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Original research

Biomechanical analysis of maxillary prosthodontic reconstruction using implants after resection for maxillary cancer

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ABSTRACT

Objective: This study analyzed stress distribution of the occlusal force in craniofacial structures around osseointegrated implants and in dental implants when maxillary reconstruction was performed using dental implants after maxillary resection. The resection because of maxillary cancer occur many physical changes such as aesthetic damage, dysarthria, and dysfunction. The patients' quality of life (QOL) deteriorates by these changes.

Methods: We constructed a three dimensional solid model using Mimics® (Materialise) based on Digital Imaging and Communications in Medicine date (DICOM date) of the maxillofacial and cranial bones obtained from a computed tomography (CT) image of a patient with edentulous maxilla.

Results: The following four defect region patterns were designed; right maxillary molar, hemimaxilla, full maxilla, and normal. Maxillary prostheses were designed with single implant in the zygomatic bone on the affected side and 1–2 implants in the maxillary alveolar bone on the affected or unaffected side based on All-on-4® treatment concept system. In case of hemi- and full-maxillary resection, our designs were not effective.

Conclusions: When planning maxillary prostheses, the chewing ability and denture weight should be considered. We considered that these elements may be improved oral functions after surgery.

1. Introduction

The resection because of maxillary cancer including the maxillary bone causes many changes in anatomical structures, resulting in many disorders. Oral cavity after resection is communicated with nasal cavity and maxillary sinus due to missing teeth and defected maxillary bone, and, therefore, patients have dysarthria and dysfunction [1,2]. Severe aesthetic damage caused by maxillary resection prevents patients from returning to work and deteriorates patients' QOL. Therefore, it is important to improve patients' QOL as well as keep the cancer under control. The condition of hard and soft tissue preservation after resection affects the functional improvement of craniofacial reconstruction. In recent years, maxillary prostheses using dental implants have been chosen to improve dysfunctions [3]. For the extensive maxillary defect, not only dental implants but also zygomatic implants are used on the affected side [3]. However, the success rate of dental implants after resection is lower compared with standard dental implants. The normal anatomical structures are lost due to resection, resulting in biomechanical changes. This is considered as one of the reasons for low success rate. Although there have been some reports about using implants for maxillofacial prostheses in recent years, most of these cases are in the mandible, and there are few reports in the maxilla. There are also few reports on the effect of zygomatic implants that allow marked functional improvement.

In the present study, maxillary defect patterns after resection were predicted using simulation models. Frequent defect patterns in the clinical settings were chosen. Several models were fabricated on the computer using patient's CT, and maxillary prostheses with dental implants were designed. This study analyzed stress distribution of the occlusal force in craniofacial structures around osseointegrated implants and in dental implants when maxillary

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reconstruction was performed using dental implants after maxillary malignant tumor resection, and investigated the utility of dental implants as supporting system of maxillary prostheses.

2. Materials and methods

2.1. Construction of craniofacial bone model

A three dimensional finite element solid model of the human skull was constructed based on the CT data [4,5] obtained from a 68-year-old Japanese male with edentulous maxilla (Fig. 1). The craniofacial area was scanned using a clinical CT scanner (SOMATRON Plus 4 Volume Zoom, Simens AG, Erlangen, Germany) in the transverse plane with both a slice thickness and slice increment of 1.00 mm, and 55 images were obtained.

Mimics® (Materiarise, Leuven, Belgium) was used to generate three dimentional external shapes of craniofacial and alveolar bones. Smoothing and wrapping procedures were performed using 3−matic® (Materiarise, Leuven, Belgium), and a solid models with smooth surface were fabricated. The reconstructed areas included maxilla, frontal sinus, maxillary sinus, nasal bone, and orbital surface. The model construction areas included the lower part of the frontal bone and anterior part of the mastoid process.

The base model was healthy edentulous maxilla, and maxillary defect models after right maxillary malignant tumor resection were fabricated. Based on the classification of Okay [6], four STL models with the following maxillary defect patterns in which implants are frequently selected to fabricate maxillary prosthesis in the clinical settings were fabricated: Class 1B; maxillary molar defect, Class 2; hemi-maxillary defect, Class 3; full-maxillary defect, and normal model. The output data were transferred to Solidworks® three dimensional computer-aided design software (SolidWorks Corp.,Concord,MA,USA) for conversion to a finite-element solid model (Fig. 2).

