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ORIGINAL ARTICLE

Study of Deflections in Maxillary Major Connectors: A Finite Element Analysis

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Abstract The Major connector is the major component of the cast partial denture to which all other parts are directly or indirectly attached. It also provides cross arch stability to help resist displacement by functional stresses. The major connector should be rigid. A flexible major connector causes an unequal distribution of forces with changes in their intensity and may cause damage to the supporting structures. Thus rigidity is of paramount to resist flexing and torquing forces. The commonly used major connectors for the maxillary arch are Anteroposterior strap, palatal strap and complete palatal plate. Application of load on the prosthesis will result in deflection. The magnitude and direction of the deflection that the prosthesis undergoes depends on the rigidity of the major connector. (1) To determine the deflection seen in maxillary removable partial denture frameworks under simulated occlusal load. (2) To compare the rigidity and deflection characteristics of different maxillary major connectors used in maxillary Kennedy's class I, class II, class III and class IV situations. A CT scan of human edentulous maxilla was taken and each section from the incisive foramen to the hamular notch was projected on the graph paper and three dimensional volumes were created from the connected successive profiles to define the final solid geometry of bone. Six framework models with different Maxillary major connectors such as Anteroposterior straps and complete palatal plate for Kennedy's class I, class II, class III and class IV situations were created. Three Dimensional Finite Element Models corresponding to the geometric model were created using *ANSYS 9.0 version*. The model was assigned the material properties. A vertical biting force of 20 N was applied. The results showed maximum displacements were observed at the posterior edge of the saddle for all the frameworks. Anteroposterior palatal strap in class III and class IV situation showed the least deflection when compared to class I and class II (distal extension situation) Anteroposterior palatal strap is more rigid connector than the full palatal plate, single palatal strap, and U-shaped palatal strap and can be used in all situations.

Keywords Finite element analysis · Major connector · Deflection · Displacement

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Introduction

Removable partial denture is a prosthesis fabricated to replace missing teeth and related tissues. It restores patient's appearance, improves speech, assists mastication and maintains a healthy, stable relationship amongst the remaining natural teeth. In cases which do not have the benefit of natural tooth support at each end of the residual ridge, it is necessary that the residual ridge be used to assist in the functional stability of the prosthesis.

During function, occlusal loads exerted on a removable partial denture are transmitted to abutment teeth and oral mucosa. To provide vertical support the removable partial denture framework should be designed to engage the tooth that encourages axial loading so that the stresses are directed towards the long axis of the tooth.

The Major connector is the major component of the cast partial denture to which all other parts are directly or indirectly attached. It also provides cross arch stability to help resist displacement by functional stresses. The major connector should be rigid. A flexible major connector causes an unequal distribution of forces with changes in their intensity and may cause damage to the supporting structures [1].

Several studies have reported that the Antero-posterior palatal strap maxillary major connector exhibited a greater degree of rigidity where as U shaped palatal bar was the most flexible maxillary major connector [2, 3].

Stresses on different dental prosthesis have been studied using various techniques such as brittle coatings, strain gauges, holography, stereo-photometry, two and three-dimensional photo elasticity, finite element analysis and other numerical methods. Stress analysis studies of inlays, crowns, fixed bridges, complete dentures, partial dentures and implants have been reported [4].

The finite element method has become a powerful tool for the numerical solution of wide range of engineering problems. Today finite element method can be applied to many areas in the field of engineering, Biomedical engineering being one of them. The developments in mainframe and availability of powerful microcomputers have brought this method within the reach of students [5].

Finite element method is one of the useful tools in estimating stresses and displacements around the restorative materials. Finite element methods have been proved to be one of the best methods for research [5].

The objective of this study is to use finite element method to

- Determine the deflections seen in maxillary removable partial denture frameworks under simulated occlusal load.
- To compare the rigidity and deflection characteristics of different maxillary major connectors used in maxillary edentulous situations i.e. Kennedy's class I, class II, class III and class IV situations.

The study of deflections in maxillary major connectors used in Kennedy's class I to class IV Situations were studied using Three Dimensional Finite Element Model created on a work station computer with a configuration of

Hardware: P4 processor with a speed of 2.1 GHz and 2 GB RAM.

Software: *ANSYS 9.0 version* for the finite element modeling, and solid geometric model was created in unigraphics CAD package.

The study was divided under the following steps:

1. Construction of the geometric model.
2. Preparing of finite element mesh.
3. Material properties.
4. Application of boundary conditions.
5. Application of loads.
6. Analysis of deflection pattern.

Creation of the Finite Element Model

Step 1 The maxilla was created using the cross section sketch options. Four different cross sections were created. The cross section outlines were drawn as per the dimensional sketches taken from the CT scan. These sketches were connected through guide strings. The solid geometry is created through form feature option (sweep along guides).

The tooth sketch is created in three different planes. The geometry is taken from the radiographic images and drawn in the sketches. These three sketches are extruded and then intersected with each other to get the individual tooth solid geometry. The specifications for the dimensions of the teeth were taken from the textbook of dental anatomy by wheelers. Using these dimensions the teeth were modeled using the software.

The frameworks were,

- Model 1—Antero-posterior palatal strap in class I (Fig. 1).
- Model 2—full palatal plate in class I (Fig. 2).
- Model 3—Antero-posterior palatal strap in class II (Fig. 3).
- Model 4—full palatal plate in class II (Fig. 4).

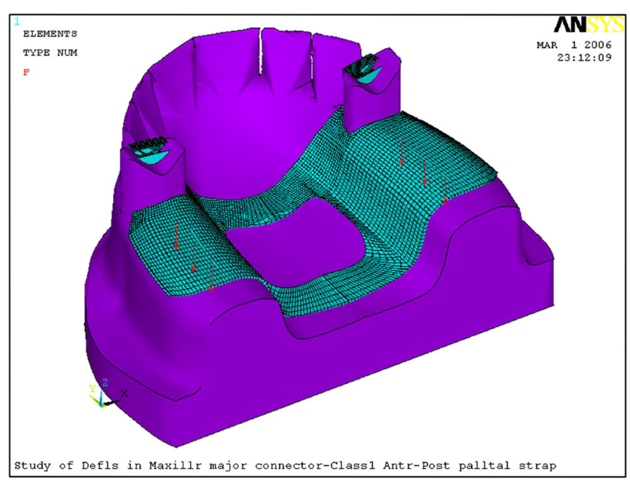

Fig. 1 Model 1—class I—anteroposterior palatal strap (load application)

