A STUDY OF TEMPOROMANDIBULAR JOINT MORPHOLOGY AND POSITIONS AMONG CLASS I, CLASS II, CLASS III MALOCCLUSION AND THE EFFECT OF PETIT FACEMASK IN CLASS III MALOCCLUSION SUBJECTS

MOHAMMED IRFAN AZHAR

UNIVERSITI SAINS MALAYSIA

2022

A STUDY OF TEMPOROMANDIBULAR JOINT MORPHOLOGY AND POSITIONS AMONG CLASS I, CLASS II, CLASS III MALOCCLUSION AND THE EFFECT OF PETIT FACEMASK IN CLASS III MALOCCLUSION SUBJECTS

by

MOHAMMED IRFAN AZHAR

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

August 2022

ACKNOWLEDGEMENT

In the name of Allah, the most beneficent, the most compassionate and the most merciful. All praise be to Allah the almighty for giving me the opportunity, strength, perseverance, and his blessings to complete my research work.

I would like to express my sincere gratitude to my supervisor Prof. Dr Rozita Hassan for her continuous encouragement, skilled supervision, guidance, keenness throughout my research study, for her patience, motivation, and vast knowledge. Her support helped me in all the stages of my research work and the writing of this thesis. I could not have wished for a better supervisor and mentor for my Master study.

Besides my supervisor, I would like to thank my co-supervisor's Dr Asilah Yusof and Dr Roselinda Abdul Rahman, for their watchful comments and encouragement throughout my study. I also wish to thank my father, mother, sister, wife and dear friends for their affection, care, and moral support. I would like to acknowledge the school of dental sciences, office staff for their kind help and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Anterior condyle
ACHP	Anterior condyle horizontal position
ACVP	Anterior condyle vertical position
AGF	Anterior glenoid fossa
AGFHP	Anterior glenoid fossa horizontal position
AGFVP	Anterior glenoid fossa vertical position
AJS	Anterior joint space
Alt-RAMEC	Alternating rapid maxillary expansion and constriction
BAMP	Bone anchored maxillary protraction
BSI	British standard institute
CBCT	Cone-beam computed tomography
CG	Control group
CI	Confidence interval
CLT	Central limit theorem
CO	Centric occlusion
CR	Centric relation
CT	Computed tomography

FH	Frankfort horizontal
FM	Facemask
Go	Gonion
HCA	Horizontal condylar angle
ICRP	International Commission on radiological protection
LCR	Lateral cephalometric radiography
LCRs	Lateral cephalometric radiographs
MCHP	Mandibular condyle horizontal position
MCVP	Mandibular condyle vertical position
MD	Mandibular base position
MEAW	Multiloop edgewise arch wire
MJS	Medial joint space
MN	Mandibular notch
MRI	Magnetic resonance induction
MX	Maxillary base position
PC	Posterior condyle
PCHP	Posterior condyle horizontal position
PCVP	Posterior condyle vertical position

PFM	Protraction facemask
PGF	Posterior glenoid fossa
PGFHP	Posterior glenoid fossa horizontal position
PGFVP	Posterior glenoid fossa vertical position
PJS	Posterior joint space
PL	Porion location
PtV	Pterygoid vertical
RL	Ramal line
RME	Rapid maxillary expansion
RME/FM	Facemask therapy with rapid maxillary expansion
RPE	Rapid palatal expansion
RTBA	Reverse twin block appliance
SC	Superior condyle
SCHP	Superior condyle horizontal position
SCVP	Superior condyle vertical position
SGF	Superior glenoid fossa
SGFHP	Superior glenoid fossa horizontal position
SGFVP	Superior glenoid fossa vertical position

SJS	Superior joint space
2D	Two dimensional
3D	Three dimensional
TMD	Temporomandibular disorder
TMJ	Temporomandibular joint
TPS	Thin-plate spline

KAJIAN MENGENAI MORFOLOGI DAN KEDUDUKAN SENDI TEMPOROMANDIBULAR BAGI KELAS I, KELAS II, KELAS III MALOKLUSI DAN KESAN PETIT-FM DALAM KALANGAN SUBJEK MALOKLUSI KELAS III

ABSTRAK

Sendi temporomandibular (TMJ) ialah sendi sinovial yang paling kompleks di dalam badan. Morfologi TMJ boleh terjejas kerana pelbagai faktor seperti usia, jantina, peningkatan atau penurunan aktiviti otot, corak pertumbuhan wajah, perubahan patologi, kekuatan oklusi dan perubahan pada oklusi gigi. Kesan perubahan ini boleh menghasilkan pembentukan dan penyusunan semula permukaan TMJ. Oleh itu, perancangan diagnosis dan rawatan yang teliti sangat penting sebelum memulakan sebarang prosedur ortodontik. Tujuan kajian kami adalah untuk menilai dan membandingkan morfologi dan kedudukan TMJ daripada 120 subjek dengan 40 subjek yang terdiri daripada Kelas 1, Kelas II dan Kelas III maloklusi menggunakan radiografi cefalometrik lateral (LCRs) sebelum dan selepas rawatan. Kajian ini juga untuk menilai serta membandingkan morfologi dan kedudukan TMJ pada 28 subjek dengan maloklusi Kelas III yang dirawat dengan petit-facemask (FM) menggunakan LCRs sebelum dan selepas rawatan. Penilaian TMJ merangkumi ukuran kedudukan dan morfologi porion (PL), fossa glenoid, kondil, ruang sendi TMJ, dasar maksila (MX) dan dasar mandibel (MD). Ini adalah kajian keratan lintang retrospektif. LCRs diperoleh menggunakan mesin Planmeca Promax 3D (Planmeca Oy, Helsinki, Finland). Pengukuran morfologi TMJ dicapai dengan menggunakan perisian cefalometrik WinCeph versi.11 (Rise Corporation, Sendai Jepun) untuk kedua-dua objektif. Analisis data dijalankan dengan menggunakan perisian SPSS ver.26 (IBM, SPSS Statistics, Armonk, NY-USA). Ujian ANOVA sehala dan ujian Bonferroni post hoc dilakukan untuk objektif 1, sementara ujian-t berpasangan dilakukan untuk objektif 2.

