xi)(1+\eta)(-\xi+\eta+1)$$

$$N_8 = \frac{1}{2}(1-\xi)(1-\eta^2)$$

……… (4)

The global coordinates X and Y inside the element can be described as:

$$X = \sum_{i=1}^{8} N_i X_i \quad \text{and} \quad Y = \sum_{i=1}^{8} N_i Y_i$$

………. (5)

Where (X_i) and (Y_i) represent the coordinates of two – dimensional nodes.

Strain Matrix: Strain component can be calculated from the following expression:

$$\{\varepsilon\} = [B][d] \quad ………. (6)$$

$$\{\varepsilon\} = \sum_{i=1}^{8} \begin{bmatrix} \frac{\partial N_i}{\partial x} & 0 \\ 0 & \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial y} & \frac{\partial N_i}{\partial x} \end{bmatrix} \begin{Bmatrix} u_i \\ v_i \end{Bmatrix} …….(7)$$

Consider for instance the set of local coordinate (ξ, η) and corresponding set of global coordinates X, Y by the usual rule of partial differentiation, the derivative can be written as:

$$\frac{\partial N_i}{\partial \xi} = \frac{\partial N_i}{\partial x}\frac{\partial x}{\partial \xi} + \frac{\partial N_i}{\partial y}\frac{\partial y}{\partial \xi}$$

$$\frac{\partial N_i}{\partial \eta} = \frac{\partial N_i}{\partial x}\frac{\partial x}{\partial \eta} + \frac{\partial N_i}{\partial y}\frac{\partial y}{\partial \eta} \quad … (8)$$

Writing in matrix from:

$$\begin{Bmatrix} \frac{\partial N_i}{\partial \xi} \\ \frac{\partial N_i}{\partial \eta} \end{Bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} \end{bmatrix} \begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \end{Bmatrix} = [J] \begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \end{Bmatrix}$$

(9)where:

$$[J] = \begin{bmatrix} \sum_{i=1}^{8} \frac{\partial N_i}{\partial \xi} X_i & \sum_{i=1}^{8} \frac{\partial N_i}{\partial \xi} Y_i \\ \sum_{i=1}^{8} \frac{\partial N_i}{\partial \eta} X_i & \sum_{i=1}^{8} \frac{\partial N_i}{\partial \eta} Y_i \end{bmatrix} ..(10)$$

The matrix [J] is known as Jacobian matrix. To find the global derivative, we invert [J] and write:

$$\begin{Bmatrix} \frac{\partial N_i}{\partial x} \\ \frac{\partial N_i}{\partial y} \end{Bmatrix} = [J]^{-1} \begin{Bmatrix} \frac{\partial N_i}{\partial \xi} \\ \frac{\partial N_i}{\partial \eta} \end{Bmatrix} \quad …… (11)$$

To transform the variables, derivatives, and the regions with respect to which integration is made a standard process will be used which involve the determinant of [J], thus the volume of the element:

$$dx\, dy = \left|J\right| .d\xi\, d\eta$$
………. (12)

Elasticity Matrix (D – Matrix):

The stress/ strain relationship for an elastic material, in the absence of initial stresses and strains, may be written in the form:

$$\{\sigma\} = [D]\,\{\varepsilon\}$$ ………. (13) Where [D] is the elasticity matrix.

For plane strain situations the D – matrix will be:

$$[D] = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1 & \frac{\nu}{1-\nu} & 0 \\ \frac{\nu}{1-\nu} & 1 & 0 \\ 0 & 0 & \frac{1-2\nu}{2(1-\nu)} \end{bmatrix}$$
………. (14)

For two–dimensional analysis the stiffness matrix is:

$$[k] = \int\int [B]^T [D][B]\, dxdy$$
………. (15) Where: D: elasticity matrix.
B: strain – displacement matrix.

Depending on the volume of the element $dx\, dy = \left|J\right| .d\xi\, d\eta$, the stiffness matrix will be:

$$[k] = \int_{-1}^{1}\int_{-1}^{1} [B]^T [D][B] \left|J\right| d\xi\, d\eta$$
………. (16)

Algebraic integration usually defines mathematical expression, and numerical integration has to be used by Hinton and Owen, 1977[15].