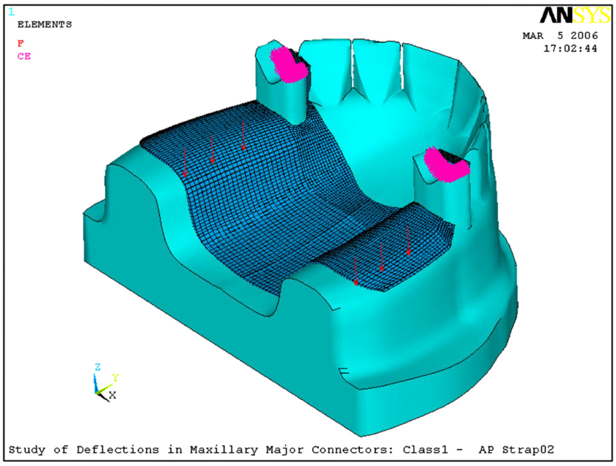

Fig. 2 Model 2—class I—full palate (load application)

- Model 5—Antero-posterior palatal strap in class III (Fig. 5).
- Model 6—Antero-posterior palatal strap in class IV (Fig. 6).

The Antero-posterior palatal strap is the most versatile of all the major connectors. The thin straps provide excellent rigidity and strength with minimal tissue coverage. The straps were 6 mm wide and the lateral straps were positioned symmetrically. The palatal opening was maintained at 15 mm in the Antero-posterior direction in class I, class II and class III situation, and in class IV situation it was 19 mm.

The palatal plate connector was assumed to be completely composed of metal. The posterior limit of the plate was located anterior to the posterior palatal seal area and the anterior limit was extended only till the rugae area.

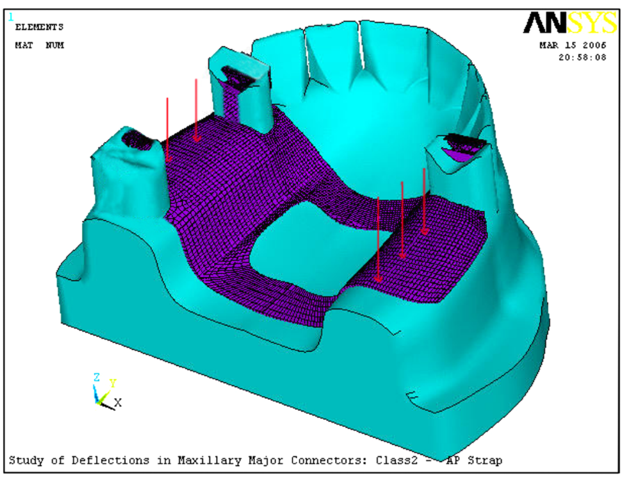

Fig. 3 Model 3—class II—anteroposterior palatal strap (load application)

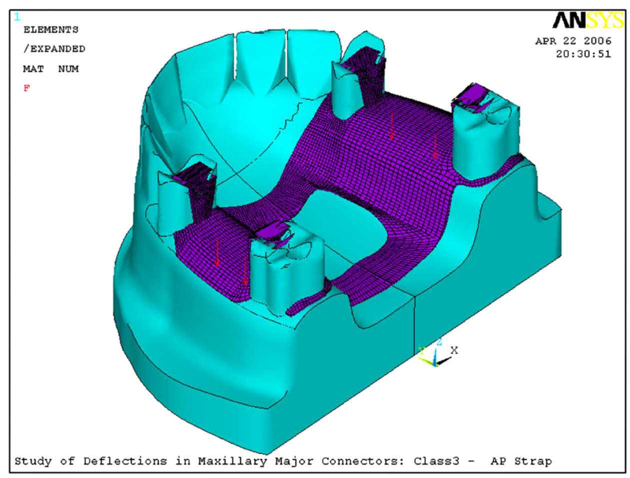

Fig. 5 Model 5—class III—anteroposterior palatal strap (load application)

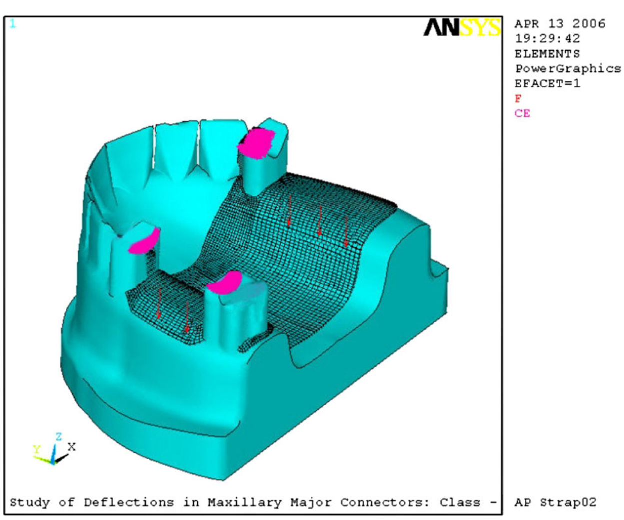

Fig. 4 Model 4—class I—full palate (load application)

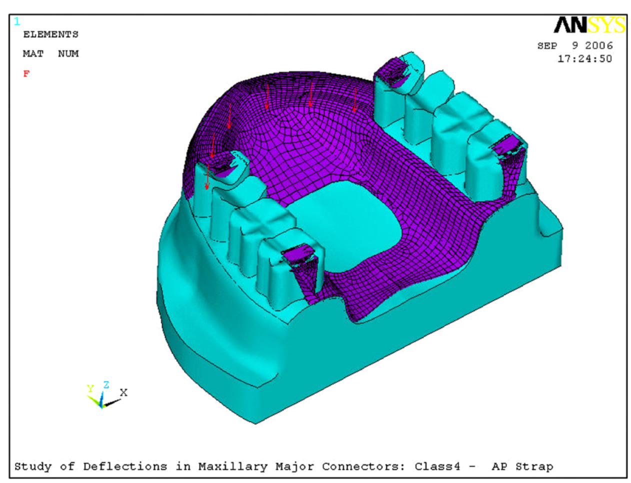

Fig. 6 Model 6—class IV—anteroposterior palatal strap (load application)

The location of the occlusal rests were as follows:

- Model 1—two mesial occlusal rests on the PM I (Fig. 1).
- Model 2—two mesial occlusal rests on the PM I (Fig. 2).
- Model 3—one mesial occlusal rests on the left PM I, one distal occlusal rests on the right PM I and one mesial occlusal rest on the M II (Fig. 3).
- Model 4—one mesial occlusal rests on the left PM I, One distal occlusal rests on the right PM I and one mesial occlusal rest on the M II (Fig. 4).
- Model 5—two distal occlusal rests on the PM I and two mesial occlusal rests on the M II (Fig. 5).
- Model 6—two mesial occlusal rests on the PM I and Two distal occlusal rests on the M II. (Fig. 6).

