DESIGN AND SIMULATION OF A DENTAL IMPLANT FOR THE INDONESIAN POPULATION

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For you,

Mother and Father.

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ABSTRACT

The growing senior citizen population of Indonesia has led to an increase in cases of edentulism amongst the population there. Current dental implants are unsuitable due to morphological differences in the oral anatomy between people of European ancestry and Indonesian ancestry. This fuels the need for a dental implant to be designed specifically for the Indonesian population in mind. The objectives of this study are to design a new dental implant specifically suitable for the average Indonesian woman and to study its mechanical behavior under normal physiological loading conditions through the use of nonlinear finite element analysis (FEA) software MSC Marc™. The size of the dental implant is determined through statistical analysis of anthropometric data from five Indonesian women with ages from 46 to 59 years old. Four conceptual designs are generated, and only one is selected as the final design. A three – dimensional (3 – D) model of the dental implant is created by using the computer – aided design software (SolidWorks™). A 3 – D model of the posterior mandible is created by using CT – scan images. These two 3 – D models are combined inside an FEA software and their combined mechanical behavior is simulated. The results show that the equivalent von Mises stress on the implant is within acceptable limits. Furthermore, other results such as the maximum principal stress on the bone, maximum compressive stress on the bone, and maximum shear stress on the bone, indicates that a dental implant has been designed for the average Indonesian population which can perform reasonably well under normal physiological loading conditions with minimal risk of failure. Further studies are needed to verify this, but for now, the results show potential.

ABSTRAK

Populasi warga emas yang sedang meningkat di Indonesia telah menyebabkan peningkatan dalam kes – kes *edentulism*. Implan pergigian yang terdapat di pasaran ketika ini dikatakan kurang sesuai untuk mereka kerana wujudnya perbezaan morfologi di dalam anatomi oral di antara orang yang berketurunan Eropah dan Indonesia. Hal ini mencetuskan lagi keperluan untuk mereka bentuk satu implan pergigian yang direka khusus untuk warga emas Indonesia. Objektif – objektif kajian ini adalah untuk mereka bentuk implan pergigian yang baharu yang sesuai untuk digunakan oleh perempuan Indonesia yang biasa serta untuk mengkaji tingkah laku mekanikal implan tersebut di dalam keadaan bebanan fisiologi yang normal melalui perisian analisa unsur terhingga (FEA) tak linear MSC Marc™. Saiz implan pergigian itu ditentukan melalui analisa statistical ke atas data antropometri daripada lima orang wanita Indonesia yang berumur di antara 46 hingga 59 tahun. Empat reka bentuk konseptual yang dijana, dan hanya satu yang dipilih sebagai reka bentuk akhir. Satu model tiga dimensi (3 – D) implan pergigian itu telah dicipta dengan menggunakan perisian reka bentuk bantuan computer (CAD) SolidWorks™. Satu model 3 – D rahang bawah posterior telah dicipta berdasarkan imej – imej *CT – scan*. Kedua – dua model 3 – D tadi dicantum di dalam sebuah perisian FEA dan tingkah laku mekanikal mereka disimulasikan. Keputusan kajian ini menunjukkan bahawa tegasan von Mises setara yang dikenakan terhadap implan itu masih lagi berada pada julat yang boleh diterima. Keputusan – keputusan lain seperti tegasan principal maksimum pada tulang, tegasan mampatan pada tulang, dan tegasan ricih pada tulang menunjukkan bahawa sebuah implan pergigian yang boleh bertindak dengan baik di dalam keadaan bebanan fisiologi biasa dengan peluang kegagalan yang minima yang boleh digunakan oleh penduduk purata Indonesia telah berjaya dicipta. Kajian selanjutnya diperlukan untuk membuktikan kesahihan pernyataan ini, tetapi keputusan kajian ini amat memberangsangkan.