The mesh for the model produced from visible light cure close fit custom tray consists of (845) elements and (2668) nodes, and (915) elements and (2886) nodes for the model produced from visible light cure spaced custom tray.

A vertical load of 100 Newton was applied on the buccal cup (supporting cusp) of the second premolar tooth, this value is less than the actual maximum load in the oral cavity during normal mastication, but it is within the measured values in many previous studies in this area of oral cavity (16). The data collected were introduced in Excel program for making the figures. The dimension of the cross section of stone cast was entering finite element program (6) and other new auxiliary programs that prepared specially for this study for finite element analysis. Surfer version 7 software program and AutoCAD software program are used in this study.

RESULTS AND DISCUSSION

After the data was analyzed by using FE program and other new auxiliary programs that were prepared specially for this study, the results were drawn in figures using surfer 7 program. The figures are colored to show the stress distribution in the model and these colors are divided every (20 MPa) for stresses and (0.1mm) for deflections.

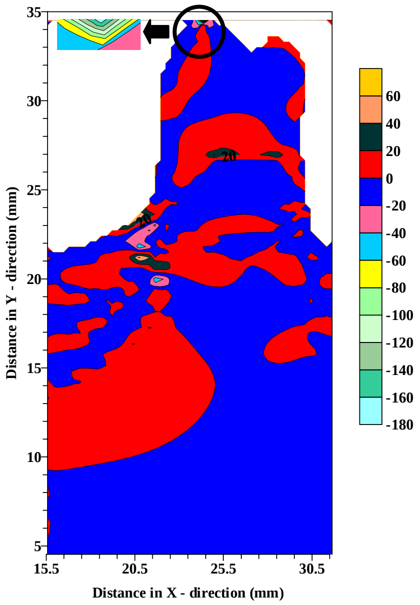
Effect of force on acrylic tooth to the underlying bone by using visible light cure close fit and spaced custom tray: A two – dimensional finite element method was used to investigate the statics for the contour of the denture and the residual ridge. The maximum compressive stresses were observed below the point of force application at the buccal cusp of the second bicuspid tooth(- 20 to -180, - 40 to - 380 MPa, closed fit tray), while for spaced tray the results was less (- 40 to -180, - 80 to - 360 MPa,) in the X and Y axes respectively., and in the mucous membrane and cortical bone (Figure 2 and 3). These results are in agreement Vollmer *et al.* [16], who reported that the forces applied to the masticatory system are manifested by the development of the internal stresses which are distributed in a coordinate with the direction of force application. The maximum tensile stresses (20 to 60 MPa) were observed in the mucous membrane in case of spaced tray. This results can be explained as to be due to the resiliency of this histological structure and low value of modulus of elasticity of mucous membrane in relation to the acrylic resin and bone structure that is more dense and have high value of modulus of elasticity [10].

The greater amount of the deflection (Close fit tray)at the crest of the ridge was seen in the mucous membrane and the cortical bone (0 to 0.4, -0.2 to -0.8 mm) in the X and Y axes respectively, while the greater amount of deflection (Spaced tray) in the bucco – lingual direction was seen acrylic tooth, denture base, and mucous membrane (0.2 to 0.6, -0.7 to -1.2 mm), in the X and Y axes respectively. This is related to the different topography of the models that produced from the tray [17]. The maximum value of shear stress was seen below the point of force application which was { Close fit tray (-220 to 60 MPa)}, and at the crest of the ridge {Spaced tray(-20 to 60 MPa)} in the mucous membrane and at the beginning of the cortical bone (figure 3). This may be related to the friction between the acrylic denture and the underlying structure [8]. The maximum principal stress value was seen in the mucous membrane(5 to 65 MPa), when the stress exceeds this value, crack and other complications will be expected to occur. These results could be explained as to be due to the resiliency and low modulus of elasticity of the mucous membrane [9].