The maxilla geometry is sliced to 10 simple geometry. These chunked geometries are imported in *ANSYS FEA* package using the translators. The imported geometries in *ANSYS* are checked for geometric continuities and errors. The error/twisted surface geometries are repaired if any.

Results

This study consisted of a finite element analysis of the deflection of various designs of chrome cobalt cast partial denture frameworks in different situations. Vertical loads of 20 N was applied towards an imaginary centre point on each of the missing teeth locations and were analyzed for the deflections of the various denture framework parts in the three dimension of space. The results showed (Table 1; Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 16, Fig. 17, Fig. 18, Fig. 19, Fig. 20, Fig. 21, Fig. 22, Fig. 23, Fig. 24, Fig. 25, Fig. 26, Fig. 27, Fig. 28, Fig. 29, Fig. 30).

Discussion

Removable partial dentures help in replacing missing teeth and the tissues to a certain extent. During function like mastication and deglutition the framework of the removable partial denture undergo stress and these stress points deform the denture from its final position.

The removable partial dentures have a design pattern which depends on the most important component that is the major connectors. The major connectors used in maxillary removable partial denture frame works are mainly the Anteroposterior palatal straps, full palatal major connector, single palatal straps and horse shoe shaped major connector. These major connectors have a specific thickness and width respectively so that they can withstand both axial and tangential load during mastication [4].

Rigidity is the prime requisite of major connectors, through which stresses that are applied to any component of the partial denture are effectively distributed over the entire supporting area, including abutment teeth, underlying bone and soft tissues. The greatest damage the partial denture can produce is from a flexible major connector.

Table 1 Maximum and minimum deflection among different Kennedy's situation under applied load

Model	X axis	Y axis	Z axis
Class 1 AP Strap			
Maximum	513*	5.1	712
Minimum	48.8	1.8	5.35
Class 1 full palate			
Maximum	485	18.7	725
Minimum	47.2	1.8	14.3
Class II AP Strap			
Maximum	9.55	10.7	33.3
Minimum	1.7	1.9	4.17
Class II full palate			
Maximum	9.8	10.9	38.7
Minimum	2.02	1.2	4.27
Class III AP strap			
Maximum	5.9	1.9	6.1
Minimum	3.4	1.3	1.5
Class IV AP Strap			
Maximum	1.7	1.2	3.2
Minimum	1.3	1.1	1.4

All in microns

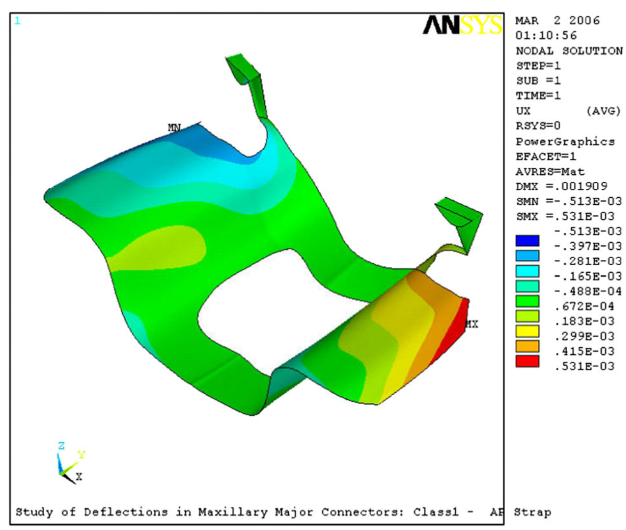

Fig. 7 Deflection in X-axis (buccolingual direction) seen in Anteroposterior palatal strap in Kennedy's class I situation

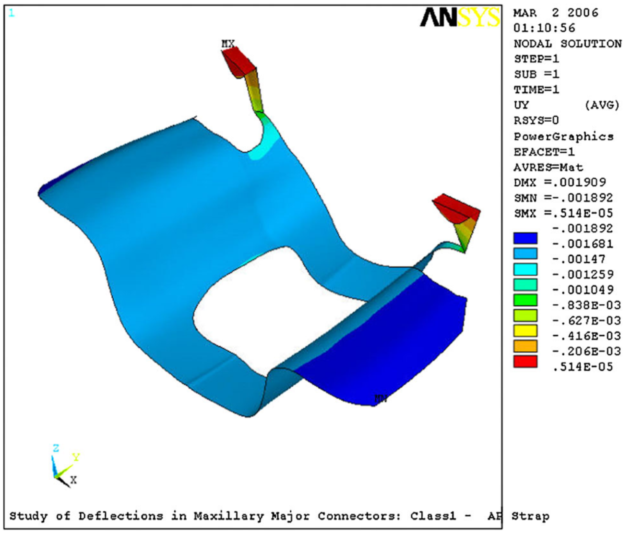

Fig. 8 Deflection in X-axis (Anteroposterior direction) seen in Anteroposterior palatal strap in Kennedy's class I situation

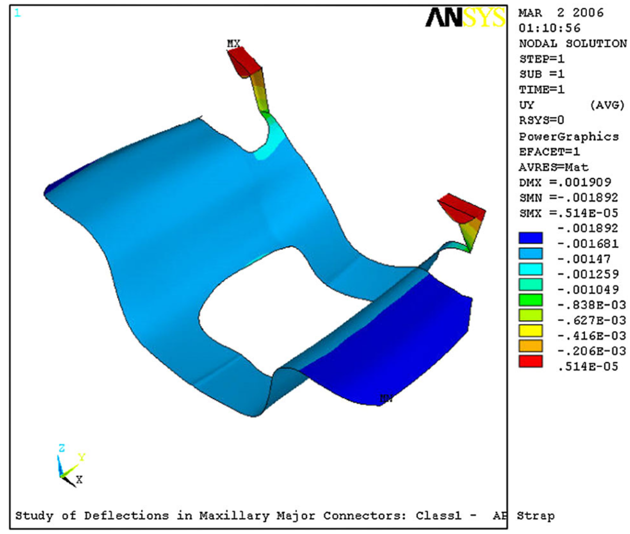

Fig. 10 Summation of deflections (X, Y & Z axis) seen in Anteroposterior palatal strap in Kennedy's class I situation

