PREDICTING THE BIOMECHANICS IN ARAMANY CLASS I OBTURATOR PROSTHESES USING DIFFERENT DESIGNS AND MATERIALS: A COMBINED FINITE ELEMENT MODELING AND EXPERIMENTAL STUDY

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UNIVERSITI SAINS MALAYSIA

2024

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by

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Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

March 2024

ACKNOWLEDGEMENTS

First, I am incredibly thankful to Allah, the most gracious creator of the universe, for giving me health, patience, and the ability to think and work to accomplish this work. I cannot find words to express my sincere gratitude and thanks to my supervisors, Prof. Adam Husein, Prof. Mohamed El-Anwar, Dr. Johari Abdullah, and Dr. Norwahida Yusoff, for their tremendous efforts, help, and encouragement in overcoming the obstacles along the way. I also thank all my supervisors, Assoc. Prof. Yanti Johari, Dr. Azirrawani Ariffin, Dr. Nafij Jamayet, and Dr. Ahmed Abbas, for their help in accomplishing this work. Special thanks must go to Dr. Belal Almarhoumy for his help during the photoelastic stress analysis. An enormous thanks must go to everyone in the Prosthodontic and Maxillofacial Laboratories in the School of Dental Sciences and the Mechanical Engineering Laboratory in the School of Mechanical Engineering, USM, for their assistance during all steps of the laboratory work. I am very grateful to both the Ministry of Higher Education and Universiti Sains Malaysia for funding this research with a Fundamental Research Grant Scheme [(FRGS), (FRGS/1/2022/SKK11/USM/01/3)] and short-term grant [(KHAS), (304.PPSG.6315661)], respectively.

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AP	Acrylic prosthesis
LDP	Linear design prosthesis
TDP	Tripodal design prosthesis
FTDP	Fully tripodal design prosthesis
AKP	ArylKetonPolymer
ANOVA	Analysis of variance
BioHPP	Bioactive High-Performance Polymer
CAD	Computer-aided design
CAM	computer-aided manufacturing
CBCT	Cone beam computed tomography
CT	Computed tomography
Co-Cr	Cobalt-chromium
DIC	Digital Image Correlation
DICOM	Digital Imaging and Communication in Medicine
FDP	Fixed Dental Prosthesis
FEA	Finite Element Analysis
FEM	Finite Element Model
IGES	Initial Graphics Exchange Specification
LM	Limited Maxillectomy
MFP	Maxillofacial Prosthesis
MPa	Mega Pascal
MRI	Magnetic resonance imaging
NURBS	Non-uniform rational B-spline
PAEK	PolyArylEtherKeton
PDL	Periodontal Ligament
PE model	PhotoElastic model

PEEK	PolyEtherEtherKeton
PEK	PolyEtherKeton
PEKK	PolyEtherKetoneKeton
PESA	Photoelastic Stress Analysis
PLM-1	Photoelastic Measurement
POM	PolyOxyMethylene
PMMA	Polymethylmethacrylate
PPKM	Pusat Pengjian Kejuruteraan Mekanik
PPSG	Pausat Pengajian Sains Pergigian
RCDP	Removable Complete dental Prosthesis
RDP	Removable Dental Prosthesis
RPD	Removable Partial Denture
RPI system	Rest, Plate, I bar gingival approaching clasp system
SG	Strain Gauge
SM	Subtotal Maxillectomy
STEP	Standard for the Exchange of Product Data
STL	Standard tessellation language
Ti	Titanium
TM	Total Maxillectomy
USM	Universiti Sains Malaysia
UTM	Universal Testing Machine
VM	von Mises
ZI	Zygomatic Implant

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RAMALAN BIOMEKANIK DALAM PROSTESIS OBTURATOR KELAS I ARAMANY MENGGUNKAN REKA BENTUK DAN BAHAN YANG BERBEZA: GABUNGAN KAJIAN PEMODELAN ELEMEN TERHINGGA DAN MAKMAL

ABSTRAK

Biomekanik mempunyai hubungan dengan kejayaan prostesis maksilofasial. Reka bentuk linear (LDP) dan tripod (TDP) adalah satu-satunya reka bentuk yang digunakan untuk MFP unilateral. Selain itu, kebanyakan penerbitan adalah berkaitan obturator berasaskan kobalt-kromium. Kajian ini meneroka biomekanik obturator kecacatan Kelas I Aramany menggunakan reka bentuk baru yang dinamakan tripodal sepenuhnya (FTDP) dan tujuh bahan berkaitan pengekalan, tekanan, dan ketegangan menggunakan analisis elemen terhingga (FEA), analisis tekanan fotoelastik (PESA), korelasi imej digital (DIC), dan mesin ujian sejagat. Sembilan model FE, 30 model resin epoksi (12 untuk PESA dan 18 untuk DIC), dan 54 kerangka yang dibahagikan kepada sembilan untuk AP, LDP, TDP, FTDP, berasaskan PEEK, dan MFP berasaskan bioton. Data mengenai pengekalan, PESA, DIC, dan FEA dikumpul dan dinilai untuk mengenal pasti perpindahan, tekanan, dan ketegangan dalam MFP dengan pelbagai reka bentuk dan bahan. Berkenaan dengan pengekalan, tidak ada perbezaan yang signifikan antara FTDP dan TDP dari segi pengekalan, tekanan, dan ketegangan. Berkaitan bahan-bahan, berasaskan logam menghasilkan pengekalan tertinggi, tekanan tertinggi pada abutments, dan tekanan dan ketegangan terendah di sisi yang rosak. MFP berasaskan bahan fleksibel menunjukkan pengekalan terendah, tekanan dan ketegangan terendah pada abutments sisi kontralateral, dan tekanan dan ketegangan tertinggi pada sisi yang rosak ($P<0.05$).

