T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF ENDODONTICS

# INVESTIGATION OF ROOT CANAL CONFIGURATION OF THE MAXILLARY FIRST MOLARS IN A TURKISH SUBPOPULATION USING MICROCOMPUTED TOMOGRAPHY

Phd Thesis

**Rawan A.A ALQAWASMI**

Supervisor
**Prof. Dr. Ali KELEŞ**

SAMSUN
2021

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## THESIS APPROVAL

The thesis prepared by **Rawan A.A ALQAWASMI** under the supervision of **Prof. Dr. Ali KELEŞ** titled **"Investigation of Root Canal Configuration of The Maxillary First Molars in a Turkish Subpopulation Using Microcomputed Tomography"** has been accepted by consensus by the jury members as a Ph.D. Thesis at the defense exam held on 07.06.2021.

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APPROVAL

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Ali BOLAT

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# ÖZET

TÜRK POPÜLASYONUNDA MAKSİLLER BİRİNCİ MOLARIN KÖK KANAL KONFİGÜRASYONUNUN MİKRO BİLGİSAYARLI TOMOGRAFİ KULLANILARAK İNCELENMESİ

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**Amaç:** Bu çalışmanın amacı, mikro BT tekniği kullanılarak Türk popülasyonunda maksiller birinci moların dişlerindeki kök kanallarının konfigürasyonunu araştırmak ve bu tür dişlerde kök kanal sistemi anatomisindeki farklılığı vurgulamaktır.

**Gereç ve Yöntem:** Çekilen maksiller birinci molar dişlerden 198 örnek toplandı ve mikro BT tekniği ile tarandı. Vertucci ve Gulabivala ve arkadaşlarının sistemlerine göre kök kanal konfigürasyonunun sınıflandırılması, kanal giriş sayısı ve major apikal foramen sayısı belirlendi. Kökler boyunca kanalların birleşme ve ayrılma dağılımı ve kanal sayısı, örneklerin her bir kökü için koronal, orta ve apikal üçlüler incelenerek ayrıntılı olarak tartışıldı. Elde edilen sonuçlar, IBM SPSS Statistics 22.0 programı ile frekans analizi kullanılarak istatistiksel olarak değerlendirildi ve anlamlılık düzeyi 0.05 olarak belirlendi.

**Bulgular:** Birinci maksiller molar dişin mesiobukkal kökü, kök kanal konfigürasyonu açısından en değişken olanıdır. Palatal ve distobukkal köklerde Tip I baskınlığı. Meziobukkal köklerde çok sayıda kanal ve çok sayıda major apikal foramen olasılığı fark edildi. Kanalların birleşme ve ayrılma, maksiller birinci molarların köklerinin palatal olanı hariç herhangi bir seviyesinde görülebilir. Ek olarak, tüm apikal üçlülerde ayrılma birleşmeden daha yaygındı.

**Sonuçlar:** Türk popülasyonundaki birinci molar dişleri, kök kanal sisteminde mesiobukkal, distobukkal ve palatal kökler arasında ve kök kanallarının seyri boyunca geniş bir değişkenlik yelpazesine sahipti. Klinisyenler, tedavi sürecinde kök kanallarındaki birleşme ve ayrılma bölgeleri hakkında bilgi sahibi olmalıdır. Bu çalışmadaki fark, birinci maksiller dişlerin tüm köklerinin, apikal üçüncü kısımdaki kanalların ayrılmasından daha büyük olduğu bulundu. böylece kanal sisteminin karmaşıklığını arttırır.

**Anahtar Sözcükler:** Maksiller birinci molar; kanal morfolojisi; Türk Popülasyon; mikrobilgisayarlı tomografi

# ABSTRACT

INVESTIGATION OF ROOT CANAL CONFIGURATION OF THE MAXILLARY FIRST MOLARS IN A TURKISH SUBPOPULATION USING MICROCOMPUTED TOMOGRAPHY


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**Aim:** The aim of this study is to investigate the configuration of root canals in the upper first molars, and emphasize the difference in the anatomy of the root canal system in such teeth in Turkish population using micro CT technique.

**Material and Method:** 198 specimens of extracted maxillary first molar teeth were collected and scanned with micro CT technique. Classification of the root canal configuration according to Vertucci and Gulabivala et al systems, number of canal orifices and number of major apical foramina were determined. Distribution of merging and splitting of canals along the roots and the number of canals were discussed in details by examining the coronal, middle and apical thirds for each root of the samples. Obtaining results were evaluated statistically using the frequency analysis with IBM SPSS Statistics 22.0 program and the level of significance was set at 0.05.