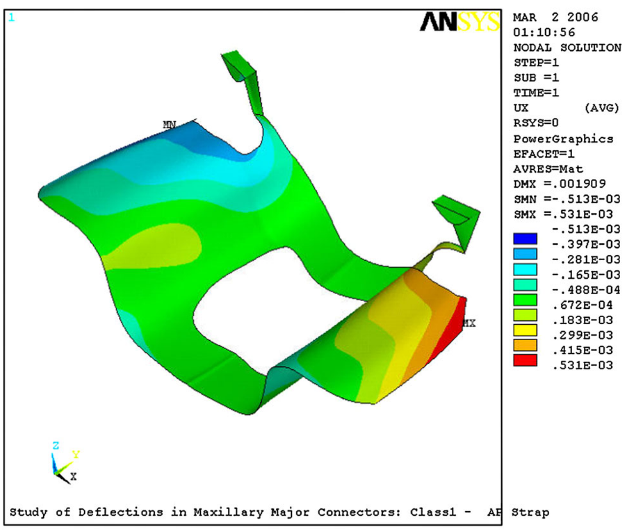

Fig. 9 Deflection in Z-axis (vertical direction) seen in Anteroposterior palatal strap in Kennedy's class I situation

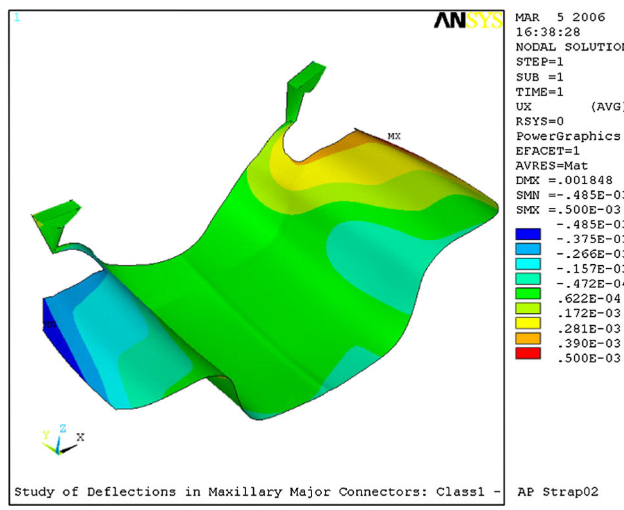

Fig. 11 Deflection in X-axis (buccolingual direction) seen in full palatal plate in Kennedy's class I situation

The commonly used major connectors for the maxillary arch are Anteroposterior palatal strap, Palatal strap, Full palatal plate and U-shaped palatal plate. Literature claims that an Anteroposterior palatal strap is more rigid and also showed the least deformation among the maxillary major connectors [3, 6, 7]. The present study was done on Kennedy's class I to class IV situations.

Class I situation—Antero-posterior palatal strap and Full palatal coverage.

Class II situation—Antero-posterior palatal strap and Full palatal coverage.

Class III and class IV situations only one design was used i.e. Antero-posterior palatal strap.

Using the finite element system static load was applied to the various designs of chrome cobalt partial denture frameworks on the saddle area. A uniform load of 20 N on each edentulous area. The finite element models with the boundary conditions were then analyzed in the *Ansys 9.0 version*, using PCG solver.

Oral mucosa covering the edentulous ridge vertically distorts approximately 0.5 under 4 N of vertical force. This is considerably greater than the intrusion exhibited by abutment teeth, at approximately 0.02 mm [1].

Taking into consideration, the class I situation deflections were studied in two maxillary major connector designs. Maximum deflection was found at the anterior part of the

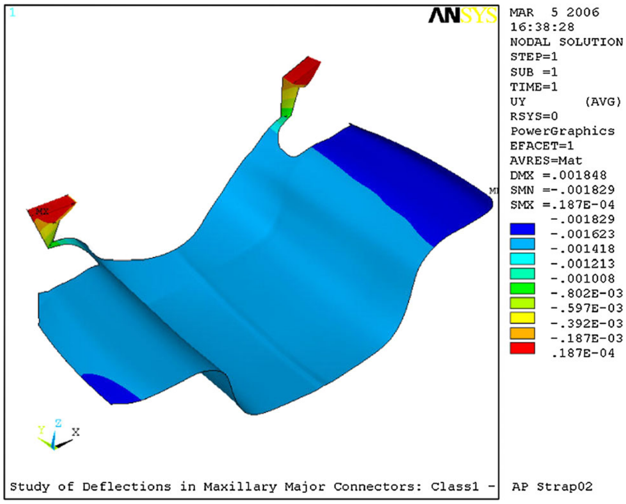

Fig. 12 Deflection in X-axis (Anteroposterior direction) seen in full palatal plate in Kennedy's class I situation

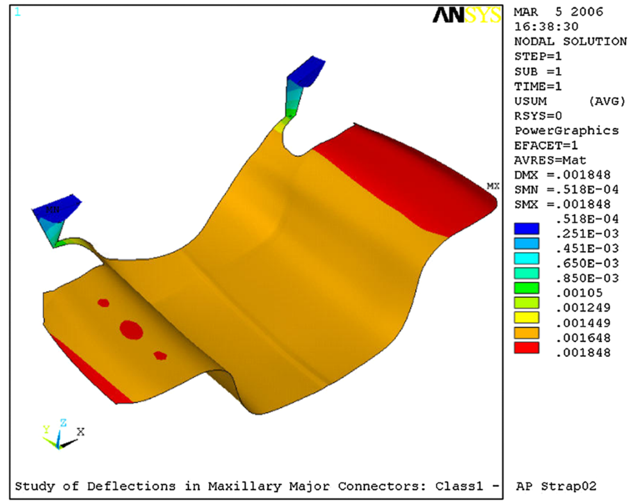

Fig. 14 Summation of deflections (X, Y & Z axis) seen in full palatal plate in Kennedy's class I situation

