Comparative Study of Different Conventional Dental Implant Numbers on Zygomatic Implant Stability – A Finite Element Analysis

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ABSTRACT

Background: Zygomatic dental implants are extensively used for the treatment of severely edentulous atrophic maxillae as an alternative to the previous protocol treatment by bone grafting. In order to achieve a high stability in supporting the prosthesis, these implants are commonly used in conjunction with conventional dental implants placed in the anterior region. However, there is no consensus found on the effects of different numbers of conventional dental implants towards bone stress and zygomatic implant stability. Through this study, three-dimensional (3D) models of craniofacial including soft tissue and prosthesis were constructed from computed tomography (CT) image datasets. The implant models were developed using computer-aided design (CAD) software and all models were analyzed via finite element analysis (FEA) software. A 230 N of vertical occlusal load was applied on the top surface of prosthesis in the first molar region and a masseter load of 300 N was applied at the zygomatic arch. Objective: To investigate the effects of different number of anterior conventional dental implants – 0, 1 and 2, for stress and displacement distribution within bone and zygomatic implant body, respectively, by using 3D FEA. Results: The result showed that the stability of zygomatic implant could be secured by the placement of conventional dental implants in the premaxillary region. Conclusion: The use of one conventional dental implant is preferable although it has significantly increased the bone stress magnitude for about 1.5-fold. The conventional dental implants have also reduced the tendency of zygomatic implant to highly displace from its original position.

INTRODUCTION

The success rate of endosseous dental implants in the posterior region of maxilla is significantly lower as compared to the other regions in the jaws due to low availability of bone volume as a result of high bone resorption (Meyer et al., 2001, Sadowsky, 2007, Corrente et al., 2009). This situation could also be associated by a poor bone quality and lower bone density of the maxilla than the mandible. An alternative method has thus been suggested to treat severely atrophic posterior maxillae by an advance surgical procedure of bone augmentation where the apparent problem of insufficient bone height may be reduced by this procedure (Meyer et al., 2001, Cordaro et al., 2010, Al-Khaldi et al., 2011). Although this procedure can improve the configuration for potential placement of implant to the affected maxillae, a lower implant success rate has been reported as compared to the non-grafted maxillae owing to harvested bone morbidity (Palmer, 2005). On top of that, the bone augmentation procedure also requires a long treatment time and longer healing time period (Aparicio et al., 2008). Therefore, a new alternative for the treatment of atrophic maxillae was introduced by Bränenmark System® in 1988 utilizing zygomatic implant to minimize complications caused by the bone augmentation procedure (Aparicio et al., 2008, Aparicio et al., 2010a, Aparicio et al., 2010b).

Zygomatic implant was initially intended to rehabilitate the maxillectomy patients owing to tumour resection, trauma or congenital defects. However, the function of this implant had been expanded for rehabilitation of edentulous resorbed maxilla patients and has recorded a high survival rate ranges from 98.4% to 100% based on numerous clinical follow-up studies (Ahlgren et al., 2006, Aparicio et al., 2006, Duarte et al., 2007, Aparicio et al., 2008). The insertion path of zygomatic implant is usually from the alveolar ridge bone in the second premolar or first molar region, going through maxillary sinus or its wall into the zygomatic bone.
According to Nkenke et al., the success of implants placed in the zygoma could be achieved by crossing the implant through four cortical layers (Nkenke et al., 2003). This is supported by Kato et al. who found the presence of wider and thicker cancellous bone at the apical end of the fixture that could be used to promote initial fixation (Kato et al., 2005).

From biomechanical point of view, zygomatic implants have a high tendency to bend under horizontal loading due to increase in implant length when compared to conventional dental implants. The bending effect may also be associated by insufficient bone quantity available in the maxillary alveolar crest to retain the coronal part of zygomatic implant body. The most common treatment planning is by utilizing one zygomatic implant placed bilaterally together with at least two conventional dental implants located in the anterior region for additional retentions. For a severe bone resorption, two or more zygomatic implants that placed bilaterally without any retention by conventional dental implants anteriorly are preferable for the treatment option.

To the best of authors’ knowledge, there is no specific study has been found, to date, to address the strength of retention by conventional dental implants for the zygomatic implant stability. It is therefore a necessity for the present study to highlight the role of anterior retention implants for the stability of prosthetic restoration.

MATERIALS AND METHOD

I. Three-dimensional Craniofacial Model Construction:

A series of CT image datasets of a real complete denture wearer with a high degree of maxillary bone resorption was utilized to generate 3D model of bones, mucosa soft tissue and prosthesis using an image-processing software of Mimics/Magics 10.01 (Materialise, Leuven, Belgium). The bone model was assumed to be symmetrical for both sides, thus, only one side of the model would be analyzed. The selected region of interest was on the left side covering the maxillary alveolar bone, palatal side, infrazygomatic crest, temporal and frontal processes, zygomatic bone and the orbital floor surface. The cortical layer of maxillary alveolar bone had a thickness ranging from 1.4 to 2.2 mm.