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ABSTRACT

There is a direct relationship between biomechanics and the success of maxillofacial prostheses (MFPs). The linear (LDP) and tripodal designs (TDP) are the only designs used for unilateral MFPs. Besides, most literature showed only Co-Cr-based obturators. This study explored the biomechanics in obturators for Aramany's Class I defect using a new design named fully tripodal (FTDP) and seven materials in terms of retention, stress, and strain using finite element analysis (FEA), photoelastic stress analysis (PESA), digital image correlation (DIC), and a universal testing machine. Nine FE models, 30 epoxy resin models (12 for PESA and 18 for DIC), and 54 frameworks divided into nine for AP retained with Adam's clasps, LDP, TDP, FTDP, PEEK-based, and biotone-based MFPs were fabricated from casts obtained from archived scanned human skull. The data on retention, PESA, DIC, and FEA data were collected and evaluated to identify the displacement, stress, and strain in the MFPs with assorted designs and materials. Regarding retention, there were no significant differences between FTDP and TDP regarding retention, stress, and strain. Regarding the materials, the metal-based produced the highest retention, the highest stress on the abutments, and the lowest stress and strain on the defective side. The flexible materials-based MFPs demonstrated the lowest retention, the lowest stress and strain on the abutments of the contralateral side, and the highest stress and strain on the defective side ($P<0.05$).

CHAPTER 1

INTRODUCTION

This section introduces the study, including its background, problem statement, research gap, objectives, scope, methodology, and significance in prosthodontics.

1.1 Background of the Study

Surgical ablation of malignancy results in acquired palatal defects. These palatal defects significantly affect patients in functional, aesthetic, and psychological terms (Ali *et al.*, 2015; Rogers *et al.*, 2016). Many classifications have been introduced into the literature to classify patients with palatal defects, with few available options for the prosthesis designs (Aramany, 1978; Brown *et al.*, 2000; Okay *et al.*, 2001; Futran & Mendez, 2006; Brown & Shaw, 2010).

One of the treatment options for palatal defects is the obturators. Obturators are the only options of choice to regain patients' functional, aesthetic, and psychological deficits related to maxillectomy surgery when surgical repair or fixed and implant-assisted prostheses are not accessible (Dhingra, 2012; Freitas *et al.*, 2012). These prostheses are frequently used to rehabilitate various maxillary defects, facial deformities, absent or deficient lips, open bites, and a lack of vertical dimensions. In addition, it is an economically feasible and noninvasive treatment option (Ohyama, 1986; Vojvodic & Jerolimov, 2001; Turkyilmaz, 2008; Balkaya *et al.*, 2014; Palmeiro *et al.*, 2015).

Although many classifications are available in the literature to classify palatal defects, few are available for prosthetic designs, such as those introduced by Aramany (Aramany, 1978). Of the six classes presented by the Aramany classification, the class I introduced describes the palatal defect that includes the teeth and palate to the midline, whilst the teeth on the contralateral side are available for retention and support (Aramany, 1978a). Besides the acrylic prostheses, two metal-based designs were introduced to treat this kind of defect, including linear (LDP) and tripodal (TDP) design prostheses. There was little effort to introduce a new design, possibly due to the lack of available abutments. Besides, limited studies introduced new base materials as a substitute for the Co-Cr-base. This study aimed to raise new prostheses with new designs and materials to replace current ones.

Photoelastic stress analysis (PESA) is an experimental method that uses epoxy resin to assess the stress qualitatively and quantitatively. Although it has been used extensively in dentistry, its use in the maxillofacial discipline was limited, possibly due to the required design's complexity (Pesqueira *et al.*, 2013; Pesqueira *et al.*, 2013). To overcome the shortcomings of PESA, finite element analysis (FEA) was extensively used in dentistry to simulate complicated structures. One of the objectives of this study was to use the FEA and PESA to identify the stress in the maxillofacial prostheses fabricated from assorted designs and materials.

Digital image correlation (DIC) is an experimental study identifying the strain in simple and linear structures in qualitative and quantitative data using special software (Palanca *et al.*, 2016; Tanasić *et al.*, 2016). However, its use in the maxillofacial prosthesis was limited mainly because of its inherited limitations. This study used DIC associated with FEA to identify the strain developed in the supporting structures and prosthetic components of different maxillofacial prostheses fabricated from different designs and materials.

1.2 Problem Statement

There is a direct relationship between the treatment success of patients with maxillofacial defects and the biomechanics of materials used for prostheses. The remaining abutments, the framework's bearing area, and the defect's base are the structures supporting the obturator. Because of the lack of these supporting structures, there is enormous pressure on the remaining components of the prosthesis. Abutment failure and fracture of the prosthetic parts are the main manifestations of this pressure because of the inability of the teeth, bone, and these components to withstand the exceeding loads. Introducing conventional and zygomatic implants to retain and support various MFPs has been scientifically validated. However, implants are not always appropriate for all patients because of the high cost, complexity, and medical conditions. Two well-validated designs (linear and tripodal) are currently being used to fabricate MFPs for cases of Brown class II-b (which is equal to Aramany's class I classification). The two designs' names were given depending on the support (but not retention) configuration. To the best of our knowledge, no study in the literature has been conducted to compare these designs in stress distribution, displacement, and retention for similar cases. Besides, no attempts were made to modify these designs to introduce a prosthesis that may show better retention and support and be more beneficial in stress, displacement, and retention.

