T.R.N.C.
NEAR EAST UNIVERSITY
HEALTH AND SCIENCES INSTITUTE

GENDER SPECIFIC CHANGES IN PALATAL VOLUME AND HEIGHT FOLLOWING EXTRACTION AND NON-EXTRACTION ORTHODONTIC TREATMENT:A 3-DIMENSIONAL COMPUTED TOMOGRAPHY EVALUATION

Dt. Kamel AL SAFADI

Orthodontics Program
PHD THESIS

THESIS ADVISOR
ASSIST. PROF. DR. Levent VAHDETTIN

NICOSIA
2019

Yakın Doğu Üniversitesi Sağlık Bilimleri Enstitüsü Müdürlüğü'ne

Ortodonti Anabilim Dalı Programı çerçevesinde yürütülmüş olan bu çalışma aşağıdaki jüri tarafından oy birliği / oy çokluğu ile Doktora tezi olarak kabul edilmiştir.

Tez Savunma Tarihi: 23.09.2019

İmza

Jüri Başkanı
Prof. Dr. Zahir Altuğ

Jüri
Prof. Dr. Mete Özer

Jüri
Assoc. Prof. Dr. Ulaş ÖZ

Jüri ve Danışman
Assist. Prof. Dr. Levent Vahdettin

Jüri
Assist. Prof. Dr. Beste Kamiloğlu

ONAY:

Bu tez, Yakın Doğu Üniversitesi Lisansüstü Eğitim - Öğretim ve Sınav Yönetmeliği'nin ilgili maddeleri uyarınca yukarıdaki jüri üyeleri tarafından uygun görülmüş ve Enstitü Yönetim Kurulu kararıyla kabul edilmiştir.

Prof. Dr. Hüsnü Can BAŞER

Sağlık Bilimleri Enstitüsü Müdürü

ACKNOWLEDGEMENT

Many individuals: family, faculty, friends, and participants have supported me through this academic journey toward a Ph.D., and it is my honor to say thank you. Thank you to all of the participants who generously gave their time and energies to this project.

I would like to thank all the faculty members in the Orthodontics Department at Near East Universityfor their wisdom and expert guidance during this residence. I also wish to express my sincere gratitude to Assist. Prof. Dr. Levent Vahdettin, who supervised this research project,Assoc. Prof. Dr. Ulaş Öz, Assist. Prof. Dr. Beste Kamiloğlu and Prof. Dr. Hakan Gögenfor theirexpertise, guidance and inspiration. I am truly in dept for their guidance and the knowledge they haveimparted in me.Under their direction, I gained an enthusiasm for the research process and valuable experience that I will apply throughout my career. In addition, I want to thank and recognize my fellow residents for their kind and lasting friendships.

Finally, I would like to thank my parents, sister and brothers: I owe all of my achievements to you. Thank you for your unconditional love and support. Without your faith in me, and your determination to never give up on me, this would not have been possible, thank you so much.

THANK YOU ALL !

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

°	Degree
µSv	microsievert
CAT	Computerized Axial Tomography
CT	Computed Tomography
CBCT	Cone-Beam Computerized Tomography
cm	Centimeters
CT	Computerized Tomography
DICOM	Digital Imaging And Communications Of Medicine
mm	Millimeters
MRI	Magnetic Resonance Imaging
MSCT	Multi-Slice Computed Tomography
NAR	Nasal Airway Resistance
OSA	Obstructive Sleep Apnea
OSAS	Obstructive Sleep Apnea Syndrome
RME	Rapid Maxillary Expansion
RPD	Removable Partial Denture
RPE	Rapid Palatal Expansion
SME	Slow Maxillary Expansion
TMD	Temporomandibular Joint Disorders
gr	Gram
kg	Kilogram
N	Newton
Ni-Ti	Nikel Titanyum

LIST OF FIGURES

LIST OF TABLES

1. ÖZET

Al-Safadi, K., Vahdettin, L., Gender specific changes in palatal height and volume following extraction and non-extraction Orthodontic treatment: A 3-dimensional computed tomography evaluation.

Bu çalışmada damak yüksekliği ve hacmi değişikliğini premolar çekimli ve çekimsiz vakaladrda ölçmek için konik ışınlı bilgisayarlı tomografi (CBCT) kullanılmıştır. Bu retrospektif çalışmada, 50 hasta (27 kadın, 23 erkek) üst çene modelleri taranmıştır, örnekler cinsiyet ve alınan tedavi türüne göre gruplandırıp analiz edilmiştir. Tedavi sonrası sonuçlar erkek çekim grubunda (%7.87) ve kadın çekim grubunda (%13.53) oranında damak hacminde azalma saptanmıştır. Ön ve arka damak hacim ortalamaları istatistiksel olarak anlamlı azalmıştır. Erkek çekimsiz grupta ve kadın çekimsiz grupta toplam damak hacmi sırasıyla (%11.51 ve%11.35) artmıştır. Çekimsiz gruplarda arka damak hacminde istatistiksel olarak anlamlı artış saptanmıştır. Çekimsiz erkek grubunda ön damak hacmi, marjinal istatistiksel olarak anlamlı olan 10 olgunun 9'unda artmıştır (P=0.0576). Bununla birlikte, çekimsiz kadın grubunda ön damak hacmi istatistiksel olarak anlamlı olmayan 15 vakanın 7'sinde artmıştır (P<0.0003). Damak yüksekliği, dört grupta da istatistiksel olarak anlamlı olan 50 olgunun 48'inde tedavi sonrası artmıştır (erkek çekim gruba: P=0.0003, kadın çekim gruba: P=0.0011, kadın çekimsiz gruba: P<0.0001, ve erkek çekimsiz gruba: P=0.0009). Sonuç olarak, çekimli veya çekimsiz ortodontik tedavi uygulanan, erkek ve kadınların damak yüksekliğinde, arka damak hacminde ve toplam damak hacminde benzer değişiklikler oluşup oluşmadığına karar verilmiştir. Ancak, çekimsiz vakaların ön damak hacmindeki değişikliklerin kadın hastalarda tutarsız olduğu görülmektedir.

Anahtar Kelimeler: Koni Işınlı Bilgisayarlı Tomografi; CBCT; Sabit Ortodontik Tedavi; Damak Boyutları; Damak Yüksekliği; Damak Hacmi

2. ABSTRACT

Al-Safadi, K., Vahdettin, L., Gender specific changes in palatal height and volume following extraction and non-extraction Orthodontic treatment: A 3-dimensional computed tomography evaluation.

This study used cone-beam computed tomography (CBCT) to measure palatal height and volumetric changes associated with premolar extraction and non-extraction orthodontic treatment. In this retrospective study, we scanned archived maxillary casts of 50 patients (27 females, 23 males), grouped and analyzed samples according to gender and type of treatment received. Post-treatment results showed total palatal volume decrease in male extraction group (7.87%) and female extraction group (13.53%). Their means of anterior and posterior palatal volume decreased with statistical significance. In male non-extraction group and female non-extraction group, total palatal volume increased by (11.51% and 11.35%) respectively. Means of posterior palatal volume in these non-extraction groups increased with statistical significance. Anterior palatal volume in male non-extraction group increased in 9 out of 10 cases with marginal statistical significance (P=0.0576). However, anterior palatal volume in female non-extraction group increased in 7 out of 15 cases with no statistical significance (P<0.0003). Palatal height increased post-treatment in 48 out of 50 cases showing statistical significance in all four groups (male extraction group: P=0.0003, female extraction group P=0.0011, female non-extraction group P<0.0001, and male non-extraction group P=0.0009). To conclude, whether receiving an extraction or a non-extraction orthodontic treatment, males and females exhibit similar changes in palatal height, posterior palatal volume, and total palatal volume. However, changes in anterior palatal volume of non-extraction cases appear to be inconsistent in female patients.

Keywords: Cone Beam Computed Tomography; CBCT; Fixed Orthodontic Treatment; Palatal Dımensıons; Palatal Heıght; Palatal Volume

3. INTRODUCTION

The roof of the mouth, or what is called the palate, is one of the major anatomical structures to be altered by orthodontic treatment. It plays an important role in speech, and provides neutral space for the tongue to rest as well as the space needed for mastication. Apart from our interventional impact, many factors are also found to influence the shape of the palate. Such factors include ethnicity, size or posture of the tongue, and mouth breathing. Our ability to anticipate these palatal changes is fairly important from a clinical standpoint, as some studies hypothesize the association of changes in palatal dimensions to oral functions and breathing. Moreover, certain patterns of palatal dimensions have been noted in various disorders, such as, cases with enlarged tonsils having high palatal vaults, Turner's syndrome cases having deeper palates, and Down's syndrome cases showing lower palatal depths and narrow widths (Ciusa et al, 2007).

There are several methods to study the metric and morphological aspects of the palate. Since plaster casting is a gold standard in orthodontic practice, many clinicians have studied the palate by direct manual measurements of plaster casts. However, this option could be troublesome, especially when measuring three-dimensional models as palatal volume, or finding the highest point of the palatal vault while measuring its height. An alternative that is more feasible at obtaining these two measurements along with other palatal metrics is by digital casting (Ciusa et al, 2007).

Nowadays, the transition to using digital casts for diagnosis and marking treatment progress has become popular. When compared to traditional means, digital casts are noted to grant some logistical advantages. More pointedly, digital casting facilitates retrieval and analysis of records at a faster pace, allows effortless sharing of results with other care providers, and eliminates the need of physical space for archives. Digital casts are obtained by scanning patients directly or by digitizing plaster casts, the latter seems to be more favorable as it refrains patients from exposure to radiation (Park and Laslovich, 2016).

Plaster casts can be digitized by cone-beam computed tomography (CBCT), laser scanners, or stereophotogrammetry. These devices provide detailed 3-dimentional images that are processed and analyzed using specialized software programs. The CBCT machine was introduced to the dental field for the first time almost two decades ago. It's accuracy in dental measurements has been very well tested since then (Hatcher et al, 2010).

In this study, we're using CBCT to better understand the palatal alterations imposed by orthodontic treatment. The null hypothesis is that premolar extractions and non-extraction orthodontic treatment have no effect on height and volume of the palate. The aim of this study is to assess palatal height and palatal volume following extraction and non-extraction orthodontic treatments.

4. LITERETURE REVIEW

4.1. Anatomy of Interest

The region that is of interest to this research project is the palatal area, specifically the hard palate. Because the palate is considered to be a major part of the maxillae, this section will first discuss the basic anatomy of maxillae, then further discuss the location and basic anatomy of the palate.

4.1.1. Maxillae

The paired maxillary bones, known as maxillae form the upper jaw of the human skull, house the upper dentition and helps forming orbit, roof of the mouth, and lateral walls of nasal cavity. Each maxilla is an irregularly shaped bone, that consists of a hollow body which is the main bulk and central portion. Maxilla has four extensions known as maxillary processes. Theese include the alveolar, frontal, palatine, and zygomatic processes. Alveolar process is the inferior extension that contains sockets (alveoli) for teeth. Frontal process is an upward extension from the body that projects toward frontal bone. Palatine process is a horizontal plate that forms anterior portion of hard palate. Zygomatic process is a lateral extension from body that projects toward zygomas (Berkovitz et al, 2009).

4.1.2. Location and Basic Anatomy of the Palate

The human palate or roof of the mouth anatomically separates the nasal cavity from the oral cavity. It serves as the roof of the oral cavity and the floor of the nasal cavity. The palate is structurally comprised of two parts; It has a bony “hard” anterior component (hard palate) which forms the anterior two-thirds (and therefore the bulk of the palate), and a muscular “soft” posterior component ending with the uvula (soft palate) which includes the remaining third (Pansky, 1982; Day and Girod, 2006; Scheid and Weiss, 2012).

The hard palate (Figure 1) is the anterior part of the palate andit forms the anterior two-thirds of the entire palatal structure.It can be defined as a bony structure overlaid by keratinized mucosa (mucous membrane), forming the rigid, arched, anterior roof of the oral cavity, separating it from the nasal cavities above (Pansky, 1982; Day and Girod, 2006).

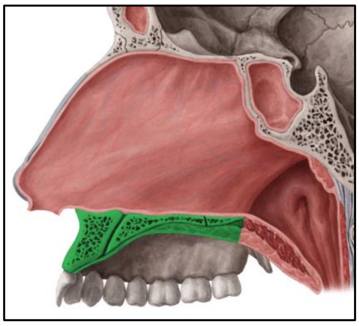

Figure 1. The Hard Palate (Highlighted in Green) (Netter, 2007)

4.2. Overview of the Palate

The palate, due to its morphology and position, has been of great interest in orthodontic literature, as it is considered to be one of the key anatomical structures in determining the type of skeletal pattern and most importantly, it can be influenced by orthodontic treatment procedures. The palate has also been of interest in orthodontic literature because palatal dimensions often need to be altered during orthodontic or orthognathic surgical treatment (Al-Zubair et al, 2015).

The palate serves a variety of important functions in the craniofacial complex, such as mastication and speech. Its shape differs significantly among humans and is potentially influenced by numerous factors such as mode of breathing, tongue size and posture, tooth inclination, occlusion, and parafunctional habits. It is a part of the interface between two functional modules (nasal and oral matrix) that are spatially integrated with each other. Beyond its interactions with adjacent parts, the palate is expected to be associated with the craniofacial complex as a whole (Parcha et al, 2016).

Many studies have been done to compare the morphological, dimensional and volumetricchanges and/or variations of the palate between male and female subjects, Class I and Class II malocclusion, normal occlusion and different malocclusion, patients treated with rapid palatal expansion (RPE) and orthodontically treated controls, extraction and non-extraction orthodontic patients, nasal breathing and oral breathing subjects, normal subjects and subjects with obstructive sleep apnea syndrome (OSAS) normal subjects and subjects with Turner's syndrome, normal subjects and subjects with Down's syndrome, normal subjects and subjects with Marfan's syndrome,normal subjects and thalassemic patients, monozygotic and dizygotic twins and subjects with open bite, deep bite and normal occlusion. On the other hand, various studies were conducted to establish the palatal index and compare it in primary, mixed and permanent dentitions (Nahidh et al, 2012).

Paulsson, et al. (2004) studied in a systematic review the consequences of premature birth on palatal morphology. They found scientific evidence of altered palatal morphology in the short term among premature children. Oral intubation was a contributing factor to the alterations. Moreover, many studies investigated the growth changes of the palate on dental casts by means of tracing its median sagittal and transverse contours at various development stages. The size and form of the palate varies among individuals according to the pattern of craniofacial growth and by several genetic and environmental factors. Heridity is suggested as a strong etiological factor in malocclusions in which palatal dimensions are involved and it`s suggested that appropriate orthodontic or orthopedic procedures be utilized at an early age to diminish or prevent undesirable genetic influences on palatal dimensions (Al-Zubair et al, 2015).

It has been also reported that palatal dimensions are influenced by ethnicity and dietary regimens. Each population affinity and ethnic group possess its own specific facial and cranial form. Gender may also play an important role in determination of palatal dimensions and their changes during developmental growth. Amirabadi et al. (2018) reported that the amount of increase in palatal dimensions was found to be greater in males than in females. In a separate study, Al-Mulla et al. investigated the palatal depth on 50 maxillary study models of patients (18 males and 32 females) aged 15-20 years old and they found no significant difference between males and females. In general, gender differences in palatal dimensions were investigated by many previous studies, some of them found males have greater palatal size than females, whereas others did not find any gender difference. Previous literature has also studied the association between the vertical dimension of the craniofacial complex and palatal height and width. Skeletal open bite and long face have been associated with a high and narrow palatal vault, whereas skeletal deep bite and short face have been associated with a shallow and wide palate (Al-Zubair et al, 2015 and Al-Qudaimi et al, 2016).