A partial prosthesis with flange was modeled based on the original patient’s complete denture with 1.5 to 3.5 mm in thickness, 12.5 to 19.1 mm in width and 15.4 to 18.4 mm in height. The prosthesis model used in the present study was a fixed restoration type which tightly connected to the implant abutment by screws. The gap existed along the maxillary arch between the palatal surface of bone and the inside surface of complete prosthesis was used to develop a soft tissue model with a thickness ranging from 0.4 to 5.58 mm.

II. Three-dimensional Implant Model Construction:

A 3D CAD software of SolidWorks 2009 (SolidWorks Corp., Concord, Massachusetts, USA) was utilized to develop the implant models. The construction of implant model required a matched abutment to connect the implant body to the prosthesis. Therefore, one 46.5 mm zygomatic implant body with a diameter of 4.5 mm and a straight multi-unit abutment from Brånemark System® (Nobel Biocare AB, Goteborg, Sweden) have been modeled for the posterior anchorage as depicted in Figure 1. For the conventional dental implant, a 4.0 mm x 10.0 mm together with an angled multi-unit abutment 30° were chosen from the same manufacturer.

III. Virtual Surgery Simulation:

All reconstructed bone and implant models were individually exported as surface triangular elements in stereolithography (STL) format into Mimics/Magics software to perform the implantation procedures virtually. The conventional dental implants were placed adjacent to the lateral incisor or first premolar region whereas the zygomatic implant was located in the first molar region. The implant configurations were in equally distributed within the arch to achieve optimal support. As a result, three different cases were created – Case 1 (without conventional dental implant support), Case 2 (one conventional dental implant support) and Case 3 (two conventional dental implants support) as shown in Figure 2.

Fig. 1: Three-dimensional solid model of (a) conventional dental implant and (b) zygomatic implant.
All models had been converted from surface triangular into solid tetrahedral elements in the FEA software of MSC/MARC 2007 (MSC Software, Santa Ana, California, USA) with four nodes element type and three degrees of freedom. A single mesh pattern with 0.5 mm triangular element size has been assigned to all models, which is corresponding with the size used in Cattaneo et al. study (Cattaneo et al., 2003). For convergence purposes, the chosen element size was almost three times smaller than the one suggested by Lin et al. (Lin et al., 1999). The total number of tetrahedral elements for Case 1, Case 2 and Case 3 were about 383,000, 392,000 and 404,000, respectively.

IV. Contact Modeling:
All contacting surfaces of implant and prosthesis were simulated via friction coefficient, $\mu$, of 0.3 to represent the immediate loading function (Huang et al., 2008). As the threaded part of all implant designs were ignored through the preparation of models, it was accordingly simulated via contact properties with a friction coefficient of 0.5 to represent its strong attachment to the bone. The contact surfaces between cortical-cancellous and cortical-mucosa soft tissue were assumed to be as perfectly bonded by merging the nodes between the two contacted models, therefore, no frictional contacts were assigned.

V. Material Properties Assignment:
All the finite element models were assumed to be isotropic, homogenous, static and linearly elastic throughout the analysis. The material properties (Young’s modulus and Poisson’s ratio) of all models are defined as follow: cortical bone, 13,400 MPa/0.30 (Ujigawa et al., 2007); cancellous bone, 1,000 MPa/0.30 (Meyer et al., 2001); mucosa soft tissue, 2.8 MPa/0.40 (Cheng et al., 2010); prosthesis, 100,000 MPa/0.30 (Ujigawa et al., 2007) and implants, 110,000 MPa/0.33 (Geng et al., 2001).

VI. Loading Conditions:
A static vertical occlusal load of 230 N (Cheng et al., 2010) was applied on the top surface of prosthesis in the first molar region to represent the chewing action. Moreover, a masseter load of 300 N (Cattaneo et al., 2003, Miyamoto et al., 2010) with the force components of 62.12 N along the x-axis, -265.20 N along the z-axis and 125.69 N along the y-axis was applied to the muscle attachment area on the zygomatic bone. For the boundary conditions, the posterior (x-z plane), midsagittal (y-z plane) and top cutting planes (x-y plane) were constrained in the x, y and z directions to prevent any movements (Figure 3).

Fig. 2: Configuration of different conventional dental implant numbers used in (a) Case 1, (b) Case 2 and (c) Case 3 shown in occlusal view.

