

BIOMECHANICAL STUDY OF DIFFERENT SURGICAL APPROACHES OF
ZYGOMATIC IMPLANT TO TREAT ATROPHIC MAXILLA PATIENTS

MUHAMMAD IKMAN BIN ISHAK

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Biomedical)

Faculty of Health Science and Biomedical Engineering
Universiti Teknologi Malaysia

JUNE 2012

This thesis is dedicated to Abah, Ma, Abang Long, Abang Ngah, Abang Chik, Abang Lang, Iki and Ikmal, who offered me unconditional love and support throughout the completion of this thesis.

ACKNOWLEDGEMENT

First and foremost, all praises be to Allah, the Almighty, the Benevolent for His blessings and guidance for giving me the inspiration to embark on this project and instilling in me the strength to see that this thesis becomes a reality.

I would like to deliver my deepest appreciation and gratitude to Assoc. Prof. Ir. Dr. Mohammed Rafiq bin Dato' Abdul Kadir, my project supervisor, for his intellectual and invaluable guidance, patience, encouragement, endless support and words of inspiration, who has taught me the meaning of hard work that eventually contributes to the success of this study. I also take this opportunity to express my sincere gratitude to Assoc. Prof. Dr. Noor Hayaty binti Abu Kasim and Dr. Eshamsul bin Sulaiman for their guidance, constant support, clinical tips and useful suggestions throughout my study. A bunch of thanks to all my batchmates and friends especially from Medical Implant Technology Group (MediTeg) who were always willing to lend a helping hand. Thanks for the sweetest memories, for the strength, for the gags and for the thoughts.

Never-ending loves to my mother, Shamshiah binti Abd. Razak, my father, Ishak bin Ishari and all my siblings who are the courage that I need to live, the air that I need to breathe, and the cure against my pain. Thank you all!

ABSTRACT

A comparative analysis was made between two different surgical approaches, the intrasinus and the extramaxillary, for the placement of zygomatic implants to treat atrophic maxillae patients. The introduction of the extramaxillary approach was claimed by some quarters to reduce implant complications caused by inappropriate emergence of the implant head. However, implant failures from this surgical approach has been reported in literature. This study utilizes the finite element technique to analyse the strength of implant anchorage for both approaches in various occlusal loading locations and directions. Three-dimensional models of the human craniofacial structures surrounding a specific region of interest, soft tissue and framework were developed using computed tomography image datasets. The zygomatic and conventional dental implants were modelled using computer-aided design software and positioned according to the respective surgical approach. The bone was assumed to be linear isotropic with a stiffness of 13.4 GPa, and the implants were made of Ti6Al4V titanium alloy with a stiffness of 110 GPa. Masseter muscle forces of 300 N were applied at the zygomatic arch, and occlusal load of 150 N were applied onto the framework surface. The results showed that the intrasinus approach demonstrated more satisfactory results under various occlusal loading locations and, hence, could be a viable treatment option. However, the technique resulted in more stress increase to sustain loads in the oblique direction. The introduction of extramaxillary approach, on the other hand, could also be recommended as a reasonable treatment option, provided some improvements are made to address the cantilever effects as exhibited by the 30% higher stress within the zygomatic implant than those in the intrasinus approach. The technique also caused an increase in motion of prosthetic components under simulated masticatory loadings.