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LIST OF ABBREVIATIONS

3 – D	Three - dimensional
BIC	Bone – implant contact
CAD	Computer – aided design
CT	Computerized tomography
DICOM	Digital Imaging and Communication in Medicine
FEA	Finite element analysis
FEM	Finite element method
ROI	Region of interest
STL	Stereolithographic
USD	US Dollars

LIST OF SYMBOLS

$\varphi\ (x, y)$	field variable at spatial co – ordinate (x, y)
B	transversal diameter (breadth) of the skull
d	distance between the alveolar crest and mandibular canal
d_{mean}	mean distance between the alveolar crest and mandibular canal
I_C	cephalic index
L	anteroposterior diameter (length) of the skull
N_a	node a (referring to a particular node)
t	thickness of the alveolar bone
t_{mean}	mean thickness of the alveolar bone

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CHAPTER 1

INTRODUCTION

1.1 Overview of the Study

This chapter serves to provide a general overview on the themes of this research. It begins by describing a picture of the supply and demand of dental implants from an economic point of view and progresses to explain the inherent need to design a new implant specifically for the Indonesian population. Next, the objectives of this research, along with its scope is stated, before finally closing with a statement on the limitations of this research as a whole.

1.2 Present Context: The Economics of Dental Implants

The average lifespan for the average human being in the 21st century is now longer than it used to be compared to any other time since the dawn of human civilization. To put this into perspective, Roser (2016) wrote that a 5 – year old child could expect to live an average of 55 years in 1845 compared to 82 years in 2016, demonstrating an increase of lifespan by 27 years within a time interval of 171 years. This pattern is followed by most countries, as shown in Figure 1.1, which shows the child mortality rate in United Kingdom and Indonesia.

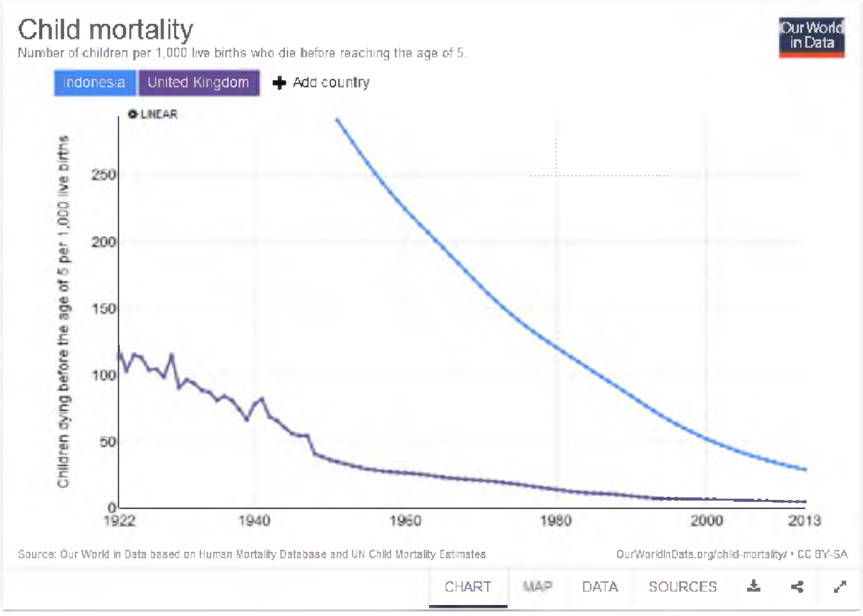

Figure 1.1 Child mortality rates in United Kingdom (in purple) and Indonesia (in blue) in the 20th century and the early 21st - century, expressed as the number of children per 1000 live births who die before reaching the age of 5 (Roser, 2016).

The 5 – year benchmark is used because average lifespans are calculated without taking child mortality rate into account. It remained obvious that these improvements do not happen by mere coincidence, but through the various improvements made in the field of medicine. One of the advances in medical technology which has contributed greatly to this increase is the development of dental implantology by a Swedish physician, Dr. Per – Ingvar Branemark.

As the global population continue to possess a longer lifespan, there will consequently be an increase in the demand on the ability of the dental profession to maintain oral health, whose scope also includes effectively treating the edentulous population. Edentulism is defined by Gilchrist (2016) to be ‘a condition where a person experiences a complete loss or partial loss of teeth’.

