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Three-dimensional finite element analysis of the application of attachment for obturator framework in unilateral maxillary defect

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SUMMARY AIMS: The aim of this study was to evaluate the stress on the abutment teeth and framework in a unilateral maxillary defect which was restored by an obturator retained by resin-bonded extracoronal attachment. METHODS: A three-dimensional finite element model of the human unilateral maxillary defect was constructed. Traditional obturator framework with four casting circumferential clasp was established (model 1). A continuous lingual guide plane of 0·5 mm thickness on all of the remaining teeth, with Mini-SG/F attachment on the mesial surface of the central incisor was also established (model 2). The modelling and analytical processes were performed using the ANSYS technologies. RESULTS: Stress was transmitted to the anterior part of the palate, with stress values being lower on the anterior teeth compared with the posteriors. The highest stress value of model 1 and model 2 was 13·1 Mpa, 19·9 Mpa respectively. Stress concentrations were found at the junction of the attachment to the lingual guide plane and the anterior part of the lingual plane. CONCLUSION: The results of this study suggest that the application of a resin-bonded extracoronal attachment for obturator retention is in accordance with the design principles for the restorative treatment of maxillary defects. The design of the attachment framework needs to be further investigated. Benefit can be gained by splinting the abutment teeth.

KEYWORDS: 3D FEA, attachment, obturator, unilateral maxillary defect

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Introduction

Obturator prostheses are considered to be the preferred choice for the restoration of acquired maxillary defects. The rehabilitation of a maxillary defect with an obturator retained by a resin-bonded extracoronal attachment, which can improve both retention and aesthetics, is commonly practiced when a central or lateral incisor is the terminal abutment adjacent to a large defect (1–4). Taylor *et al.* demonstrated the use of resin-bonded metal components in the fabrication of definitive obturators for dentate maxillectomy patients (1). The resin-bonded metal components served as guide plane, cingulum rest seats which have been used for abutment teeth modification, so that the remaining teeth will be in a favourably position to support and retain an obturator prosthesis. And it may also serve as splints to splint the abutment that can reduce functional tooth movement by averaging the movement of individual teeth when either the abutment teeth or obturator are subjected to loading (2, 4–6).

Because of a lack of supporting tissues, including teeth and bone, the objective of the framework design of an obturator is to preserve the remaining support structures (7). Research has been conducted to evaluate the stress transmitted to the remaining teeth and other supporting structures by attachments with different framework designs. Although the use of attachments with guide planes for maxillary obturators have been successful in the clinic, their biomechanical analyses had rarely been found in the literature. It has been assumed that the components

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of the resin-bonded casting guide plane with attachment would be subjected to more severe stress in comparison to the conventional removable partial denture attachment. This study investigated, by three-dimensional finite element of analysis, the stress transmitted to the abutment teeth and the casting guide plane with attachment in the unilateral maxillary defect that is commonly seen in the maxillectomy patient.

Materials and methods

Three-dimensional data of the human maxilla were obtained via helical CT (GE-Lightspeed Qx/I, GE, USA), which were transferred into MIMCS software (Materialise, Belgium) generating a 3D model of the maxilla. The model was converted into ANSYS to establish the 3D FEM of the maxilla that simulated the unilateral maxillary defect along with the remaining teeth from the central incisor to the second molar on one side. The area around the teeth root with 0·5 mm uniform thickness was treated as periodontal membrane .The 3D FEM of two kind of obturator prostheses were established:

Model 1 (traditional treatment)

Removable partial denture frameworks with extension bases extending into the defect were constructed. The framework designs included cast palatal base with 0·5 mm thickness with four cast circumferential clasp using 0·25 mm undercut on the buccal surface (Fig. 1).

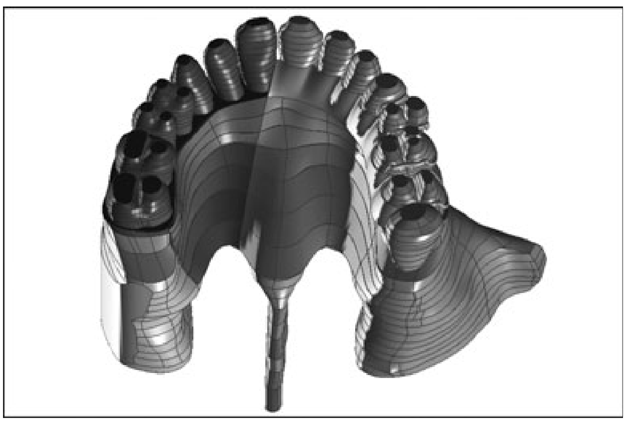

Fig. 1. 3D FEM of traditional obturator prostheses with four cast circumferential clasp.