Achieving a long-lasting functional prosthesis (MFP that can provide maximum retention with less stress on the remaining abutment and supporting structure) remains a goal for maxillofacial prosthodontists. However, most of the literature showed only the use of Co-Cr-based PMMA and conventional acrylic for constructing obturators. There is a lack of evidence regarding using different materials as a substitute for Co-Cr and acrylic obturators. Those materials may have better potential than existing ones for constructing MFPs regarding the prostheses' retention, stress, and displacement.

1.3 Gap Statement and Justification of The Study

1.3.1 Research gap 1

As per our limited knowledge, there is a lack of evidence in the literature regarding the study of the biomechanics of prostheses in the currently used designs of Aramany class I defect (Brown class IIb), which are linear and tripodal (besides the conventional acrylic prostheses). This lack of information causes the estimation of the stress distribution, deflection, and retention of obturators to be dependent only on a prospective view. Besides, no attempts have been made to modify the current designs in Aramany class I to produce a prosthesis that may show better retention and optimum support. Understanding the influences of the currently used designs and finding if the newly modified one has better retention, stress distribution, and displacement ability is essential to be known before designing prostheses that can benefit the patients.

1.3.2 Research gap 2

The main reasons for MFP failure are the lack of remaining dentition and the weight of the prostheses. Using light and strong materials as a framework may produce optimal retention, minimum displacement, and lower stress on the supporting structure. That can be considered a key to the success and survival of MFPs. Although many lighter materials have been introduced to dentistry, a lack of study in the literature about applying these materials as a substitute for traditional acrylic and Co-Cr base MFP was apparent as far as we are aware. Therefore, evaluating more materials for MFPs may benefit clinicians and patients regarding prosthetic construction, retention, stress distribution, displacement, and strain distribution.

1.4 Objectives of Study

1.4.1 General objectives

This study aimed to explore and elucidate the biomechanics in obturators for Brown's Class IIb (Aramany's Class I defect) using different designs and materials. The aim of the study was achieved using finite element analysis (FEA) and experimental approaches, including photoelastic stress analysis (PESA), digital image correlation (DIC), and a universal testing machine (UTM).

1.4.2 Specific objectives

1. Exploring and elucidating the biomechanics of the conventional acrylic (AP), linear design (LDP), tripodal design (TDP), and fully tripodal design (FTDP) in terms of retention, stress, and strain.

2. Exploring and elucidating the biomechanics of seven materials, including AP, metal-based (Co-Cr and Ti), thermoplastic milled-based (PEEK and PEKK), and thermoplastic injectable-based (biotone and talladium) MFPs in terms of retention, stress, and strain.

1.5 Scope and methodology

The study's first aim was to explore and elucidate the retention and biomechanics of the various assorted designs (AP, LDP, TDP, and FTDP). Nine frameworks and four finite element (FE) models were used to evaluate the retention using UTM and FEA, respectively. The biomechanics was evaluated regarding stress concentration, displacement, and strain distribution. Eight photoelastic (PE) models and four FE models were used to assess the stress and displacement using PESA and FEA, respectively. For strain evaluation, 12 DIC models and the same mentioned four FE models were used using DIC and FEA, respectively.

The study’s second aim was to explore and elucidate the retention and the biomechanics of the various materials-based MFP, including AP, metals (Co-Cr and Ti), thermoplastic milled (PEEK and PEKK), and thermoplastic injectable materials (biotone and talladium). For the experimental evaluation and due to the cost, one material was chosen as a representative for each group besides the AP, including Co-Cr for metal, PEEK for thermoplastic milled, and biotone for thermoplastic injectable materials. Nine frameworks, eight PE models, and 12 DIC models were used to evaluate the retention, stress, and strain, using UTM, PESA, and DIC, respectively. Numerically, seven FE models were used for assigned materials to evaluate the same mentioned parameters.

1.6 Research hypotheses

The null hypotheses that were tested are summarized as follows:

1. There was no difference in the displacement (retention) of MFPs with the assorted designs.
2. The supporting structures and prosthetic components of the MFPs with the assorted designs receive an equal stress distribution.
3. The supporting structures and prosthetic components of the MFPs with the assorted designs receive an equal strain distribution.
4. There was no difference in the displacement (retention) of MFPs with the assorted designs.
5. The supporting structures and the prosthetic components of the MFPs with the assorted materials receive an equal stress distribution.
6. The supporting structures and the prosthetic components of the MFPs with the assorted materials receive an equal strain distribution.

1.7 Significance of the Study

Providing long-served MFPs necessitates careful diagnosis, treatment planning, and adequate maintenance. Due to the nature of MFP, which includes the size of the prosthesis, lack of abutments, lack of saliva, and inadequate care, the prosthesis may fail or contribute to caries development. Besides, poor prosthesis design can exacerbate the mentioned problems, so practitioners should always consider the design that best preserves the abutment and remaining supporting structures. Aramany introduced two designs to treat this defect; one provided complete coverage to the palate and mucosa, which may lead to the development of periodontal disease, caries, and resorption of the other supporting structures, especially in the absence of adequate maintenance. The second design used less tissue coverage and fewer abutments for support, which may overload the abutments during function. This study introduced a new design to take advantage of both designs, using less tissue coverage and more teeth for support.