Although there is speculation that the rate of edentulism amongst the population is dropping, the increased number of people living past the onset of the elderly age offsets that number, thus resulting in an increase in the number of patients experiencing edentulism. In fact, the total number of edentulous arches is expected to reach 37.9 million by the year 2020. Consequently, this results in a rise in the number of patients requiring at least one full arch of tooth replacement. The global market for dental implants is currently estimated to be worth 3.4 billion USD, with expected growth in the coming years (Turkyilmaz and Soganci, 2015).

From an economic point of view, one of the factors affecting the feasibility of a dental implant is its manufacturing cost. The manufacturing cost of a dental implant depends on a few other factors such as the price of materials needed to fabricate the dental implant and the complexity of the design of the dental implant. The second factor, design, is to be the main focus of this research.

1.3 Problem Statement: Suitability of Dental Implants for the Average Indonesian Population

There are many factors affecting the suitability of a dental implant in a patient. This suitability, which is measured by the primary stability of the implant, is important as it provides an indicator for the functional lifespan of a dental implant. The primary stability of a dental implant is the mechanical stability obtained by the implant immediately after insertion. For the ideal dental implant, having a good primary stability means being able to provide strength, rigidity and resistance to movement of the implant before the gum tissue begins to heal (Elias et al., 2012).

The primary stability of the dental implant is very much affected by the design of the implant (Gehrke and Marin, 2015, Elias et al., 2012). The secondary stability is provided by osseointegration and requires the optimal amount of bone – implant contact (BIC) without the interposition of connective tissue. Both of these stabilities constitute the overall stability of the implant, and thus, contribute to its functional lifespan. Although there are studies which focus solely on studying the design and stability of dental implants, both by using simulation and experimental data (Wang et al., 2016, Bicudo et al., 2016), the data is collected based on the anthropometric data of the people residing in that particular region or country. Despite the similarities found in the overall pattern of mechanical behaviour of dental implants regardless of the anthropometric data of the subjects used to conduct the research in these papers, it becomes problematic when individual patients are considered.

Consider the edentulous Indonesian population, for instance. Due to distinct anthropometric differences between the Indonesian population and the African or European population, the dental implants manufactured in those countries, are unsuitable for their use. This results in a host of problems for the average Indonesian. To date, there have been no studies concentrating solely on the stability of dental implants in people of Indonesian descent. The particular focus of this research is on the design of a dental implant and the simulated mechanical behaviour of the designed implant which uses anthropometric data from the average Indonesian population.

1.4 Objectives of Study

There are two objectives which this study will hope to achieve, namely:

(1) To design a dental implant based on anthropometric data from the average Indonesian population.

(2) To study the mechanical behaviour of the designed dental implant by using finite – element analysis.

1.5 Scope of Study

The scope of this study is as follows:

(1) Computer – assisted design (CAD) of a new dental implant by using Solidworks™.

(2) Sizing of the dental implant through statistical analysis of anthropometric data from five patients.

(3) Construction of a 3 – dimensional (3 – D) model of a mandible from data taken from Universitas Airlangga Dental Hospital, Indonesia.

(4) Finite element analysis (FEA) of the combined implant – mandible model.

1.6 Significance of Study

This study will pave the way for the development of a dental implant which can be suitably used by the average Indonesian woman. The suitability here will be determined based on morphological characteristics, which will directly influence the initial stability of the implant. Through the results of this study, it is hoped that a locally – produced implant can be manufactured, which will then reduce the cost of expenditure of edentulous patients in Indonesia.

1.7 Limitations of Study

There are two limitations in this study, and they are as follows:

(1) The sample size is made up of only six women, with an age range of 46 to 59 years old.

(2) The model of the mandible is developed to cover only the region of interest i.e. the molar region.

The first limitation is due to the difficulty in securing medical consent when using biological data from living persons. Only six patients consented to having their data used for this study. The second limitation is due to the redundancy involved in developing models that are larger in size than necessary. If a larger model is developed, not only it will have no discernible effect on the final results (since only the area in the immediate vicinity of the dental implant will experience noteworthy changes), it will also greatly increase the computation time since a greater number of elements and nodes will be present.

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