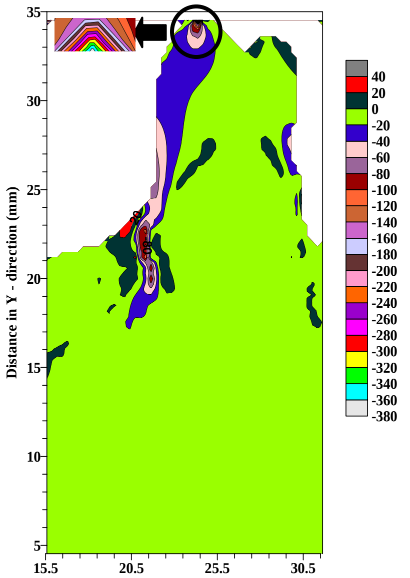
Finite element analysis is a good method used to assess the stress distribution on the supporting structures and by using this method in this study it recommended to use the visible light cure spaced custom tray to obtain acrylic denture that lead to less stress concentration and less value of maximum principal stress and deflection that distributed over large surface area when compared with the models that produce from metal stock tray and visible light cure close fit custom tray so that the visible light cure spaced custom tray recommended to be use in patients with sever alveolar bone resorption, knife edge ridge and flabby mucous membrane.

CONCLUSIONS

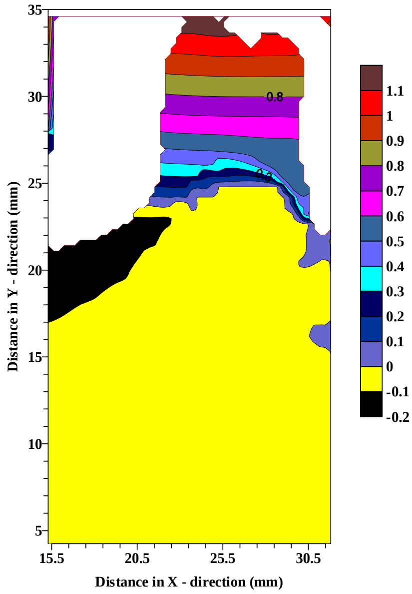
The more stress concentration and deflection were found below the point of force application, in the mucous membrane, at the beginning of the cortical bone and along the buccal vestibule. The less stress concentration, deflection and less value of shear and maximum principle stress that distributed over large distance was found by using visible light cure spaced custom tray