Traditional MFPs involve using either conventional acrylic prostheses or Co-Cr-based prostheses. Although Co-Cr-based MFP is widely considered, the material's physical properties are not ideal in addition to the esthetic issues with metal display, potential hypersensitivity, oral galvanism, adverse tissue reactions, and biofilm production. The advances in thermoplastic materials, mechanical and physical properties improvement, and their fabrication methods may provide a valid alternative to the metal maxillofacial prosthodontists while designing the MFPs. That was the second important point of this study.

CHAPTER 2

REVIEW OF LITERATURE

This chapter aimed to provide information about the origin and classification of palatal defects, the prosthodontic rehabilitation of palatal defects, and the associated problems. It also reviews the materials used for the removable prostheses, including metal, thermoplastic milled, and injectable materials, their properties, and limitations. Besides, it explains the principles of biomechanics of removable prostheses and the methods used for evaluation, including PESA, DIC, and FEA, their advantages, limitations, and their application in dentistry.

2.1 Origin of palatal defects

Maxillary palatal defects can be congenital or acquired in nature. Acquired palatal defects are mainly because of accidents or surgical excision of benign or malignant tumors. Patients with such malignancy mostly require the removal of part or a whole palate by ablative surgery. That may result in a significant anatomical defect that affects patients in terms of their ability to speak, swallow, and masticate. These defects affect those patients' physical, psychological, and social well-being (Ali *et al.*, 2015; Rogers *et al.*, 2016).

2.2 Classification of maxillary palatal defects (critical appraisal)

Many classifications have been introduced into the literature to classify patients with palatal defects. The main reason for that is the treatment plan for each patient that is followed to eradicate cancer in the facial area, which involves a variety of anatomical structures. Most of these classifications depended on a retrospective cohort population of maxillectomy patients that presented to that practice or institution. The classification done in this way may not be easy to generalize to the other population. Besides that, the other maxillectomy cases that may not fit the criteria of one classification may be omitted or ignored by that classification system. The diversity of these classifications reveals the challenges in categorizing the palatal defects and the deficiencies of the classifications with no universal acceptance to a single classification till now (Shrime & Gilbert, 2009; Bidra *et al.*, 2012; Wang *et al.*, 2017).

The classification of the maxillary defect generally depended on criteria such as the state of dental and oroantral communication, soft palate and other contiguous structure involvement, and superior-inferior, anterior-posterior, and mediolateral extent of the defect. (Bidra *et al.*, 2012; Cordeiro & Chen, 2012).

In 1978, Aramany classified patients with maxillary defects into six groups, depending on the relationship of the defects to the remaining teeth, which were divided into six classifications. When the defect involves the teeth and palate to the midline, while the teeth on the contralateral side are available for support and retention of the prosthesis, it is called class I. When the defect involves the posterior teeth and palate of one side, and the anterior teeth and contralateral side abutments are available for retention and support of the prosthesis, it is called class II. The defect involving the palate without affecting the teeth is called class III. The defect involves the teeth on one side and extends to the premaxilla of the contralateral side; however, posterior teeth on the contralateral side are still available for retention and support of the prosthesis; it is called class IV. Class V was introduced to describe the defect that affects the posterior palate and associated teeth, whilst Class VI was introduced to describe the defect that affects the anterior palate and associated teeth (Aramany, 1978).

The primary advantage of Aramany's classification is that it helps the clinician design the framework of MFPs, considering the same principles described in the management of conventional, partially edentulous patients. Besides, it is regarded as a useful classification tool in teaching, developing framework designs, and enhancing communications among prosthodontists. However, it only considers the defect in the horizontal plane and does not consider the vertical extent of the defect (Ali *et al.*, 2015).

In 1995, Wells and Luce introduced new classifications to cover mainly vertical extension of the palatal defect into five categories. Class I was prescribed for the defect that includes only the loss of midfacial skin with no bone loss. Class II involves maxillectomy of the midface, but the palate and the orbital floor are entirely preserved. Class III is described when the maxillectomy includes removing a part of the palate with the orbital floor wholly preserved. In class IV, the palate is completely resected while the orbital floor is entirely held, while in class V, the orbital floor is included in the maxillectomy with the palate (Wells & Luce, 1995).

The main advantages of Wells and Luce's classification are the simplicity and logical consequences of the midface loss after the maxillectomy. However, it did not provide a clear explanation of the prosthodontic view as it was mainly directed to categorize the vertical, not the horizontal, bone loss. It can only give the clinician and prosthodontist an adequate idea of the prognosis of the surgical reconstruction of the patient after the maxillectomy (Bidra *et al.*, 2012).

In 1997, Spiro and his colleagues introduced a new classification for the palatal defect into three terms depending on the walls of the antrum removed. The defect that involved the removal of one wall of the antrum was termed "Limited maxillectomy" or (LM). The term "Subtotal Maxillectomy" or (SM) describes the defect that involves the removal of two walls of the antrum with their associated palate. The third term, "Total maxillectomy" or (TM), was introduced to describe the complete removal of the antrum and associated palatal structures (Spiro *et al.*, 1997).

Simplicity was the main advantage of Spiro's classification. However, the classification is not descriptive regarding prosthodontics, as it is more related to surgical communication. Besides that, it doesn't provide a clear idea about the remaining dentition and the horizontal extension of the defect (Durrani *et al.*, 2013).