Perbandingan morfologi TMJ antara maloklusi Kelas I, II dan III menunjukkan perbezaan yang signifikan untuk ruang sendi atas (SJS), ruang sendi belakang (PJS), dan MD dengan ($p = 0.00$). Sejajar dengan itu, perbandingan morfologi TMJ antara subjek sebelum dan selepas rawatan maloklusi Kelas III sebagai tindak balas terhadap rawatan petit-FM menunjukkan perbezaan yang signifikan untuk kedudukan mendatar fossa glenoid dengan ($p = 0.00$) dan ($p = 0.03$) masing-masing. Perbezaan signifikan dapat diperhatikan pada paksi engsel dengan ($p = 0.00$) dan ($p = 0.04$) dan semua pemboleh ubah kedudukan condyle dengan ($p = 0.00$). Akhir sekali, semua ruang sendi, rahang atas dan rahang bawah menunjukkan perbezaan yang signifikan secara statistik dengan ($p = 0.00$). Kesimpulannya, objektif pertama menunjukkan SJS dan PJS tertinggi untuk maloklusi Kelas III dan terendah untuk maloklusi Kelas II. Terdapat peningkatan panjang pangkal rahang bawah (MD) dalam subjek Kelas III yang menunjukkan rahang bawah terletak ke hadapan dan penurunan pada subjek Kelas II yang menunjukkan rahang bawah yang ditempatkan ke belakang. Sejajar dengan itu, objektif kedua menunjukkan paksi engsel dan kepala condyle (atas dan belakang) diletakkan secara atas-belakang manakala condyle hadapan (AC) diletakkan secara bawah-belakang dan ini menunjukkan rahang bawah berputar mengikut arah jam selepas tamat rawatan. Terdapat peningkatan panjang pangkal rahang atas (MX) yang menunjukkan rahang atas yang ditempatkan ke hadapan dan penurunan pada pangkal rahang bawah yang menunjukkan rahang bawah yang ditempatkan ke belakang. Di antara ruang sendi, ruang sendi hadapan (AJS) didapati lebih besar dan lebih kecil untuk SJS dan PJS selepas rawatan dan ini menunjukkan pergerakan ke atas dan ke belakang rahang bawah.

A STUDY OF TEMPOROMANDIBULAR JOINT MORPHOLOGY AND POSITIONS AMONG CLASS I, CLASS II, CLASS III MALOCCLUSION AND THE EFFECT OF PETIT FACEMASK IN CLASS III MALOCCLUSION SUBJECTS

ABSTRACT

The temporomandibular joint (TMJ) is the most complex synovial joint in the body. TMJ morphology can be affected due to various reasons such as age, sex, increased or decreased muscle activity, the growth pattern of the face, pathological changes, occlusal forces, and changes in the dental occlusion. The effect of these changes can result in remodelling and reconfiguration of the TMJ surfaces. Therefore, careful diagnosis and treatment planning is very essential before the initiation of any orthodontic procedure. The purpose of our study was to evaluate and compare the TMJ morphology of 120 subjects with 40 subjects each in Class I, Class II and Class III malocclusion using pre-treatment lateral cephalometric radiographs (LCRs) and to evaluate and compare the TMJ morphology of 28 subjects with Class III malocclusion treated with petit-FM (Facemask) using pre-and post-treatment LCRs. TMJ evaluation included the measurements of porion location (PL), glenoid fossa, condyle position, condylar height (CH), joint spaces, maxillary base position (MX) and mandibular base position (MD). This was a retrospective cross-sectional study. LCRs were obtained using Planmeca Promax 3D machine (Planmeca Oy, Helsinki, Finland). TMJ morphology measurements were accomplished using the WinCeph cephalometric software version.11 (Rise corporation, Sendai, Japan) for both objectives. Data analysis was performed using SPSS ver.26 software (IBM, SPSS Statistics, Armonk, NY-USA). A one-way ANOVA and Bonferroni post hoc test was done for objective 1, while paired t-test was carried out for objective 2. The comparison of TMJ morphology between Class I, II and III malocclusions showed a significant difference for superior joint space (SJS), posterior joint space (PJS), and

MD with (p = 0.00). Correspondingly, the comparison of TMJ morphology between pre-and post-treatment subjects of Class III malocclusion in response to petit-FM therapy revealed significant difference for horizontal positions of the glenoid fossa with (p = 0.00) and (p = 0.03) respectively. Significant difference was observed in hinge axis with (p = 0.00) and (p = 0.04) and all variables of condyle position with (p = 0.00). Lastly, all the joint spaces, MX, and MD showed statistically significant differences with (p = 0.00). In conclusion, the first objective revealed highest SJS and PJS for Class III malocclusion and lowest for Class II malocclusion respectively. There was increase in the length of mandibular base (MD) in Class III subjects which indicate forwardly placed mandible and decrease in Class II subjects which represent backwardly placed mandible. Correspondingly, the second objective demonstrated significant alterations in horizontal position of the glenoid fossa indicating posterior displacement after FM therapy. The hinge axis and condylar head (both superior and posterior condyle) were placed postero-superiorly, while the anterior condyle was placed postero-inferiorly suggesting clockwise rotation of the mandible post treatment. There was an increase in the length of maxillary base which indicate forwardly placed maxilla and decrease in the length of mandibular base which exhibit backwardly placed mandible. Among joint spaces, the anterior joint space (AJS) was found to be larger, and smaller for SJS and PJS post treatment suggesting upward and backward movement of the mandible.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

One of the most complex joints in the body due to its anatomic, histological, and biomechanical features is the temporomandibular joint (TMJ). Morphological variations of the TMJ can occur amongst individuals and significant differences between the left and right sides of the same individual (Caruso *et al.*, 2017; Piancino *et al.*, 2018).

The global prevalence rate of malocclusion in permanent dentition for Class I, Class II and Class III were 74.7%, 19.56%, and 5.93% respectively (Alhammadi *et al.*, 2018). However, Class III malocclusion varied significantly between different racial groups. The prevalence rate of Class III malocclusion amongst Asians was 23% while Europeans represented about 3-8% (Huang *et al.*, 2018). The Malaysian and Chinese population exhibited the highest prevalence rate of Class III malocclusion approximating to about 16.59 % and 15.69 %, while the lowest was observed among Indians constituting about 1.19 % (Zere *et al.*, 2018).

The influence of occlusion in TMJ morphology remains to be a controversial subject. Pullinger *et al.* (1987) suggested malocclusion has a direct influence on the TMJ morphology, while Vitral *et al.* (2011) observed negative associations. White and Pharoah (2014) revealed a significant correlation between occlusal factors and TMD, while some studies presented no substantial relationship between malocclusion and TMD (McNamara Jr *et al.*, 1995; Lagerström *et al.*, 1998; Alhammadi *et al.*, 2016). Burley (1961) assessed TMJ in Class I, Class II and Class III and revealed that malocclusions are not the reason for functional stimuli to cause articular changes in the temporal region. Therefore, there is no reliable data to defend the role of malocclusion in the progression of TMD.