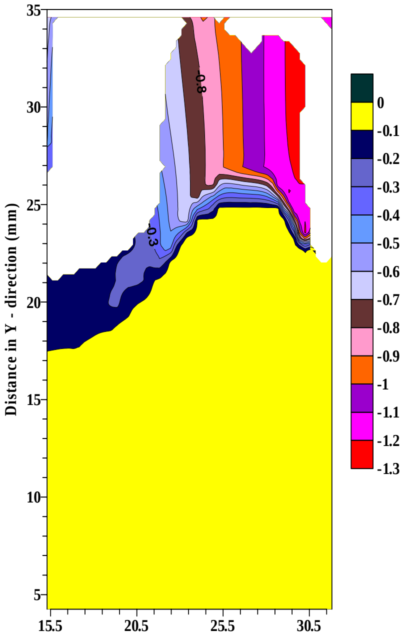
(A) Stress in X direction



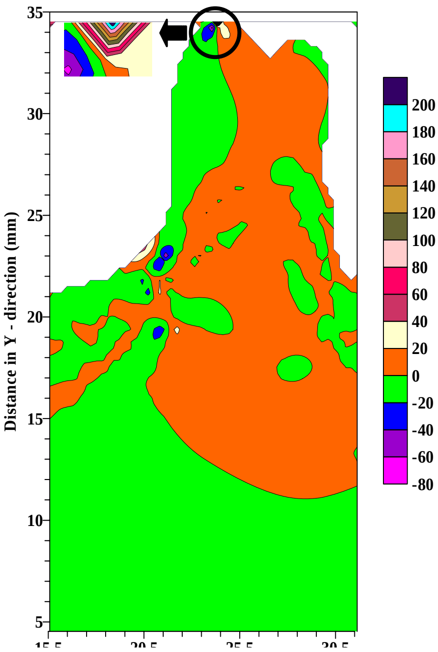
(B) Stress in Y direction



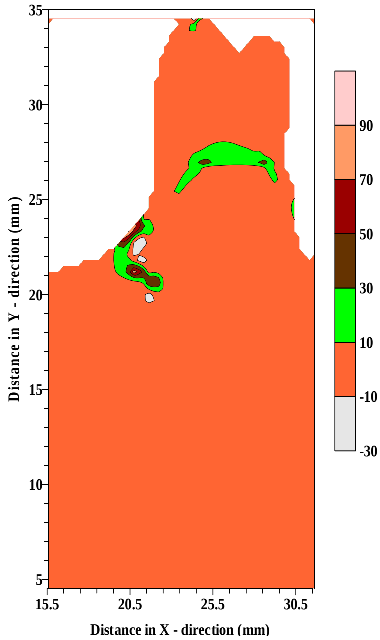
(C) Deflection in X direction



(D) Deflection in X direction(mm)

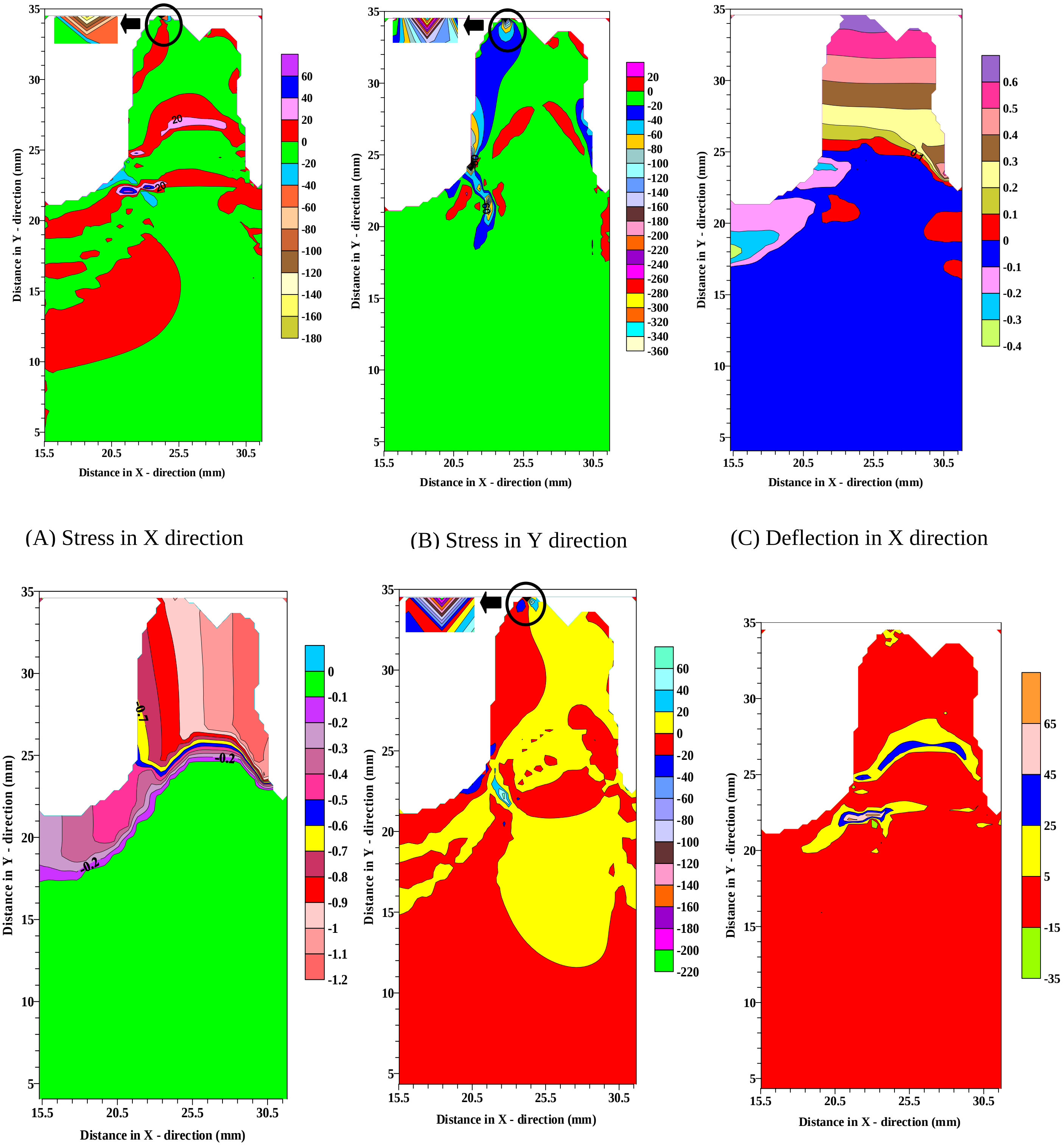


(E) Shear stress (MPa)