ABSTRAK

Analisis perbandingan telah dilaksanakan di antara dua jenis pendekatan pembedahan yang berbeza, *intrasinus* dan *extramaxillary*, untuk penempatan implan tulang pipi bagi merawat pesakit yang kehilangan kuantiti tulang rahang atas. Pengenalan pendekatan *extramaxillary* telah didakwa oleh sesetengah pihak untuk mengurangkan komplikasi implan yang disebabkan oleh ketidaksesuaian kemunculan kepala implan. Walaubagaimanapun, kegagalan implan daripada pendekatan pembedahan ini telah dilaporkan dalam kajian terdahulu. Kajian ini menggunakan kaedah unsur terhingga untuk menganalisis kekuatan pautan implan untuk kedua-dua pendekatan dalam pelbagai arah dan lokasi beban kunyahan. Model tiga dimensi struktur tengkorak manusia di sekitar rantau tertentu, tisu lembut dan gigi gantian dihasilkan menggunakan dataset imej tomografi berkomputer. Model implan tulang pipi dan implan gigi konvensional direka menggunakan perisian rekaan berpandukan komputer dan diposisikan mengikut pendekatan pembedahan yang berkenaan. Tulang dianggap memiliki sifat isotropi linear dengan ketegaran 13.4 GPa, dan implan diperbuat daripada aloi titanium Ti6Al4V dengan ketegaran 110 GPa. Daya-daya otot *masseter* sebanyak 300 N dikenakan pada lengkungan tulang pipi, dan beban kunyahan sebanyak 150 N dikenakan ke atas permukaan gigi gantian. Keputusan menunjukkan bahawa pendekatan *intrasinus* mempamerkan keputusan yang lebih memuaskan di bawah pelbagai lokasi beban kunyahan dan oleh itu, berupaya untuk digunakan sebagai rawatan pilihan. Walaubagaimanapun, teknik ini telah mengakibatkan peningkatan tegasan yang lebih untuk menampung beban dalam arah serong. Pengenalan pendekatan *extramaxillary*, sebaliknya, boleh juga disyorkan sebagai rawatan pilihan yang munasabah, dengan syarat beberapa penambahbaikan dilakukan untuk menangani kesan juluran seperti yang dipamerkan oleh tegasan 30% lebih tinggi dalam implan tulang pipi berbanding implan dalam pendekatan *intrasinus*. Teknik ini juga menyebabkan peningkatan dalam pergerakan komponen gigi gantian di bawah simulasi beban-beban kunyahan.

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LIST OF SYMBOLS

μ	-	Friction coefficient
E	-	Young's modulus
ν	-	Poisson's ratio
x, y, z	-	Cartesian coordinates
%	-	Percentage
σ	-	Stress
$^{\circ}$	-	Degree

LIST OF ABBREVIATIONS

<i>Al</i>	-	Aluminium
<i>AMA</i>	-	Angulated Multi-unit Abutment 30°
<i>ANS</i>	-	Anterior Nasal Spine
<i>Ave</i>	-	Average
<i>B</i>	-	Buccal
<i>CAD</i>	-	Computer-Aided Design
<i>C11</i>	-	Conventional implant placed in the left side
<i>C12</i>	-	Conventional implant placed in the right side
<i>CT</i>	-	Computed Tomography
<i>D</i>	-	Diameter, Distance
<i>DICOM</i>	-	Digital Imaging and Communications in Medicine
<i>EA</i>	-	Extramaxillary Approach
<i>EQV</i>	-	Equivalent von Mises Stress
<i>F</i>	-	Force
<i>FDI</i>	-	Federation Dentaire Internationale
<i>FEA</i>	-	Finite Element Analysis
<i>FOS</i>	-	Factor of Safety
<i>GPa</i>	-	Giga Pascals
<i>h</i>	-	Height
<i>HA</i>	-	Hydroxyapatite
<i>IA</i>	-	Intrasinus Approach
<i>IC</i>	-	Infrazygomatic Crest
<i>IF</i>	-	Infraorbital Foramen
<i>INF</i>	-	Incisive Foramen
<i>Ju</i>	-	Jugale

<i>L</i>	-	Lingual, Load, Length
<i>LFP</i>	-	Left Frontal Process
<i>LTP</i>	-	Left Temporal Process
<i>M</i>	-	Moment
<i>Max</i>	-	Maximum
<i>Md</i>	-	Midsagittal
<i>mm</i>	-	Millimeter
<i>MPa</i>	-	Mega Pascals
<i>MSL</i>	-	Maxillary Sinus Lateral
<i>N</i>	-	Newton, Nasal
<i>No.</i>	-	Number
<i>OF</i>	-	Orbital Floor
<i>PA</i>	-	Palatal Area
<i>PTBIF</i>	-	Plane Through the Bilateral Infraorbital Foramen
<i>RFP</i>	-	Right Frontal Process
<i>RTP</i>	-	Right Temporal Process
<i>SMA</i>	-	Straight Multi-unit Abutment
<i>t</i>	-	Thickness
<i>TMJ</i>	-	Temporomandibular Joint
<i>Ti</i>	-	Titanium
<i>V</i>	-	Vanadium
<i>w</i>	-	Width
<i>W</i>	-	Weight
<i>ZI1</i>	-	Zygomatic implant placed in the left side
<i>ZI2</i>	-	Zygomatic implant placed in the right side
<i>2D</i>	-	Two-Dimensional
<i>3D</i>	-	Three-Dimensional
<i>1st</i>	-	First
<i>2nd</i>	-	Second
<i>3rd</i>	-	Third