**Results:** The mesiobuccal root of the first maxillary molar is the most variable in terms of root canal configuration with dominance for type I in the palatal and distobuccal roots. The highest percentage of multiple canals probability and apical deltas was noticed in the mesiobuccal roots. Mergence and divergence in canals could be seen at any level of the roots of the maxillary first molar except the palatal one. In addition, divergence was more common than mergence in all the apical thirds.

**Conclusions:** The first molars in the Turkish population had a wide range of variability in the root canal system between their mesiobuccal, distobuccal and palatal roots, and along the course of the root canals themselves. Clinicians must be knowledgeable about the sites of root canal merging and splitting, which simplifies the treatment process. It was found that the divergence in the present study is greater than the mergence in the apical thirds of all roots of the first maxillary molars, which increases the complexity of the canal system.



**Keywords:** Maxillary first molar; canal morphology; Turkish population; microcomputed tomography

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## ICONS AND ABBREVIATIONS

| | |
|---|---|
| % | : Percentage sign |
| Micro CT | : Micro computed tomography |
| OEE | : Outer enamel epithelium |
| IEE | : Inner enamel epithelium |
| AC | : Apical constriction |
| CDJ | : Cemento- dentinal junction |
| AF | : Apical foramen |
| MB2 | : Second mesio-buccal canal |
| cc | : Unit of volume of a cube |
| CBCT | : Cone beam computed tomography |
| X-ray | : Type of radiation |
| SEM | : Scanning Electron Microscopy |
| 2D | : Two dimensional |
| 3D | : Three dimensional |
| I - VIII | : Roman numerals from 1 to 8 |
| µm | : Micrometre |
| kV | : Kilovolt |
| µA | : Microampere |
| MP. | : Megapixel |
| FOV | : Field of view |

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# 1. INTRODUCTION

Successful root canal treatment can be summed up with various phenomena such as resolution of apical periodontitis, pain relief, good sealing of the inner root canal and coronary segment, as well as improving in dental function (Estrela et al., 2014). Which can be achieved by the main objective of root canal therapy thorough shaping and cleaning of all pulp spaces and its complete obturation with an inert filling material. Together with diagnosis and treatment planning, knowledge of the canal morphology and its frequent variations is a basic requirement for endodontic success. It is important to visualize and to have knowledge of internal anatomy relationships before undertaking endodontic therapy to be familiar to the dentist the various pathways that root canals take to the apex (Vertucci, 2005).

The most significant causes for endodontic failures are missed root canals, incomplete canal instrumentation, followed by incorrect canal obturation. Variation in root canal morphology suggested as the most likely reason for the high frequency of endodontic flare-ups and failures (Ingle, 1961). Hence, there is persistence of microbial infection in the root canal system (Nair et al., 1990). Thus, a better understanding of root canal morphology and its variations is crucial for endodontists and dentists to implement advanced endodontic interventions and to correct operational errors.

Studies of the internal and external anatomy of teeth have shown that anatomic variations can occur in all groups of teeth and can be extremely complex (Awawdeh, Abdullah and Al-Qudah, 2008; Vertucci, 2005). Numerous factors contribute to the variations found in the root and canal studies reported (Vertucci, 2005). These factors include ethnicity (Gulabivala et al., 2001), age (Gulabivala et al., 2001), gender (Sert and Bayirli, 2004), trauma (Robertson et al., 1996) and study design *(in vitro or in vivo)* (Neaverth et al., 1987). Thats why the clinician must be well informed about the basics about root canal morphology and keep updating to any new variations scientifically.

The maxillary permanent first molar tooth, has been described as possibly the most treated, least understood, posterior tooth (Burns, 1987). In assessing the root canal anatomy of these teeth prior to treatment clinicians must rely on intraoral radiography, and a thorough knowledge of both the commonly occurring configurations of the root canal system and the variations that may occur (Slowey, 1974; Weine et al., 1969). When anatomic variations are detected clinically, treatment can be performed with conventional or rotary preparation and root canal filling techniques respecting technical and biological principle (Barbizam et al., 2004; Jerome and Hanlon, 2003).