Merigue *et al.* (2016) stated that the TMJ morphology varies among individuals significantly and one of the prime features that can affect and alter the shape of TMJ morphology are the functional loads imposed on it. This is due to the close relationship between form and function, and it justifies the assumed variations in the condyle and glenoid fossa morphology among malocclusion subjects. Arieta-Miranda *et al.* (2013) described sagittal discrepancies that occurred due to compression forces on the TMJ may alter the condyle glenoid fossa relationship. The craniofacial structures and the TMJ are greatly affected by the sagittal relationship between the maxilla and mandible. These functional changes lead to continuous adaptation and remodelling processes.

The mandibular condylar cartilage is regarded as the primary growth centre in the mandible during young adulthood. The oral structures and the associated muscles directly control the position and function of the condyle. Therefore, the TMJ easily gets affected by the treatment given by the orthodontists. Hence, careful diagnosis and treatment planning is very essential before initiating any orthodontic procedure (Tecco *et al.*, 2010; *al.*, 2018).

The studies conducted in Class II division 1 subjects by (Vitral and de Souza Telles, 2002; Vitral *et al.*, 2004) and subjects of Class I, Class II division I and Class III malocclusion showed no significant articular asymmetry and noncentralization of condyle on both sides of the TMJ (Rodrigues *et al.*, 2009b; Rodrigues *et al.*, 2009a). While, noncentralization of the mandibular condyle was the characteristic feature of Class III malocclusion in the study conducted by (Cohlmia *et al.*, 1996b; Alhammadi *et al.*, 2016).

Various studies have investigated the relationship between TMJ morphology and various anteroposterior features such as condyle-fossa relationship, condyle position, mandibular fossa depth, showed contradictory findings (Vitral and de Souza Telles, 2002; Vitral *et al.*, 2004; Rodrigues *et al.*, 2009a; Zhang *et al.*, 2013). Computed tomography (CT) was utilized to assess TMJ parameters, however, these studies have less clarification regarding the method of standardization of data due to variation in condylar position.

Class III malocclusion typically comprises of the deficient maxilla and or prognathic mandible, with maxillary deficiency reporting to about 42-63% (Kapust *et al.*, 1998; Huang *et al.*, 2018).

Different types of treatment modalities have been used in the past and existing times in the management of Class III malocclusion. These include Reverse twin block appliance, Frankel III appliance, Jasper jumper (JJ), Chin cup therapy, Protraction facemasks (PFM) such as Delaire or petit-FM (Facemask) involving RME (Rapid maxillary expansion) or Alt-RAMEC (Alternate rapid maxillary expansion and contraction), Multiloop edgewise arch wire with modified Class III elastics, and Active skeletonized sutural distractor (ASSD) appliance. PFM is a functional appliance developed for adolescents with Class III malocclusion (Kiliçoĝlu and Kirliç, 1998; Huang *et al.*, 2018). Studies have shown that orthognathic surgeries can be avoided if treated early during growth with the use of PFM respectively (Mandall *et al.*, 2016). The most contemporary approach in the treatment of Class III malocclusion is the protraction of the maxilla using FM along with RME. The RME initiates maxillary protraction with the opening of circummaxillary sutures. The greater the disarticulation of circummaxillary sutures the larger the maxillary protraction. The goal is to disarticulate circummaxillary sutures and produce anterior displacement of the maxilla, rather than trans-palatal distraction (De Clerck *et al.*, 2009; De Clerck *et al.*, 2010).

Studies conducted by (De Clerck *et al.*, 2012; Azamian and Shirban, 2016) on Class III malocclusion subjects have shown the movement of the condyle posteriorly, which was well correlated with the bone apposition at the articular eminence of the TMJ and bone resorption at the posterior wall of the glenoid fossa. The protractive forces from the RME device produce effective skeletal change resulting in anterior displacement of the maxillary complex (Hino *et al.*, 2013).

The purpose of this study was to evaluate and compare the TMJ morphology in Class I, Class II, Class III malocclusion and the short-term effect of petit-FM (facemask) in Class III malocclusion subjects.

1.2 Problem statement

The condylar position and morphology are crucial features that play an important role in TMJ-oriented orthodontic treatment planning. The orthodontic treatment could affect the TMJ or vice versa. Orthodontic diagnosis, treatment and its effects are also dependent on the skeletal pattern (Girardot Jr, 2001; Ponces *et al.*, 2014; Shroff, 2018). Concerning the condylar position, Class III malocclusion subjects tend to show anteriorly positioned condyles, but no difference was observed in the condylar position for Class I and Class II malocclusion subjects (Cohlmia *et al.*, 1996b; Park *et al.*, 2015). However, there is a lack of comprehensive analysis on TMJ morphology between different Classes of malocclusion among individuals of different age, gender, and ethnicity. Hence evaluation of TMJ morphology in different types of malocclusions will help in better orthodontic diagnosis and treatment planning by elucidating the relationship between glenoid fossa morphology, joint space, condyle morphology and its position.

Orthopaedic correction of skeletal Class III malocclusion in a growing patient is very essential to avoid future surgical procedures and the advantage from this treatment will aid in avoiding the unfavourable effects produced by the facial deformity on the patient's social life from surgical procedures (Muthukumar *et al.*, 2016a). A combination of rapid maxillary expansion (RME) with an FM to protract the maxilla has become a common procedure in the early management of maxillary deficiency cases over the last two decades (Muthukumar *et al.*, 2016a). However, this treatment can cause continuous shear strain on condylar cartilage, thus leading to distortion, damage, fatigue, and secondary tissue damage. Gradually, this damage may lead to condylar cartilage degradation and internal derangement of the TMJ (Tanaka *et al.*, 2008; Huang *et al.*, 2018). The posterior displacement of the condyle and anterior displacement of the articular disc has indicated the possibility of nerve or vessel compression which could eventually result in clinical signs of TMD (Wyatt, 1987; Huang *et al.*, 2018). Hence, it is very important to study the effect of petit-FM on the TMJ morphology of Class III malocclusion to recognize the differences associated with the TMJ.

1.3 Justification of the study

TMJ examination and its associated structures are very crucial in the estimation of the bony changes and the abnormalities that affect the TMJ. The purpose of this study is to investigate the differences in the TMJ complex especially the glenoid fossa, condyle, and joint spaces amongst different classes of malocclusion and the difference between the pre- and post-treatment group of Class III malocclusion patients.