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The number of edentulous or toothless patients has shown an increase over the last decade [1-3]. The prevalence of edentulism is usually proportional to age or may even be due to tooth extraction [3-5]. Patients can be categorised into two; either fully edentulous or partially edentulous. The latter commonly caused by bone resorption in both jaws, upper (maxilla) and lower jaw (mandible). According to the national surveys conducted by the National Institute of Dental Research [4], the rate of edentulism increases at 4% per ten years in early adult years and increases to more than 10% per decade after the age of 70. The number of adult pronounced total edentulism of a single arch was few between the age of 30 to 34 years, however, it increased at the age of 45 to 11% and then remained constant after 55 years old to approximately 15% of the adult population. The data also showed that the edentulous maxilla was 35 times more frequent than the mandible. Traditionally, patients with edentulous maxillae and mandibles are treated via conventional, complete denture to restore aesthetics, functions (chewing and speaking) and comfort [1, 4]. However, there were report of dissatisfactions from denture wearers due to reduced comfort and inefficient oral functions [1, 6]. The report on upper denture dissatisfaction is higher compared to the lower denture application [1]. The use of

partial or complete dentures could also result in accelerated bone loss rather than maintaining it. This is due to the applied occlusal load which is transmitted to the bone surface causing a reduction in blood supply and the eventual bone loss [4]. A new alternative method has thus been introduced to rehabilitate edentulous atrophic bone patients with osseointegrated dental implants [1, 4, 7].

The osseointegrated dental implant is widely used either to treat complete toothless patients or just for a single restoration [6]. There are various concepts of dental implant application in clinical practice depending on specific cases. The use of dental implants could eliminate several problems faced by denture wearers hence improving their quality of life [1]. Among the advantages of implant-supported prostheses are preservation of bone and facial aesthetics, improving the phonetics, occlusion and retention of removable prosthesis as well as increasing the survival rates of prostheses [4]. Anatomical considerations in terms of bone quality and bone quantity play an important role to determine the types of rehabilitation using osseointegrated implants.

The treatment of edentulous maxillary arch through conventional method or total complete denture application is easier to perform compared to similar treatment for the mandibular arch [1]. However, the maxilla is a difficult arch to restore with osseointegrated implants due to its complex morphology and configuration. The limited bone quantity caused by bone resorption especially in the posterior region has resulted in a low implant success rate based on numerous clinical follow-up studies [8]. In comparison, the implant success rate in the maxilla is significantly lower when compared to the implant placed in the mandible [4, 9]. Maxilla possesses relatively poor bone quality and lower bone density compared to the mandible [2, 4, 9]. In addition, the anterior region is reported to have a higher bone density than the posterior region for both jaws. The quality of bone density in the edentulous site is crucial since it becomes a key factor in treatment planning, surgical approach, implant design, healing time and initial progressive bone loading during prosthetic reconstruction [4].

The loss of alveolar bone height in the posterior maxilla is likely a consequence of periodontal disease before tooth loss. The tooth loss in the posterior maxilla will result in a decrease of bone width and it is more common than the other regions of jaw. Naturally, the amount of available bone volume in the posterior maxilla is insufficient for implant placement. In order to increase bone volume for dental implant placement in that region, an advanced surgical technique of bone augmentation has been suggested [9-10]. The apparent problem of insufficient bone height can be reduced by this procedure. The augmentation procedure can be performed by harvesting some portion of bone usually from the iliac crest, mandible or other appropriate locations [11-12]. Onlay grafting, inlay grafting and sinus lifting are some of bone augmentation techniques that can be applied to the affected region. Although this procedure can improve the configuration for potential placement of implant to the affected maxillae, a lower implant success rate has been reported compared to the non-grafted maxillae [13]. Furthermore, the bone augmentation procedure also requires a long treatment time, longer healing time period and a possibility of harvested bone morbidity [14]. Therefore, a new alternative for the treatment of atrophic maxillae was introduced by Brånemark System[®] in 1988 utilising zygomatic implant to minimize problems or complications caused by the bone augmentation procedure [14-15].