Model 2 (an obturator retained by a resin-bonded extracoronal attachment)

The continuous lingual guide plane, with a thickness of 0·5 mm thick on all lingual surface of the remaining teeth (from central incisor to second molar) with Mini-SG/F* attachment on the mesial surface of the central incisor was constructed (Fig. 2). The obturator prostheses with casting palatal plate were also constructed according to the lingual guide plane and the condition of the maxillary defects (Fig 3).

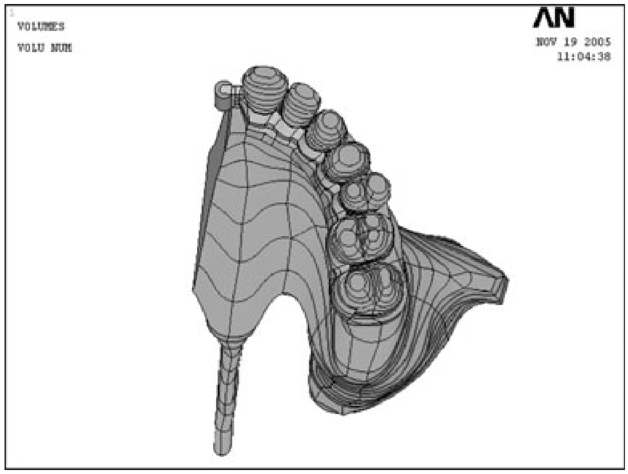

Fig. 2. 3D FEM of the lingual guide plane on all the remaining teeth (from central incisor to second molar) with attachment on the mesial surface of the central incisor.

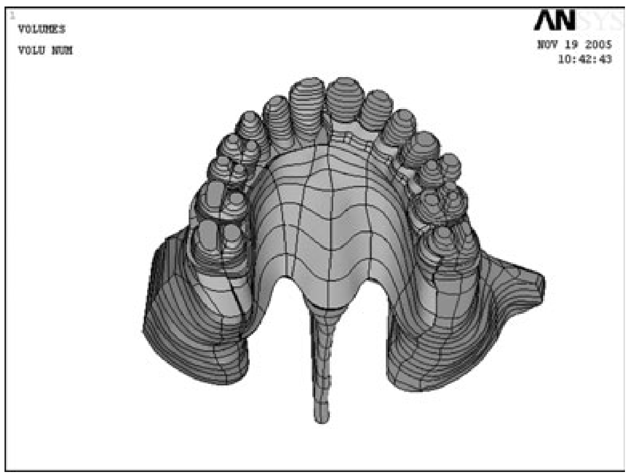

Fig. 3. 3D FEM of the obturator prostheses with casting palatal plate.

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The whole vertical load on all of the remaining natural teeth was 300N, out of which the load is distributed as, 20N on every anterior teeth, 40N on every premolar, 80N on every molar. While the whole vertical load on all of the artificial teeth was 150N, the load is distributed as 10N on every anterior teeth, 20N on every premolar, 40N on every molar. And the load on every tooth was evenly distributed. The non-defect sides of the Maxilla were designated as fixed regions with zero displacement. And it was assumed that the prostheses and maxilla would have perfect bonding.

With respect to material properties, the elastic modulus of cortical bones, spongy bone, chrome–cobalt alloy and artificial teeth was 13 700, 1850, 18 500, 2799 Mpa respectively. The Poisson's ratio was 0·35 for artificial teeth and 0·30 for the other materials. The area around the teeth roots with 0·5 mm uniform thickness was treated as periodontal membrane. And the elastic modulus of periodontal membrane was 6·5 Mpa. The Poisson's ratio was 0·45. A tetrahedron, iso-parametric element was adopted. All of the materials used in these models were considered to be isotropic, homogenous and linearly elastic. The modelling and solution processes were performed using ANSYS 5·6.

Results

Figures 4–6 show a conventional von Mises stress pattern in the traditional obturator prosthesis and the remaining teeth (model 1). Figures 7–10 show a

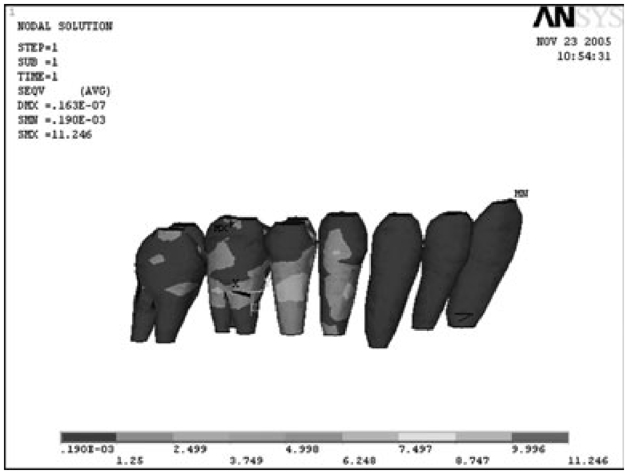

Fig. 5. Stress on the remaining teeth (model 1).