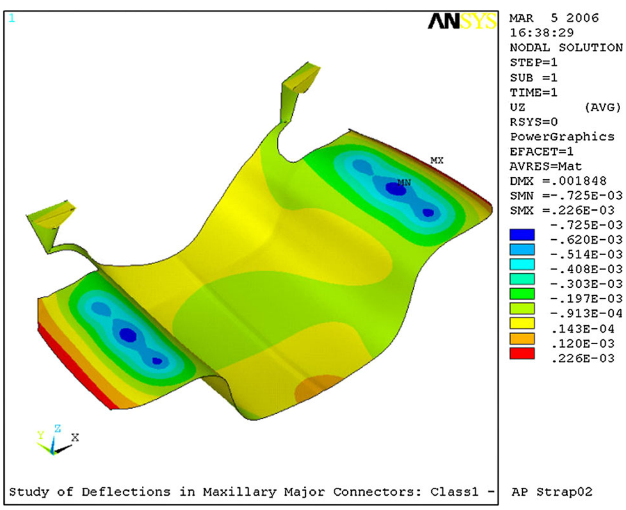

Fig. 13 Deflection in Z-axis (vertical direction) seen in full palatal plate in Kennedy's class I situation

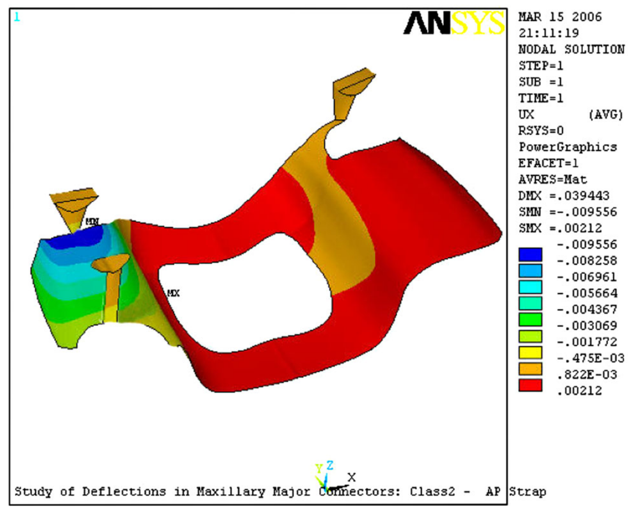

Fig. 15 Deflection in X-axis (buccolingual direction) seen in Anteroposterior palatal strap in Kennedy's class II situation

buccal slope in X-axis, occlusal rests and entire saddle area in Y-axis and entire buccal slope on the ridge and centre of the crest in the Z-axis in the A-P strap framework.

Anterior part of the buccal slope in the X-axis showed maximum deflection and occlusal rest, crest of the ridge and the buccal slope together showed deflections, since it is subjected to greater stresses because their support is a combination of tooth and soft tissue. These deflections can be controlled by-

- Maximum coverage of the soft tissues.
- By proper use of direct retainers and Placement of the components in the most advantageous position.

Similarly in the class II situation deflections were studied with two frameworks Anteroposterior palatal strap and Full palatal coverage. Both showed deflections which were maximum at the crest of the ridge on the saddle area and the entire plate excluding the posterior palatal strap. Where as in a class III situation the load was taken maximum by the rest and outer part of the anterior and posterior straps because of the situation being mostly teeth supported.

In a class 4 situation the Anteroposterior palatal strap was only studied for deflections, here maximum deflection was seen at distal rests and the distal most part of the palatal strap.

The findings are in harmony with the Miho et al who investigated the effect of major connector design on deflection in maxillary removable partial denture frameworks under simulated occlusal loading which was analyzed by means of FEM. They concluded that major connector with decreased thickness or width showed more

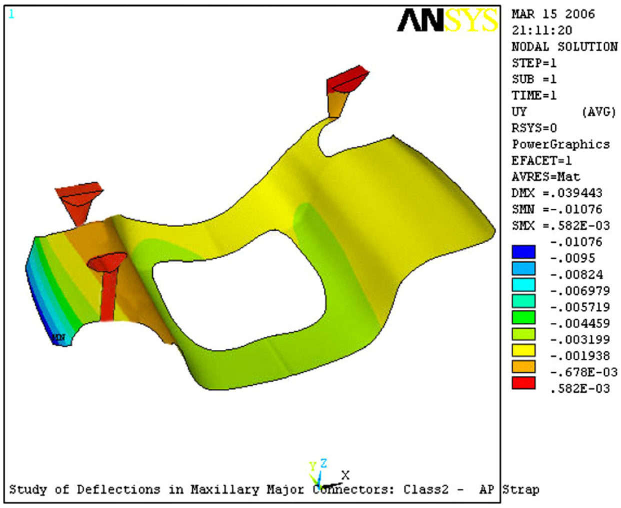

Fig. 16 Deflection in X-axis (Anteroposterior direction) seen in Anteroposterior palatal strap in Kennedy's class II situation

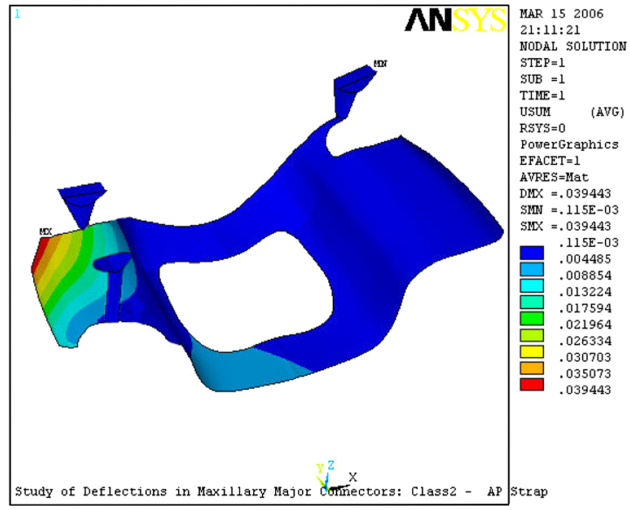

Fig. 18 Summation of deflections (X, Y & Z axis) seen in Anteroposterior palatal strap in Kennedy's class II situation

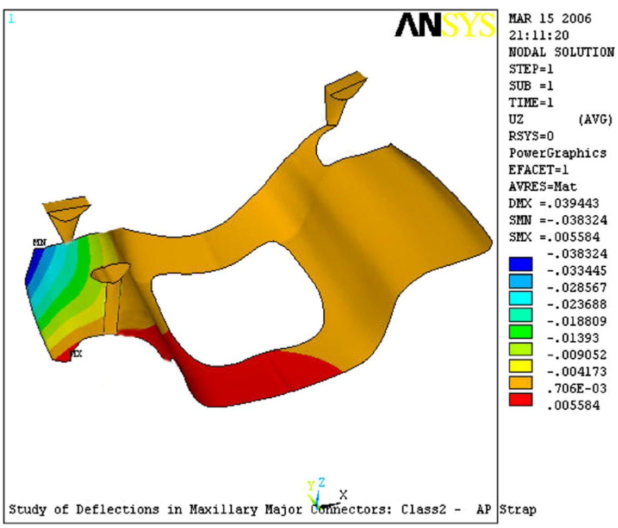

Fig. 17 Deflection in Z-axis (vertical direction) seen in Anteroposterior palatal strap in Kennedy's class II situation