Measurements from lateral cephalometric radiographs and dental casts have shown that posterior alveolar height decreases, whereas palatal width increases as mandibular plane angle decreases. In contrast, findings from skull collections did not significantly correlate palatal height to vertical dimension of the face. Anterior open bite has been associated with decreased maxillary posterior width, considered skeletal in nature, and normal palatal height. The relationship between palatal morphology and vertical dimension of the craniofacial complex remains inconclusive. Regarding the anteroposterior dimension of the craniofacial complex, Class II and III skeletal patterns are usually associated with posterior transverse arch discrepancies that may not be apparent due to dentoalveolar compensations. For example, a posterior crossbite is often produced when the study models of a Class II division 1 case are 'hand-articulated' into a Class I canine relationship, due to maxillary constriction. Maxillary expansion can allegedly lead to spontaneous correction of the Class II relationship, although this is heavily disputed (Parcha et al, 2016).

Furthermore, mouth breathing induces morphological change of the palate by not allowing the tongue to exert its expander action on the hard palate as to allow the entry of air into the airway to keep open lips and tongue at the floor of mouth. The absence of a negative pressure in the nasal cavity prevents the lowering of the palate and the action of other bones and muscles of the face assists in compressing the outer maxillary dental arch, so that growth is more pronounced in the vertical dimension. Mouth breathing alters vertical and transverse dimensions of the hard palate mainly in the posterior part (Maria et al, 2013 and Al-Zubair et al, 2015).

Many studies have found that subjects with prolonged mouth breathing have a significant reduction of the palatal surface area and volume leading to a different development of palatal morphology when compared to subjects with normal breathing pattern. Moreover, children with allergies or enlarged tonsils were found to have high palatal vaults, and these children would possibly be expected to develop malocclusion in the future (Maria et al, 2013 and Al-Zubair et al, 2015).

In addition, harmful oral habits cause atresia of the maxillary dental arch, and the change is often reported as the pressures of maintaining the habit alter the morphology of the bone bases. Hard palates of children with non-nutritive sucking habits are deeper and narrower in anterior regions. Oral parafunctions or other spoiled habits can also affect normal palatal growth in a pathological way, causing structural abnormalities in the underlying bones. Breathing, sucking, chewing (mustication), swallowing, and articulating the word (sound pronunciation) are under the brainstem and driven by the neuromuscular functional system. Respiratory performance is of great importance for stimulating and maintaining balance during and after craniofacial development. All these functions represent natural mechanisms of growth control and any sustained alteration may lead to the appearance of structural anomalies of the osseous basis (Ciusa et al, 2007 and Maria et al, 2017).

Maxillary growth disorders are complications that are not only significant in width but also in depth and height. Several studies assessed palatal height in craniofacial syndromes. Skrinjarić et al. and Dellavia et al, compared palatal dimensions (width, depth, length) obtained from patients with Down's syndrome to a control population. Their results demonstrated that the palatal dimensions of participants with Down's syndrome were narrower in width, lower in depth and shorter in length. Johnson and Baghdady found that the palate was deeper in Turner's syndrome individuals. Palatal changes have considerable implications on diagnosis and treatment planning in a modern dentistry based on prevention and early diagnosis of oral disease that orthodontists should accurately take into consideration. The naturally occurring changes of arch dimensions during growth were used as comparative "gold standards" to distinguish changes induced by appliance therapy. These changes have been employed to assist diagnosis, orthodontic planning and postretention stability. Moreover, knowledge about normal palatal dimensions values can be used as a baseline for studies on oral developmental abnormalities (Al-Zubair et al, 2015).

4.2.1. Growth and Development of the Palate

Growth of the upper jaw is influenced by genetic and/or environmental factors. It has been suggested that growth in width is completed first, then in length, and finally growth in height. Growth in width, including width of the dental arches, tends to be completed before the adolescent growth spurt and is affected minimally, if at all, by adolescent growth changes. However, as the maxillary bone grows posteriorly, it also grows wider. Growth in length and height of the maxillary bone continues through the period of puberty. Palatal growth modifications were detected during primary dentition through early and intermediate mixed dentition stages. Orthopedic treatment in the upper jaw should be performed during this period to enhance treatment efficiency. To monitor palatal vault changes during growth, palatal surface area should be preferred over palatal volume (Primozic et al, 2012).

At birth, the growth ofthe maxilla is already accompanied by extension of the sinus maxilaris. The expansion of maxilla is carried out by apposition and resorption in the area of the thin-walled structures over the roots of premolars and molars. In contrast to the mandible, the maxilla can increase in width (because of the palatal suture) until the end of the growth period. Growth of the maxilla and mandible becomes coordinated by the interdigitation of the molars and premolars, incipiently starting at the age of 16 months, when the first deciduous molars move into occlusal contact. Teeth take, as a reaction to the cusp fossa mechanism, a suitable occlusal position. As soon as good intercuspation is obtained, the jaws find the same cusp-fossa relationship whenever the closing movement occurs. The typical occlusal morphology of teeth and correct indentation in an angle Class I occlusion, especially of the first molars, play leading roles in the growth of the face (Heiser et al, 2004).

In a newborn child, the tongue fills the oral cavity. Brodie et al. regarded macroglossia as a physiologic situation in a newborn child. In the absence of teeth, the tongue touches the palate and is in contact with lip and cheek tissue. The tongue grows more quickly than the jaw, achieving its definite size by eighth year, whereas jaw growth continues until puberty or later. When teeth erupt, the tongue position sinks and it shifts backwards. Mason and Proffit described this as “maturation to the back” for oral structures. At this age, sound formation and articulation shift back from labial to palatal velopharyngeal areas.On one hand, the position of the teeth is fundamentally influenced by the force of the lip and cheek muculature. Breathing mode and body posture also affect tongue pressure on mandibular incisors. The orofacial complex is an important functional part of a very balanced system. Thus, it’s understandable that every disturbance can alter to some extent the stomatognathic system, which can affect tooth position, breathing mode, articulation and general body condition. Because of these strong mutual influences, treatment can be successful only if stomatognathic system is considered in the long term (Heiser et al, 2004).

4.2.2. Morphological, Dimesnional and Volumetric Features of the Palate

The hard palate is the bony structure that forms the division between the oral and nasal cavities and maintains a close relationship with the functional orofacial activities. The morphometric features and the dimensional characteristics of the palate are of great importance in clinical dental sciences. The various dimensions of the palate including its length, depth, and width, have had considerable importance in orthodontic treatment planning and in the early diagnosis of oral disease.. The harmonious growth of the face and the proper development of breathing, sucking, chewing, swallowing and speech depend on the balance of the hard palate with the other structures of the sensory-motor-oral system. This can be attributed to the fact that the hard tissues are closely related to function (Maria et al, 2013 and Mustafa et al, 2019).

4.2.3. Previous Methods to study Palatal Morphology and Dimensions

In orthodontic literature, morphological and dimensional changes of the palate during growth have been a topic of great interest, because dimensions of the palate or even its morphology often need to be altered during orthodontic or orthognathic surgical treatment. Several quantitative and qualitative studies of craniofacial and palatal morphology in individual patients have been performed by various authors such as Revelo and Fishman (1994), de Freitas et al. (2001), Ferrario et al. (2001), Tsai and Tan (2004), Heiser et al. (2004), Ciusa et al. (2007), and Primožič et al. (2012). These studies aimed to determine the effect of therapy and to aid comprehensive facial dysmorphology diagnosis. However, when performing such investigations that are usually concerned with interceptive treatment effects, some of these studies suggested that that the influence of growth should be as small as possible. Moreover, the results of these studies were considered to be more meaningful and useful when a comparison with normal reference subjects was available (Thilander et al, 1995; Arslan et al, 2007 and Ciusa et al, 2007).

Many studies reported that the human dentition and the surrounding dentoalveolar processes undergo continuous and complicated alterations as they grow, being a part of the craniofacial complex, and are influenced by changes in different parts of the skull. Orthodontists can benefit from understanding these changes during every stage of human development. Implant studies have been used to determine the growth pattern of the hard palate on cephalograms by Björk et al. (1966), and Björk and Skieller (1974 and 1977). Although these studies present clear-cut evidence of growth, they are not only invasive, but also have two-dimensional limitations. The maturation of the midpalatal suture at different developmental stages has been histologically examined using autopsy specimens (Melsenet al, 1975; Melsen and Melsen, 1982; Revelo and Fishman, 1994; Thilanderet al, 1995; Arslan et al, 2007; Ciusa et al, 2007 and Yang et al, 2013).

Information about the development of the palate in normal subjects, especially palatal height, is scarce. One of the reasons for that, might be attributed to the difficulty in describing the three-dimensional palatal growth in nature. Most of the studies regarding palatal dimension assessments have focused on craniofacial syndromes. Therefore, such investigations have not produced a consistent view of palatal height and width in healthy children (Panchón-Ruiz et al, 2000; Hermann et al, 2003; Ciusa et al, 2007; Cha et al, 2007 and Suri et al, 2010).

Direct measurements performed on dental casts have been used to evaluate width and length of the palate. For height and volume determination, special techniques were used. They included the use of a specialized compass by de Freitas et al. (2001), plastic sheet with a hole by Thilander et al. (2009), photographs of sectioned casts by Tsai and Tan (2004), computerized 3D instruments by Ciusa et al. (2007) and Ferrario et al. (2001), and silicon impressions by Bourdiol et al. (2010) and Heiser et al. (2004). Although reliable, these methods are very time-consuming and labor intensive. In addition, it is difficult to three dimensionally depict the entire area of the palate due to methodological limitations. To overcome these problems, Primožič et al. (2012) recently reported on the longitudinal changes from primary to mixed dentition using 3D laser scanners. He determined the volume and surface area of the palatine vault in growing patients (Primožič et al, 2012 and Yang et al, 2013).

Technology including 3D scanners and reconstructed virtual models has been widely used in dentistry for various applications. Studies of 3D reconstructions have resulted in accurate and reliable techniques for restorative procedures and for facial analyses to aid clinicians in planning more effective treatments. In addition, the use of these 3D reconstructions and specialized softwares allowed for measurements that have been nearly impossible or extremely difficult using conventional means (Park et al, 2007; Park et al, 2011; Veli et al, 2011; Ahn et al, 2012 and Kim et al, 2012

4.2.4. Genetic Influence on Palatal Morphology and Dimensions

The size and form of the palate varies among individuals according to pattern of craniofacial growth and by several genetic and environmental factors. Heridity is suggested as a strong etiological factor in malocclusions in which palatal dimensions are involved and it is suggested that appropriate orthodontic or orthopedic procedures be utilized at an early age to diminish or prevent undesirable genetic influences on palatal width, depth and length (Cakan et al, 2012).

Although, it is very challenging to reveal the genetic component of most skeletal and dental anomalies because of the polygenic nature of craniofacial traits, data provided by the human genome project have made it feasible to map inherited conditions related to dentofacial development. However, further genetic studies are required to clearly determine all the specific genes leading to a particular skeletal variability. The rapid development in this field could lead to the genetic correction of the genetically controlled dentofacial anomalies and malocclusions, perhaps in near future (Cakan et al, 2012 and Al-Zubair et al, 2015).

4.2.5. Effect of Ethnicity on Palatal Morphology and Dimensions

It has been reported that palatal dimensions are influenced by ethnicity, dietary regimens and environmental factors. Each population affinity and ethnic group possess its own specific facial and cranial form. Many previous studies tried to define and put specific measurements for dental arches dimension in different ethnic groups. It should be taken into consideration that these studies may be specific to an ethnic group and cannot always be applied to other ethnic types. Many researchers have tried to define and prove certain correlation between the different components of biometric anatomical landmarks, facial features and the malocclusion properties in Spainish population (Baca-Garcia et al, 2004), Chinese population (Zeng et al, 2007), Malay population (Mohammad et al, 2011), Arabic population (AlBarakati and Baidas, 2010) and Kerman ethnic groups (Elham and Adhami, 2010).

4.2.6. Consequences of Premature Birth on Palatal Morphology

Like other tissues and organs of the body, the facial bones and the palate can be affected by premature birth. Most studies on oral defects have shown that premature birth can cause enamel defects, classified as quantitative loss of enamel (hypoplasia), qualitative change in the translucence (opacity) of the enamel, or a combination of both. These effects are usually located on the primary teeth, although even permanent teeth can be affected. The pathogenesis is considered multifactorial, the most important factor being calcium disturbances in the neonatal period. However, contributing causes of the enamel defects include local trauma from laryngoscopic and endotracheal intubation, which abuts against the maxillary anterior alveolar ridge. Other defects, such as notching of the alveolar ridge, palatal grooving, high arched palate, dental crossbite, and palatal asymmetry, have also been reported with higher frequencies. Moreover, delayed eruption and developmental defects of both the primary and permanent dentitions have also been noted (Paulsson et al, 2004).

Many of the studies considering altered palatal morphology due to premature birth have also highlighted that pressure from the orotracheal or the nasotracheal tube or direct trauma from the laryngoscope when the tube is placed might account for the palatal defects. Thus, the presence of the tube on the palate can conceivably inhibit a normal growth process, and it has also been discussed whether altered morphology of the alveolar ridge and palate can be eliminated by compensating remodeling and growth. Conceivably, the altered palatal morphology can lead to an increase in the incidence of various malocclusions such as crossbite, resulting in an increasing need for orthodontic treatment (Paulsson et al, 2004).

Scientific evidence was found for altered palatal morphology in the short term among premature children, and oral intubation was a contributing factor to the alterations. However, because of contradictory results and lack of longitudinal studies, the scientific evidence was too weak to answer the questions whether premature birth causes permanent alteration of palatal morphology and alterations of dental occlusion (Paulsson et al. 2004).

4.2.7. Palatal Morphology and Dimensions related to Gender

Sex may play an important role in determination of palatal dimensions and their changes during developmental growth. Gender differences were investigated by many previous studies, some of them found male have greater palatal size than female, whereas others did not find any gender difference. Al-Mulla et al. (1997) investigated the palatal depth on 50 maxillary study models of patients (18 males and 32 females) aged 15-20 years old and they found no significant difference between males and females. In another study by Amirabadi et al. (2018), the amount of increase in palatal dimensions was found to be greater in males than in females. Zarringhalam et al. (2014) concluded that palatal height is different in females and males in normal occlusion and class III malocclusion being significantly more in males than in females (Al-Zubair et al, 2015 and Al-Qudaimi et al, 2016).

The observed greater palatal width and depth in men than in women by Al-Zubair et al. (2014) were in agreement with the findings of Borgan (2001) and in contrast with the absence of a sex difference in these dimensions reported by Al-Mulla et al. (1997). In many other studies, maxillary or mandibular (or both) widths were also found larger in male than in female subjects. However, in the few investigations, no width or depth variables indicated a statistically significant sexual dimorphism. This corresponds with the findings of Ferrario et al. who suggested that arch size was not influenced by sex in their sample. In general, most width variables were greater in male subjects and depth variables greater in female subjects. Arch segment lengths were similarly distributed between boys and girls. It seems that arch width is a dominant parameter in males and arch depth in females, but the results were not statistically significant (Slaj et al., 2003; Al-Zubair et al, 2014 and Mustafa et al. 2019).

4.2.8. Palatal Morphology related to Malocclusion and Skeletal Pattern

Further knowledge of palatal morphology and its relationship to skeletal pattern in a general orthodontic population could provide useful information for treatment planning and understanding of morphological integration mechanisms. As puberty affects both structures (palate and craniofacial complex), it is important to study their association pre- and post-pubertally. Any differences observed in their covariation could, then, reflect adaptive mechanisms to the altered functional demands established after the pubertal growth spurt period (Parcha et al, 2016).