Another classification was introduced by Umino and his colleagues in 1998 to classify maxillectomy into two major categories with three subclasses. The classification depended on communicating the oral and nasal cavities due to the maxillectomy procedure. Class I was prescribed for the defect that is confined to the hard palate only, either with no communication (Class Ia), with unilateral communication (Class Ib), or with bilateral communication (Class IC) with the nasal cavity. Class II was provided when the defect involves the soft palate with the hard palate, either with unilateral communication (Class IIa) or bilateral communication (Class IIb) with the nasal cavity (Umino *et al.*, 1998).

In the same year (1998), Davison and his co-workers introduced a more straightforward (but general) classification of the maxillectomy patient into two categories. Class I includes partial removal of the palate, and class II includes complete removal of the palate (Davison *et al.*, 1998).

In 2000, to overcome the Aramany classification shortage, Brown and his co-workers provided four new classes expressing the vertical extension of the maxillary defect. They also added subclasses (a-c) to describe the horizontal extension of the defect. The classification started from the least invasive class I, which involves a maxillectomy with no oroantral communication; Class II includes oro-antral communication; Class III includes orbital floor resection; and Class IV includes orbital exenteration. The subclasses (a-c) were added to the main classification to describe the horizontal extension of the defect, including (a) in which the defect involves one side of the palate, (b) in which the defect involves one side and section of the contralateral side of the palate, and (c) in which the defect involves the whole palate (Brown *et al.*, 2000).

This classification allowed a comparison of maxillectomy defects in the best form of facial and oral rehabilitation for these patients. Although Brown's classification incorporated grading (a-c) to qualify the horizontal extent of the defect, the classification directed mainly toward the vertical extent of the resection rather than the horizontal extent, making designing the prosthesis depending on it is not an easy process (Iyer & Thankappan, 2014).

In the same year (2000), Teriana and his colleagues gave a general classification of the maxillectomy into three categories: Class I is for the defect that involves removing half of the palate or the anterior arch, Class II is for the complete removal of the palate with the orbital floor preserved, and class III is for the complete removal of the palate with or without orbital exenteration (Triana Jr *et al.*, 2000).

Okay *et al.* divided maxillary defects into three major classes and two subclasses to establish a new surgical and prosthodontic classification. The classification mainly depended on the involvement of the canine and associated alveolus in the defect area. For example, in class Ia, the defect involves the hard palate but not the teeth or their alveolus; in class Ib, the defect involves the teeth posterior or anterior to the canine and their alveolus, but not the canine. While class II is for the defect that involves any portion of the hard palate or alveolus with one canine and premaxilla with two canines but within 50% of the palate, class III involves both canines but with more than 50% of the palate. In the same class, if the inferior orbital rim was included in the defect, it is subclass f, while if the zygomatic bone is involved in the defect, it is subclass z (Okay *et al.*, 2001).

The Okay's classification can organize and define the complexity of rehabilitation and surgical correction for the maxillectomy patient. However, there was agreement about the complexity of the classification to be followed by the clinicians and technicians (Bidra *et al.*, 2012).

In (2005), Carrillo et al. provided a new classification depending on the involvement of the antrum and orbit in the ablation process into three types: Type I is given when five walls of the maxillary antrum are ablated while the floor of the orbit is preserved, Type II is given when four walls of the antrum removed either to preserve the palate (IIa) or to preserve the orbit (IIb), and type III when the ablation involves the medial wall of the antrum with extension to the orbit or the ethmoidal cells (Carrillo *et al.*, 2005).

In (2006), Futran and Mendez introduced a new general classification for the maxillectomy patient to define the maxillectomy as a palatal defect that involves the teeth and associated structure either involving the inferior maxilla (Ia) or involving the total maxilla with orbital preservation (Ib), or total maxilla with complete exenteration of the orbital contents (Ic) (Futran & Mendez, 2006).

In (2007), Rodriguez et al. classified the maxillectomy into four classes: Class I for the unilateral involvement of the teeth and associated structures, Class II for the unilateral defect with the lower orbital floor of the same side involved, Class III for the bilateral loss of the teeth and associated structures, and Class IV for the bilateral dentoalveolar loss with at least one orbital floor involved (Rodriguez *et al.*, 2007)

Lastly (2010), Brown and Shaw modified the classification they introduced in 2000 (Brown *et al.*, 2000) to become more comprehensive. They classified the defect into six vertical and four horizontal classes. Vertically: Class I was provided for the maxillectomy that does not cause an oroantral fistula; Class II for the maxillectomy that causes oroantral communication but with the orbit preserved; Class III for the maxillectomy that involves the orbital adnexa with orbital retention; Class IV for the maxillectomy that involves enucleation or exenteration of the orbit, Class V for the orbitomaxillary defect, and Class VI for naso-maxillary defect. Horizontally: Class I was provided for the palatal defect only with no dental involvement; Class II for unilateral palatal removal with equal or less than ½ of the palate; Class III for bilateral palatal defect with equal or less than the ½ of the palate; and Class IV for bilateral palatal defect with more than ½ of the palate (Brown & Shaw, 2010).

2.3 Management of patients with maxillectomy

2.3.1 Factors affecting the success of maxillectomy rehabilitation.

Choosing the appropriate modality of rehabilitation depends on multiple factors, such as restoring the anatomic structures, aesthetics, oral function, and the patient's psychological well-being and quality-of-life perception (Cawood & Stoelinga, 2006). Specifically, six criteria affect the success of prosthodontic rehabilitation of maxillectomy patients. These criteria are existing dentition status, oro-antral or -nasal communication, the involvement of contagious structures, superior-inferior, anteroposterior, and mediolateral extent of the defect.