Different methods have been used to ensure adequate visualization of the root canal system. *In vitro* studies have been performed because of their superiority compared to the internal limitations of *in vivo* studies. Micro CT imaging has proven to be a viable method compared with others such as root sectioning, microscopic examination, CBCT, and even canal staining with tooth clearing, also considered to be the reference standard for laboratory morphological studies of the root canal system. The micro CT method is a noninvasive and thus nondestructive method that allows an accurate morphological analysis of the root canal (Briseño-Marroquín et al., 2015).

The aim of this study is to determine the configuration of the root canals in the upper first molar in Turkish society by using micro CT technique and to obtain data to help reduce operational errors during root canal treatment by performing two and three dimensional morphometric analyzes of the root canals. In addition, our aim is to emphasize the difference in the anatomy of the root canal configuration in the upper molars and to provide more detailed information for the endodontist when applying root canal treatment to the upper first molar teeth in the Turkish population. The data obtained can play an important role in reducing the percentage of failure and increase the success rate of endodontic treatment.

# 2. GENERAL INFORMATION

## 2.1. Tooth Development

Dental development is a complex process in which teeth are formed, grown and erupt into the mouth from embryonic cells. All parts of the tooth must develop during appropriate stages of fetal development in order to have a healthy tooth and oral environment. Primary teeth start to form between the sixth and eighth week of prenatal development, and permanent teeth begin to form in the twentieth week.

The process of accumulation of cells derived from the ectoderm of the first pharyngeal arch and the external parenchyma of the neural crest considered as the first step in tooth formation through the development of the tooth germ that eventually forms the tooth (Nanci, 2013; Thesleff et al., 1995). Tooth development is commonly divided into stages: the initiation stage, the bud stage, the cap stage, the bell stage, and finally maturation (Figure 2.1). This gradual arrangement in stages helps to comprehensively understand and classify the changes that occur during tooth development (Nanci, 2013).

### 2.1.1. Initiation Phase

It occurs in the sixth to seventh week of the embryonic life. Distinction between the vestibular lamina and the dental lamina can be seen microscopically during this stage, which considered as one of the earliest signs of formation the tooth. The dental lamina connects the developing tooth bud to the epithelial layer of the mouth for a significant time.

### 2.1.2. The Bud Phase

The bud stage is characterized by the appearance of a tooth bud without a clear arrangement of cells. The stage technically begins once epithelial cells proliferate into the ectomesenchyme of the jaw (Nanci, 2013). Typically, this occurs when the fetus is around 8 weeks old (Young et al., 2013). The tooth bud itself is the group of cells at the periphery of the dental lamina.

Each bud is separated from the ectomesenchyme by a basement membrane. Ectomesenchymal cells congregate deep to the bud, forming a cluster of cells, which is the initiation of the condensation of the ectomesenchyme. The remaining ectomesenchymal cells are arranged in a more or less haphazardly uniform fashion.

### 2.1.3. Cap Phase

At this stage cell arrangement occurs in the tooth bud. A small group of ectomesenchymal cells stops producing extracellular substances, which results in an aggregation of these cells called the dental papilla. The tooth bud takes on the appearance of a cap, grows around the ectomesenchymal aggregation and form the enamel organ that covers the dental papilla. The enamel organ will produce enamel, the dental papilla will produce dentin and pulp, and the dental sac will produce the supporting structures of a tooth (Nanci, 2013).

### 2.1.4. Bell Phase

This stage is known as the bell stage because the tooth organ takes the form of a bell. Meanwhile, histodifferentiation and morphodifferentiation takes place. During this interval the cells around the enamel organ are divided into four important layers; the outer enamel epithelium (OEE), inner enamel epithelium (IEE), stratum intermedium formed from the cells between the IEE and the stellate reticulum and the cervical loop which is the rim of the enamel organ where the outer and inner enamel epithelium joins.

During the late bell stage, hard tissues including enamel and dentin start developing and important cellular changes occur at this time (Nanci, 2013). The adjacent layer of cells in the dental papilla suddenly increases in size and differentiates into odontoblasts, which are the cells that form dentin (Ross et al., 2006). The odontoblasts secrete a substance, an organic matrix, into their immediate surrounding. The organic matrix contains the material needed for dentin formation. As odontoblasts deposit organic matrix termed predentin, they migrate toward the center of the dental papilla. Thus, unlike enamel, dentin starts forming in the surface closest to the outside of the tooth and proceeds inward. After dentin formation begins, the cells of the IEE secrete an organic matrix against the dentin. This matrix immediately mineralizes and becomes the initial layer of the tooth's enamel. Outside the dentin are the newly formed ameloblasts in response to the formation of dentin, which are cells that continue the process of enamel formation; therefore, enamel formation moves outwards, adding new material to the outer surface of the developing tooth (Nanci, 2013)