Fig. 3: Applied loadings and boundary conditions on the finite element models as viewed from (a) frontal and (b) sagittal plane.
Results:

I. Von Mises Stress Result within the Bones:

Our results showed that the placement of conventional dental implants in the anterior region of maxilla has significantly increased the magnitude of stress generated within the bones as depicted in Figure 4. This could be shown by a larger stress distribution area was developed where the stress was highly concentrated at the alveolar crest bone around zygomatic implant head and also within the zygomatic bone. The maximum stress (173.26 MPa – 270.33 MPa) in all cases was found within the zygomatic bone. The use of one (Case 2) and two (Case 3) conventional dental implants increased the maximum cortical bone stress about 36% and 31%, respectively as compared to model without conventional dental implant (Case 1). There was less discrepancy of stress value between Case 2 and Case 3 which merely 5%.

II. Displacement and Deformation of Zygomatic Implant:

When the results were interpreted in terms of displacement of zygomatic implant, it was clearly observed that Case 3 has shown considerably lower implant displacement value than the one in Case 2 and Case 1 (Figure 5). The highest value of zygomatic implant displacement was 0.0128 mm (Case 1), followed by 0.0119 mm (Case 2) and 0.0057 mm (Case 3). These results were in accordance with the deformation of implant body where the most significant bending effect was noted in Case 1, Case 2 and the least in Case 3. The coronal part of implant body showed a greater deformation than the apical part towards buccal and mesial direction.

Discussion:

Prosthetic design plays a vital role in determining the success of zygomatic implants either in a short-term or long-term performance evaluation. Among parameters majorly contribute in the prosthetic restoration associated with zygomatic implants are stability, precision and barrier. The prosthetic design stability is defined as the potential of bridge framework to sustain the implants position by having minimum implant movement under physiological function whilst the precision is referred to the strength of connecting screw joints between prosthesis and abutment. The design criteria of prosthetic restoration have also to decrease the bending moments as the bending moments may cause the deformation of implant body that leading to the failure of implants or screw loosening.

Based on the results, the restoration of zygomatic implant together with conventional dental implants in the anterior maxilla has considerably increased the maximum bone stress magnitude approximately 1.5-fold. The increase in bone stress might be due to the presence of more opening holes for the placement of implants which allowing internal stress to concentrate at the sharp edges relevant to the coronal part of implant body. In comparison, the placement of one and two conventional dental implants exhibited less significant difference of bone stress value (5%) in which therefore, it is suggested that only one conventional dental implant (Case 2) is preferable for the additional retention anteriorly. The rationale behind this is also in relation to reduce the
treatment cost as well as to avoid bone damage due to high stress concentration. According to Ujigawa et al., the combination of zygomatic and conventional dental implants could distribute the functional loading, however, the stress concentration at the implant-abutment connection could not be avoided under both vertical and lateral loadings (Ujigawa et al., 2007). The present results also parallel with literatures where at least two implants are required in the anterior maxilla for an optimal prosthetic components stabilization, considering full dental arch restoration (Ujigawa et al., 2007, Maló et al., 2008, Stiévenart and Malevez, 2010).

In terms of implant displacement, it is noteworthy that the increase in conventional dental implant numbers has significantly decreased the tendency of zygomatic implant to move from its original position. The additional implants in the anterior region of maxilla may secure the zygomatic implant position by preventing the rotational load effects that could initiate rotational displacements. On top of that, the implants can also reduce the bending moment effects on zygomatic implants as more stresses are dissipated and spread out in a larger region. According to Stievenart et al., the success rate of zygomatic implants is highly dependent on the cortical bone anchorage (Stiévenart and Malevez, 2010). The zygomatic implant body in all three cases have a low potential to failure as the value of micromotion between 50 and 150 µm could negatively influence osseointegration and bone remodeling at the bone-implant interface (Javed and Romanos, 2010). Moreover, the apical part of implant body showed less deformation when compared to the coronal part that possibly due to a high strength of anchorage in the zygomatic bone (Nkenke et al., 2003).

In all models tested, the highest stress value was recorded within the zygomatic implant body. This could be probably due to a high titanium alloy modulus of elasticity of 110,000 MPa as compared to the bones. The maximum stress values generated within the zygomatic implant bodies have no tendency to the implant failure as titanium alloy is known can tolerate stresses up to 900 MPa (Koca et al., 2005).

Conclusion

In conclusion, the prosthetic restoration of zygomatic implants associated with the treatment of severely atrophic maxillae could be more stable if the implants are rigidly connected with the conventional dental implants in the anterior region. The increase in conventional dental implant numbers is proportional to the bone stress result whilst the reverse is observed for the displacement of zygomatic implant.

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REFERENCES