Zygomatic implant was initially intended to rehabilitate the maxillectomy patients owing to tumour resection, trauma or congenital defects [14]. However, the function of this implant had been expanded for rehabilitation of edentulous resorbed maxilla patients. It is believed that the anchorage of implant can be achieved at other bone regions that are free from bone regeneration or remodelling [16]. Thus, the selection of zygomatic bone as implant anchorage site is appropriate, evaluated in terms of its anatomical as well as biomechanical aspect. The bone augmentation procedure can be eliminated or slightly reduced via the zygomatic implant approach because of the strength of zygoma arch to retain the implant and prosthesis in position successfully. Four types of surgical approach for zygomatic implant placement that are available in practice are intrasinus (original Brånemark), sinus slot (Stella), extrasinus and extramaxillary approach. In the intrasinus approach, the position of implant body has to be maintained at the maxillary sinus boundaries

resulting in a bulky dental prosthesis since the implant head emerges in a more palatal aspect [14, 17]. Extrasinus approach, on the other hand, mainly used to treat patients who have pronounced buccal concavity [14, 18]. In this approach, the zygomatic implant head will be positioned closer to the alveolar crest bone, and therefore, the size of prosthesis could be reduced. Extramaxillary approach is the latest surgical procedure introduced by dental maxillofacial surgeons [19]. This technique is significantly different to the other approaches because the implant body only anchors to the zygomatic arch bone. The emergence of the implant head will be more prosthetically correct compared to intrasinus or extrasinus approach. The main reason for the existence of various different surgical approaches for fixation of zygomatic implants are due to the appearance of implant head location causing mechanical resistance during mastication as well as for aesthetical outcome. The introduction of new surgical approach aimed at eliminating the drawbacks of the previous approach, however, several complications are still reported in clinical follow-up studies for all the four approaches [14, 18-19].

There are limited numbers of biomechanical studies on zygomatic implants, many of which have examined the success rate of the implants by clinical follow-up studies. Nearly in all reported clinical studies, the zygomatic implants were demonstrated to have more favourable success rates than standard implants placed in the similar region in maxilla. The cumulative success rate of zygomatic implant ranges from 98.4% to 100% during 1 to 10 years follow-up studies for classical surgical approaches [14]. There are fewer numbers of finite element studies that have investigated the biomechanical aspects related to the zygomatic implants. Many of them have concentrated on the performance of implant in maxillary defect restoration. More attentions are therefore needed to examine the performance of zygomatic implants biomechanically for different surgical approaches to treat severe edentulism cases. In clinical setting, the most common classical approach is the intrasinus whilst the new approach of extramaxillary was introduced to simplify all other protocols of zygomatic implant surgery.

There are various methods available to measure the stress distribution within peri-implant bone such as photo elastic model studies, strain gauge analysis and two-dimensional (2D) or three-dimensional (3D) finite element analysis (FEA). As FEA is a numerical procedure and requires several assumptions, it is imperative to assess the solution accuracy in terms of stress and strain distribution. Moreover, the procedure could also provide accurate representation of complex geometries and simple model modification [1, 7, 20-21]. It has also been proven as an acceptable method to evaluate dental implant systems accurately over other methods [7, 22-23]. The use of 2D FEA is not recommended to simulate clinical situation because of invalidity of model representation [21]. Therefore, 3D FEA is a more preferable technique to evaluate mechanical behaviour of bone and prosthetic components.