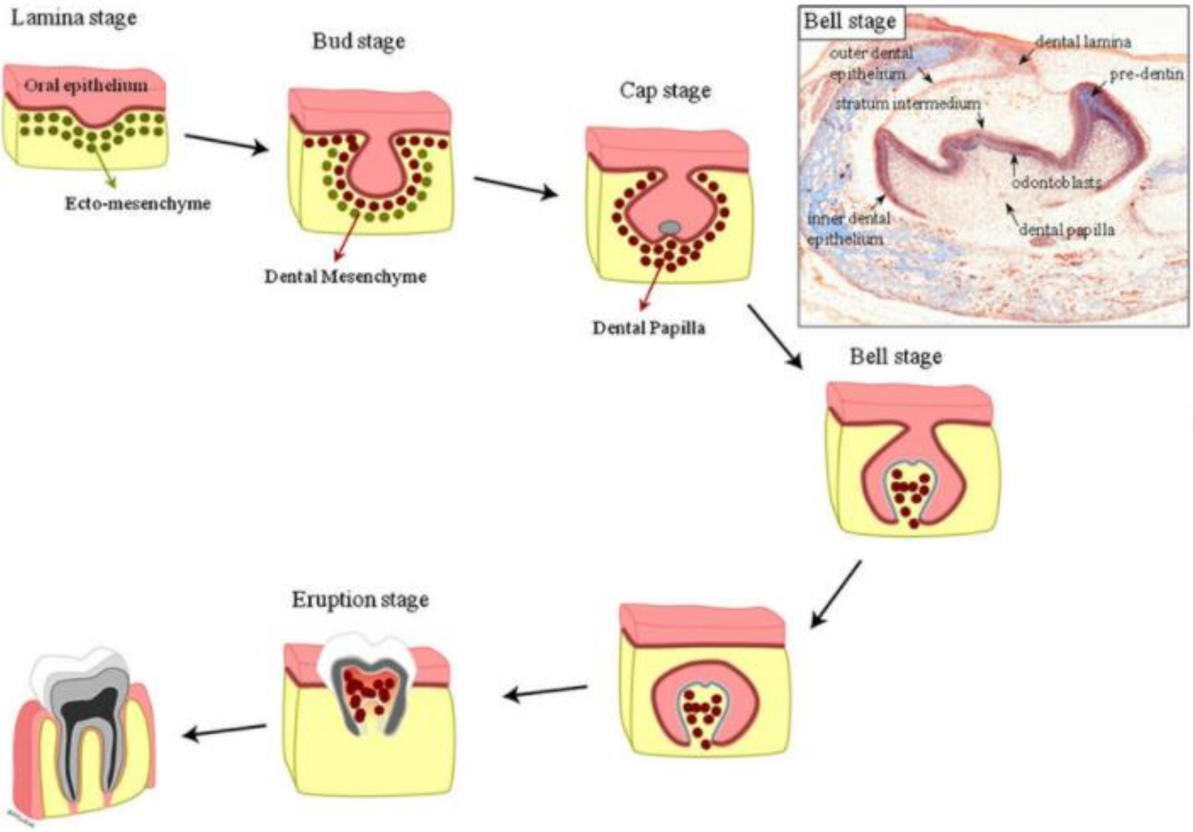


**Figure 2.1.** The Bud, Cap, and Bell Stages during tooth development (Martens et al., 2013)

## 2.2. Root Formation

The developing tooth germ begins to form its root after the completion of crown morphogenesis and arrangement of coronal dentin and enamel extracellular matrix, a process that will establish its connection to the surrounding alveolar bone (Thomas, 2003).

Root development is managed by interactions that include the Hertwig epithelial sheath, basement membrane, mesenchymal papilla, and dental follicle (Burns, 1987). The Hertwig epithelial sheath originates from the reflection zone or cervical loop and has a ring shaped structure surrounded by a basal membrane that separates it from the pulpal and follicular mesenchyma. This basement membrane has fibrils act as an anchor on the pulp side. The internal epithelium faces the papilla and the external epithelium faces the dental follicle. The Hertwig epithelial sheath will radiate extensions towards the center until fuses in the central part of the papilla and form loops from which the roots can be identified. The number of extensions emitted is proportional to the number of roots that each molar can have. For example, for the molar which will have two roots, two extencions are formed, and after fusion of two loops, each of the two will be at the origin of the formation of a root.