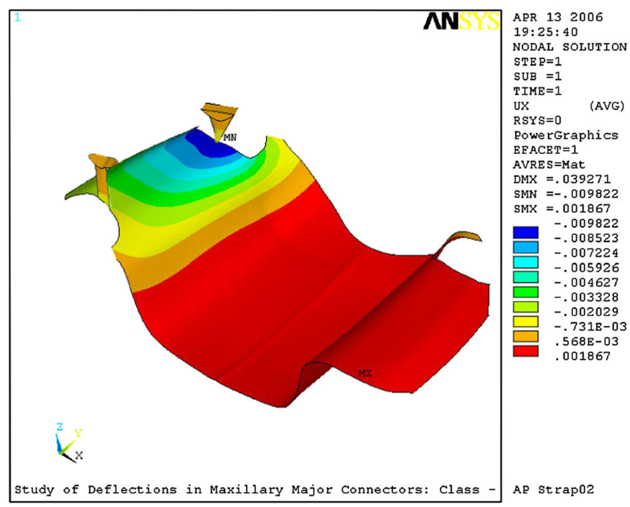

Fig. 19 Deflection in X-axis (buccolingual direction) seen in full palatal plate in Kennedy's class II situation

displacement. They also found the use of additional occlusal rest decreased the amount of displacement [3]. Studies have shown that Anteroposterior strap may be used for most maxillary partial denture designs and when Tori are present. It has the circle and L-beam effect. It should be at least 8 mm in width for optimum rigidity. Complete palatal plate is used for bilateral distal extension partial dentures of long span and in combination with plastic resin [8].

Limitations of Finite Element Model

The present study has certain limitation like the vital anisotropic tissues were considered isotropic. Next the loads applied by the static loads that were different from dynamic loading seen during function. FEM is an extremely accurate and precise method for analyzing structures. However living structures are more than mere objects, which are beyond the confines of set parameters and values. Since biology is not a compatible entity, though FEA provides a sound theoretical basis of understanding the behavior of a structure in a given environment, it should not be considered alone. Hence actual experimental techniques and clinical trials should techniques such as brittle coatings, strain gauges, holography, stereophotometry, two and three-dimensional photo elasticity, finite element analysis and other numerical methods. Stress analysis studies of inlays, crowns, fixed bridges, complete dentures, partial dentures and implants have been reported [4].

The finite element method has become a powerful tool for the numerical solution of wide range of engineering problems. Today finite element method can be applied to

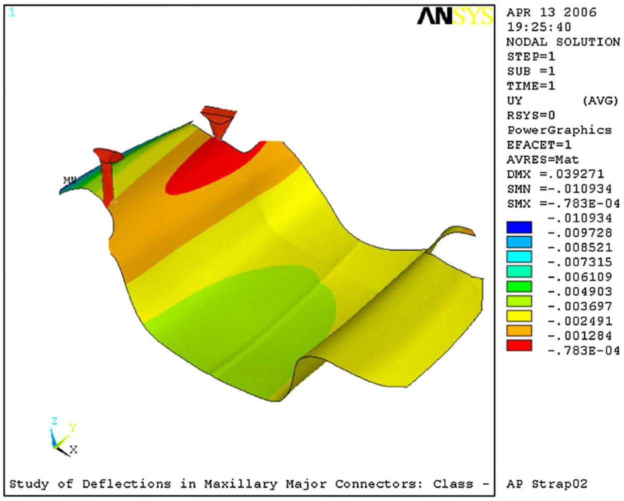

Fig. 20 Deflection in X-axis (Anteroposterior direction) seen in full palatal plate in Kennedy's class II situation

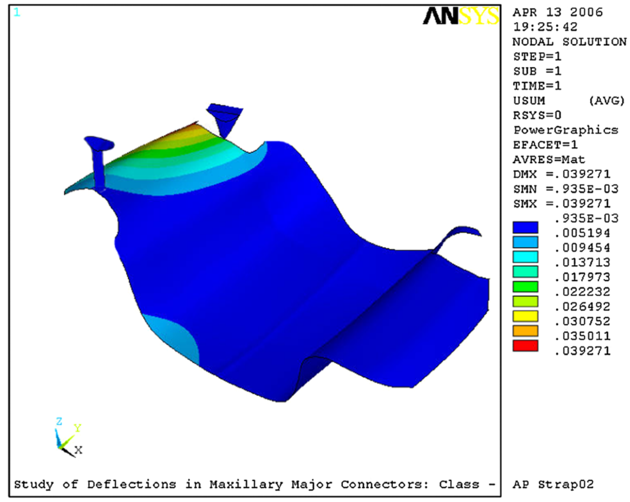

Fig. 22 Summation of deflections (X, Y & Z axis) seen in full palatal plate in Kennedy's class II situation

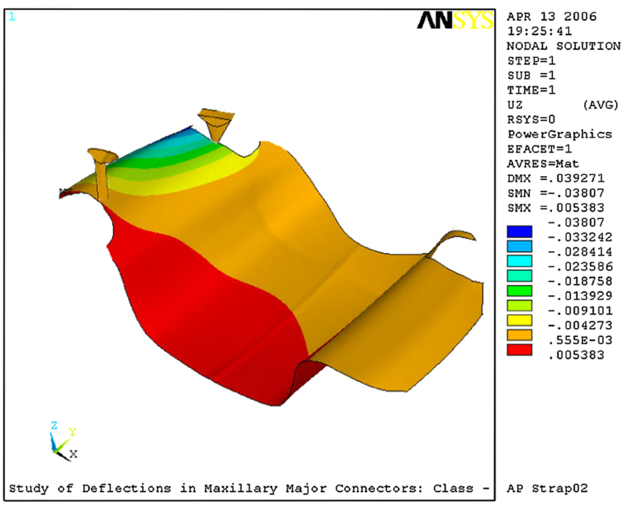

Fig. 21 Deflection in Z-axis (vertical direction) seen in full palatal plate in Kennedy's class II situation