(F)Maximum principle stress(mm)

Figure (2): Finite elements analysis of acrylic denture to the underlying bone (VLC close fit custom tray)



(A) Stress in X direction

(B) Stress in Y direction

(C) Deflection in X direction

(D) Deflection in Y direction (mm)

(E) Shear stress (MPa)

(F) Maximum principal stress

Figure (3) Finite elements analysis of acrylic denture to the underlying bone
(VLC spaced custom tray)

REFERENCES

1. Breeding LC, Dixon DL, Moseley JP. Custom impression trays: Part 1 – Mechanical Properties. *J Prosthet Dent*. 1994; 71: 31 – 34.
2. Ogle RE, Sorensen SE, Lewis EA. A new visible light – cured resin system applied to removable prosthodontics. *J Prosthet Dent*. 1986; 56: 497 – 506.
3. Caputo A., Wylie L. Role of biomechanics in periodontal therapy (Internet). 2001.
4. Hirabayashi M, Motoyoshi M, Ishimaru T, Kasai K, Namura S. Stresses in mandibular cortical bone during mastication: biomechanical consideration using a three – dimensional finite element method. *J Oral Sci*. 2002; 44 (1): 1 – 6.
5. Nishigawa G, Matsunaga T, Maruo Y, Okamoto M, Natsuaki N , Minagi S. Finite element analysis of the effect of the bucco – lingual position of artificial posterior teeth under occlusal force on the denture supporting bone of the edentulous patients. *J Oral Rehabil*. 2003; 30 (6): 646 – 651.
6. Rees J, Huggett R, Harrison A. Finite element analysis of the stress – concentrating effect of fraenal notches in complete dentures. *Int J Prosthod*. 1990; 3: 238 – 240.
7. Sertgoz A, Guvener S. Finite element analysis of the effect of cantilever and implant length on stress distribution in an implant – supported fixed prosThesis. *J Prosthet Dent.* 1996; 76: 165 – 169.
8. Darbar U, Huggett R, Harrison A, Williams K. Finite element analysis of stress distribution at the tooth – denture base interface of acrylic resin teeth debonding from the denture base. *J Prosthet Dent*. 1995; 74: 591 – 594.
9. Nakamura Y. Stress analysis of an overly denture and a magnetic attachment using finite element method. *J Japan Prosthodontic Society*. 1998; 42: 243.
10. Sato Y, Tsuga K, Abe Y, Akagawa Y. Finite element analysis of the effect of vertical curvature on half oval cast clasps. *J Oral Rehabil*. 1999; 26: 554 – 558.
11. Hong – So Y, Lisa AL, Anthony M, David AF. The effect of dowel design and load direction on dowel and core restoration. *J Prosthet Dent*. 2001; 85: 558 – 567.
12. Yang HS, Lang LA, Felton DA. Finite element stress analysis on the effect of splitting in fixed partial dentures. *J Prosthet Dent*. 1999; 81 (6): 721 – 728.
13. Torparli M. Stress analysis in a post – restored tooth utilizing the finite element method. *J Oral Rehabil*. 2003; 30: 470 – 6.
14. Pegoretti A., Fambri L, Zappini G Bianchetti M. Finite element analysis of glass fiber reinforced composite endodntic post. *J Biomaterial*. 2002; 23: 2267 – 2282.
15. Hinton E, Owen DRJ. Finite element programming. Academic Press Ltd. London. 1977; PP: 95 – 122.
16. Vollmer D, Meyer U, Joos U, Vegh A, Piffko J. Experimental and finite element study of a human mandible. *J Eur Assoc*. 2000; 28: 91 – 96.
17. Hatim NA. Volumetric changes in acrylic denture base material. M.Sc Thesis, College of Dentistry, University of Baghdad(1988).