If developmental defects of the Hertwig sheath at the apical third of the root happened, following a stop of dentinogenesis and nondifferentiation of pulp fibroblasts into odontoblasts, that will be the origin of the formation of the lateral canals at that site.

During the progress of the development process of the root many actions take place like the reduction in mitosis, shrinkage in the band forming the Hertwig epithelial sheath, reducing in the size of the root tube. Thus, this contraction allows the development of one or more apical foramina, through which the vascular and nerve supplements will pass (Rhrich and Aghoutan, 2019).

### 2.3. Anatomy of the Pulp Cavity

Pulp and dentin derived from the same origin which is the dental papilla of the tooth germ. During odontogenesis, dentin forms around the dental papilla, the innermost tissue represent the pulp (Nanci, 2013).

Cells at the periphery of the dental papilla differentiated to odontoblasts, while undifferentiated fibroblast-like cells (pulpoblasts) forms in the middle of the pulp completing the formation process of the pulp (Hand and Frank, 2014).

The pulp consist of the pulp chamber, pulp horns, and radicular part. The pulp chamber is the bulk of the pulp and simulates the general shape of a tooth crown (Luukko et al., 2011). With aging according to the continuous deposition of secondary dentin, the pulp chamber becomes smaller (Moore, 1970). This process is not homogeneous throught the coronal pulp, but is more prominent on the roof and floor of the pulp chamber. Other stimulus like irritation, induce the formation of irritation dentin that contributes the reduction of the size of the pulp chamber (Pashley et al., 2002). The pulp is the nerve and vascular supplement center of each tooth, with a volume of 0.02cc for single adult human pulp (Luukko, 2011). Radicular pulp or root canal extend down from the cervical region of the crown beginning as the funneled orifice and existing as the apical foramen (Walton and Vertucci, 2009). Each root is served by at least one such pulp corridor. The shape of the canal compatabile with the shape of the root (Bhaskar, 1991). A curve at the end of the root means almost invariably that the canal follows this curve (Pashley et al., 2002).

The shape of the canal can be changed depending on many factors such as the presence of irritation, the shape and size of the root, the degree of curvature of the root, the age and condition of the tooth (Pashley et al., 2002; Walton and Vertucci, 2009). Most canals are curved especially in the faciolingual direction, but its difficult to detected with the two dimensioal radiograph. As a common facts about the shape of the root canal; that when a root having two canals, they tend to be oval. Also, if a canal have the oval shape cervically so, usually it take the oval or ribbon shape at the end of the apical third. Generally, whatever the shape of the canal at the cervical third, it tends to become more oval and slightly flat in the apical curvature.

Irregularities and abnormalities in the root canals are common in the posterior teeth such as the connection between canals (isthmus), fins and other variations that are often inaccessible through instrumentation or irrigation, thereby preventing consistent obturation (Walton and Vertucci, 2009).

### 2.4. Anatomy of the Apical Portion of the Canal System

A comprehensive knowledge about the anatomy of the apical third of the canal system is mandatory for a successful endodontic treatment as it characterized by a complex and variable anatomy. That will help clinicians to perform endodontic procedures without causing any damage to the periradicular tissues and disinfect the apical part of the root canal system effectively (Keles and Keskin, 2018).

Histologically, the number and location of apical blood vessels present at the time of formation of the apex, play a role in determining the anatomy of the root apex. During the tooth eruption, the foramen is open and the cementum layers continue to be deposited, causing the canal narrowing gradually. The foramen anatomy is not fixed and the center of the foramen deviates away from the apical center (Pashley et al., 2002).

Estimating the number of foramen in a particular tooth is impossible because the potential for vascular branching at the apex is variable. Generally, the incidence of multiple foramina is more common, and the multirooted teeth tend to have a more complex apical anatomy (Pashley et al., 2002).

Apical root anatomy contains basically three anatomic and histologic landmarks; the apical constriction (AC), the cemento- dentinal junction (CDJ) and the apical foramen (AF).