1.2 Problem Statements

To date, despite the reported high success rate of zygomatic implants, failures do occur regardless of the types of surgical approach used. The use of classical surgical approach of intrasinus could result in a higher complication as been reported in many clinical experiences [14, 18]. Feedback from patients normally regarding discomfort was identified as the main problem on the use of zygomatic implants. The bulky prosthesis may affect dental hygiene and increases the mechanical resistance [19, 24]. Complications of peri-implant soft tissues bleeding and increased in probing depth probably occur due to inappropriate position of zygomatic implant head and abutment [14]. In contrast, implant body mobility and fracture of abutment screw are among complications that have been reported by the use of latest surgical approach, the extramaxillary [19]. Most of the complications are mainly caused by insufficient primary stability achieved by zygomatic implant in supporting the prosthesis. On top of that, the role of alveolar ridge bone support is still questionable since the strength of zygomatic implant anchorage highly depended on zygoma cortical penetration [16]. It is important to highlight that every surgical approach introduced has its own unique characteristic in order to increase the

survival rate of zygomatic implants during physiological function. However, there is no specific indication has been found, to date, to point out the best approach for implant placement. A key factor for dental implant success or failure is dependent on stress transmission to the surrounding bone. Inappropriate loadings may result in stress concentration at bone region around implant and could lead to bone resorption. It is known that the vertical component plays a major contribution in masticatory loading. Conversely, the role of horizontal component cannot be compromised although its value is minimal especially when angled implant is used. Therefore, there is a necessity to consider different occlusal loading types, vertical and oblique loading in various directions to examine the performance of zygomatic implants in both approaches. The location of loading application on prosthesis was also being another important factor. In short, the statement of current problems can be summarised through the following questions:

1. Which surgical approach promotes better implant stability?

Complications reported on zygomatic implants are mainly associated with the biomechanical factors of the chosen surgical approach. High quality rehabilitation in terms of function, aesthetics and comfort is crucial with regard to a proper surgical approach selection.

2. What is the impact of various occlusal loading locations and directions on predicting the success rate of different surgical approach?

1.3 Aims and Objectives

Due to limited availability of data, there is no consensus in terms of the best surgical approach for placement of zygomatic implants. There is a necessity to determine the optimal biomechanical circumstances associated with zygomatic implants placed by different surgical approaches so that they can be admitted as a

better alternative treatment modality for severe atrophic maxillae. Follow-up clinical studies and trials alone cannot provide sufficient answers to the problems associated with implant instability. The bio-computational evidence through FEA is also required to explore the load transfer mechanism from zygomatic implant body to the surrounding bone based on stress distribution and implant deformation. Comparative biomechanical study between various surgical approaches can highlight their strengths and weaknesses and provide crucial information for potential improvement.

The objective of the study is to determine the effects of different surgical approaches of zygomatic implants installation on stress and displacement distribution within bones and prosthetic components using 3D FEA. The respective surgical approaches involve are the intrasinus and the extramaxillary approach.

Other than that, the biomechanical behaviour of bones and prosthetic components under different occlusal loading directions and locations are also examined. The magnitude of loadings among all models is identical to allow for a reasonable comparison. It is expected that variation of occlusal loading directions and locations exhibit a significant difference on the generated biomechanical criteria between both surgical approaches.

1.4 Scope of Study

Analyses performed in this study placed an emphasis on the treatment of edentulous maxilla patients with certain degree of resorption due to zygomatic implants. There were two surgical approaches investigated, the intrasinus and the extramaxillary approach. The implant-supported fixed restoration has been selected as the prosthetic restoration types and loaded by immediate functions. Three-dimensional model of cranial bone with a particular degree of resorption surrounding

the region of interest together with the framework and soft tissue were developed from computed tomography (CT) image datasets. The zygomatic and conventional dental implants were modelled using a computer-aided design (CAD) software, SolidWorks 2009. The implants were placed in the prepared bone site through a simulated implantation procedure using Mimics/Magics 10.01 which is an image-processing software. The prepared models were then exported into a finite element software, MSC/MARC 2007 to simulate the effects of masseter loading and different occlusal loading conditions on bones and zygomatic implants. The material properties for all finite element models were assumed to be isotropic, homogenous and linearly elastic throughout. Results of equivalent von Mises stresses and displacements are among the biomechanical aspects examined numerically and plotted by spectrum colouring scale.

1.5 Importance of Study

This study provides an improved understanding of the biomechanics of the treated atrophic maxilla through computational analyses to study the effect of stress distribution and displacement on bones, zygomatic implants and framework under various occlusal and masseter loading. The simulations utilised the meticulous finite element model to represent the clinical settings accurately and act as a prediction tool for the zygomatic implant stability from different surgical approaches for short-term or long-term evaluation.

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