The prevalence of Class III malocclusion is very high among the Malaysian population and there is no adequate data available to evaluate the variations in TMJ morphology (Zere *et al.*, 2018). FM used in the treatment of Class III malocclusion not only produces disarticulation of circummaxillary sutures but also causes forward and downward movement of maxillary complex, changes in the morphology of glenoid fossa, clockwise rotation of the mandible and positional changes in the condyles and mandible (Cha, 2003; Vaughn *et al.*, 2005). Most of the studies with PFM treatment on Class III malocclusion emphasize skeletal and dental changes (Katsavrias, 2006; Cordasco *et al.*, 2014; Zhang *et al.*, 2015). But very little has been discussed regarding the effect of PFM on TMJ which has been the most debated topic among clinicians in the field of orthodontics. Our study emphasizes the variations related to TMJ morphology between different classes of malocclusion and TMJ variations after FM therapy among Class III malocclusion subjects.

1.4 Objectives of the study and hypothesis

1.4.1 General objective

This study aims to evaluate and compare the TMJ morphology and positions among Class I, Class II, Class III malocclusion subjects and assess the effect of petit-FM on TMJ morphology and positions in Class III malocclusion subjects.

1.4.2 Specific objective

The specific objectives of the study are:

1. To evaluate and compare glenoid fossa, condylar, joint space, maxillary base, and mandibular base measurements among Class I, Class II and Class III malocclusion subjects using lateral cephalometric radiographs (LCRs).
2. To evaluate and compare glenoid fossa, condylar, joint space, maxillary base, and mandibular base measurements between pre-and post-treatment subjects of Class III malocclusion treated with petit-FM, using LCRs.

1.5 Research questions

1. What is the significant difference in TMJ morphology among Class I, Class II and Class III malocclusion subjects using LCRs?
2. What is the significant difference in TMJ morphology between pre-and post-treatment subjects of Class III malocclusion treated with petit-FM, using LCRs?

1.6 Research hypothesis

1. There is a significant difference in TMJ morphology among Class I, Class II and Class III malocclusion subjects using LCRs.

2. There is a significant difference in TMJ morphology between pre-and post-treatment subjects of Class III malocclusion treated with petit-FM, using LCRs.

1.7 Null hypothesis

1. There is no significant difference in TMJ morphology of Class I, Class II and Class III malocclusion subjects using LCRs.

2. There is no significant difference in TMJ morphology between pre-and post-treatment subjects of Class III malocclusion treated with petit-FM, using LCRs.

CHAPTER 2

LITERATURE REVIEW

2.1 Temporomandibular joint and its structures

Zhang *et al.* (2017) disclosed that the most active joint in the human body is the TMJ with more than 2000 movements every day through chewing, biting, swallowing, talking, and snoring. David and Elavarasi (2016) demonstrated TMJ as one of the most complex and important joints in the body. It is also known as a diarthrodial synovial joint since the joint has two articular bony components – superiorly the articular eminence and glenoid fossa of the temporal bone and inferiorly the mandibular condyle. The articulation is between the immovable temporal bone and the movable mandible. The joint consists of the mandibular condyle, articular eminence/articular tubercle, articular disc, glenoid fossa, capsule, and ligaments. The articular disc divides the joint space into the upper and lower compartments. The articulating surface is covered by fibroelastic tissue, and the condylar cartilage is considered as the growth centre which aids in the overall development of the mandible. Since the TMJ functions bilaterally, it easily gets influenced by dental occlusion. The articular disc acts as a shock absorber, which is intact and movable throughout the joint movements. Surface anatomy of the TMJ - mouth closed (left) and mouth open (right) shown in Figure 2.1.

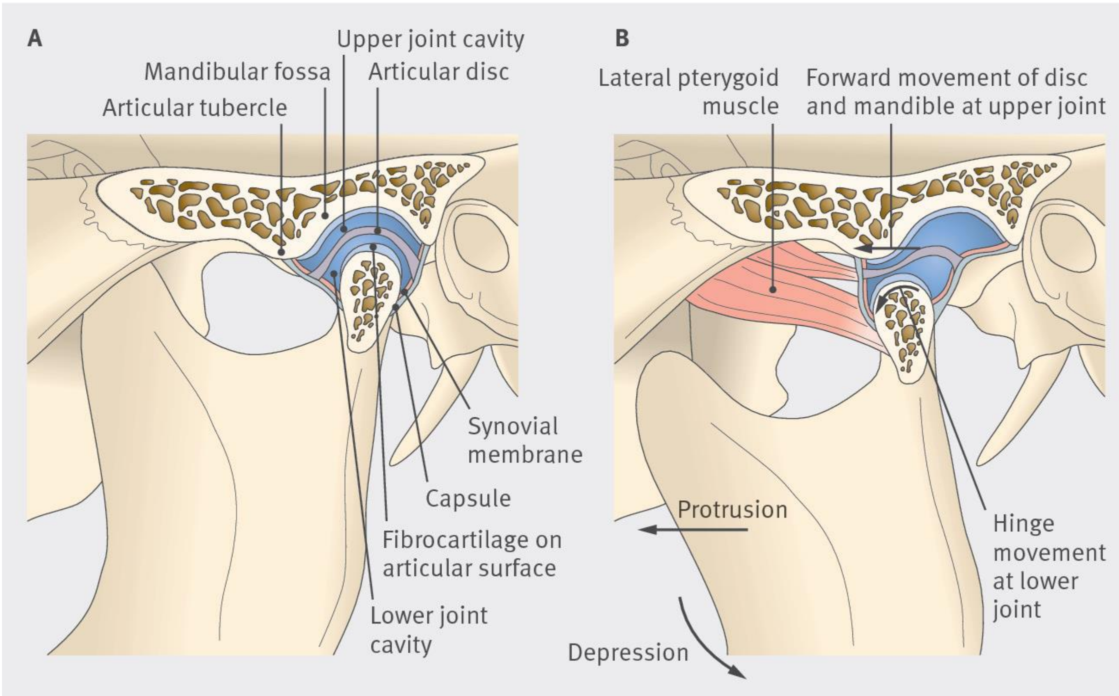

Figure 2.1 Surface anatomy of the TMJ - Closed (left) and open mouth (right), (Durham *et al.*, 2015).