The apical constriction or minor diameter defined as the narrowest part of the canal, which is found at a distance before the apical foramen. The distance from the the apical constriction to the apical foramen varies from 0.5 to 1.5 mm and changes with age. It was estimated to be approximately 0.5 mm in young people and 0.67 mm in the elderly (Kuttler, 1955). Minor diameter used to be as a reference point for the apical termination of shaping, cleaning and obturation procedures (Kuttler, 1980).

CDJ is the area of the apical canal where the cementum ends, pulp tissue ends and periodontal tissues begin. CDJ is not at the same point with the apical constriction and just rarley coincide. The CDJ is frequently observed to be 1mm higher from AF (Smulson et al., 1996).

The AF defined as the circumference or the rounded edge, like one a funnel or crater, that differentiates the termination of the cemental canal from the exterioer surface of the root (Kuttler, 1980). Generally, AF end at a point shorter from the the anatomic apex, approximatley offset 0.5 to 3.0 mm from the anatomic apex. This distance may vary in elderly people due to cementum apposition (Vertucci, 2005).

### 2.5. Maxillary First Molar

The maxillary first molars are the second most common carious teeth and the second most common teeth to undergo endodontic treatment or extraction, up to 21% of all extracted teeth are maxillary first molars (Zadik et al., 2008).

According to the position of the maxillary first molar in the upper jaw and the possibility for the superimposition from anatomical structures on radiograph, the diagnosis for extra canal or other anatomic variations becomes difficult.

In the literature it is usually stated that the first permanent maxillary molar has three roots and four canals (Vertucci et al., 2006). With minimal possibility of permanent maxillary first molars with two roots, four roots or single root (Gu et al., 2015). The root canal morphology of the maxillary first molar is one of the most complex root canal anatomies in human dentition (Vertucci et al., 2006).

A greater variations observed in the root canal system of the mesiobuccal roots of maxillary molars than distobuccal and palatal roots (Silva et al., 2014). Presence of MB2 canals with high prevelence between 40% to 95% (Hartwell et al., 2007), incidence of isthmuses in mesiobuccal roots that ranges from 5 to 53%, and become higher at 3-5 mm from the apex also reported (Hsu and Kim, 1997).

Methods used by the researchers, type of study (*in vivo or in vitro*), and sample size can be causes for the variation in incidence of MB2. Age, sex, ethnics also considered as factors affect that variance. Martins et al. reported that the proportions of MB2 were significantly higher in younger patients and 3 rooted first maxillary molars (Martins et al., 2018d).

Periapical lesion is one of the features of failure for an endodontic treatment. The colleration between unfilled MB2 canal and periapical lesions with endodontically treated maxillary molars was documented by researchers. Karabucak et al. (2016) in a CBCT study discussed the prevalence of apical periodontitis in endodontically treated premolars and molars with untreated canal and found that the proportion of unfilled MB2 canals in maxillary first molars with previous root canal therapy was 46.5%, and 72.7% of these molars were associated with periapical lesions. According to the same study, a tooth with a missed canal has the ability 4.38 times more to be associated with a lesion (Karabucak et al., 2016).

### 2.6. Factors Affecting Root Canal Morphology

#### 2.6.1. Age

Important changes in the root canal system take place with physiologic aging. The size and shape of the pulp are influenced by age; in the young person, pulp horns are long, pulp chambers are large, root canals are wide, apical foramen are broad, and dentin tubules are wide, regular, and filed with protoplasmic fluid. With increasing age pulp horn recede, pulp chambers becomes smaller in height rather than in width, and root canals become narrower from deposition of secondary and reparative dentin. Moreover, apical foramen deviates from the exact anatomic apex, and their minor diameter becomes narrower while their major diameter becomes wider from the deposition of dentin and cementum. Dentinal tubules become narrower and even obliterated by the deposition of peritubular dentin forming sclerotic dentin, and losing their regularity and become tortuous.

Reparative dentin may be devoid of dentinal tubules, and the moisture content of the dentin is reduced.

Previous studies provided data on the presence or absence of the MB2 in different age groups. Three of those studies (Lee et al., 2011; Naseri et al., 2016; Zheng et al., 2010) reported that over 60 years the prevalence of MB2 was lower when compared to younger groups. Thomas and his colleagues (1993) studied the canal anatomy of the mesiobuccal root of maxillary first molars at different ages, and reported that differentiation of root canals started at an early age but the rate of progression appeared to be variable (Thomas et al., 1993). Furthermore, Adriana Gurgel et al. (2013) reported that the prevalence of MB2 canals, and the number of canals in the mesiobucal root of the maxillary first and second molars decreased with age. Regarding the same study, the chance of identifying the MB2 canal decreases with age, as a result of the deposition of dentin in root canal walls (Reis et al., 2013).