Previous literature has studied the association between the vertical dimension of the craniofacial complex and palatal height and width. Skeletal open bite have been associated with long face and a high and narrow palatal vault, whereas skeletal deep bite with ashort face and a shallow and wide palate. Measurements from lateral cephalometric radiographs and dental casts have shown that posterior alveolar height decreases, whereas palatal width increases as mandibular plane angle decreases. In contrast, findings from skull collections did not significantly correlate palatal height to vertical dimension of the face. Anterior open bite has been associated with decreased maxillary posterior width, considered skeletal in nature, and normal palatal height (Parcha et al, 2016).

The relationship between palatal morphology and vertical dimension of the craniofacial complex remains inconclusive. Regarding the anteroposterior dimension of the craniofacial complex, Class II and Class III skeletal patterns are usually associated with posterior transverse arch discrepancies that may not be apparent due to dentoalveolar compensations. For example, a posterior crossbite is often produced when the study models of a Class II division 1 case are 'hand-articulated' into a Class I canine relationship, due to maxillary constriction. Maxillary expansion can allegedly lead to spontaneous correction of the Class II relationship, although this is heavily disputed. In any case, the extent of the compensation, i.e. whether it is restricted to the teeth and alveolar process or it extends to the palatal vault, has not been established (Parcha et al, 2016).

4.2.9. Palatal Morhology related to Growth Pattern of the Face

Face, usually is not of a single type or can be stored under one standard or category of facial forms. Facial type assessment is crucial for the planning and prognosis of orthodontic treatment. The proper determination of various facial types is important in orthodontics since certain orthodontic procedures may attenuate or enhance facial features. Morphological changes can occur in several structures such as the hard palate, a structure of the maxillofacial complex that is involved anatomically and functionally in all stages of the craniofacial development. Moreover, the facial pattern indicates the direction of growth of craniofacial complex and must be taken into consideration when selecting the orthodontic biomechanics. In this sense, the shape of the palate is one of the individual characteristics that are subject to influence of the facial typology and may have different morphologies (Parcha et al, 2016).

It has been reported in various studies that the brachyfacial type has a tendency to horizontal facial growth, mesofacial type is characterized by balanced growth of all facial thirds and the dolichofacial type has a tendency to vertical facial growth and mouth breathing. These studies have also related palatal morphological and dimensional features to certain facial types. According to the facial type, the palate was found to be, for example, deep and narrow in the dolichofacial individuals while wide and shallow in brachyfacial subjects (Ahmed et al, 2014 and Barbosa et al, 2015).

The morphology of the hard palate is directly related to the facial growth pattern of the face. In subjects with medium facial type the depth of the palate tends to show itself as medium, in balance with other oral structures. Thus, the medium hard palate hardly entails functional impairment, being considered normal. Similarly, the hard palate classified as low, which is typically observed in individuals with short face, it may not significantly alter the vertical dimension of the oral cavity as to induce adaptations of oral functions. The hard palate with increased depth is characteristic of individuals who have long facial types and most frequently induces adaptations of breath, chewing, swallowing and speech, as the increased vertical dimension complicates the accommodation of this language structure both at rest and in the execution of functions (Maria et al, 2013 and Barbosa et al, 2015).

4.2.10. Palatal Morphology related to Craniofacial Syndromes

There are several studies regarding palatal height assessment, most have focused on craniofacial syndromes. Skrinjarić et al, Dellavia et al, and Westerman et al. compared palatal dimensions (width, depth, length) obtained from patients with Down's syndrome to a control population. Their results demonstrated that the palatal dimensions of participants with Down's syndrome were narrower in width, lower in depth and shorter in length. Johnson et al. and Baghdady et al. found that palatal depth was deeper in individual with Turner's syndrome (Al-Zubair et al, 2015).

Perkiomaki et al. and Alvesalo et al. observed an increased distance between the tongue and the palatal plane in Turner syndrome subjects, indicating a low position of the tongue. Such a position of the tongue is claimed to cause an imbalance between the pressure from the cheek and the tongue and increases the relative pressure from the cheeks on the maxillary arch, which, therefore, is narrowing. The narrow maxilla, the broad mandible and the increased maxillary arch depth which has been reported in several recent studies reflects previous reports on an increased occurrence of distal molar relation, large overjet and lateral crossbite in Turner Syndrome. De Coster et al. concluded that there is a strong correlation between maxillary/mandibular retrognatia, long face, highly arched palate and Marfan syndrome (Rizell et al, 2013 and Miševska et al, 2015).

4.2.11. Palatal Morphology related to Oral Habits

Habits that may damage the palate generally begin in childhood, as in the first years of life, this area is very susceptible to being affected by external agents, agitating other tissues in the mouth. Oral habits can cause atresia of the maxillary dental arch, and the change is often reported as the pressures of maintaining the habit alter the morphology of the bone bases. Children with non-nutritive sucking habits were found to have their hard palate deeper and narrower in anterior regions. Non-nutritive sucking can cause undesirable effects on the palatal morphology and dimensions. Continuous presence of thumb or finger in the oral cavity can exert sufficient pressure to deform the maxillary arch or palate or both (Jyoti and Pavanalakshmi, 2014).

4.2.12. Palatal Morphology and Dimensions related to Respiratory Mode

It is well known that normal breathing occurs through the nose with the mouth closed and the tongue at rest on the palate. In contrast, mouth breathing induces morphological changes by not allowing the tongue to exert its expander action or any force on the upper teeth and hard palate as to allow the entry of air into the airway to keep open lips and tongue at the floor of mouth. Thus, mouth-breathing causes the tongue to rest in a low position in the oral cavity rather than the palate. This will result in an imbalance of forces between the cheeks and tongue. When the outer forces of the cheeks exceed those expanding inner forces exerted by the tongue, the growth and development of the upper and lower jaws can be directly affected as the upper arch may remain undeveloped (Maria et al, 2013).

Mouth breathing may induce morphological changes due to the absence of a negative pressure in the nasal cavity which prevents the lowering of the palate and the action of the other bones and muscles of the face assists in compressing the outer maxillary dental arch, so that growth is more pronounced in the vertical dimension. Mouth breathing alters the vertical and transverse dimensions of the hard palate mainly in the posterior part. There have been several reports of common oral features and different types of malocclusion, such as anterior open bites, anterior and/or posterior crossbites, class II malocclusion, contraction of the upper dental arch, and constricted high arched palates (Maria et al, 2013).

Bresolin et al. and Mattar et al. found that mouth-breathing individuals showed greater palatal height and narrower intermolar width than did nasal-breathing subjects. When compared with normal breathers, mouth breathers have shown significant constriction and narrowness of the maxillary arch and the palate with an increasing gradient from the anterior to the posterior part of the palate. They have also shown a significant reduction of the palatal surface area and volume leading to a different development of the palatal morphology. The palatal height was also found to be significantly increased in mouthbreathing subjects in the posterior region and the palatal vault showed a higher and sharper morphology especially at the level of the first permanent molars. Furthermore, subjects with a mouth breathing pattern were found to have a significantly smaller palatal surface areas and volumes when compared with subjects with normal breathing pattern (Lione et al, 2013 and Lione et al, 2014).

4.2.13. Palatal Morphology related to Ostructive Sleep Apnea (OSA)

A shorter, narrower, and tapered maxillary arch with a mandibular deficiency is associated with OSA. Small upper airway size may be the specific determinant of OSA in relation to smaller palatal volume when compared with a healthy population. A negative correlation between palatal volume and soft palate area in OSA indicates that the interaction between the hard and soft tissues of the palate when breathing is restricted (Kecik et al, 2017).

Guilleminault et al. studied the relationship between maxillary constriction and the etiology of OSA and reported a familial tendency of narrow, high palates in the relatives of OSA patients. Maxillary morphological differences exist between OSA and control subjects, identifying a potential etiological role in OSA. Statistically significant differences exist between OSA and control subjects, in both maxillary skeletal morphology and oropharyngeal dimensions. Study model analyses demonstrated that OSA subjects differ significantly from control subjects in palatal height measurements (Johal and Conaghan, 2004).

4.2.14. Palatal Dimensions related to Orthodontic Treatment

Many investigators reported on the morphological and dimensional changes of the palate following RME treatment. Authors such as McCurdy et al. (1909), Black et al. (1909) and Haas et al. (1961) have actively debated the inferior or superior characteristics of expanding the palate. From early to mid- 1900s, it was believed that palatine processes were lowered as a result of the expanding of alveolar processes; RPE caused lowering of the roof of the palatal vault. Other studies, as Davis and Kronman (1969), Linder-Aronson and Lindgren (1979), and Linder-Aronson and Aschan (1963) used tracings of plaster casts and found that palatal vault height remained constant or was elevated during growth, but there was no relation between intermolar width and palatal vault height (Gohl et al, 2010).

In a retrospective study, Gohl, Naguyen and Enciso (2010) used CBCT to compare the 3D changes of skeletal and dental structures of the maxillary palatal vault in a group of growing patients treated for maxillary constriction and posterior crossbite before and after RPE with changes over time in an age-matched orthodontically treated control group. The sample for the study included 19 patients treated with a hyrax palatal expander and 19 control subjects who received no RPE (only orthodontic treatment). They analyzed beginning and progress CBCT scans of all patients to measure the anatomic volume, width, height, and AP dimensions of the palate. Only hard-tissue changes were considered in the study. It was concluded that RPE was effective in increasing the palatal volume of patients with constricted maxillary arches (21.7%) compared with growing matched controls (10.8%). The study also concluded that the increase in palatal volume of the RPE patients was mostly due to molar-to-molar and canine-to-canine widths. There was no significant change in some other palatal vault parameters such as height or AP length after RPE compared with orthodontically treated controls (Gohl et al, 2010).

Gracco, Malaguti, Lombardo, Mazzoli and Raffaeli (2010) evaluated volumetric variations in the palate following RPE, both immediately after treatment (subsequent to RME) and over time (on follow-up), in patients in early mixed dentition, using the 3D acquisition technique of laser scanning plaster models. They investigated volumetric alterations in the palate following the active phase of expansion and stability over time of the results achieved. The sample was composed of 30 patients in early mixed dentition treated with a Haas-type device cemented onto the primary second molars. The mean age of the patients upon commencement of expansion was 7 years and 6 months. Measurement of palatal volume was conducted via 3D acquisition of plaster models using laser scanning. The study concluded that palatal volume significantly increased with RPE treatment with insignificant relapse and the use of virtual 3D models with the aid of Apposite software permited the evaluation of the morphologic and volumetric changes induced by orthodontic treatment (Malaguti et al, 2010).

Phatouroset al. (2008), in a retrospective study, estimated the area change of the palate after RME in the early mixed dentition stage by using a 3D helical CT scanning technique. Morphologic changes in the palate after RME were investigated using 3D images obtained via CT scanning of plaster models. RME produced clinically significant increases in interdental widths across the canines, the deciduous first molars, and the permanent first molars in the maxillary arch. 3D helical CT scanning was found to be an accurate and cost-effective method of assessing dental cast morphologic changes. It can also provide fast and accurate data acquisition and subsequent analysis (Phatouros and Goonewardene, 2008).

Marini and Bonetti (2006) assessed using a digital photogrammetric technique the relative dimensional changes in the palate before and after RME treatment. In their study, they investigated the effect of RME on 3D change of the palatal vault by evaluating the changes in palatal shape and volume immediately after expansion and six months after completion and removal of the appliance. Their findings in patients who underwent RME treatment without any subsequent retention or fixed appliances, showed that there was an increase in palatal volume and a change was observed in the morphology of the palate in all these patients. The palatal vault has also became more symmetrically harmonious, wider, and less deeply arched in all subjects (Marini et al, 2006).

De Felippe et al. (2008) evaluated the effects of RME by calculating the variations it induced on interdental diameters, molar tipping, and palatal area and volume, using 3D digital images obtained via laser scanning of plaster models. The study concluded that RME induced statistically significant short-term effects that include mean increases in palatal area, volume, and intermolar distance. The long-term findings of the study suggested that mean palatal area and intermolar distance were reduced, while palatal volume was stable (De Felippe et al, 2008).

Shahen et al. (2018) developed a reproducible method to measure the change of palatal volume and area through superimposition using expansion digital casts. A total of 10 pre- and 10 post-expansion dental casts were scanned by the same CBCT machine. The study concluded that palatal volume and area measurements based on the proposed superimposition are reproducible and reliable. The used novel approach represented a valid alternative to the other methods used to evaluate palatal volume and area (Shahen et al, 2018).

Bukhari et al. (2018) retrospectively evaluated and compared palatal symmetry, dimensions, and molar angulations following SME in the early mixed-dentition stage with parameters in normal controls. The study concluded that the use of SME with a Haas-type expander in the early mixed dentition resulted in the following: Pretreatment palatal surface areas and volumes that were smaller than the untreated controls became significantly larger after expansion; Surface areas in the palate were bilaterally similar, except for the central postexpansion region; A palate that is symmetrical before SME may become asymmetrical after it, but only in the middle segment (Bukhari et al, 2018).

Derech et al. (2010), assessed the relationship between palatal height and width on plaster casts from 33 growing subjects (10 males and 23 females) with Class II Division 1 relationships who received non-extraction orthodontic treatment. All individuals had a bilateral Class II molar and canine relationship and an overjet of at least 5 mm before treatment. The correction of the class II relationship and the overjet was achieved primarily by cervical headgear and occasionally by Class II elastics. The study marked a statistically significant increase in average palatal height and basal width at the end of treatment. The increase in height and basal width in combination with cervical width decrease have lead to a change from an initially triangular-shaped palate into a squarer configuration with parallel alveolar processes (Derech et al, 2010).

Only few studies compared palatal changes associated with extraction and non-extraction treatment. Heiser et al. (2004) is one of the first publications to extensively study dental arch and palatal form changes in extraction and non-extraction cases. They investigated the impact of extraction and non-extraction orthodontic treatment on different parts of the palate. The purpose of their 3-part study was to evaluate 3-dimensionally the treatment and posttreatment changes during growth and treatment in patients treated with and without premolar extractions. In part 1, dental arch length and area were examined; in part 2, palatal height and volume were assessed; and in part 3, the sagittal and transversal palatal forms were compared (Heiser et al, 2004).

In the study by Heiser et al, the only criterion for inclusion was good occlusion at bracket removal (ie, each patient met the 6 keys to normal occlusion). Records were collected at 4 points: pretreatment, bracket removal, end of retention, and follow-up. Patients were treated between the years 1981 and 1991. The non-extraction group consisted of 25 class II patients (19 girls, 6 boys; average age: 11 y 4 m) who were treated with fixed appliances (straightwire) without extractions. The extraction group consisted of 24 patients (18 girls, 6 boys; average age: 13 y 7 m) who were treated with fixed appliances (straightwire) and 1st or 2nd premolar extractions. Average active treatment time was 1 year 9 months in both groups (Heiser et al, 2004).

In part 1, Heiser et al. concluded that arch length and area in both arches and both groups decreased. In part 2, palatal height increased over the observation periods in both groups while palatal volume increased in the non-extraction group and decreased in the extraction group. In part 3, palatal form was similer in both groups before orthodontic treatment but it reacted differently (vertically and sagittally) to premolar extraction compared to non-extraction. From pretreatment to follow-up, palatal form stayed stable in non-extraction group but it changed in extraction group (Heiser et al, 2004).

4.3. Digital Era of Orthodontics

Digital dentistry is gradually overtaking the analog systems of the past. These same changes are occurring in the orthodontic specialty. The Journal of Clinical Orthodontics (JCO) conducted surveys in 1986, 1990, 1996, 2002, 2008, and 2014 concerning results and trends in orthodontics. In photography, for example, there has been a rapid swing from film to digital. In 1996, 82% of orthodontists took extraoral photographs with a conventional film camera, but by 2008 this dropped to just 8%. In 2008, 87% of orthodontists took extraoral photographs with a digital camera and by 2014 this number jumped to 95%. Digital impressions and models are also showing an increase in orthodontics. 18% of orthodontists routinely used digital models in 2008, but by 2014 this number increased to 27%. Orthodontic residency programs are showing increased interest in digital study models; however, many programs find plaster models to be helpful in a teaching environment. In a 2013 survey of accredited orthodontic postgraduate programs, 38% of graduate clinic directors and chair-persons felt that plaster casts were better for learning than digital (Keim et al. 2014).