2.1.1 Glenoid fossa

Schiffman *et al.* (2014) exhibited that the glenoid fossa also known as mandibular fossa provides attachment to the posterior capsule. It is the concavity along the squamous part of the temporal bone with articular eminence situated anteriorly and a tympanic plate of the temporal bone placed posteriorly.

The upper wall of the external auditory meatus forms the posterior aspect and the anterior border of the glenoid fossa forms the articular eminence (Bag *et al.*, 2014; Bender *et al.*, 2018).

2.1.2 Mandibular condyle

The mandibular condyle differs significantly among different individuals and age group. Changes in the condyle morphology may occur due to developmental inconsistency, remodelling due to various treatment methods, trauma, malocclusion and other developmental abnormalities and diseases. A comprehensive understanding of the morphology and anatomy of the TMJ is necessary to differentiate the normal variation from an abnormal condition (Standring *et al.*, 2005; Alomar *et al.*, 2007; Hegde *et al.*, 2013).

David and Elavarasi (2016) demonstrated that the condyle consists of medial tubercle, lateral tubercle, and joint capsule. It is narrow anteroposteriorly and broad mediolaterally. The condyle is covered by a dense layer of fibroelastic tissue on the articular surface. The shape of the condyle is roughly ovoid. It measures about 8-10 mm anteroposteriorly and 15-20 mm mediolaterally.

2.1.3 Articular disc

Alomar *et al.* (2007) showed the space between the condyle and the temporal bone is filled by the articular disc. The shape of the disc is biconcave. It consists of three portions- anterior band, intermediate zone, and posterior band. It is non-innervated avascular fibrocartilage. The ligaments of the articular disc are the anterior, posterior, lateral, medial, and discomalleolar ligaments. All these are vascular, innervated, and fibroelastic ligaments.

2.1.4 Synovial membrane

The non-articulating surfaces of the disc ligaments and the inner aspect of the TMJ capsule are lined with a synovial membrane. The superior joint compartment contains synovial fluid in a volume of 1.2 ml, and the inferior joint compartment contains a volume of 0.9 ml. The fluid exits during negative intra-articular pressure. The surface tension of the synovial fluid allows the fluid to spread over and help in lubrication of the joint during condylar movements (Bumann and Lotzmann, 2002; Alves, 2008).

2.1.5 TMJ capsule

Sharawy (2000) disclosed the TMJ capsule as a richly vascular, fibroelastic with thick connective tissue. It is attached laterally to the zygomatic tubercle, medially to the glenoid fossa, posteriorly to the petrotympanic fissure and inferiorly to the neck of the condyle.

2.1.6 Extracapsular ligament

The main extracapsular ligaments are lateral temporomandibular and sphenomandibular ligaments. The other two accessory ligaments are the stylomandibular ligament and pterygomandibular raphae. These ligaments provide stability to the joint (Sharawy, 2000; David and Elavarasi, 2016).

2.1.7 Articular eminence

Sharawy (2000) demonstrated that the articular eminence consisted of two slopes. A descending slope and an ascending slope. It is covered by thick, compact fibrous tissue consisting of collagen and elastic fibres. Underneath the covering of fibrous tissue was the chondroid bone, which was followed by a layer of compact bone.

2.1.8 Vascular supply of TMJ

The main blood supply to the joint is from the external carotid artery. Two important branches of an external carotid artery, the lingual and facial arteries are supplied to the region. The external carotid artery bifurcates at the level of the condylar neck into a superficial temporal artery and internal maxillary artery to supply the muscles of mastication and the TMJ (Bumann and Lotzmann, 2002; Alomar *et al.*, 2007).

2.2 Growth and development of the mandible

The formation of the head and neck are derived from the cephalic portion of the neural tube, from which arises 5 pairs of branchial arches. Each arch consists of 3 layers: outer ectoderm, middle mesoderm, and inner endoderm. At the 4^{th} week of intrauterine life, the pharyngeal arches are laid down. The first branchial arch which is also known as the mandibular arch was the first of six pharyngeal arches. This arch divides into a maxillary process and a mandibular process, giving rise to structures including the bones of the lower two-thirds of the face and the jaw. The maxillary process becomes the upper jaw and palate, while the mandibular process becomes the lower jaw. This arch also gives rise to the muscles of mastication. The first structure to develop in the primordium of the lower jaw is the mandibular division of the trigeminal nerve that precedes the mesenchymal condensation forming the mandibular arch. At around the 5th week of intrauterine life, there is ectomesenchymal condensation and some mesenchymal cells enlarge to acquire a basophilic cytoplasm and form osteoblasts. These osteoblasts secrete a gelatinous matrix called osteoid and result in the ossification of an osteogenic membrane. The resulting intramembranous bone lies lateral to Meckel's cartilage of the first mandibular arch. In the 6th week of the intrauterine life, a single ossification centre for each half of the mandible arises at the bifurcation of the inferior alveolar nerve into mental and incisive branches (Sperber, 1989; Carlson, 1994; Paulsen and Waschke, 2013; Zohrabian *et al.*, 2015). The embryological development of the prenatal mandible is shown in Figure 2.2.

