

Preface

The number of edentulous or toothless patients has shown an increase over the last decade. The edentulism phenomenon usually occurs proportional to age or can be due to tooth extraction. 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 (The United States), the rate of edentulism increases at 4 % per 10 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 and 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. Traditionally, patients with edentulous maxilla and mandible are treated via conventional complete denture to restore esthetics, functions (chewing and speaking) and comfort. However, there were reports of dissatisfactions from denture wearers due to reduced comfort and inefficient oral functions. A new alternative method has thus been introduced to rehabilitate edentulous atrophic bone patients with osseointegrated dental implants.

The osseointegrated dental implant is widely used either to treat complete toothless patients or just for a single restoration. Among the advantages of implant-supported prostheses are preservation of bone and facial esthetics, improve phonetics, occlusion and retention of removable prosthesis as well as increasing the survival rates of prostheses. 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. 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. In comparison, the implant success rate in the maxilla is significantly lower when compared to the implant placed in the mandible. Maxilla

possesses relatively poor bone quality and lower bone density compared to the mandible.

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. The augmentation procedure can be performed by harvesting some portion of bone usually from the iliac crest, mandible or other appropriate locations. 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 maxillas, a lower implant success rate has been reported compared to the non-grafted maxillas. Furthermore, the bone augmentation procedure also requires a long treatment time, longer healing time period and a possibility of harvested bone morbidity. Therefore, a new alternative for the treatment of atrophic maxillas was introduced by Brånemark System® in 1988 utilising zygomatic implant to minimise problems or complications caused by the bone augmentation procedure.

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. It is believed that the anchorage of implant can be achieved at other bone regions that are free from bone regeneration or remodelling. 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. Extrasinus approach, on the other hand, mainly used to treat patients who have pronounced buccal concavity. 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. This technique is significantly different from 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.

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 1–10 years follow-up studies for classic surgical approaches. There are fewer number 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 attention is therefore needed to examine the performance of zygomatic implants biomechanically for different surgical approaches to treat severely edentulism cases. In the clinical setting, the most common classic 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 access 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. It has also been proven as an acceptable method to evaluate dental implant systems accurately over other methods. The use of 3D FEA is a more preferable than 2D technique to evaluate mechanical behaviour of bone and prosthetic components.

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 classic surgical approach of intrasinus could result in a higher complication as has been reported in many clinical experiences. 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 increase the mechanical resistance. Complications of peri-implant soft tissues bleeding and increase in probing depth probably occur due to inappropriate position of zygomatic implant head and abutment. In contrast, implant body mobility and fracture of abutment screw are among complications that have been reported by use of the latest surgical approach, the extramaxillary. 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. 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, to date, there is no specific indication 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 another important factor. In short, the statement of current problems can be summarized through the following questions:

- 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, esthetics and comfort is crucial with regard to a proper surgical approach selection.
- What is the impact of various occlusal loading locations and directions on predicting the success rate of different surgical approaches?

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 severely 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.

This text 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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