35% of the programs are using digital models on most of their cases and of the 65% who aren't using them, 37% stated that they want to switch to them. In addition, 75% of those that want to switch wish to make that within 3 years. A 2016 survey of practicing orthodontists investigated their use of digital models, intraoral scanners and CBCT. 54% of orthodontists primarily use plaster models while 46% primarily use digital ones. Of those that used plaster ones, 34% planned to switch to digital models within the next 5 years. The respondents to this survey felt the main advantages of plaster models were the 3D feel and low cost, while the main advantage of digital model was ease of storage and retrieval. For those that did not want to switch to digital models, the main reason was the cost of making the transition. Digital models are a relatively recent addition to orthodontist's armamentarium but are becoming more prevalent in private practice and residency programs (Shastry and Park, 2014; Park and Laslovich 2016).

4.3.1. Technological Revolution in Orthodontics

Orthodontics as a specialty is going through a technological revolution. During the last 10 years there were more new developments in orthodontics than in the whole history of our specialty; this progress is parallel to the world‘s technological evolution. Technological changes include almost all aspects of orthodontic practice, research and education; from internet search databases to the public availability of information, from better diagnosis tools to appliances completely designed and produced by computers, from interactive teaching sessions to distance learning applications. One of the areas undergoing rapid progress is three-dimensional (3D) imaging (Grauer et al, 2010).

The changes occurring in the orthodontic specialty have a direct effect on diagnosis, treatment planning, knowledge generation, treatment implementation, design and fabrication of appliances, communication, marketing, interdisciplinary interaction and education in orthodontics. A search performed with the key words "Three-Dimensional" in the American Journal of Orthodontics and Dentofacial Orthopedics, showed that there were 25 related articles published in the entire year 2000, and 145 related articles published between January and October 2010 (Grauer et al, 2010).

New technology and new research create more questions and unknowns. Three-dimesnional (3D) images are impressive in their detail and ability to show spatial relationships in three-dimensions. However, today we do not have a clear link between the morphological findings and our orthodontic diagnosis and prognosis systems, which are based on two-dimensional concepts and two-dimensional (2D) databases. Because of that, indications and contraindications of the use of three-dimensional (3D) images are not clear yet. Representatives of the American Association of Orthodontists and the American Association of Maxillofacial Radiology have worked on a joint paper on the appropriate selection of diagnostic images for orthodontics (Grauer et al, 2010).

Technology is usually ahead of the evidence to support it. This happens because in a first stage more money is invested in the development of new products rather than in validation studies. In a second stage more money is again invested in marketing rather than in validation studies. In orthodontics, this translates into a practice guided by a sales pitch. Clinicians and researchers should be critical with new developments and also avoidthe acceptance of claims if not supported by evidence (Grauer et al, 2010).

The advent of 3D technology creates the need for normative data. For ethical and legal reasons, the use of radiation in untreated individuals (i.e. those who will not benefit individually) in order to generate growth databases is not longer available. Because of that, it is not likely that we will generate normative data in three dimensions. It makes sense then to compare the data generated with these new modalities with historical growth databases. Three-dimensional images allow for extraction of simulated two-dimensional images. Three-dimensional (3D) imaging in orthodontics also includes surface-type images generated with scanners or 3D cameras. Research in this area is conducted at universities and at the development laboratories of various companies. Working with scanned surfaces requires specific software packages for visualization, measurement, orientation, registration, Boolean operations and CAD/CAM procedures. Validation studies of these procedures are difficult to publish given that they involve a technical background (Grauer et al, 2010).

The cutting-edge in customization of delivery of orthodontic treatment is CAD/CAM procedures to fabricate orthodontic appliances. 3D imaging and technology plays a key role in this area. The main three patient-customized treatment planning and manufacturing techniques are Insignia, SureSmile and Incognito. In order to validate the use of goal-oriented techniques of this type, a method of comparing tooth positions in 3D is needed. It is a very exciting time in orthodontics and in dentistry. Digital dentistry and digital orthodontics are around the corner. “Three-dimensional technology has arrived and we should all be part of it” (Grauer et al, 2010).

4.3.2. Origin and Evolution of Digital Technology in Orthodontics

Orthodontics and Dentofacial Orthopaedics, the most complex branch of dentistry, requires a careful acquisition and interpretation of a large amount of information to achieve a correct diagnosis and treatment planning. Imaging technology in dental field has emerged as one of the most important aspects of diagnosing and treating oral disorders, especially since the advent of 3D techniques, which have found various applications in orthodontics and maxillofacial surgery. Methods used to examine the oral and maxillofacial anatomy have existed for many decades, dating back to 1940s. But current technologies have allowed much faster and efficient analysis abilities than before. Medical imaging has become a major tool in almost every aspect of orthodontic practice, research and education. The evolution of orthodontics and dentofacial orthopaedics and learning about malocclusions at different levels of stomatognathic system have led to a more accurate diagnosis and a more effective treatment planning. In addition, the adult orthodontic treatment, a direction in continuous development, requires a broader interdisciplinary collaboration between Orthodontics, Oral and Maxillofacial Surgery, Periodontics, Prosthodontics and Oral Implantology. Within this collaboration, an enormous amount of information from each of the involved specialties should be presented, analyzed and evaluated (Chakraborthy et al, 2016).

No effective therapy is possible without walking with the radiographs, photographs or models from one specialist to another. All these problems have found solutions in the present digital age with Computer-Aided Diagnosis (CAD) and treatment planning. The 21st century will be the digital era of dental imaging much as film imaging dominated the 20th century. Computer-Aided Diagnosis involves the use of imaging techniques and image processing tools. Biomedical Imaging is one of the most dynamic development directions between medicine and computer sciences and involves the creation of images of the human body for clinical, medical or scientific purposes (Chakraborthy et al, 2016).

Successful orthodontic treatment is based on a comprehensive diagnosis and treatment planning. A few of the fundamental factors in diagnosis are the spacing condition, tooth size, arch form and its dimensions, as well as the tooth-arch discrepancies. The model analysis is a time-consuming procedure. Nevertheless, it is a vital part in diagnosis and subsequent treatment planning process. However, in a day-to-day practice many orthodontists judge the models subjectively, without applying analytical tests. Traditionally, measurements on dental casts were performed with the aid of either Vernier calipers or needle pointed dividers. But this process can be very simple, effective, reliable and less time consuming by taking digital impressions, converting to digital models and analyzing on the respective softwares (Chakraborthy et al, 2016).

Digital photography is widely used today to document orthodontic adult patients. The digital Single Lens Reflex (SLR) cameras were tested for use in intra- and extraoral photography and proved to generate perfect images when used with the recommended macro-lens and macro-flash techniques. Digital photography allows clinicians to evaluate facial harmony and establish a more proportional focus on all three structures of the triad to assess patient's deformity. An accurate assessment of facial deformity or a preoperative prediction of surgical outcome in two dimensions, especially regarding asymmetry, is always a lacuna that is deficient since it does not address the volumetric changes of all the facial portions that determine neuromuscular balance and facial harmony. As a consequence, with 2D representation of facial appearance, it is not possible to achieve a realistic and acceptable result. From the 1980s, the shortcomings of these techniques induced an increase in the use of 3D imaging techniques, such as facial surface laser scanning, 3D stereophotogrammetry and 3D video-imaging. Reconstructions of Digital Imaging and Communications Of Medicine (DICOM) files from Multislice Computed Tomography (MSCT), Cone-Beam Computed Tomography (CBCT) or Magnetic Resonance Imaging (MRI) slices to display the dentition, skeletal structures and digital models were investigated (Chakraborthy et al, 2016).

3D virtual planning software programs with a Virtual Operating Room (VOR) were also introduced by the end of the 1980s. The IT revolution (2000s) has enabled significant improvements of these software modules. The reconstruction of DICOM files in a VOR enables the clinician to document, analyze and plan orthognathic surgery on a facial skeleton model as often and in as many different ways as required. Programs to analyze the facial soft tissue surface and dental models were also introduced. For the first time, these programs gave the clinicians true insight into all three structures of the triad, albeit separately and routinely on a 2D computer screen (Chakraborthy et al, 2016).

Since most 3D imaging techniques only display one of the three structures with optimal quality, it is evident that these imaging techniques are more powerful when they are used together. This emphasizes the importance of image fusion of 3D image modalities to document and analyze the triad of a patient's face accurately. This has enhanced a search for an 'all in one 'assessment of the face. The three methods that have been used to display the facial skeleton and the dentition include the Life-Sized Stereo Lithographic (STL) or milled models augmented with dental casts; digital casts integrated in cephalograms; and a 3D reconstruction of the CBCT with integrated digital casts. Amongst these, the first two methods are actually considered to be obsolete and outdated. The third method virtually displays the facial soft tissue surfaces and the facial skeleton in all the three dimensions The integration of digital dental casts into the CBCT reconstruction establishes an augmentation with improved visualization of the dentition (Chakraborthy et al, 2016).

After impression taking, models, 3D reconstruction and photography, the introduction of digital radiography is another important digital tool in the actual concept of virtual reality in orthodontics. Sometimes, on the way, the documentation is deteriorated or lost and there is no possibility to see again the initial or intermediary clinical situation (Chakraborthy et al, 2016).

Therefore, sending digital images directly over phone lines virtually eliminates the chances of losing or destroying this vital piece of information during the course of treatment. The actual possibility to send images electronically to another dental office allows for consultation between different dental professionals in almost instantaneous fashion and this interoperability is important for the success of the interdisciplinary team. The digital storage of the information allows printing copies for patients and dentists at the same quality after many years. Also, specific annotations can be printed on each image. The digital cephalometric radiograph can be analyzed more precisely using dedicated, digital software. Because of the ability to optimize the display of an image the orthodontist may choose to enlarge areas of greatest diagnostic interests, for example in the positioning of thespecific landmarks. This was done until now manually using a magnifier. What is really amazing at the latter software is that after pointing the requested landmarks on the cephalometric radiograph, one can choose a lot of measurements and analysis that can be done to a particular case and can get a final label with the actual value, the deviation from the standard values and also, the clinical significance of the findings. Another important tool, Cone Beam Computed Tomography (CBCT), is ideally suited for dentomaxillofacial scanning and offers a lot of useful information for the interdisciplinary consideration of orthodontic diagnoses, with the risk from ionizing radiation that results from this examination, especially while working on growing children, is the only concern that needs a little attention (Chakraborthy et al, 2016).

In a recent study, it was concluded that depending on the size of the scanned field, the effective doses with CBCT vary significantly. They proposed that a scan of 13 cm height, which was sufficient in most growing child patients, in a fast scanning mode, results in a dose approximately two times than a conventional set of orthodontic radiographs. Even in the digital decade, always when indicating a radiographic examination, one must follow the ALARA principle (of “as low as reasonably achievable”) (Chakraborthy et al, 2016).

The digital radiography has a lot of benefits over the classic one beginning with the elimination of the requisite dark rooms, processors and flatbed scanners, all capital expenses. With no need for chemical processing, the monthly costs of chemicals, maintenance of the processors, film mounts and films are all eliminated with the use of digital equipments. There is also a significant environmental benefit to this technology since the heavy metal waste stream that results from chemical processing gets eliminated. Today, with the use of computerized imaging and CAD/CAM technologies, orthodontists can integrate the computer in the manufacture process of the orthodontic appliances. The best example is the Invisalign system where the series of trays are made using a computer-assisted simulation of the needed movements (Chakraborthy et al, 2016).

In education, the introduction of computer sciences has a tremendous effect. Virtual reality in orthodontics by creation of diagnosis websites provides the undergraduate and postgraduate students in orthodontics an accessible source of complete, good-quality study materials. Webbased digital orthodontic records are as effective in teaching clinical orthodontic diagnosis as were conventional records. In the orthodontic research, one cannot imagine any important result without the use of computer sciences even for epidemiological studies and/or, for biomechanical and material studies (Chakraborthy et al, 2016).

All this big quantity of information needs to be protected; else, it can be destroyed as easily as the previous versions of the clinical records. The digital tools have a lot of advantages over the classical diagnostic tools but are equally vulnerable to loss as the last ones. For this reason, if we want to have success with this paperless work environment and innovative imaging technology, we have to apply adequate backup protocols for this crucial data. Respecting the TEAM (together everyone achieves more) principle from interdisciplinary orthodontics, one can say that today, the computer science is the first partner in every team that tends to optimizethe treatment effects for every patient (Chakraborthy et al, 2016).

Everyday, one sees that the introduction of digital technology has improved our lives; making things better, easier to use, relatively economical and more reliable. Steadily, digital technology was introduced to manage practices in a more efficient manner. In the beginning, one used to have personal computers in the front office to manage the business part of offices which was considered a great leap and was later replaced by the computers on the chair-side for better communication with the patients, in educating them, for behavioral management and increasing the efficiency of patient's record keeping. Interdisciplinary orthodontic treatment of adults and in general orthodontics, use of digital imaging technology and computerized treatment planning tools have helped the orthodontists in many ways and one of them is by giving better communication and care for the patients. Orthodontics is undergoing a gradual transition from plaster to digital decade, mainly due to advancements in computertechnology, bringing the dental specialists to a new way of imaging, diagnosing, documenting and communicating between them and with the patients, thereby, mandating each specialist in orthodontics or other specialties of dentistry to have a sound knowledge in bioinformatics and should be trained to use these new digital devices in order to provide better medical care for the complex cases (Chakraborthy et al, 2016).

4.3.3. Three-Dimesnional (3D) Imaging in Orthodontics

Orthodontic records are one of the main milestones in orthodontic therapy. They are essential not only for diagnosis and treatment planning but also for case follow-up, communicating with colleagues, and evaluating treatment outcomes. Recently, 2D imaging technology as cephalometric and panoramic radiographs, photographs, and plaster casts were routinely used. However, 2D imaging have some limitations as significant amount of radiographic projection error, enlargement, distortion, exposure to radiation, weaknesses of landmark identification, inaccurate duplication of measurements, significant variation of reference points, and limitations in assessing soft tissue balance (Erten and Yılmaz, 2018).

When clinicians use 2D imaging to view 3D anatomical craniofacial structures, some cephalometric structures and landmarks that do not exist in the patient appear such as mandibular symphysis, articulare, pterygoid fossa, and "key ridges." Averaging bilateral structures (such as the right and left inferior borders of the mandible) to create a unified anatomic outline (mandibular plane) results in loss of parasagittal information and, if present, asymmetry of the patient. Thus, using 2D imaging systems to view a 3D object will cause data loss (Erten and Yılmaz, 2018).

After the introduction of 3D technologies such as laser scanner, stereophotogrammetry, CT and CBCT into dentistry, 3D imaging systems are more preferred than 2D ones, especially in cases with craniofacial deformities. In fact, 3D imaging provided more detailed and realistic diagnostic information about the craniofacial hard, as well as, soft tissue and allowed to perform easier, faster, and more reliable 3D analyses. It was possible to evaluate structures in real three anatomical dimensions. These new systems have several other advantages. First, most of them are non-invasive, and, therefore, repeat of images are not of ethical matter. Second, all images may also be stored in digital forms, consequently archiving is much more practical, and extra space need for storage is handled in this way. The development of software programs enables to precisely and reliably analyze the 3D data. Furthermore, thanks to opportunities such as zooming and rotation function, software programs are really simple and easy to be used and thus these new systems are user-friendly (Erten and Yılmaz, 2018).