Regarding dental status, it is crucial not only for the retention and support of the maxillofacial prosthesis but also for chewing, speech, aesthetics, and the future self-esteem of the patient. Any surgical maxillectomy surgeon should consider preserving the remaining dentition and provide adequate treatment regarding the existing dentition's caries, periodontal, and occlusal status (Bidra *et al.*, 2012).

The presence or absence of the oroantral communication of the maxillary defect has a massive impact on the prognosis and function of the MFP in terms of speech, retention of the prosthesis, deglutition, and quality of the remaining dentition, which can be affected by the weight of the existing prosthesis (Chigurupati *et al.*, 2013).

Due to tumor extension, the surgeons may have to extend the resection around the diseased area, including tissues such as the soft palate, lip, nose, and adjacent skin. From a prosthodontic point of view, the obturator prosthesis that extends to restore the soft palate is bulkier, heavier, and may require an extraoral prosthesis attached to the intraoral one. That may show issues in the retention of the prosthesis and leakage of oral and nasal exudate, which affect the prognosis of the prosthesis and quality of life (Cordeiro & Chen, 2012; Chigurupati *et al.*, 2013; Braun & Maricevich, 2017).

The mediolateral extension of maxillary defect can be isolated, unilateral, and bilateral horizontal defects. From a prosthodontic perspective, isolated palatal defect management is more straightforward and has a better prognosis compared to unilateral defect, which is preferred over bilateral defect in the same regard. That is mainly due to the reduced volume of tissues that need to be replaced by prostheses and the availability of dental and their supporting structures (dos Santos *et al.*, 2018).

The defect after maxillectomy ranges from minor removal of dentoalveolar structures (without oroantral communication) to a major defect bordered by the base of the skull superiorly and the tongue inferiorly. From a prosthodontic perspective, as the superior extension of the prosthesis extended superiorly, it may affect the mandibular movement, insertion and removal of the prosthesis, and the retention of the prosthesis (Chigurupati *et al.*, 2013; dos Santos *et al.*, 2018).

The anterior-posterior extent of a maxillectomy defect can be described in horizontal and sagittal planes as the involvement of the right and left, anterior and/or posterior regions of the maxilla, which may be associated with the soft palate. From a prosthodontic perspective, if three out of four areas of the maxilla remain around the defect, the treatment outcomes are more favorable because of improved support and favorable biomechanics due to tripodization. On the other hand, the anterior bilateral defect is challenging because of the collapse and fibrosis of the facial tissues. Defects involving the posterior region may have prosthetic contours terminating in the pterygoid area or extend further to the posterior pharyngeal wall when the soft palate has been resected or has limited functional movement. That increases the prosthesis's weight and results in a lack of retention and stability of the MFP (Bidra *et al.*, 2012).

2.3.2 Treatment options for maxillectomy rehabilitation

The prosthetic rehabilitation of individuals with cleft lip and palate can be FDPs, MFPs, RCDPs, overlay dentures, or implant-assisted MFPs (Lopes *et al.*, 2010; Ottria *et al.*, 2014).

Although most patients with palatal defects can be rehabilitated surgically or with a combination of bone grafting and implant-assisted fixed or removable prostheses, some may not be appropriate for this treatment modality because of many factors. These factors include significant medical co-morbidities, lack of suitable donor sites, cleft position, maxillomandibular relationship, presence of remaining teeth, and extent and location of bone grafts. These factors can be considered determinants of implant alignment and prosthetic appliance type. For those patients, the prosthetic obturation using a conventional fixed or removable prosthesis represents a more conservative option, especially for patients who refuse surgical intervention (Brosco, 1999; Francischone *et al.*, 1999; Hickey & Salter, 2006; Boyes-Varley *et al.*, 2007).

MFPs have a long history of restoring the functional, cosmetic, and psychological problems associated with the defects caused by maxillectomy when there is no possibility of using fixed or implant-assisted MFPs (Dhingra, 2012; Freitas *et al.*, 2012). These prostheses are frequently used to rehabilitate maxillofacial bone discrepancies, midfacial deficiency, absent or deficient lip, open bite, and decreased vertical dimension. In addition, it is an economically feasible and noninvasive treatment option (Ohyama, 1986; Vojvodic & Jerolimov, 2001; Turkyilmaz, 2008; Balkaya *et al.*, 2014; Palmeiro *et al.*, 2015).

2.3.3 General Prosthodontic principles in the framework design of Aramany's Class I (Brown's Class IIa) obturator

Many authors have discussed prosthesis designs relative to all phases of prosthodontics. The need for support, retention, and stability during designing MFPs should be understood if the objectives of prosthodontic care are to be attained. For the patient with an acquired maxillary defect, it is often necessary to modify, and sometimes violate, some of the basic principles of the design of prosthesis because of the fundamental nature of the defect (Aramany, 1978; Desjardins, 1978; Keyf, 2001; Balkaya *et al.*, 2014).