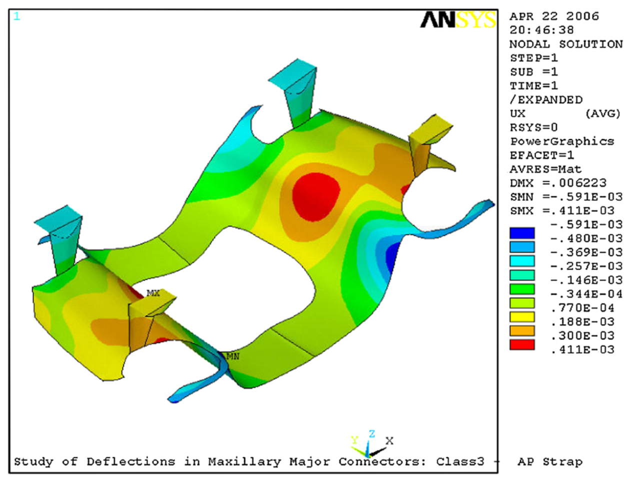

Fig. 23 Deflection in X-axis (buccolingual direction) seen in Anteroposterior palatal strap in Kennedy's class III situation

many areas in the field of engineering, Biomedical engineering being one of them. The developments in mainframe and availability of powerful microcomputers have brought this method within the reach of students [5].

Finite element method is one of the useful tools in estimating stresses and displacements around the restorative materials. Finite element methods have been proved to be one of the best methods for research [5].

Merits of Finite Element Method

The systematic generality of finite element procedure makes it a powerful and versatile tool for a wide range of problems.

- FEM can be easily interpreted in physical terms as well it has a strong mathematical base. Hence, FEM can be easily applied to any problem with a proper knowledge of the physical system under consideration ands can be solved to a greater accuracy of proper mathematical tool.
- Non homogeneous structure can also be dealt with by merely assigning different properties to different elements. It is even possible to vary the properties within an element according to the polynomial applied.
- Finite element method accommodates complex geometry with ease and is capable of handling non-linear and time dependent system also.

Demerits of Finite Element Method

- The solution obtained from FEM can be realistic if and only if the material properties are precisely known.

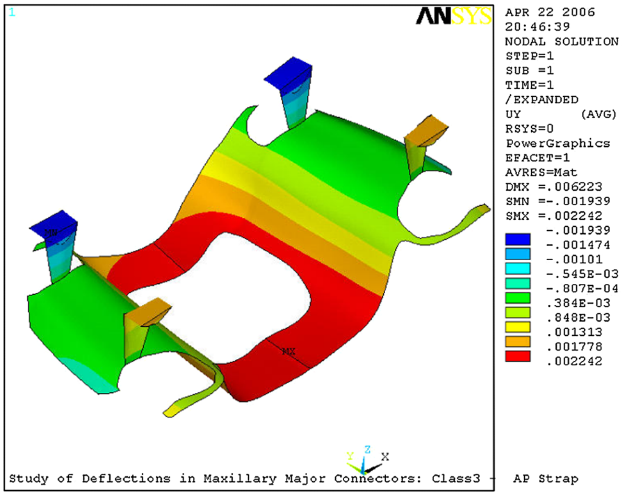

Fig. 24 Deflection in X-axis (Anteroposterior direction) seen in Anteroposterior palatal strap in Kennedy's class III situation

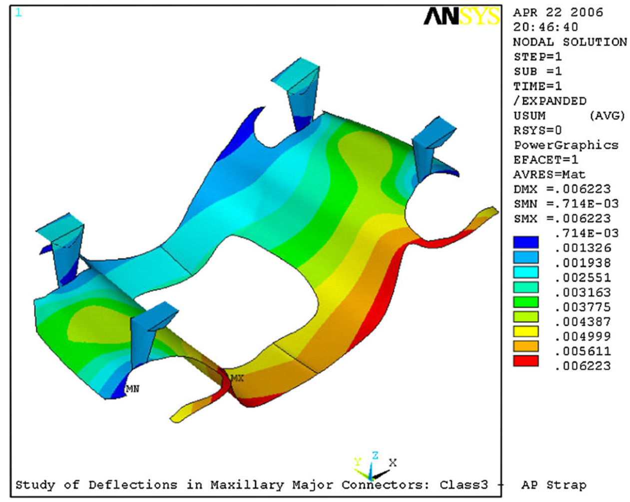

Fig. 26 Summation of deflections (X, Y & Z axis) seen in Anteroposterior palatal strap in Kennedy's class III situation

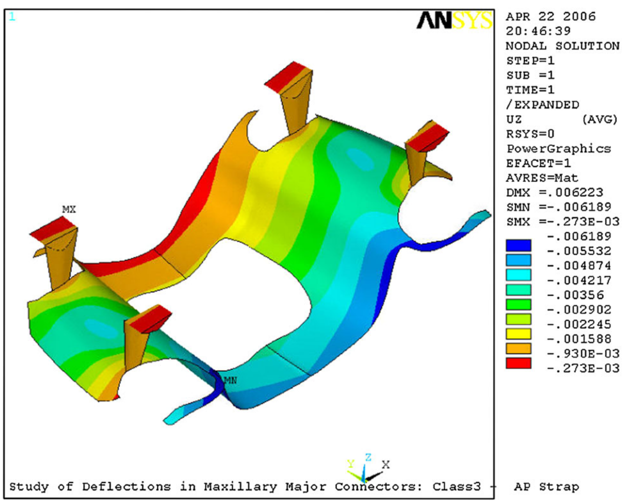

Fig. 25 Deflection in Z-axis (vertical direction) seen in Anteroposterior palatal strap in Kennedy's class III situation

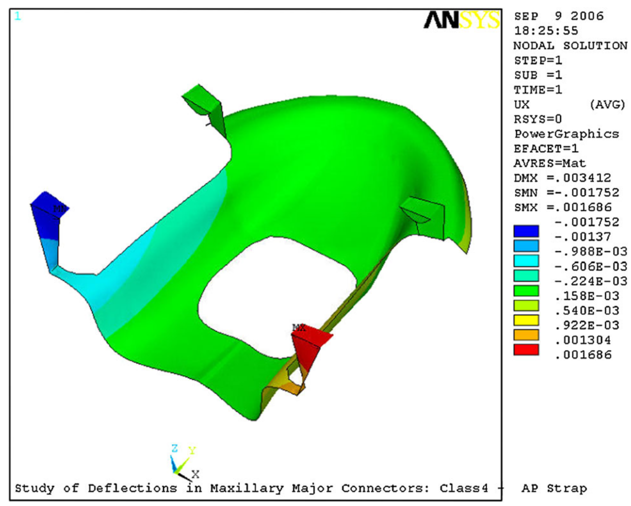

Fig. 27 Deflection in X-axis (buccolingual direction) seen in Anteroposterior palatal strap in Kennedy's class IV situation

- The major drawback of FEM is sensitivity of the solution on the geometry of the element such as type, size, number, shape and orientation of elements used.
- The computer program of FEM requires relatively a large computer memory and time.
- FEM programs yield a large amount of numerical data as results. It is very difficult to separate out the required results from the pile of numbers.