3D imaging systems are especially favorable for patients with craniofacial syndromes and anomalies such as cleft lip and palate (CLP). This patient group is frequently treated for a long period starting in infancy and not finishing until adulthood, undergoes several surgeries, and requires treatment from specialists of several disciplines or, in other words, interdisciplinary approaches. The treatment plans have to involve the dentition, the hard tissue jaw position, as well as the facial bone position, and the covering soft tissue (Erten and Yılmaz, 2018).

Although the Eurocleft and Americacleft studies proposed documentation at certain time periods, the guidelines are based on 2D records except the 3D dental casts. However, more and more studies have been published about the introduction, the advantages over 2D, and the indications of 3D imaging systems of craniofacial patient treatment teams. However, compared with 2D systems, the cost and also radiation dose of some of these 3D imaging systems are high and should be considered by the specialists before indicating (Erten and Yılmaz, 2018).

4.3.3.1.Various Methods and Techniques of 3D Imaging

Over the years, orthodontic and dentofacial orthopedic diagnosis and treatment planning have relied essentially upon technological and mechanical supports. When counting all the different kind of tools available for orthodontists in their daily routine, imaging definitely has to be mentioned as it is of huge aid in evaluating and recording size and form of craniofacial structures. The development of imaging technologies led, in the last few years, to the introduction of new kinds of technologies such as the three-dimensional ones. 3D devices allow to have the perception of depth on a 2D surface. Nowadays, different kinds of devices have been applied in different fields and, of course, also orthodontics has begun to take advantage of this new technology (Pacella et al, 2017).

The use of 3D devices in orthodontics has two purposes: on one side to reproduce teeth's shape and cast, and on the other side facial imaging, which allows the recognition and measurement of certain landmarks and their eventual superimposition to check changes generated by growth or orthodontic treatment. There are many 3D imaging methods and techniques. The most important ones in orthodontics may include: Conventional Computed Tomography (CT), Cone-Beam Computerized Tomography (CBCT), Micro-Computerized Tomography (MCT), Laser Scanning, Stereophotogrammetry, Magnetic Resonance Imaging (MRI), and Intraoral Scanning (Karatas and Toy, 2014; Erten and Yılmaz, 2018).

4.3.3.1.1.Conventional Computed Tomography (CT)

CT imaging, also called computerized axial tomography (CAT) imaging, uses special X-ray equipment to generate cross-sectional images of the body. CT devices are divided into 2 groups: Cone beam and fan beam. Using conventional fan beam CT devices, the X-ray source and detectors with the circular metal frame rotate around the patient. Patients are placed in a horizontal position on a table when CT scanner works. The table slowly passes through the center of a large X-ray machine. The procedure causes no pain, but some tests require a contrast material to make some parts of body appear better in the image. The first commercially viable CT scanner was invented by Sir Godfrey Hounsfield in Hayes, United Kingdom at EMI Central Research Laboratories using X-rays. Hounsfield gave his idea in 1967,and later it was published in 1972. Allan McLeod Cormack independently invented a similar process. This technique has become an important method for diagnosing medical diseases (Karatas and Toy, 2014).

The usage area of CT is quite wide in dentistry, such as in diagnosis of some pathologies, and even the contents of the boundaries (solid, liquid, Agar-Agar) in determining the salivary gland pathologies, examination of TMJ structure, ankylosis or fractures, examination of the maxillary sinus, orofacial trauma and fractures, differences in airway volumes after RPD, and implant applications. Some disadvantages are: Expensive; Not available in every hospital; Skips lesions far away from the sections; Foreign objects as restoration and prosthetics create artifacts; CT data is insufficient compared with other soft-tissue imaging techniques (Karatas and Toy, 2014).

4.3.3.1.2.Cone-Beam Computerized Tomography (CBCT)

Craniofacial CBCT devices are designed to overcome some of the limitations of conventional CT scanning devices. There are a lot of differences among the CBCT devices including patient positioning, scan time, resolution, radiation dose, and clinical ease of useof cross-sectional area. In addition, while some CBCT devices scan all head area, others scan only the chin area. With the cone-beam systems, dental therapists canachieve 3D (volumetric) data with very low radiationdose at one time.At the same time, CBCT allows re-alignment of 2D images in coronal, sagittal, oblique, and various incline planes (Karatas and Toy, 2014).

When we compare CBCT with CT, patient's visualization with less radiation dose is possible. CBCT provide 15 times less radiation dose than conventional CT do. The radiation dose of CBCT equals to a dose of average 12 panoramic radiographs. In orthodontics, craniofacial images obtained with CBCT provide important information in different categories. Complex relation between treatment, development, and craniofacial data can be explained or data can be used as an independent solution for one and more of the following categories: Determination of normal and abnormal anatomy; Making decision on root length and alignment; Jaw size and distance of examined teeth; Determination of relationship between jaw size and examined teeth size; Determination of 3D maxillo-mandibular relationship; Determination of TMJ status; Determination of orthodontic treatment effects in craniofacial anatomy; Detection and localization of impacted or supernumerary teeth (Karatas and Toy, 2014).

The ability of providing 3D images of craniofacial structures with minimum amount of distortion has increased the availability of this technology. CBCT has many advantages in orthodontics which may include the following: The cost of CBCT imaging devices is very low compared to CT scanning devices; The maintenance cost of CBCT devices is much less as well;CBCT devices have gained smaller size, thanks to technological developments; Image processing iseasier because it is limited to the head and face; Reduction of radiation dose compared to CT scanners. Referring to the results of the different studies, CBCT devices emit up to 98% less radiation; CBCT devices emit on average 36.9-50.3 microsievert (μSv) of radiation dose: On average, 1.320 to 3.324 μSv for the mandible and 1.031 to 1.420 μSv for maxilla; Quick scan of CBCT devices as all raw data are obtained in a single turn. In this way, the patient'slength of stay is reduced and the device increases patient satisfaction; Dimensional reconstruction feature: The mostimportant advantage of CBCT is possible to display and arrange 3D data in personal computers; Image processing: Various comprehensive softwares for implant placement and orthodontic measurements are available (Karatas and Toy, 2014).

CBCT applications in orthodontics include the following: Impacted teeth and intraoral anomalies; In determining position of the ectopic cuspids accurately, CBCT can be used for the establishment of therapeutic strategies to employ minimal invasive surgery. In determining the position of oral abnormalities in patients; Previous studies showed that after using the CBCT, incidence of oral abnormalities has increased compared to the earlier studies. Another application of CBCT is the nasopharyngeal airway analysis; While enlarging the airway is not a direct goal of orthodontic treatment, CBCT and lateral cephalographs are widely used for airway measurements. As a result, either surgical removal of the adenoids/tonsils or OSA therapy due to narrow airways can be applied if necessary. The potency of CBCT to measure airway volumes has helped orthodontists for studying in airway volume differences as a result of RPD and premolar extraction. In both studies, airways were found to be unchanged after orthodontic treatment. In another study using lateral cephalograms and CBCT, there was a moderate difference in upper airway area and volume measurements of 11 patients (Karatas and Toy, 2014).

For CBCT image analyses, the front or profile photos can be converted to DICOM (Digital Imaging And Communications Of Medicine). database with a new software programs. 3-dimensional (3D) view of the face can be created in any desired direction. Changing the image transparency, anatomic relationships between the hard and soft tissues can be defined. Changes in the appearance of the face after tooth movement, orthognathic surgery or other craniofacial treatment can be detected with CBCT image. In addition, models of images obtained from CBCT can be prepared with 3D fotoscan devices. There are four main CBCT system providers in the world market. They include: NewTom 3G (Quantitative Radiology, Verona, Italy); i-CAT (Imaging Sciences International, Hatfield, USA); N CB MercuRay (Hitachi Medical Corporation, Tokyo, Japan); N 3D Accuitomo (J Morita Mfg Corp, Kyoto, Japan) (Shetty et al, 2011 and Karatas and Toy, 2014).

4.3.3.1.3.Micro-Computed Tomography (MCT)

Micro-ComputedTomography (MCT) is substantially the same as Computed Tomography (CT) except that the reconstructed cross-sections are bounded to a much minor area.Thin Cross-sections of0.012mm can be taken with conventional CT, but Micro-Computed Tomography (MCT) can be obtained with the nano-sized sections. MCT, a non-invasive and a non-destructive technique, is used for the analysis of mineralized tissues (Karatas and Toy, 2014).

4.3.3.1.4. 3D Laser Scanning

As a less invasive method of capturing the face, laser scanning supplies 3D images for treatment planning or evaluating effects of orthodontic and especially orthognathic treatment. In addition, the 3D laser scanners can produce digital models. However, this technique has several disadvantages for 3D scanning. For example, the procedure is so slow that distortion occurs on the scanned image; While the scanner revolves around the patient's head, the patients should stay motionless for one minute or longer (Karatas and Toy, 2014).

4.3.3.1.5. Sterophotogrametry

Stereophotogrammetry includes photographing a 3D object from 2 different coplanar planes in order to acquire a 3D reconstruction of the images. This technique has proven to be very effective in the face display. It mentions to the private case with 2 cameras, arranged as a steropair, are used to recover 3D distances of features on the surface of the face. The technique has been implemented clinically by using a mobile stereometric camera. Contemporary stereophotogrammetry may be used to clear up accurate 3D skull mapping. In 1944, the first clinical use of stereophotogrammetry was applied by Thalmann-Degan and recorded the changes that occur on the face of the patients as a result oforthodontic treatments. Ras et al. have developed a stereophotorammetric system that presents the 3D coordinates of any chosen facial landmarks. Thissystem includes 2 synchronized semi-metric cameras installed on an outline with distance of 50 cm between them and located convergent in a 15° angle. Due to tissue reflections, hair and eyebrows intervention, change of posture between the different views and movements during imaging decrease the probability of obtaining the most accurate facial images. In addition, since laser or light cannot penetrate to excessively curved and reflective surfaces, certain structures, such as the eyes and ears, cannot give a good image (Karatas and Toy, 2014).

4.3.3.1.6. Magnetic Resonance Imaging (MRI)

MRI operates by achieving a resonance signal from the hydrogen nucleus. Advantages of MRI in orthodontics include the following: It gives very valuable information about the position and morphology of disk and excellent soft-tissue resolution with radiation-free imaging technique; Based on the changes in the signal intensities, it can also display detailed osseous tissues; It can be safely used in patients who are allergic to the contrast agent; The images can be obtained without repositioning the patient; It also provides opportunity to examine inflammatory processes and scar tissues. Disadvantages of MRI in orthodontics include the following: It requires expensive and advanced equipment; Unavailability in every medical center and dentaloffice; It takes a long time to use in TMJ; It is contraindicated in the patients with claustrophobia; Stainless steel and other metals used in orthodontic brackets were shown to produce artifacts. Therefore, patients undergoing orthodontic treatment should be carefully evaluated for MRI needs (Karatas and Toy, 2014).

4.3.3.1.7. Intraoral Scanning

Intraoral scanner is an equipment that consists of an intraoral camera, computer, and software. It creates a digital 3D model of scanned objects that can be teeth, impression, or dental cast. With the introduction of intraoral scanning technique, disadvantages of conventional impression techniques such as dimensional changes of impression materials, storage problem, and dental stone errors are overcome. In addition, it is easier to take impressions from the patients with gag reflexes by using intraoral camera. The development of digital models allows to obtain 3D diagnostic information, communicate between laboratory and orthodontists, create virtual set-ups and treatment planning, and fabricate custom-made fixed or removable appliances. Orthodontists are able to plan the treatment on the digital model, control the bracket positioning, and superimpose the before and after models (Erten and Yılmaz, 2018).

Intraoral scanning can provide the following: Archiving study casts; Examining intra- and inter-arch relationships; Treatment planning; Virtual treatment and virtual set-ups; 3D prefabrication of arch wires; Construction of 3D aligners; CAD/CAM retainer; Fabricated lingual brackets; Indirect bracket bonding. However, according to a systematic review, inter-arch measurements such as overjet, overbite, molar relationship, and canine relationship need to be verified on virtually occluded digital models. Moreover, the time requirement for full arch scanning in routine practice can be counted as disadvantage of this technique (Erten and Yılmaz, 2018).

OraScanner™ the first 3D hand-held intra-oral scanner, has been developed by OraMetrix Company in the USA, and depends on the structured light technique. A video camera records the structured light distortions on the dental crowns as it passes over the dentition in about one minute. The computer processes these images and merges them together to create a complete 3D dental arch (Hajeer et al, 2004).

4.3.3.2. Clinical Applications of 3D Imaging

Three-dimensional (3D) imaging has evolved greatly in the last two decades and has found applications in orthodontics, as well as in oral and maxillofacial surgery. In 3D medical imaging, a set of anatomical data is collected using diagnostic imaging equipment, processed by a computer and then displayed on a 2D monitor to give the illusion of depth. Depth perception causes the image to appear in 3D. The applications of 3D imaging in orthodontics include pre- and post-orthodontic assessment of dentoskeletal relationships and facial aesthetics, auditing orthodontic outcomes with regard to soft and hard tissues, 3D treatment planning, and 3D soft and hard tissue prediction (simulation). Three-dimensionally fabricated custommade archwires, archiving 3D facial, skeletal and dental records for in-treatment planning, research and medicolegal purposes are also among the benefits of using 3D models in orthodontics (Hajeer et al, 2004).

4.3.4. Virtual Digital Models vs. Plaster Dental Study Casts

Dental study casts are accurate, 3D replicas of a patient’s teeth which are made by pouring dental plaster or acrylic into impressions (imprints, or molds) of the teeth, and allowing it to harden. Dental casts can be created from many types of dental stone, metal or plastic, depending on the intended use and the durability requirements of the cast. Dental casts are created whenever the dentist needs to study the size and relationship between the teeth, gums and dental arches. This is the case whenever the dentist is studying a patient’s growth and development, or when significant dental treatment is being contemplated. Dental casts are also made when the patient needs an athletic mouthguard, an orthodontic retainer, or fluoride/ tooth whitening trays. If the dentist wishes to communicate with a laboratory, dental casts will be made. They are also a great tool for recording treatment progress (Greany, 2018).

Orthodontic study models are the cornerstone of diagnosis and treatment planning. Additionally, study models are essential for didactic purposes, assessing progress, and documenting cases and research. Plaster study models are considered to be the gold standard in orthodontic diagnosis and treatment planning. A majority of orthodontic programs are currently using plaster study models, with the main advantages being their three-dimensional feel and the ability to be mounted on an articulator. Although traditional plaster models have a long history as diagnostic materials, but they present some drawbacks such as space problems and/or the risk of rupture as a result of the nature of the materials with which they are made (Shastrya et al, 2018).

The dental cast are known to be the traditional three-dimensional (3D) patient record for measuring linear changes in the dental arch. However, it does not provide important information such as structural and volumetric changes in the palate or 3D measurements of orthodontic tooth movement. In recent decades three dimensional virtual study models have made headway into dentistry. Digital study models were introduced commercially in 1999 by OrthoCad and have given way to the most recent reverse engineering technology used to capture and recreate three dimensional images (Shastrya et al, 2018).

The replacement of plaster casts with virtual models has potential benefits including instant accessibility without need for retrieval of plaster models from storage area, ability to perform accurate and simple diagnostic set ups of various extraction patterns, virtual images can be transferred anywhere in the world for referral and consultation. Superimposition of orthodontic study models is of a greater significance since they are the only evidence of pretreatment occlusion, which is irreversibly altered by the treatment. The records are essential for retrospective reference and analysis of treatment outcome, success and failure. However superimposition of dental casts has inherent limitations due to the lack of anatomic reference points or areas for superimposition (Grauer et al, 2011).