2.3.4 Designs of Aramany's Class I (Brown Class IIb)

Aramany's class I classification is when the hard palate, alveolar, ridge, and associated dentition are removed to the midline (Figure 2.1), while Brown class IIb is horizontally the same as Aramany class I but vertically, where the antrum is removed while the orbit floor remains intact. Aramany and Parr made several recommendations regarding the framework design for class I, such as proposing a linear design when the remaining anterior teeth were not strong enough for support or retention. A tripodal design was suggested when anterior teeth were strong enough for retention and support (Aramany, 1978; Parr *et al.*, 2005).

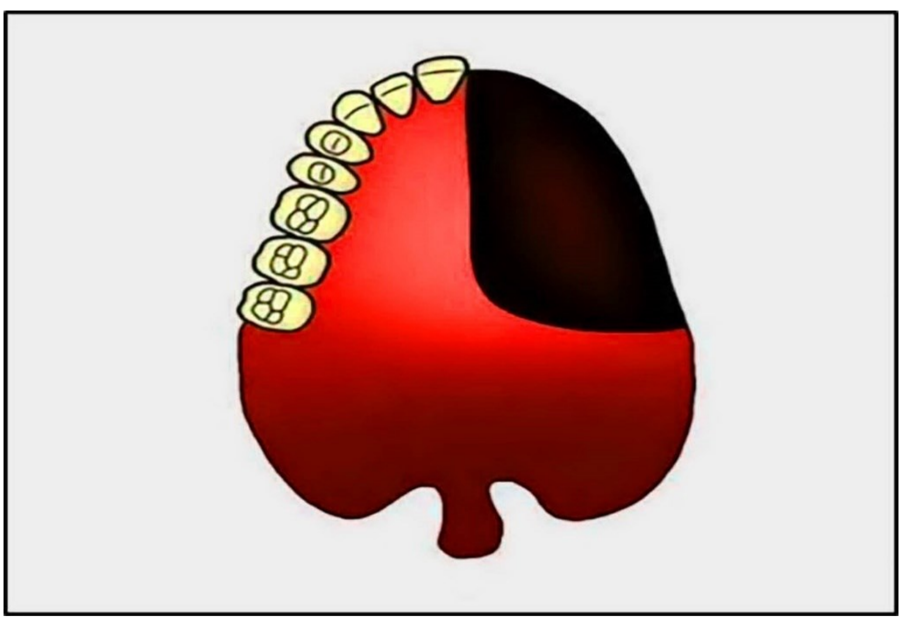

Figure 2.1: Aramany's class I maxillary defect (the photo adopted from Ali *et al*., 2015)

In tripodal configuration, support is obtained from the remaining part of the palate, defect site, and teeth through rests that are placed on the most anterior abutment (the closest one to the defect) and the most adjacent posterior teeth (Aramany, 1978; Parr *et al.*, 2005). The retention is obtained by direct retainers placed on the mid-labial surface of the anterior abutment, such as a 19- or 20-gauge wrought wire clasp or 'I-bar' clasp to engage a 0.25-mm undercut on the anterior and posterior abutments. Additional protection to the anterior abutments can be afforded by splinting them to one or two next teeth with full crowns or composite filling when the fixed crown fabrication is not applicable. Indirect retention is obtained from occlusal rests on a tooth perpendicular and as far forward as possible to a fulcrum line connecting the most anterior and posterior abutment, which can be canine or first premolar (Figure 2.2).

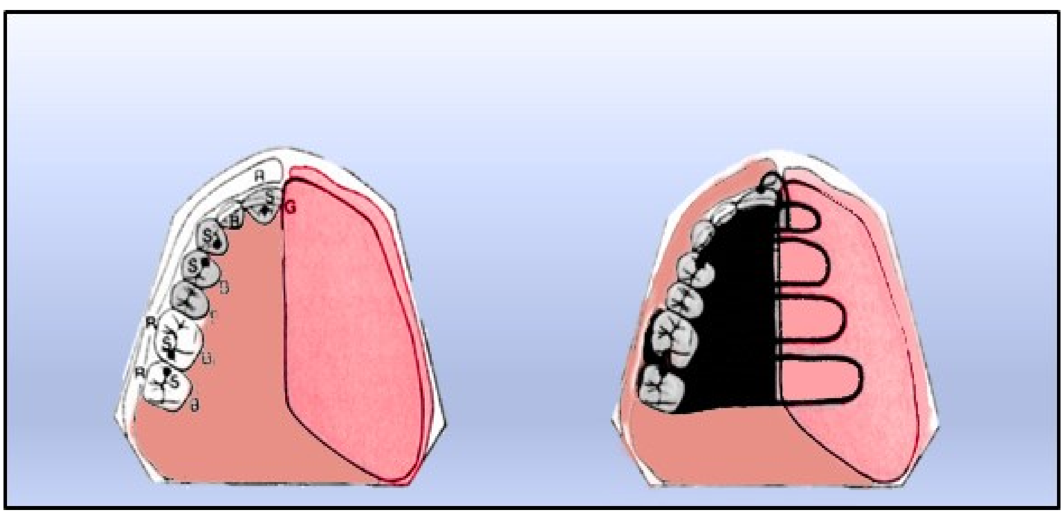

Figure 2.2: Tripodal design for Aramany Class I (adapted from Parr *et al*., 2005), while the letter **G** means guiding plane, **S** means support, **R** for retention, and **B** for bracing

In linear configuration, the support is in a linear design. It is usually used when insufficient anterior teeth exist or the prosthodontist does not prefer to use them. The remaining posterior teeth are in a relatively straight line. The most common example is using double occlusal rests between the most forward posterior teeth (usually first and second premolars) and double occlusal rests between the farthest posterior teeth (typically first and second molars) from the defect (Figure 2.3).