2.2. Implant model and Maxillary prosthesis models

Bra◦nemark System® (Nobel Biocare AB,Geteborg,Sweden) implants were used in the present study. Multi-unit abutment RP, standard implants with 3.75 mm × 13.0 mm in diameter and 3.0 mm in height were used in the alveolar bone, and multi-unit abutment zygomatic implants with 3.75 mm × 40.0 mm in diameter and 3.0 mm in height were used in the remaining zygomatic bone of the edentulous maxilla. The superstructure was constructed bar of 10 mm × 8 mm in size [7] that the shape of a superstructure was symmetrical horseshoe-shaped gold alloy bar of 10 mm × 8 mm in size.

Maxillary prostheses models with different number of dental implants were prepared for the right maxillary defect. The number of implants and implant placement site were planned based on all-on-4® treatment concept in the remaining alveolar bone [8,9]. Two implant placements were planned in the maxillary lateral incisor and second premolar. In the right maxillary defect, implant was placed in the zygomatic bone of the affected side. It was called a zygomatic implant. Affected side was R, and unaffected side was L. For each defect pattern, four standard implant placements were planned in the alveolar bone of the bilateral maxillary incisors and second premolars in the normal bone model. Class 1B; In the molar defect model, 3 standard implant placements were planned in the alveolar bone of the lateral incisor and second premolar on the unaffected side, and the lateral incisor on the affected side. One zygomatic implant placement was planned in the remaining zygomatic bone on the affected side. Class 2; In the hemi-maxillary defect model, 2 standard implant placements were planned in the alveolar bone of the lateral incisor and second premolar on the affected side. One zygomatic implant placement was planned in the remaining zygomatic bone on the affected side. Class 3; In the full-maxillary defect model, 2 zygomatic implant placements were planned in the remaining bilateral zygomatic bone. Zygomatic implants were tilted 90° relative to the resection plane, and dental implants were tilted 90° relative to the vertical plane. Craniofacial and maxillary prosthesis models were observed to be simultaneously related, and transferred to a finite-element program (COSMOS/Works, Structural Research & Analysis Corp., Los Angeles, CA, USA) for mesh generation. The number of triangles needed to be markedly reduced to clearly describe the external shape. The results of the mesh generation were approximately 233,000 total elements and 360,000 nodes. The average element size was 3.0 mm for the craniofacial model and 1.0 mm for the implant model. The mechanical properties of the components of these models were based on our previous class studies [8,9].

3. Loading

For the 4 maxillary defect patterns, stress was applied in the following two regions where the same level of stress concentration as Ujigawa's study was expected [8]. Craniofacial and maxillary prosthesis models were craniofacial bone and implant models. The measuring points in the craniofacial model were maxillary alveolar bone and zygomatic bone surrounding the implants, and that in the implant model was fixture-abutment joint. The boundary condition was full constraint at the skull and the back of the head. For the top cutting plane, the restraint was chosen to simulate the presence of the rest of the skull. For boundary conditions, movement was restricted symmetrical to the midsagittal plane. A 300 N of posteroinferior stress was applied from the zygomatic arch along the masseter muscle to simulate mastication [10]. Loading conditions included 150 N of the vertical load on the superstructure of the implant model, and 50 N of the lateral load on the lateral surface of a superstructure [5,11]. Comparative stress analysis was performed using the three dimentional finite-element method for calculating the von Mises stress (Fig. 3).

4. Results

Craniofacial bone model construction (Fig. 4)

Stress distribution of the surrounding maxillary alveolar bone and zygomatic bone

1) Under a vertical load, a higher stress was observed in the maxillary lateral incisor in the normal case. Class 1B; Stress was the highest (12.5 MPa) in the maxillary lateral incisor on the affected side. Class 2; There was no stress concentration. Class 3; In the full-maxillary defect, a significant stress concentration was observed in the bilateral zygomatic bones (76.0 and 89.3 MPa).
2) Under a right lateral load, a higher stress was observed (9.8 MPa) in the maxillary second premolar in the normal case. Class 1B; Stress was the highest (13.3 MPa) in the maxillary lateral incisor on the affected side. Class 2 (hemi-maxillary defect) and Class 3 (full-maxillary defect); Stress were 21.6 and 31.0 MPa respectively in the zygomatic bone on the affected side, suggesting a higher stress in Class 3.
3) Under a left lateral load, the highest stress concentration was observed in the maxillary second premolar in all cases. There was no stress concentration in the zygomatic bone on the affected side.

Implant model and Maxillary prosthesis models (Fig. 5)

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