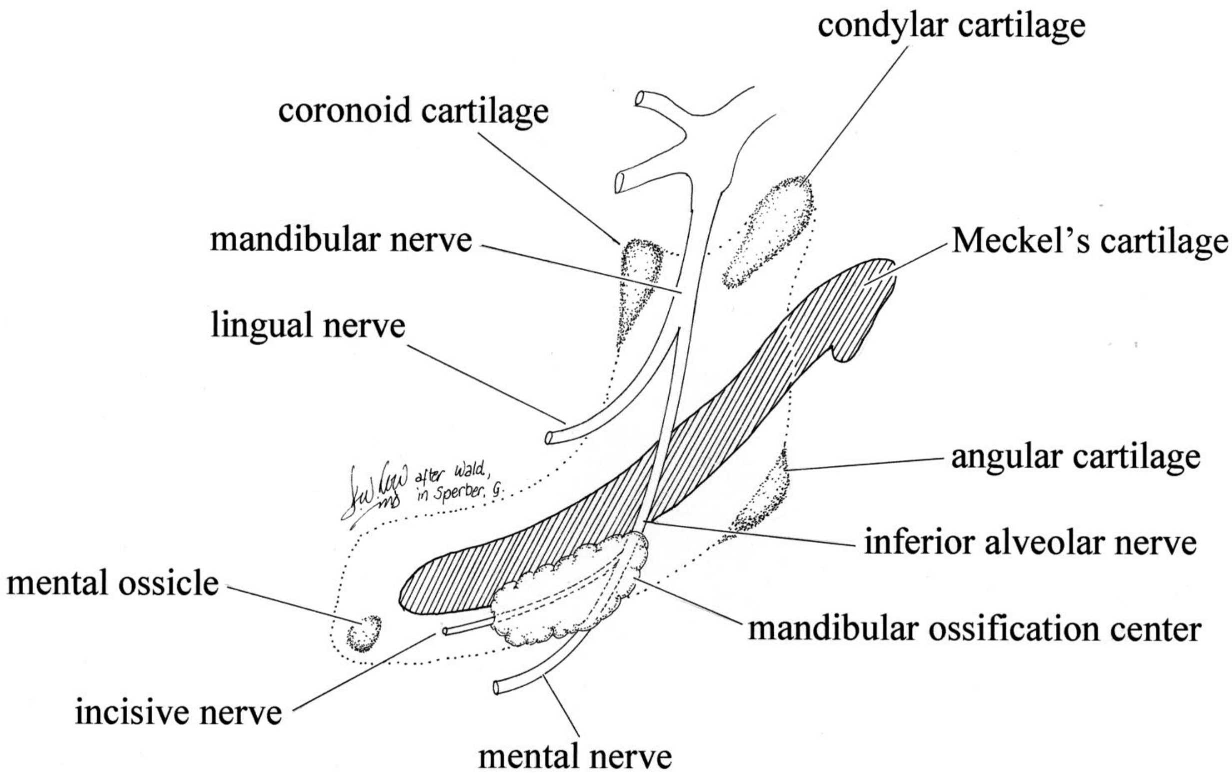

Figure 2.2 Embryological development of the prenatal mandible. (Smartt Jr *et al.*, 2005).

2.2.1 Fate of Meckel's cartilage

The cartilage of the first arch is Meckel's cartilage. This cartilage extends as a solid hyaline cartilaginous rod surrounded by a fibro cellular capsule. Their proximal or cranial ends connect to the ear capsules, and their distal extremities are joined to one another at the symphysis by mesodermal tissue. Bone formation spreads rapidly anterior to the midline and posteriorly to the point where the mandibular nerve divides into the lingual and inferior alveolar branch. The new bone forms a trough that consists of medial and lateral plates that unite beneath the nerve. The trough is soon converted into a canal as bone forms over the nerve, joining the lateral and medial plates. Its posterior end forms the malleus and incus of the inner ear and the sphenomalleolar ligament, but its fibro cellular capsule persists to form the sphenomandibular ligament. From the lingula, anterior to the division of the alveolar nerve into its incisor and mental branches and lastly, the Meckel's cartilage degenerates (Sadler *et al.*, 2005; Nanci, 2017).

2.2.2 Ramus of the mandible

It develops by a rapid spread of ossification backwards into the mesenchyme of the first branchial arch diverging away from Meckel's cartilage. This point of divergence is marked by the lingula in the adult mandible, where the inferior alveolar nerve enters the mandibular foramen. By the 10^{th} week of intrauterine development, the rudimentary mandible is formed almost entirely by intramembranous ossification (Nanci, 2017; Moore *et al.*, 2018). Stages of embryonic development of the TMJ are shown in Figure 2.3.

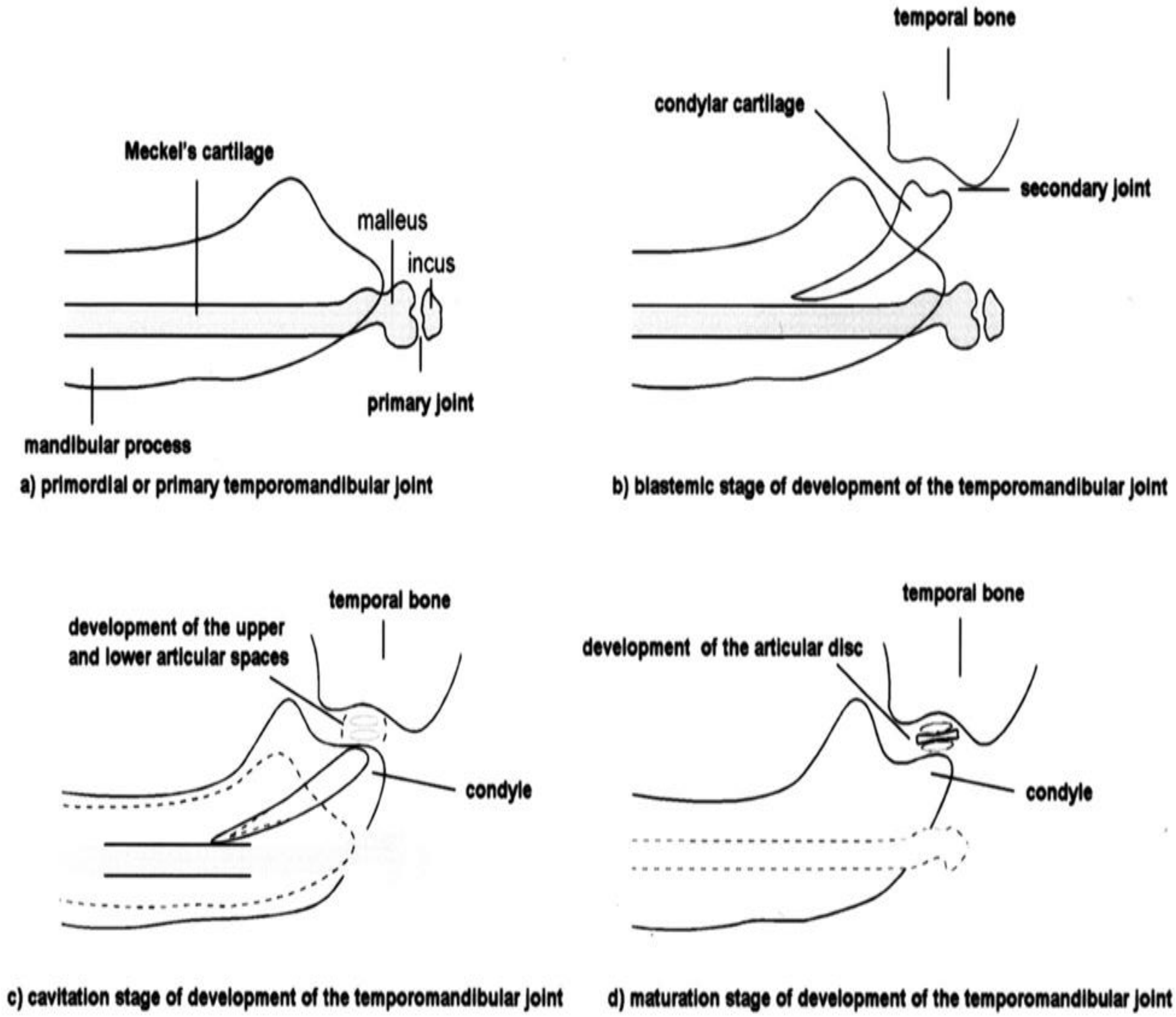

Figure 2.3 Stages of embryonic development of the TMJ (Badel *et al.*, 2011).