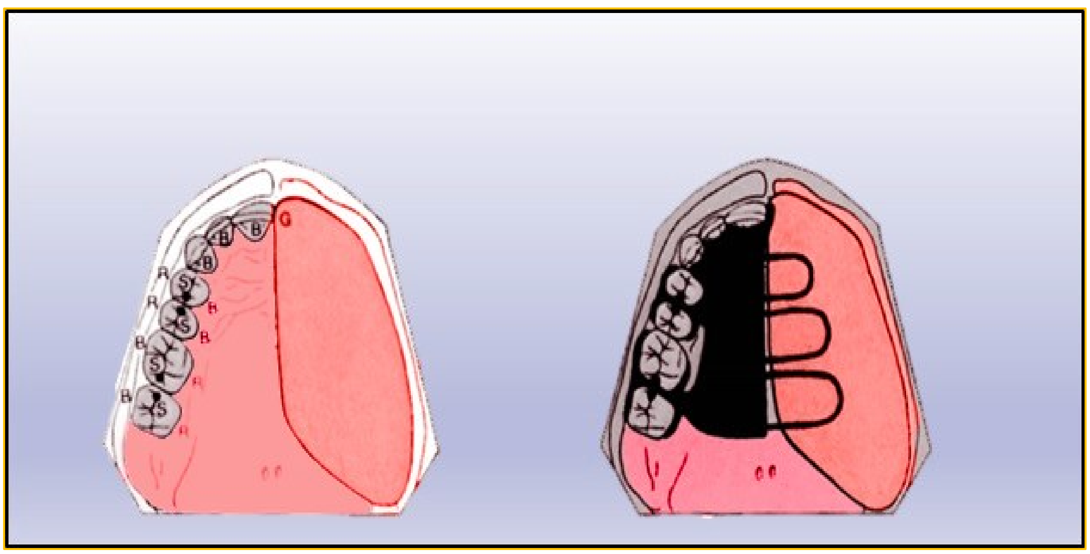

Figure 2.3: A linear design for Aramany's class I (The picture quoted from Parr *et al*., 2005), while the letter **G** means guiding plane, **S** means support, **R** for retention, and **B** for bracing

2.4 Problems associated with removable MFPs.

Like all removable dental prostheses (RDPs), obturators can put additional stress on abutments and their supporting structures, causing gingivitis, periodontitis, and caries (Kratochvil *et al.*, 1982; Vanzeveren *et al.*, 2003). These alterations are attributed to poor oral hygiene, increased plaque and calculus accumulation, and transmission of excessive forces to the periodontal structures from the prosthesis (Vallittu & Kokkonen, 1995; Correia *et al.*, 2018; Koyama *et al.*, 2018). Therefore, the correct design is crucial to address those drawbacks.

Obturators may displace either superiorly because of the chewing force or inferiorly due to a lack of retentive sources and the weight of the prosthesis. Displacement varies depending on the number and position of remaining abutments, the size and position of the defect, the amount and contour of the remaining palatal shelf, the height of the residual alveolar ridge, the size, contour, lining mucosa of the defect and the availability of undercuts (Ohyama, 1986; Kornblith *et al.*, 1996; Keyf, 2001). The displacement potential for the obturator prosthesis increases as the remaining tooth number decreases. In cases requiring extensive resections, significant problems regarding the retention, support, and stability of maxillary obturators are usually elaborated (Rogers *et al.*, 2003; Zarrati *et al.*, 2015; Fraga De Almeida *et al.*, 2016).

Because of the lack of adequate bone support, the MFPs framework, supporting structures, and abutment teeth are affected by the development of unequal stress within the prosthesis and underlying structures. The biomechanical stress and displacement developed within the prostheses are increased as the number of remaining teeth decreases and the size of the defect increases. The pressure transmitted to the abutment teeth and associated structures from the prostheses depends on the location of the occlusal rests, the extension of the saddles, the design of connectors and retainers, materials of fabrication of the framework, and position of implants (if it was used) (Hase *et al.*, 2014).

In Aramany's class I, the maximum stress concentration is located around the cervical half of the roots of the central and lateral incisors on the contralateral side. The Cobalt-Chromium (Co-Cr) alloy produces more stress on the remaining teeth than the titanium (Ti) alloy. That is mainly attributed to the increase in the hardness of Co-Cr compared to the Ti alloy. However, the decrease in the hardness of the Ti leads to deflection in the same direction as the applied forces, which can be disadvantageous (Arabbi *et al.*, 2019; Shah *et al.*, 2019).

Zygomatic implants (ZI) were advocated to decrease the stresses on abutments and the remaining part of the palate and to optimize the retention of MFPs. When conventional dental implants are not applicable due to inadequate maxillary bone, ZI can enhance the stability and promote the retention of the MFPs (Chiapasco *et al.*, 2006; Miyamoto *et al.*, 2010).

Despite the adequate survival rate of ZIs, which reaches 94%, they still pose challenges to maxillofacial surgeons because of their complexity (Aparicio *et al.*, 2014; Chana *et al.*, 2019). There are many contraindications associated with ZI approaches, such as lack of available bone, pathology in the zygoma, the inability of the patient to undergo surgery, and medications that may contradict the placement of zygomatic implants, such as intravenous bisphosphonate (Aparicio *et al.*, 2014; Rosenstein, 2020;