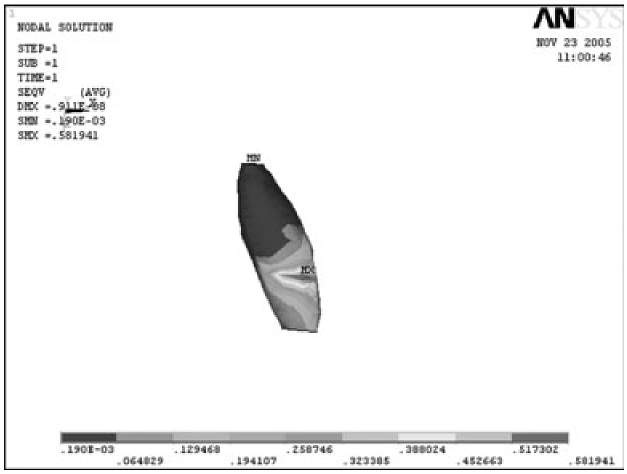

Fig. 6. Stress on the central incisor (model 1).

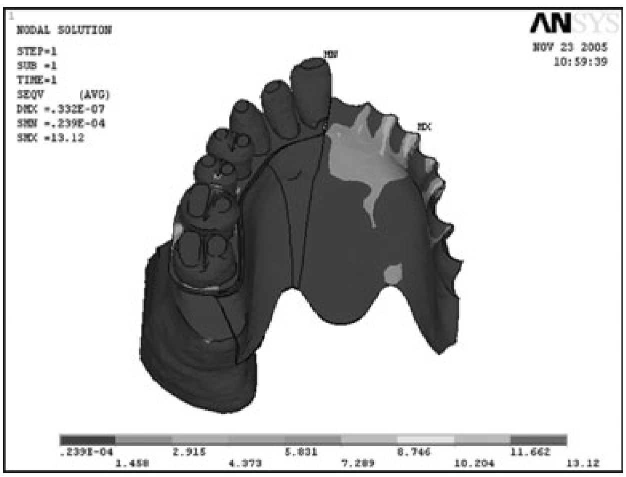

Fig. 4. Stress on the prostheses (model 1).

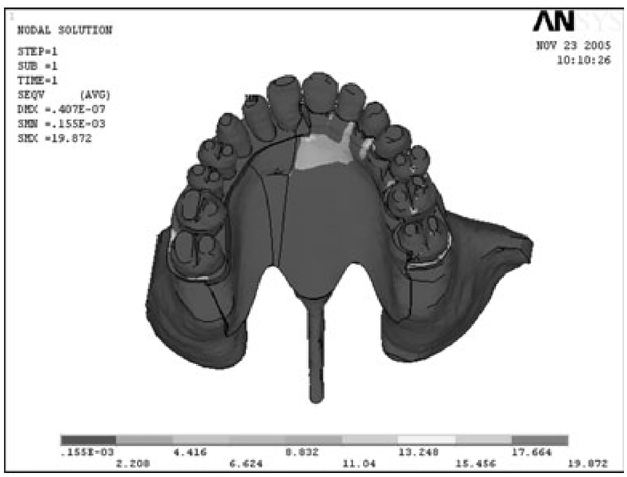

Fig. 7. Stress on the prostheses with attachment (model 2).

Fig. 8. Stress on the remaining teeth (model 2).

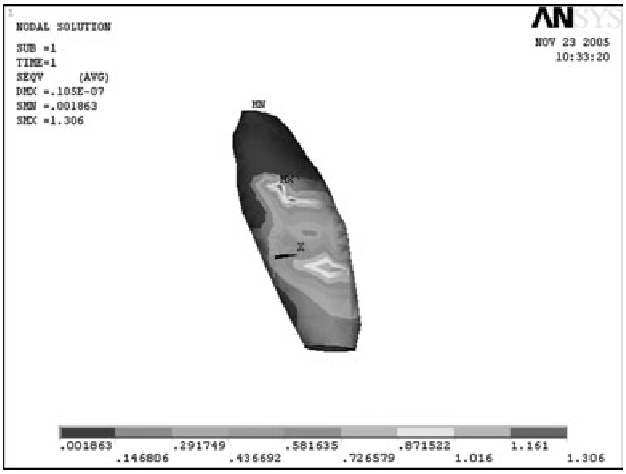

Fig. 9. Stress on the central incisor (model 2).