2.2.3 Growth of the mandible by secondary cartilages.

The growth of the mandible is further influenced by the appearance of 3 secondary cartilages – the condylar cartilage, coronoid cartilage and symphyseal cartilage**.**

2.2.3 (a) Condylar cartilage

The carrot-shaped cartilage appears at the 12th week of intrauterine development in the region of the condyle and occupies most of the developing ramus. It rapidly gets converted into bone by endochondral ossification, which gives rise to the condyle head and neck of the mandible and the posterior half of the ramus to the level of the inferior dental foramen. At 20th week, a thin layer of cartilage remains on the condylar head. Remnants of cartilage persist until the end of the second decade of life (Nanci, 2017). During growth, the direction of primary cartilage is influenced by mechanical appliances, but the extent of growth is not affected. Whereas, in the case of the secondary cartilage, both the direction and extent of growth are altered by mechanical appliances such as fixed functional appliances (Stutzmann and Petrovic, 1982; Ren and Yang, 2014).

2.2.3 (b) Coronoid cartilage

It is a temporary growth cartilage centre that gives rise to the coronoid process, the anterior half of the ramus to the level of inferior dental foramen disappears long before birth (Smartt Jr *et al.*, 2005; Nanci, 2017).

2.2.3 (c) Symphyseal cartilage

They are two in number, which appear in the connective tissue between the two ends of Meckel’s cartilage. They are obliterated within the first year after birth (Nanci, 2017).

2.3 The relationship between maxillofacial skeletal morphology and occlusion

Based on vertical jaw relationship, it can be classified into three types –

- Low angle – hypodivergent type, skeletal deep bite, brachycephalic pattern and short face (decreased anterior facial height and mandibular plane angle, deep bite, shallow antegonial notches, and large mandibular ramus length).
- Medium angle - mesiofacial pattern, normal face.
- High angle - hyperdivergent type, skeletal open bite, dolichofacial pattern, and long face (Increased anterior facial height and mandibular plane angle, open bite, deep antegonial notches, and small mandibular ramus length) (Mizoguchi *et al.*, 2013). Different types of maxillofacial skeletal morphology shown in Figure 2.4

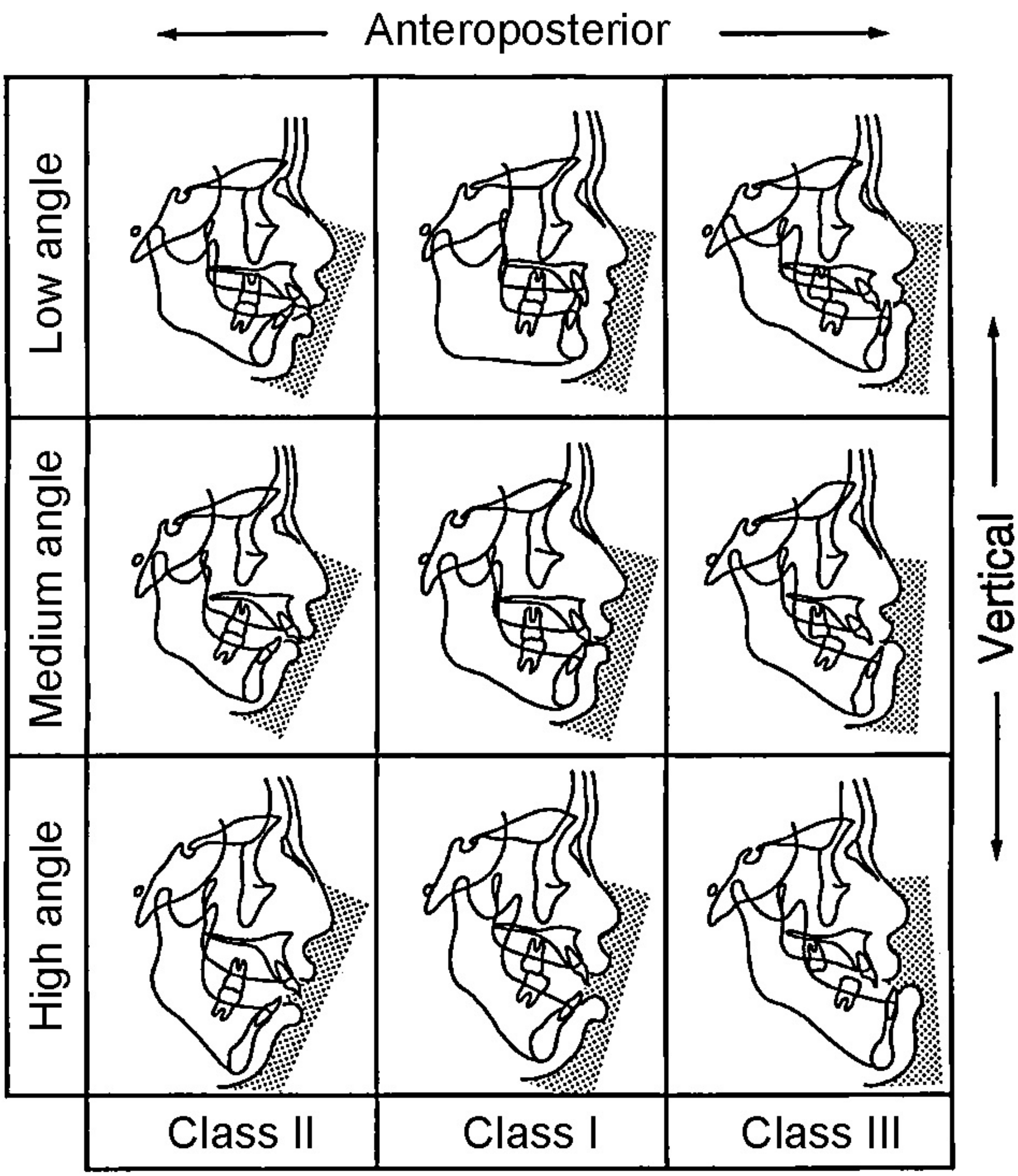

Figure 2.4 Different types of maxillofacial skeletal morphology (Mizoguchi *et al.*, 2013).