4.4. Extraction vs. Non-Extraction Orthodontic Treatment

Orthodontics, is rich in its history as well as controversies. Controversies unlike disputes, never end and cannot be resolved completely validating any one side of the argument through scientific evidence. One such controversy is extraction vs. non-extraction.Since years it has been a key question in planning orthodontic treatment whether the teeth are to be extracted or not.The last two decades have seen noticeable decline of extraction treatment. This is augmented with increased pressure from the referring dentist to treat the patient without extraction treatment modality, being unaware of the literature supportive of extractions in specific cases (Heravi1 et al, 2012; Umrani et al, 2017 and Khanum et al, 2018).

Two major reasons to extract are: To provide and create the necessary space to align the remaining teeth in the presence of severe crowding and to allow teeth to move for protrusion to reduce or camouflage for skeletal Class II or Class III problems can happen. The alternative to extraction in treating dental crowding is to expand the arches; the alternative for skeletal problems is to correct the jaw relationship, by modifying growth or surgery. All other things being equal, it is better not to extractbut in some cases extraction provides the best treatment. All other things being equal, it is better not to extractbut in some cases extraction provides the best treatment (Heravi1 et al, 2012; Umrani et al, 2017 and Khanum et al, 2018).

In the common man's perspective, crowding, more often than spacing constitutes malocclusion. Treatment of a crowded arch requires space gaining. This has been achieved through two ways of treatment – extraction or non-extraction modality. Extraction to create space for accommodation of the remaining teeth of crowded dental arches was written up in the dental literature as long as 1771. It was a new idea then and certainly is not so now (Khanum et al, 2018).

4.4.1. Facial Profile and Esthetic Considerations in Extraction Treatment

Esthetics should always be considered first when planning for an extraction or a non-extraction treatment. Non extractionists believe that extractions result in "dish in" of the face, while extractionists claim that without extractions in certain cases the periodontal health will be compromised and the profile will appear full. The choice between extraction and non-extraction (expansion) is a critical esthetic decision for some patients who are toward the extremes of incisor protrusion or retrusion initially, but because there is an acceptable range of protrusion, many if not most can be treated with satisfactory esthetics either way (Umrani et al, 2017).

It is well known that expansion of the arches moves the patient in the direction of more prominent teeth, while extraction tends to reduce the prominence of the teeth. Facial esthetics can become unacceptable on either the protrusive or retrusive side. Similarly, expansion tends to make arches less stable and extraction favors stability, but the extraction-non-extraction decision probably is a critical factor in stability largely for patients who are toward the extremes of the protrusion retrusion distribution. When the prominence of the incisors creates excessive lip separation at rest, the patient must strain to bring the lips together, so that improves facial esthetics. More than 4 mm lip separation at rest is unesthetic. Note that this has nothing to do with the prominence of the teeth relative to the supporting bone. Incisor prominence in thick lips patients gives better esthetics than thin lips. Excessive protrusion of incisors requires lip strain to close the lips over the teeth, as in this patient, and therefore also is characterized by excessive lip separation at rest (lip incompetence). In patients with excessive incisor protrusion, retracting the incisors improves facial esthetics (Umrani et al, 2017).

The size of the nose also has a profound effect on relative lip prominence. For a patient with a large nose and/or a large chin, the choices are to treat without extraction and move the incisors forward, is better. The incisors retracted to the point of adversely affecting facial esthetics too depends largely on the soft tissues. A concave profile with thinning of the lips, so that there is little vermilion border, is an anesthetic trait. In a patient with thin lips, proclining the incisors tends to create fuller lips with more vermilion show, and this is likely to be perceived as more attractive. Furthermore, the mandible grows more than the maxilla, which tends to straighten the profile over-time, throughout adulthood. This was attributed to the fourth dimension ‘‘time’’, as termed by Sarver and Ackerman in 2003. This could be a confounding factor. They advised the orthodontists to give adequate emphasis on the growth of soft tissues, maturation and aging in their treatment planning (Umrani et al, 2017 and Khanum et al, 2018).

The studies conducted by Rushing et al. (1995), Stephens et al. (2005) and Erdinc et al. (2007), support the fact that general dentists and orthodontists were unable to distinguish between the facial profiles of subjects treated with extraction and non-extraction orthodontic treatment. A 3D soft-tissue analyses by Solem et al. (2013) following extraction treatment revealed that distinct changes were observed in patients who had protrusion, and the retraction of the lip was directly associated with retraction of the upper and lower incisors. Therefore, extraction in few patients with fuller profiles, does not necessarily cause “dish-in” of the face, and in fact can result in better esthetics than non-extraction treatment in such patients. Hence, clinicians have to plan the cases suitably, to avoid over-retraction of the anterior segment leading to unfavourable profile changes (Khanum et al, 2018).

4.4.2. Contemporary Extraction Guidelines

- < 4 mm arch length discrepancy: extraction rarely indicated.
- 5 - 9 mm arch length discrepancy: non-extraction (posterior expansion) /extraction.
- 10 mm or more arch length discrepancy: extraction is required to obtain space.

There are many factors that enforce extraction of teeth for orthodontic treatment. These factors include increased tooth size in relation to the arch size (crowding), supernumeraries, hypodontia (if decided to close the space, may need extraction), carious teeth, increased overjet, open bite cases, impacted teeth, camouflage orthodontic treatment, correction of the buccal segment, malformed teeth, periodontally involved teeth, orthognathic surgery and cleft lip and palate. Identifying extraction guidelines vs non-extraction decision in orthodontic treatment is a complex task. Presently, the controversy is not afflicted by as much beliefs as it was almost 100 years ago and both treatment options are still open. The option to treat with extraction or non-extraction should be made objectively for each case based on strong evidence with equal attention on the soft tissue paradigm (Al-Ani and Mageet, 2018; Khanum et al, 2018).

5. MATERIALS AND METHODS

5.1. Approval and Study Design

Before the investigation was begun, approval for this retrospective study was obtained from the Near East University institutional review board. We reviewed our hospital records for patients who underwent a complete orthodontic treatment between the year 2008 and 2019. We retrieved maxillary casts of our selected cases, which were collected at the beginning of treatment (pre-treatment) and at bracket removal (post-treatment).

5.2. Inclusion and Exclusion Criteria

In this study, we included those who had full presence of all permanent teeth up to 1stmolars, patients treated with non-extraction fixed orthodontic treatment, and patients treated with first or second upper premolars extraction. We excluded patients in the mixed dentition stage, patients who had congenitally missing teeth, unerupted or impacted teeth, patients known to be mouth breathers, and patients who received functional orthodontic treatment or any type of maxillary expansion.

5.3. Data Recording and Measurements

Retrieved maxillary casts were scanned and digitized using our institutional NewTom-3G CBCT (Quantitative Radiology, Verona, Italy). First author scanned all models by placing each one in the CBCT machine at the same direction and specific angle to avoid measuring errors. Scanned 3D images were manually cut and processed using Invivo-5 Anatomage software to measure palatal height and volume of each sample. As illustrated in (Figure 2), the landmarks for measuring total palatal volume start at the incisal edges of the central and lateral incisors, extending to the cusps of canines, back to the various contact points and palatal cusps of the premolars and 1st molars, and ending at contact point between the 1st and 2nd molars.

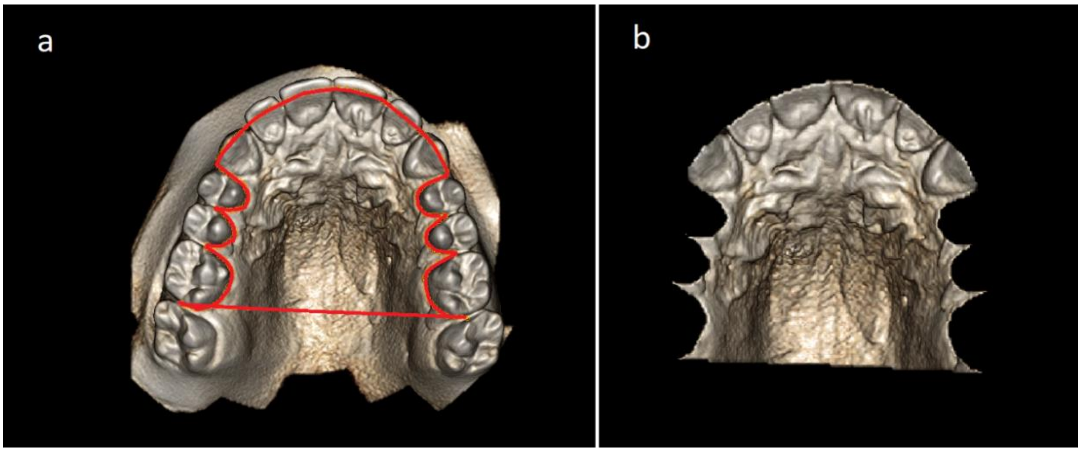

Figure 2. Processing CBCT Images to measure Palatal Volume

(a) Manually plottingLandmarks

(b) Unwanted Portions of Data Outside Landmarks are removed

To further investigate changes in palatal volume, total palatal volume was then divided into an anterior and posterior portion by a coronal plane that separates canines and first premolars (Figure 3).

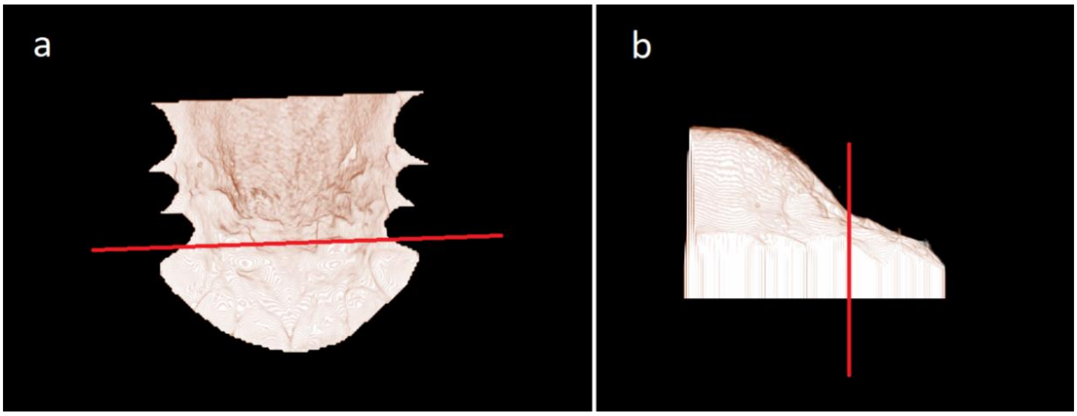

Figure 3. Three-dimensional model representing total palatal volume with a coronal plane (red color) dividing total palatal volume into anterior and posterior portions

(a) Top View

(b) Lateral View

Palatal height landmarks were observed from a coronal view of the maxilla at the level of 1st molars. As illustrated in (Figure 4), we added a horizontal plane connecting bases of the permanent 1st molars; cervical aspects of the distolingual cusps at the junction of the teeth and gingival margin. Palatal height was then obtained by drawing a vertical line that is perpendicular to the horizontal plane and extending to the highest point of the palatal vault.

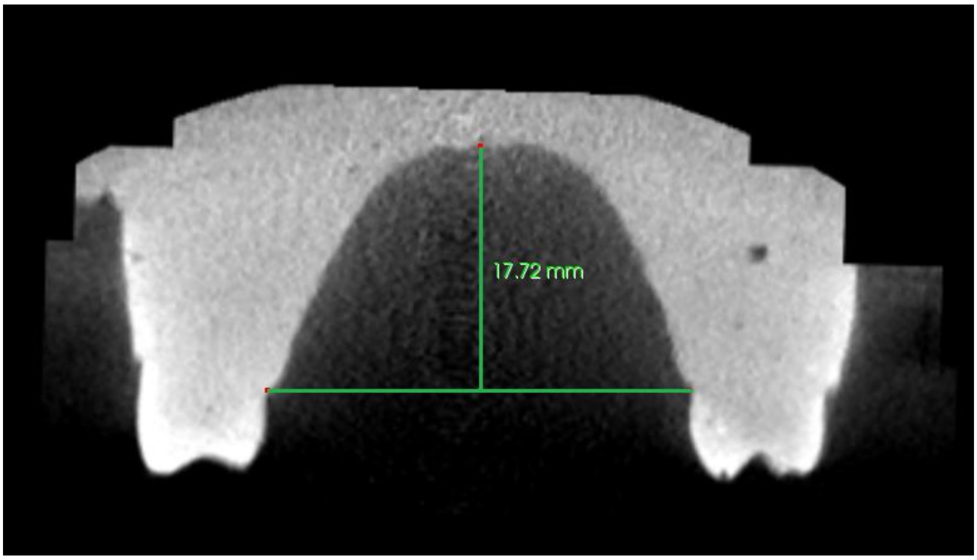

Figure 4. Measuring Palatal Height

(Coronal View of the Palate at the 1st Molar Level)

6. STATISTICAL ANALYSIS

For statistical analysis, we used Paired t-tests to compare pre- and post-treatment changes in regards to palatal height, anterior palatal volume, and posterior palatal volume. P-values less than 0.05, reject the null hypothesis, rendering a statistically significant difference in means. In addition, we calculated the post-treatment percentage change in total palatal volume and palatal height using the following formula;

$$\text{Measuring percentage of change} = 100 - \left(\frac{pre\ treatment\ height\ or\ volume\ x\ 100}{post\ treatment\ height\ or\ volume}\right).$$

7. RESULTS

A total of 50 patients (27 females, 23males) fulfilled our inclusion criteria. The patients were grouped according to gender and to whether they underwent an extraction orthodontic treatment; male extraction, female extraction, male non-extraction, and female non-extraction.Male extraction group consisted of 13 patients (average age 17y +/- 4y; treatment duration 1y7m +/-7m). Female extraction group consisted of 12 patients (average age 17y +/- 4y; treatment duration 1y 7m +/- 8m). Male non-extraction group included 10 patients (average age 16y +/- 4y; treatment duration 1y 2m +/- 7m). Female non-extraction group included 15 patients (average age 17y +/- 7y; treatment duration of 1y 7m +/- 8m) (Table 1).

Table 1. All Four Groups Included in our Study

(All subjects were grouped according to gender and treatment modality)

Group	N	Mean Age	Treatment Duration
Male Extraction	13	17 years	1 year 7months
Female Extraction	12	17 years	1year 7 months
Male Non-Extraction	10	16 years	1year 2months
Female Non-Extraction	15	17 years	1year 7 months

All extraction cases, thirteen males and twelve females, displayed a decrease in anterior and posterior palatal volumes at the end of treatment. As shown in changes in mean volumes of both extraction groups were statistically significant. At the end of treatment, total palatal volume decreased in male extraction group by an average of 7.87%, and in female extraction group by 13.53% (Table 2).

All non-extraction cases, ten males and fifteen females, displayed an increase in the posterior palatal volume with significant p-values. On the other hand, anterior palatal volume in non-extraction females increased in 7 out of 15 cases with no statistical significance, while in non-extraction males the volume increased in 9 out of 10 cases, and was found to be of a marginal statistical significance. At the end of treatment, total palatal volume increased in male non-extraction group by an average of 11.51%, and in female non-extraction group by an average of 11.35% (Table 2).

In regards to changes in palatal height, all male and female (extraction and non-extraction) groups showed a statistically significant change at the end of treatment. 48 out of 50 patients had an increase in palatal height, while the remaining two were male patients who had no change by the end of treatment (Table 3).