FEM Errors

- Error during conversion of Mathematical model to Solid Model (Modelling error).
- Discretisation errors.
- Solution errors.

The power of the finite element method is its versatility. The structures analyzed may have arbitrary support, and arbitrary loads. Therefore, it is ideally suited for the analysis of bibliographical structure because it can model complex geometric shapes and materials, which are not homogeneous. A finite element analysis does not produce formula as a solution, nor does it solve a class of problems. This method is a way of getting a numerical solution to specific problem.

Conclusion

The following conclusions were drawn from this study.

The total maximum deflection seen in class I Anteroposterior palatal strap major connector and class I full

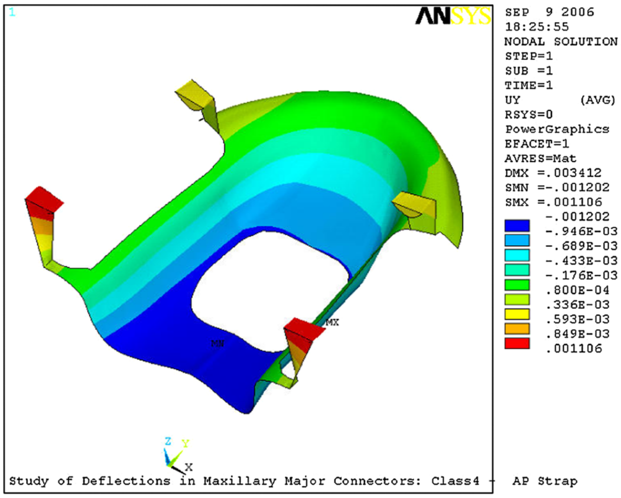

Fig. 28 Deflection in X-axis (Anteroposterior direction) seen in Anteroposterior palatal strap in Kennedy's class IV situation

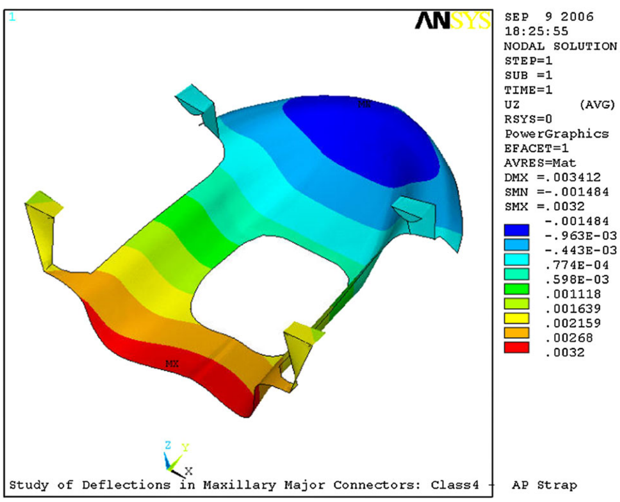

Fig. 29 Deflection in Z-axis (vertical direction) seen in Anteroposterior palatal strap in Kennedy's class IV situation

palate major connector was at the entire crest, the buccal slope of the edentulous ridge & the occlusal rests. But when compared between the two, later showed more deflection than the former.

The total maximum deflection seen even in class II Full palate major connector was more when compared to class II Anteroposterior strap major connector. The areas where the deflection was observed were almost same.

In a class III situation the amount of deflection which was observed were considerably less compared to class I and class II situations, when Anteroposterior palatal strap major connector were used.

Similarly Anteroposterior palatal strap major connector when used in class IV situation showed least amount of deflection when compared to other situations, but was close

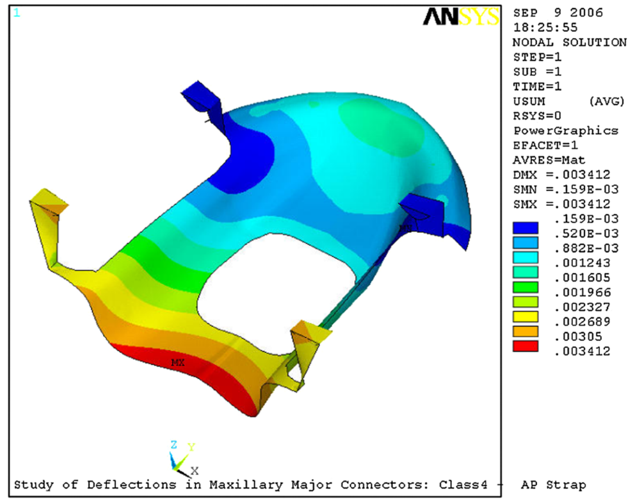

Fig. 30 Summation of deflections (X, Y & Z axis) seen in Anteroposterior palatal strap in Kennedy's class IV situation

to class III situation since it was of a very short span and replaced only 6 anterior teeth.

Maximum displacements were observed at the posterior edge of the saddle for all the frameworks, especially in the distal extension situation.

Summary

This study was aimed to determine the deflections seen in maxillary removable partial denture frameworks under simulated occlusal load and to compare the rigidity and deflection characteristics of different maxillary major connectors used in maxillary edentulous situations i.e. Kennedy's class I, class II, class III and class IV situations.

Finite element method is one of the useful tools in estimating stresses and displacements around the restorative materials. Finite element methods have been proved to be one of the best methods for research.

In this study, Finite Element Models depicting Kennedy's class I to class IV partially edentulous maxilla were created. On class I and class II models two framework designs and one framework design each on class III and class IV were created. A uniform vertical static load of 20 N was applied on each of the missing teeth locations on the denture saddle to check the deflection characteristics of the frame works.

The maximum displacements in the vertical direction under a specified vertical load was found in class I full palate, smallest maximum displacement was found in class IV Anteroposterior palatal strap .

On the other hand the maximum displacements in the buccal—distal direction with the same vertical load were found in class I Anteroposterior palatal strap major connector where as the smallest maximum buccal displacement was found in class IV Anteroposterior palatal strap.

Hence Anteroposterior palatal strap may be used for most maxillary partially edentulous situation because of its circle and an L-beam effect which makes it more rigid than any other maxillary major connector.

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