Martins et al. (2018) reported a high tendency to the prevalence of Vertucci type I configuration in young patients in a study of variations of root canal system configuration in human permanent teeth in different age groups. In the elderly, a greater increase in the number of root canals has been observed mainly in the upper and lower second premolars and the distal root of the lower first molars. The second type of Vertucci was more common in older groups (Martins et al., 2018a)

Clinicians should be aware about the changes in the root canal system which may take place over different ages during application of the endodontic treatment.

**2.6.2. Racial Differences**

Many studies have stated that root morphology, numbers, and root canal types and morphology may vary according to race. Martins et al. (2018) through studying the difference on the root and root canal morphologies between Asian and White Ethnic groups, demonstrated that the number of roots per tooth and canal configuration variability noticed between the two ethnics (Martins et al., 2018b).

In literature there are also researches about the Turkish population examining the changes of root canal system, root numbers and shape related to the race; Ok et al. (2014) , Kartal et al. (1998), Bulut et al. (2015) study the canal configuration of the premolars teeth (Bulut et al., 2015; Kartal et al., 1998; Ok et al., 2014). Çalışkan et al. (1995), in a comprehensive study on the root canal morphology of permanent teeth in the Turkish population, in addition of the investigation of the number and type of root canals, their effects, transverse anastomoses, apical foramina locations, the frequency of the apical deltas also the length of the teeth were examined, and found that it is shorter compared to other studies which illustrate that the root and root canal system may change due to the difference between communities.

The clinician should consider the factors that may cause changes in the root canal system and its morphology in order to apply and achieve a successful endodontic treatment.

### 2.6.3. Gender

Few studies have evaluated gender differences in ethnic populations and its relation to root canal morphology. In the literature, researches on the effect of trauma on root and root canal morphology is divided into two sections according to its results. A part showed that no significant difference in the root and/or root canal morphology between male and female (Abella et al., 2015; Pattanshetti et al., 2008; Wang et al., 2010). While other researches represented that differences in root and root canal morphology may noticed among gender (Lee et al., 2011; Martins et al., 2018c; Naseri et al., 2018).

About Turkish population Celikten et al. (2016) collected 272 CBCT for Turkish patients to evaluate the root canal morphology of mandibular molars, and reported that no difference observed between the two genders. However, Sert and Bayirli (2004) in an *in vitro* study using the demineralization and staining method for investing 2800 teeth of mandibular and maxillary teeth observed differences in root canal configurations in Turkish population among gender.

### 2.6.4. Trauma

Traumatic injuries of the primary dentition may interfere with the development of permanent teeth. Result in morphologic variations in the sequele permanent dentition include the discoloration of the enamel, enamel hypoplasia, crown or root dilacerations, root duplications, and partial or complete cessation of the root formation (Andreasen et al., 1971).

Root duplication or multiple roots of a permanent tooth is a rare complication after injury of primary teeth. It occurs when half or less than half of the crown is formed at the time of injury (Andreasen et al., 1971). Generally, its a result of an intrusive luxation of the primary teeth into the follicle of the developing tooth germ of the permanent tooth, which in turn causes a traumatic division for the cervical loop and 2 separate roots formed (Wilson, 1995).

Intrusive luxation and avulsion appeared to be the types of injuries most often associated with disturbances in tooth development. Andreasen and Ravn (1971) discussed the effect of traumatic injuries to primary teeth on permanent successors. The study reported developmental disturbances in 41% of 213 injured teeth in which the rate of occurrence of disturbances increases with the decrease in the age at which the trauma happened for the primary teeth. Sakai et al. (2008) reported root dilacerations of a permanent tooth as a result of avulsion and replantation of a primary tooth. During replantation of primary tooth, the coagulum forced into the follicle area can disrupt the permanent successor. Therefore, theoretically and clinically the idea of replantation have been rejected (Holan, 2013).

Other variations in the root canal syetem can ocur after trauma such as pulp necrosis, pulp hyperaemia, pulp haemorrhage, obliteration of the pulp chamber and/or root canal, and inflammatory root resorption (Colak et al., 2009; Rocha and Cardoso, 2004). Robertson et al. (1996) investigated the incidence of pulp necrosis after pulp canal obliteration from trauma of permanent incisors. The study showed that as a continuation of post-traumatic canal obliteration, the appearance of pulp necrosis in teeth increases over time, nevertheless preventive prophylactic root canal treatment intervention is not justified.