Table 2. Anterior, Posterior, and Total Palatal Volume in male and female groups

Group	Number of Patients	Anterior Palatal Volume Pre-treatment	Anterior Palatal Volume Post-treatment	Posterior Palatal Volume Pre-treatment	Posterior Palatal Volume Post-treatment	Change in Total Palatal Volume
Male Extraction	13	Mean 2803mm^3 SD 926 mm^3	Mean 1965 mm^3 SD 928 mm^3	Mean 27014 mm^3 SD 2667 mm^3	Mean 25500 mm^3 SD 2738 mm^3	-7.87%
		P-value < .0001*		*P*-value 0.0005*		
Female Extraction	12	Mean 2435 mm^3 SD 1115 mm^3	Mean 1491 mm^3 SD 593 mm^3	Mean 20073 mm^3 SD 3264 mm^3	Mean 17981 mm^3 SD 3139 mm^3	-13.53%
		P-value 0.0023*		*P*-value 0.0013*		
Male Non-Extraction	10	Mean 2546 mm^3 SD 1455 mm^3	Mean 3199 mm^3 SD 1132 mm^3	Mean 20083 mm^3 SD 2298 mm^3	Mean 21872 mm^3 SD 2174 mm^3	+11.51%
		P-value 0.0576		*P*-value < .0003*		
Female Non-Extraction	15	Mean 2488 mm^3 SD 1795 mm^3	Mean 2441 mm^3 SD 1694 mm^3	Mean 17997 mm^3 1833 mm^3	Mean 19960 mm^3 SD 2279 mm^3	+11.35%
		P-value 0.9159		*P*-value < .0001*		

Table 3. Palatal Height (mm) in male and female groups

Group	Number of Patients	Total Palatal Height Pre-treatment	Total Palatal Height Post-treatment	Change in Total Palatal Height
Male Extraction	13	Mean 17.45 mm SD 1.53 mm	Mean 18.20 mm SD 1.15 mm	+4.53%
		P-value 0.0003*		
Female Extraction	12	Mean 15.32 mm SD 1.92 mm	Mean 16.52 mm SD 2.08 mm	+8.04%
		P-value 0.0011*		
Male Non-Extraction	10	Mean 14.55 mm SD 2.01 mm	Mean 15.62 mm SD 2.11 mm	+5.98%
		P-value 0.0009*		
Female Non-Extraction	10	Mean 15.11 mm SD 1.32 mm	Mean 16.03 mm SD 1.69 mm	+7.45%
		P-value 0.0001*		

8. DISCUSSION

To date, the decision to extract or not to extract in orthodontics is still a matter of debate. For an objective decision to be made, researching outcomes of these treatments has been of great interest in recent years. Many studies looked for changes in palatal arch area, width, and length. Others studied cephalometric and soft tissue changes, as well as, treatment impact on different classes and divisions. Perhaps the investigation of functional and contour changes correlated to these treatment modalities may eventually add up to the development of much needed treatment protocol.

Heiser et al. (2004) is one of the early publications to extensively study palatal changes in extraction and non-extraction cases. Following our study's landmarks in terms of measuring total palatal volume, their group of non-extraction cases showed an increase in total palatal volume by an average of 1.27 cm^3, while in their extraction group, the volume decreased by 1.64 cm^3 at bracket removal stage. Both of these changes were found to be statistically significant. In another study by Gohl et al. CBCT was used to investigate palatal changes in a control group who underwent a non-extraction orthodontic treatment. Follow-up scans of these patients showed an increase in the means of total palatal volume by 10.8%. Similar to both of these studies, our sample of cases showed an increase in mean of total palatal volume in non-extraction groups, as well as a decrease in mean of total palatal volumes in extraction groups (Table 2).

Furthermore, Heiser et al. investigated the impact of treatment on different parts of the palate. The means of anterior palatal volume were found to increase at bracket removal in both extraction (+0.59 cm^3 and non-extraction cases (+0.2 cm^3, both noted with statistical significance. In contrast, both of our extraction groups (males and females) showed a statistically significant decrease in means of anterior palatal volume. This contradiction in extraction group findings could be attributed to the relatively older age sample depicted in our study, where growth factor is believed to have a minimal influence on palatal volume. On the other hand, our male non-extraction group had a marginal statistical significance for increased anterior volumes at bracket removal, on an individual scale, this increase was noted in 9 out of the 10 patients. However, changes in female non-extraction group were of no statistical significance, having decreased anterior volumes in 8 out of 15 cases at bracket removal.

All extraction cases (males and females) have shown decreases in total palatal volume (Table 2). These decreases in our volumetric findings are thought to be attributed to the constriction or narrowness that have occurred in the maxillary arch size due to upper premolar extractions. On the other hand, all non-extraction cases (males and females) have shown increases in posterior palatal volume (Table 2). These increases in our volumetric findings could be attributed to the expansive movements in both sagittal and tranversal dimesions as a result of fixed orthodontic treatment.

In terms of measuring palatal height changes, findings by Naidu and Raghunath as well as Heiser et al. showed increased means in both non-extraction and extraction groups at bracket removal. In both studies, changes in non-extraction groups alone were found to be of a statistical significance. A couple of more studies measured palatal height changes in nonextraction groups; Derech, Locks, and Bolognese marking a statistically significant increase in average height at the end of treatment of class 2 division 1 cases, and Gohl et al. noting a 9.81% increase on follow-up scans. These changes in means of height do agree with our study findings, however, our results found the increase in height to be of a statistical significance in both extraction and non-extraction groups (Table 3).

9. CONCLUSION

In this retrospective study, we used cone beam computed tomography (CBCT) technique to scan archived maxillary dental plaster casts and transform them into digital casts in order to investigate the changes of palatal volume and height in these patients who were treated with edgewise orthodontic appliances (straightwire), with or without premolar extractions. In this study our findings are as follows:

- Males and females exhibitedan increase in palatal height in both extraction and non-extraction orthodontic treatment and this could arguably be related to growth rather than treatment impact.

- Males and females exhibited similar total palatal volume changes in relation to extraction and non-extraction orthodontic treatment.

- Total palatal volume tends to increase in non-extraction cases and decrease in extractions.

- Anterior palatal volume increase in non-extraction cases is more consistent in male samples.

RFERENCES

Ahmed, Haider and Alkhawaja, Noor and Nahidh, Mohammed. (2014). Assessment of Palatal Dimensions in a Sample of Iraqi Adults with Different Facial Forms. *Iraqi Orthod J* 2014; 10(1): 8-11.

Ahn J S, Park M S, Cha H S, Song H C, Park Y S. (2012). Three-dimensional interpretation of intercanine width change in children: a 9-year longitudinal study. *American Journal of Orthodontics and Dentofacial Orthopedics* 142: e323–e332.

Aksu, M. and I. Kocadereli, Arch Width Changes in Extraction and Nonextraction Treatment in Class I Patients. *The Angle Orthodontist*, (2005). 75(6): p. 948-952.

Al-Ani MH, Mageet AO. Extraction Planning in Orthodontics. *J Contemp Dent Pract* (2018);19(5):619-623.

AlBarakati, S.F. and L.F. Baidas, (2010). Orthognathic surgical norms for a sample of Saudi adults: Hard tissue measurements. *Saudi Dental J*., 22: 133-139.

Al-Qudaimi NH, Ali FA, Madfa AA and Al-Sanabani FA. Palatal Depth in Normal Occlusion and Class-I with Dental Crowding for a Group of Yemeni School Children. *Austin Dent Sci*. (2016); 1(1): 1005.

Al-Zubair, N., M. Al-Labani, and F. Al-Motareb, Yemeni palatal morphology. *Saudi Journal for Health Sciences*, 2015. 4(2): p. 88-91.

Arslan, S. G., Kama, J. D., Sahin, S. and Hamamci, O. Longitudinal changes in dental arches from mixed to permanent dentition in a Turkish population. *Am J Orthod Dentofacial Orthop* 132, 576 e515–521 (2007).

Ayman G. Mustafa, Ayssar A. Tashtoush, Othman A. Alshboul, Mohammed Z. Allouh, and Ahmad A. Altarifi, "Morphometric Study of the Hard Palate and Its Relevance to Dental and Forensic Sciences," *International Journal of Dentistry*, vol. 2019, Article ID 1687345, 6 pages, 2019.

Baca-Garcia, A., M. Bravo, B. Pilar, A. Baca and P. Junco, (2004). Malocclusions and orthodontic treatment needs in a group of Spanish adolescents using the Dental Aesthetic Index. *Int. Dental J.*, 54: 138-142.

Baccetti T, Antonini A, Franchi l, Tonti M and Tollaro I. (1997). Glenoid Fossa Position in Different Facial Types: a Cephalometric Study. *British Journal of Orthodontics*.,Vol. 24:55–59.

Bajraktarova Miševska, C., Kočova, M., Kanurkova, L., Curcieva, Cuckova, G., Bajraktarova, B., Maneva, M. and Valjakova, E. (2015). Craniofacial morphology in Turner syndrome karyotypes. *South European journal of orthodontics and dentofacial research*, 2 (1), 7-13.

Barbosa, Gabriella Lopes de Rezende, Ramirez-Sotelo, Laura Ricardina, Alencar, Phillipe Nogueira Barbosa, and Almeida, Solange Maria de. (2015). Comparison of palatal bone height in different facial morphological patterns by cone beam computed tomography. *Brazilian Journal of Oral Sciences*, 14(3), 182-185.

Basciftci, F.A. and S. Usumez, Effects of Extraction and Nonextraction Treatment on Class I and Class II Subjects. *The Angle Orthodontist*, (2003). 73(1): p. 36-42.

Berkovitz, B. K. B., Moxham, B. J., and Holland, G. R. (2009). Oral anatomy, histology and embryology. (A. Taylor and L. Stader, Eds.) (4th ed.). Mosby Elsevier.

Berwig LC, Silva AM, Côrrea EC, Moraes AB, Montenegro MM, Ritzel RA. (2011). Hard palate dimensions in nasal and mouth breathers from different etiologies. *J Soc Bras Fonoaudiol.* 23(4):308–314.

Bhagyalakshmi, G., Renukarya, A. J. and Rajangam, S. (2007). Metric analysis of the hard palate in children with Down syndrome: a comparative study. *Downs Syndr Res Pract*, 12, 55-9.

Bianchini, A. P., Guedes, Z. C. and Vieira, M. M. (2007). A study on the relationship between mouth breathing and facial morphological pattern. *Braz J Otorhinolaryngol*, 73, 500-5.

Bishara S.E.(2001): Text book of orthodontics. W.B Saunders Company. Section I, pp.45-48.

Björk A, Skieller V. (1974). Growth in width of the maxilla studied by the implant method. *Scandinavian Journal of Plastic and Reconstructive Surgery* 8: 26–33.

Björk A, Skieller V. (1977). Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *British Journal of Orthodontics* 4: 53–64.

Björk, A. (1966). Sutural growth of the upper face studied by the implant method. *Acta Odontologica Scandinavica* 24: 109–127.

Bourdiol P, Mishellany-Dutour A, Abou-El-Karam S, Nicolas E, Woda A. (2010). Is tongue position influenced by the palatal vault dimensions? *Journal of Oral Rehabilitation* 37: 100–106.

Bukhari, A., Kennedt, D., Hannam, A., Aleksejuniene, J. and Yen, E. (2018). Dimensional changes in the palate associated with slow maxillary expansion for early treatment of posterior crossbite. *Angle Orthod*, 88, 390-396.

Burris, B.G. and E.F. Harris, (2000). Maxillary arch size and shape in American blacks and whites. *Angle Orthod*., 70: 297-302.

Cakan, D. G., Ulkur, F. and Taner, T. U. (2012). The genetic basis of facial skeletal characteristics and its relation with orthodontics. *Eur J Dent*, 6, 340-5.

Cakan, D. G., Ulkur, F., and Taner, T. U. (2012). The genetic basis of facial skeletal characteristics and its relation with orthodontics. *European journal of dentistry*, 6(3), 340–345.

Cassidy K, Harris EF, Tolley EA, Keim RG. Genetic influence on dental arch form in orthodontic patients. *Angle Orthod*. (1998);68:445–454.

Caterini L, Mezio M, Dari M, Pacella E, Giovannoni D. Orthodontic management of missing maxillary lateral incisors: a systematic review. *WebmedCentral Orthodontics* (2017);8(10):WMC005346.

Cha B K, Lee J Y, Jost-Brinkmann P G, Yoshida N. (2007). Analysis of tooth movement in extraction cases using three-dimensional reverse engineering technology. *European Journal of Orthodontics* 29: 325–331.

Chakraborthy P, Krishnamurthy K and Pratheeth G. Digital Era of Orthodontics: A Review. *J Dent and Oral Disord*. (2016); 2(1): 1008.

Chambi-Rocha, A., Cabrera-Domínguez, M.E., and Domínguez-Reyes, A. (2017). Breathing mode influence on craniofacial development and head posture. *Jornal de pediatria*, *94 2*, 123-130 .

Cistulli, P. A. , G. N. Richards , R. G. Palmisano , G. Unger , and C. E. Sullivan . Influence of maxillary constriction on nasal resistance and sleep severity in patients with Marfan's syndrome. *Chest* (1996). 110:1184–1193.

Cistulli, P. A. and C. E. Sullivan. Sleep-disordered breathing in Marfan's syndrome. *Am Rev Respir Dis*. (1993).

Ciusa, V., et al, Three-dimensional palatal development between 3 and 6 years. *Angle Orthod*, 2007. 77(4): p. 602-6.

Erten, O. and B.N. Yılmaz, Three-Dimensional Imaging in Orthodontics. *Turkish journal of orthodontics,* (2018). 31(3): p. 86-94.

Day, T. A., and Girod, D. A. (Eds.). (2006). Oral Cavity Reconstruction. New York: Taylor and Francis Group.

De Felippe, N. L. O. , A. C. Da Silveira , G. Viana , B. Kusnoto , B. Smith , and C. A. Evans . Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: short- and long-term effects. *Am J Orthod Dentofacial Orthop*. (2008). 134:370–382.

De Freitas F C N, Bastos E P, Primo L S, de Freitas V L. (2001). Evaluation of the palate dimensions of patients with perennial allergic rhinitis. *International journal of paediatric dentistry / the British Paedodontic Society [and] the International Association of Dentistry for Children* 11: 365–371.

Dellavia, C., Sforza, C., Orlando, F., Ottolina, P., Pregliasco, F. and Ferrario, V. F. (2007). Three-dimensional hard tissue palatal size and shape in Down syndrome subjects. *Eur J Orthod,* 29, 417-22.

Derech, C., A. Locks, and A. Bolognese, Height and width of orthodontically treated palates in Class II Division 1 patients: a longitudinal study. *World journal of orthodontics.* Vol. 11. (2010). 49-54.

Drake, R., Vogl, A., and Mitchell, A. (2015). Gray’s Anatomy For Students (3rd ed.). Philadelphia.

Elham, F. and S. Adhamy, (2010). Age and sequence of permanent canine and premolar teeth eruption in 102-174 months old children in kerman province. *Curr. Res. Dent.*, 1: 6-10.

Eslami Amirabadi, G., et al, Palatal dimensions at different stages of dentition in 5 to 18-year-old Iranian children and adolescent with normal occlusion. *BMC Oral Health*, 2018. 18(1): p. 87.

Ferrario V F, Sforza C, Colombo A, Dellavia C, Dimaggio F R. (2001). Threedimensional hard tissue palatal size and shape in human adolescents and adults. *Clinical Orthodontics and Research* 4: 141–147.

Franco, F. C., De Araujo, T. M., Vogel, C. J. And Quıntao, C. C. (2013). Brachycephalic, dolichocephalic and mesocephalic: Is it appropriate to describe the face using skull patterns? *Dental Press J Orthod*, 18, 159-63.

Gallão S, Faltin K, Santos L, Ary D, Martins L (2013) Facial type measurements influence on transverse dimensions of normal occlusion arches. *J Health Sci Inst.*;31(3):20-3.

Gohl, E., Nguyen, M. And Encıso, R. (2010). Three-dimensional computed tomography comparison of the maxillary palatal vault between patients with rapid palatal expansion and orthodontically treated controls. *Am J Orthod Dentofacial Orthop*, 138, 477-485.