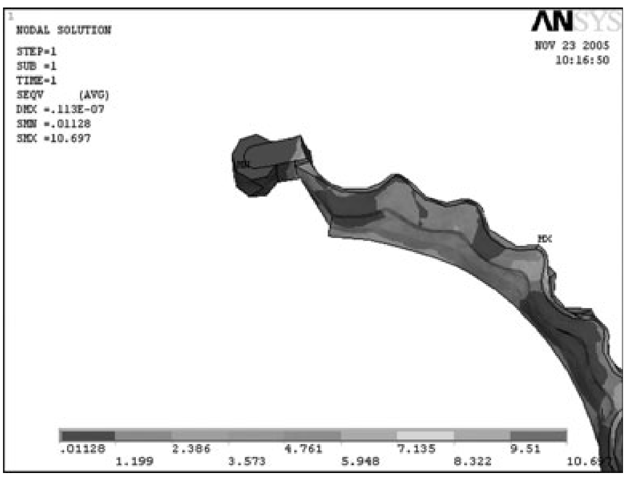

Fig. 10. Stress on the lingual guide plane with attachment.

conventional von Mises stress pattern in the obturator prosthesis with extracoronal attachment and the remaining teeth (model 2).

The palatal stress for the two designs was both located in the anterior area and adjacent to the defect (Figs 4 and 7). The highest stress value of model 1 and mole 2 was 13·1, 19·9 Mpa respectively.

For both models, stress distribution was uniform in the remaining posterior teeth with almost the same stress value, which were relatively higher than that in the anterior teeth (Figs 5 and 8). The highest stress value of model 1 and mole 2 was 11·25, 11·38 Mpa respectively.

And at the central incisor region adjacent to the attachment, an area of stress concentration was found at the mesial surface of the central incisor, with a maximum stress value of 1·306 Mpa (Fig. 9). While for model 1, it was also found that the mesial surface of the central incisor, with a maximum stress value of 0·582 Mpa (Fig. 6).

As for the continuous lingual guide plane with attachment, the stress concentrations were found at the junction of the attachment and the lingual guide plane and the anterior part of the lingual plane, especially at the position between canine and premolar. And the maximum stress value was 10·7 Mpa (Fig. 10).

Discussion

Because of the inadequate prosthesis support in the maxillectomy patient, stress distribution to both the palate and the remaining teeth is optimal for the health of the remaining structures. Based upon the findings of this study, for both models, stress concentration was seen in the anterior area of the palate and the remaining teeth, especially the posterior teeth, which also supports the findings found in previous studies (5, 8). However, the highest stress value of model 2 was higher than that of model 1 by about 6·8 Mpa. On one hand, these findings all demonstrate that the design of the obturator attachment framework in this study are in accordance with the established design principles for the restoration of maxillary defects. On the other hand, it was also indicated that more consideration should be taken into to preserve the remaining structures as much as possible when attachment framework was applied.

Stress concentration was also seen at the junction of the attachment and the lingual guide plane and the anterior part of the lingual guide plane, which may reduce the life of the abutment and cause adhesion failure. This occurrence could be explained by the creation of a dynamic fulcrum line during loading. The maximum stress value in the lingual guide plane was 10·7 Mpa, which was lower than adhesive strength of acid-etched enamal resin (16–20 Mpa) and yield strength of the chrome–cobalt alloy(692 Mpa), according to the literature (9). And it was also found that the maximun value of the central incisor with attachment was almost twice as that of in model one. Therefore, it is suggested to splint the two incisors together. It is also strongly recommended that rest seats must be developed to allow the stress to be transferred to the long axis of the abutment (1, 2, 5, 8). To accommodate for the obturator and reduce the stress on the abutment teeth, it is suggested that a resilient attachment be selected (1, 2). The Mini-SG/F attachment used in this study has nylon washer between the male and female parts which not only can give a cushion effect but also be easily changed to maintain the retentive force due to wear.

In this study, a continuous lingual guide plane from the central incisor to the second molar with an attachment on central incisor was designed. The use of attachment on the tooth adjacent to the defect can provide adequate retention and better aesthetics of the prosthesis. The purpose of guide plane was not only to modify the abutment contours, but more importantly to serve as splint. This kind of design may prolong the life of the abutment and lead to a successful prosthodontic rehabilitation for maxillary defect.

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