2.3.1 Mandibular growth pattern and function of condylar cartilage

The condylar growth not only provides increased mandibular size but also causes a shift of the mandible anteroinferiorly. Condylar growth is associated with the displacement of the mandible and vertical deviations of the jaw. In low angle individuals, the mandibular growth is described by the growth of the condyle anterosuperiorly, displacement of the mandible anteriorly, and inferior gonial border absorption. Whereas, in high angle individuals, it exhibits condylar growth posterosuperiorly, displacement of the mandible inferoposteriorly, and inferior gonial border apposition. The mandible consists of single condylar cartilage which lasts in the mandible throughout life. The maxillofacial morphology and occlusion are drastically affected if the condylar growth is disturbed. If the condyle is affected unilaterally, it results in the displacement of the mandible to the affected side, lateral crossbite, and asymmetry of the face. And if the condyles are affected bilaterally, it results in anterior open bite and rotation of the mandible in the clockwise direction The chondroid bone in the glenoid fossa has altered structural properties and during the growth of the mandible, remodelling of the glenoid fossa also takes place (Mizoguchi *et al.*, 2013).

2.4 Morphological characteristics and development of the cranium

A comprehensive understanding of the development of facial growth is very essential in the field of orthodontics to identify the residual growth which varies among malocclusion bound subjects using orthopaedic appliances. Sutures and periosteum are predominantly influenced by heredity and are the best examples of adaptive growth and craniofacial cartilages (Carlson, 2005). During the foetal and postnatal phase, the dimensions of cranial development exhibit 65% at birth, which reaches 85% by 3 years of age and attaining 95%

by 5 years old, respectively. The development of the facial skeleton is first accelerated between 5 to 8 years of age and again observed at the age of puberty (Beals and Joganic, 2004). The general pattern of mandibular development occurs in two modes, that is bone deposition at the posterior border of the ramus and bone resorption at the anterior border of the mandible. These modifications lead to enlargement of the body of the mandible posteriorly to accommodate the erupting permanent molars. The posterior body of the mandible constitutes about 80% of the whole length and the condylar area representing about 8% of the total ramus height correspondingly. (Sarnat, 1983; Bishara and Ferguson, 2001).

The variations in the development spurt of the maxilla among males and females play an important role in the diagnosis and treatment of orthodontic subjects. The Caucasian females showed two-year early pubertal maturation at the age of 10 to 14 years when compared to males at the age of 12 to 16 years and some subjects up till the age of 18 years. This difference in sexual dimorphism makes it a challenging task in the management of orthodontic subjects (Ochoa and Nanda, 2004). Cassidy *et al.* (1998) showed the maxillary development in all linear dimensions among females was significantly smaller when compared to male subjects. The remodelling of various sutures such as zygomaticomaxillary, zygomaticotemporal, zygomaticosphenoidal, ethmoidomaxillary, ethmoidofrontal, nasomaxillary, nasofrontal, frontomaxillary, frontolacrimal, palatine and vomer resulted in the movement of the maxillary bone (Enlow and Hans, 1996). The growth for maxillary length was greatest between 11 to 15 years, which is approximately 35% by 12 years, and 15% by 15 years of age. The highest maxillary development at peak time was 3.0 mm and the lowest being 1.5 mm (O'Reilly, 1979).

2.5 Growth modification of the craniofacial complex

Various theories in the past have emphasized the process of growth modification of the craniofacial complex. In terms of growth modification, the functional matrix theory is regarded as the most acceptable one. Several kinds of skeletal discrepancies were treated using growth modification devices by most of the clinicians. Functional appliances aid in the increase of mandibular growth, whereas the headgear enables the restriction of the maxilla. Also, skeletal problems of the Class II malocclusion are corrected using functional appliances intending to produce forward and downward mandibular growth, while most of the clinicians use FM therapy to achieve forward and downward growth of the maxilla. Transverse growth modification involves the expansion of mid palatal sutures with the narrow maxilla and vertical growth modification deals with the deep bite correction for patients with long faces. Through these different approaches, the fundamental objective of growth modification is determined by the treatment timing, treatment length, working mechanism of an appliance, dental and skeletal features of the subject, and lastly subject's cooperation towards the orthodontic treatment (Vithanaarachchi, 2018).

Transverse expansion of the maxilla is easy to achieve before adolescence. But transverse expansion during adolescence requires substantial forces and after adolescence, it can be achieved only with partial or complete surgical osteotomy. Whereas the transverse expansion or constriction of the mandible both requires surgery. Orthodontic treatment in Class II malocclusion subjects during the preadolescent or adolescent stage can be achieved with favourable anteroposterior growth. Whereas management of excessive vertical growth in long face subjects during adolescence is rarely successful. Restriction of mandibular growth with external forces in Class III malocclusion subjects mostly causes downward and backward rotation of the mandible. Maxillary advancement before adolescence can be accomplished easily using external forces. Whereas maxillary advancement and forward mandibular growth restriction during adolescence are possible with intermaxillary traction to bone anchors. The short-term effects of this therapy are greater in both the jaws than the previous methods, but individual differences do occur and yet the accurate prediction of the outcome is not possible. 3-D imaging, biomarkers or genetic identification of the subjects is required for all types of growth modification to suggest possible treatment responses (De Clerck and Proffit, 2015).

2.6 Prevalence of malocclusion

The global prevalence rate of malocclusion in permanent dentition for Class I is 74.7%, Class II to about 19.56%, and Class III representing about 5.93% respectively. Hence, Class I malocclusion is more prevalent than Class II malocclusion, and Class III malocclusion being the least prevalent among all the Classes of malocclusion (Alhammadi *et al.*, 2018). The global prevalence rate of Class III malocclusion differs significantly among ethnic groups and within different races. Populations of Southeast Asian countries, Chinese and Malaysian showed the highest prevalence rate of 15.80%, 15.69% and 16.59% respectively. Middle Eastern countries had a prevalence rate of 10.18%, African countries with a prevalence rate of 4.59%. The lower prevalence rate of 2% to 6% was seen in European countries and the lowest prevalence rate of 1.19% was observed in Indians (Zere *et al.*, 2018). Soh *et al.* (2005) evaluated the occlusal status