Grippaudo, C., Paolantonio, E. G., Antonini, G., Saulle, R., La Torre, G. and Deli, R. (2016). Association between oral habits, mouth breathing and malocclusion. *Acta Otorhinolaryngol Ital*, 36, 386-394.

Graber T.M. and Vanarsdall R.L. (2000): Orthodontics current principles and techniques. *Third ed Mosby Inc* pp:385

Gracco, A., Malagutı, A., Lombardo, L., Mazzolı, A. And Raffaelı, R. (2010). Palatal Volume Following Rapid Maxillary Expansion İn Mixed Dentition. *Angle Orthod*, 80, 153-9.

Gianelly, A.A., Arch width after extraction and nonextraction treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*, (2003). 123(1): p. 25-28.

Grauer, D. (2010). Three-dimensional applications in orthodontics. Chapel Hill, NC: University of North Carolina at Chapel Hill.

Hajeer, M.Y., Millett, D.T., Ayoub, A.F., and Siebert, J.P. (2004). Applications of 3D imaging in orthodontics: part I. *Journal of orthodontics, 31 1*, 62-70.

Hashim, H.A. and S. Al-Ghamdi, (2005). Tooth width and arch dimensions in normal and malocclusion samples: An odontometric study. *J. Contemp Dent*. Pract., 6: 36-51.

Hassanali, J., and Mwaniki, D. (1984). Palatal analysis and osteology of the hard palate of the Kenyan African skulls. *The Anatomical Record*, 209(2), 273–280.

Heiser, W., et al, Three-dimensional dental arch and palatal form changes after extraction and nonextraction treatment. Part 1. Arch length and area. *American Journal of Orthodontics and Dentofacial Orthopedics*, 2004. 126(1): p. 71-81.

Heiser, W., et al, Three-dimensional dental arch and palatal form changes after extraction and nonextraction treatment. Part 2. Palatal volume and height. *American Journal of Orthodontics and Dentofacial Orthopedics*, 2004. 126(1): p. 82-90.

Heravi F, Shojaeian S, Sadafi M. A Comparative Study of Dentoskeletal Changes Following Orthodontic Treatment with First Premolar Extraction in Long Face and Normal Patients. *J Dent Mater Tech* (2012); 1(2): 63-9.

Hermann N V, Kreiborg S, Darvann T A, Jensen B L, Dahl E, Bolund S. (2003). Craniofacial morphology and growth comparisons in children with Robin Sequence, isolated cleft palate, and unilateral complete cleft lip and palate. *The Cleft Palate-Craniofacial Journal* 40: 373–396.

Klosek, S. K., and Rungruang, T. (2009). Anatomical study of the greater palatine artery and related structures of the palatal vault: Considerations for palate as the subepithelial connective tissue graft donor site. *Surgical and Radiologic Anatomy*, 31(4), 245–250.

Maria CM, Silva AMT, Busanello-Stella AR, Bolzan GP, Berwing LC. Avaliação da Profundidade do Palato Duro: Correlação entre Método Quantitativo e Qualitativo. Rev. *CEFAC*. 2013; 15(5):1292-1299.

Mohammad, H.A., Hassan, M.I., and Hussain, S. (2011). Dental Arch Dimension of Malay Ethnic Group. *American Journal of Applied Sciences*. 8. 1061-1066.

Moore, K. ., Agur, A. M., and Dalley, A. F. (2011). Essential Clinical Anatomy (4th ed.). Baltimore: Lippincott, Williams, and Wilkins.

Nahidh, Mohammed and Alkhawaja, Noor and Ghazi, Ata'a. (2012). Palatal dimensions in different occlusal relationships. *Journal of Baghdad College of Dentistry*. 24. 116-120.

Netter, F. H. 1. (2010). Atlas of human anatomy. 5th ed. Philadelphia, PA: Saunders/Elsevier.

Norton, N. S. (2012). Netter’s Head and Neck Anatomy for Dentistry (2nd ed.). Philadelphia: Elsevier Saunders.

Norton, N. S., and Netter, F. H. (2007). Netter's head and neck anatomy for dentistry. Philadelphia, PA: Saunders Elsevier.

J. Daniel Subtelny. (1954). The Significance of Adenoid Tissue in Orthodontia. *The Angle Orthodontist*. Vol. 24, No. 2, pp. 59-69.

Jiménez-Gayosso SI, Lara-Carrillo E, López-González S, et al. Difference between manual and digital measurements of dental arches of orthodontic patients. *Medicine (Baltimore).* (2018);97(22):e10887.

Johal, A. and Conaghan, C. (2004). Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. *Angle Orthod*, 74, 648-56.

Jyoti, S. and Pavanalakshmi, G.P. (2014) Nutritive and Non-Nutritive Sucking Habits-Effect on the Developing Oro-Facial Complex: A Review. *Dentistry*, 4, 203-206.

KECIK, D. (2017). Three-dimensional analyses of palatal morphology and its relation to upper airway area in obstructive sleep apnea. *Angle Orthod*, 87, 300-306.

Keim, R.G., et al, 2014 JCO study of orthodontic diagnosis and treatment procedures, Part 1: results and trends. *J Clin Orthod*, (2014). 48(10): p. 607-30.

Khanum A, Prashantha GS., Mathew S, Naidu M, Kumar A. Extraction vs Non Extraction Controversy: A Review. *J of Dentand Oro-fac Res*. (2018); 14(1):41-8.

Kim H K, Moon S C, Lee S J, Park Y S. (2012). Three-dimensional biometric study of palatine rugae in children with a mixed-model analysis: a 9-year longitudinal study. *American Journal of Orthodontics and Dentofacial Orthopedics* 141: e590–e597

Klingel, D., Hohoff, A., Kwiecien, R., Wiechmann, D. and Stamm, T. (2018). Correction: Growth of the hard palate in infants with Down syndrome compared with healthy infants-A retrospective case control study. *PLoS One*, 13, e0203899.

Kook, Y.A., K. Nojima, H.B. Moon, R.P. McLaughlin and P.M Sinclair, (2004). Comparison of arch forms between Korean and North American white populations. Am. *J. Orthod. Dentofacial Orthop*, 126: 680-686.

Kriel, E.A. (2008). Earl Kriel, "Changes in arch dimensions after extraction and non-extraction orthodontic treatment" master's thesis . University of the Western Cape, 2008, *http://hdl.handle.net/11394/2470.*

Lagana, G., Palmacci, D., Ruvolo, G., Cozza, P. and Paoloni, V. (2019). 3D evaluation of maxillary morphology in Marfan growing subjects: a controlled clinical study. *Progress in Orthodontics*, 20, 12.

Laganà, G.; Venza, N.; Paoloni, V.; Bertoldo, F.; Ruvolo, G.; Cozza, P. A 3D Geometric Morphometric Analysis of the Palatal Morphology in Marfan's Syndrome: A Preliminary Study. *J. Clin. Diagn. Res*. (2018), 12, 14–17.

Lione R, Franchi L, Huanca Ghislanzoni LT, Primozic J, Buongiorno M, Cozza P. Palatal surface and volume in mouth-breathing subjects evaluated with three-dimensional analysis of digital dental casts-a controlled study. *Eur J Orthod* (2015);37:101-4.

Liselotte Paulsson, Lars Bondemark, and Björn Söderfeldt (2004) A Systematic Review of the Consequences of Premature Birth on Palatal Morphology, Dental Occlusion, Tooth-Crown Dimensions, and Tooth Maturity and Eruption. *The Angle Orthodontist*: April 2004, Vol. 74, No. 2, pp. 269-279.

Marini, I., Bonetti, G. A., Achilli, V. and Salemi, G. (2007). A photogrammetric technique for the analysis of palatal three-dimensional changes during rapid maxillary expansion. *Eur J Orthod*, 29, 26-30.

Melsen B, Melsen F. (1982). The postnatal development of the palatomaxillary region studied on human autopsy material. *American Journal of Orthodontics* 82: e329–e342

Melsen, B. (1975). Palatal growth studied on human autopsy material. A histologic microradiographic study. *American Journal of Orthodontics* 68: e42–e54.

Mladen Šlaj, Marina A. Ježina, Tomislav Lauc, Senka Rajić-Meštrović, and Martina Mikšić. (2003). Longitudinal Dental Arch Changes in the Mixed Dentition. *The Angle Orthodontist*, Vol. 73, No. 5, pp. 509-514.

Mohammad, H.A., M.I.A. Hassan and S.F. Hussain., (2011). Cephalometric evaluation for Malaysian Malay by Steiner analysis. *Sci. Res. Essays*, 6: 627-634.

Mustafa, A. G., Tashtoush, A. A., Alshboul, O. A., Allouh, M. Z., and Altarifi, A. A. (2019). Morphometric Study of the Hard Palate and Its Relevance to Dental and Forensic Sciences. *International journal of dentistry* , 1687345.

Naidu, D.M., Raghunath, D. Three Dimensional Assessment of the Palate and Palatal Contoural changes in Orthodontically treated cases using Reverse Engineering 3-D LASER scanner. *Journal of Dental and Oro-facial Research*. (2015) Vol 11, Issue 1.

Panchón-Ruiz A, Jornet-Carrillo V, Sanchez del Campo F. (2000). Palate vault morphology in Down syndrome. *Journal of Craniofacial Genetics and Developmental Biology* 20: 198–200.

Paranhos L, Ramos M, Benedicto E et al. (2014). Is there any association between facial type and mandibular dental arch form in subjects with normal occlusion? *Acta Scientiarum. Health Sciences Maringá*, vol. 36(1), p. 129-134.

Parcha, E., E. Bitsanis, and D.J. Halazonetis, Morphometric covariation between palatal shape and skeletal pattern in children and adolescents: a cross-sectional study. *European Journal of Orthodontics*, 2016. 39(4): p. 377-385.

Park Y S, Chang M S, Lee S P. (2011). Three-dimensional topography of the gingival line of young adult maxillary teeth: curve averaging using reverse-engineering methods. *The International Journal of Oral and Maxillofacial Implants* 26: 1217–1224.

Park Y S, Lee S P, Paik K S. (2007). The three-dimensional relationship on a virtual model between the maxillary anterior teeth and incisive papilla. *The Journal of Prosthetic Dentistry* 98: 312–318.

Phatouros, A. and Goonewardene, M. S. (2008). Morphologic changes of the palate after rapid maxillary expansion: a 3-dimensional computed tomography evaluation. *Am J Orthod Dentofacial Orthop*, 134, 117-24.

Phillips, Jillian, "Comparative Assessment of Hard Palate Thickness Using Micro - CT and Gross Cadaveric Measurements: Implications for the Safe Placement of Orthodontic Miniscrews" (2015). *Masters of Clinical Anatomy Projects*. 6.

Primožič J, Perinetti G, Richmond S, Ovsenik M. (2012). Three-dimensional longitudinal evaluation of palatal vault changes in growing subjects. *The Angle Orthodontist* 82: 632–636.

Primozic, J., Perinetti, G., Richmond, S. and Ovsenik, M. (2013). Three-dimensional evaluation of facial asymmetry in association with unilateral functional crossbite in the primary, early, and late mixed dentition phases. *Angle Orthod*, 83, 253-8.

Revelo B, Fishman L S. (1994). Maturational evaluation of ossification of the midpalatal suture. *American Journal of Orthodontics and Dentofacial Orthopedics* 105: e288–e292.

Riley, R. , C. Guilleminault , and J. Herran . Cephalometric analysis and flow volume loops in obstructive sleep patients. *Sleep* (1983). 6:303–311.

Rizell, S., Barrenas, M. L., Andlin-Sobocki, A., Stecksen-Blicks, C. and KJELLBERG, H. (2013). 45,X/46,XX karyotype mitigates the aberrant craniofacial morphology in Turner syndrome. *Eur J Orthod*, 35, 467-74.

Ross, M. H., and Pawlina, W. (2011). Histology: A Text and Atlas (sixth.). Baltimore: Lippincott, Williams, and Wilkins.

Scheid, R. C., and Weiss, G. (2012). Woelfels Dental Anatomy (8th ed.). Philadelphia: Lippincott, Williams, and Wilkins.

Seto, B. , H. Gotsopoulos , M. R. Sims , and P. A. Cistulli . Maxillary morphology in obstructive sleep apnoea syndrome. *Eur J Orthod* (2001). 23:703–714.

Shastry S, Park JH. Evaluation of the use of digital study models in postgraduate orthodontic programs in the United States and Canada. *Angle Orthod* (2014);84:62-7.

Shereef Shahen, Gennaro Carrino, Rossella Carrino, Reham Abdelsalam, Carlos Flores-Mir and Letizia Perillo. (2018). Palatal volume and area assessment on digital casts generated from cone-beam computed tomography scans. *The Angle Orthodontist*. 88:4, 397-402.

Shete P, Tupkari J, Benjamin T, Singh A. Treacher Collins syndrome. *J Oral Maxillofac Pathol*. (2011);15(3):348–351.

Skrinjaric, T., Glavina, D. and Jukic, J. (2004). Palatal and dental arch morphology in Down syndrome. *Coll Antropol*, 28, 841-7.

Smith, R.J. and H.L. Bailit, (1977). Problems and methods in research on the genetics of dental occlusion. *Angle Orthod*., 47: 65-77.

Song, W. C., Jo, D. I., Lee, J. Y., Kim, J. N., Hur, M. S., Hu, K. S., … Koh, K. S. (2009). Microanatomy of the incisive canal using three-dimensional reconstruction of microCT images: An ex vivo study. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, 108(4), 583–590.

Sung-Tae Yang, Hong-Kyun Kim, Young Seol Lim, Mi-Sook Chang, Seung-Pyo Lee, Young-Seok Park, A three dimensional observation of palatal vault growth in children: a 9 year longitudinal study, *European Journal of Orthodontics*, Volume 35, Issue 6, (2013), Pages 832–840.

Suri S, Ross R B, Tompson B D. (2010). Craniofacial morphology and adolescent facial growth in Pierre Robin sequence. *American Journal of Orthodontics and Dentofacial Orthopedics* 137: e763–e774.

Thilander, B. (1995). Basic mechanisms in craniofacial growth. *Acta odontoLogica Scandinavica.* 53: 144–151.

Thilander, B. (2009). Dentoalveolar development in subjects with normal occlusion. A longitudinal study between the ages of 5 and 31 years. *European Journal of Orthodontics* 31: 109–120.

Toni B, Coppotelli E, Debora L, Costantini A, Vompi C. The study of the palatal vault morphology. Webmed Central 2017;8(11):WMC005401.

Tsai, H. H. Tan, C.T. (2004). Morphology of the palatal vault of primary dentition in transverse view. *The Angle Orthodontist* 74: 774–779.

Umrani S, Mathew P, Hemant AV, Tiwari R, Dixit H. A review on Extraction versus Non-extraction on Facial and Smile Esthetics. *Int J Oral Health Med Res* (2017);4(3):83-86.

Veli I, Uysal T, Ucar F, Eruz M, Ozer T. (2011). Cone-beam computed tomography assessment of mandibular asymmetry in unilateral cleft lip and palate. *Korean Journal of Orthodontics* 41: 431–439.

Wu, J., U. Hagg and A.B.M. Rabie, (2006). Chinese norms of McNamara's cephalometric analysis. *Angle Orthod*., 77: 12-20.

Younes S.A. Maxillary arch dimensions in Saudi and Egyptian population sample. *Am J Orthod Dentofacial Orthop*. (1984);85:83–87.

Zeng, Z.S., X.D. Zheng, Y.L. Zhu, Z.Q. Wang and Z.D. Xiang et al, (2007). Population genetic data of 15 STR loci in Han population of Henan province (central China). *Legal Med*., 9: 30-32.