Based on the above, it can be assumed that traumatic damage to the teeth plays a role in abnormal root morphology or subsequent changes in the root canal system. Therefore, clinicians should be careful to obtain a comprehensive history from the patient and consider the potential prognoses and complications of traumatic injuries teeth before applying the endodontic treatment, which in turn can reduce the percentage of mistakes could faced and increase the success rate of the treatment and postoperative expectations.

#### 2.6.5. Pathosis

Previous studies reported that certain conditions such as dentinal exposure, improper medication, harmful filling material, carious lesions, deep restorations or periodontal disease act as irritant stimulant and may cause changes in root canal morphology or changes in pulp dentinal complex due to deposition of reactionary dentin (Diamon et al., 1966; Kuttler, 1959).

### 2.7. Examination Techniques of Root Canal Morphology

#### 2.7.1. Creating a Copy Model

The primary purpose of this method is to make a replica simulates the shape of the original canal. Canal thoroughly dried and filled using pressure or vacuum technique with a low viscosity synthetic resin or silicone impression material. After polymerization, the excess removed and the teeth must placed in acid until acheiving complete decalcification, to dissolve the calcified tissue and obtain the resin replicas. The silicone or resin impression material not affected by the acid used, and resulted replicas then examined with microscope (Goldman et al., 1989; Wakabayashi et al., 1988).

#### 2.7.2. Sectioning

In this method root inserted into block and by means of a disc transverse grooves were made over the margins of the block, according to the proximal surfaces of the tooth. The obtained sectioned portions then mounted and stained on slides to be ready for the investigation process macroscopically or microscopically. McCann and his colleagues (1990) modified this technique, whereby a reproducible casted metal muffle system developed. That enable the clinician-researcher to apply the instrumentation process for the canal and examine it both before and after instrumentation at any level within the same canal system (Bramante et al., 1987; McCann et al., 1990).

#### 2.7.3. Radiographic Techniques

##### 2.7.3.1. Routine Periapical Radiograph Which Taken for Patients Before, During, and after Treatment

Periapical X-rays are still the most widely used method for determining root canal morphology prior to endodontic treatment (Vandenberghe et al., 2010). Accurate detection of complex canal morphology on X-ray is necessary to avoid missing root canals for example during treatment, but this can be difficult by two-dimensional X-rays in order that it compresses three dimensional anatomy into two dimensional image or shadow which could limit the diagnosis quality (Sun et al., 2016).

##### 2.7.3.2. Radiograph Taken in In-Vitro Studies for Evaluating the Root Canal Morphology

Radiographs used in studies dealing with extracted teeth, generally taken from both mesiodistal and buccolingual directions for investigate number of root canals and their different divisions in each root and tooth; the curvatures of the root canals in both directions; the ramifications of the main root canals; and determining the canal shape (long-oval, oval or flat) (Jou et al., 2004; Pineda and Kuttler, 1972). Other *in vitro* studies used radiograph after injecting radioopaque material into the canals (Shearer et al., 1996).

### 2.7.4. Clearing Technique

The clearing technique is a procedure that is routinely used to examine the internal anatomy of calcified tissue. It allows the study of root canal anatomy by converting the teeth into transparency and allowed to have a three dimensional view of the pulp cavity in relation to the exterior of the tooth. Physical and chemical changes must take place for making the teeth transparent, which consists first of the decalcification process with demineralizing acids like (nitric acid, formic acid, hydrochloric acid), then dehydration with alcohol, and finally clearing with methyl salicylate and injection of dye into root canal to visualize the root canal morphology (Vertucci, 1978).

The idea to make teeth transparent were first applied by Okumura (1927). It was later modified by Tagger et al. (1994). Robertson and Leeb (1982) used this technique to investigate root canal morphology in endodontically filled teeth.

From the endodontic perspective, the irreversible changes that have occurred in the tooth structure and artifacts created from this technique can be considered as the main limitations of this method while studying the root canal system because this prevents the accurate reflection of the true morphology of the root canal system (Grover and Shetty, 2012).

### 2.7.5. Investigation with Scanning Electron Microscopy (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. SEM is capable of displaying a relatively large area of the sample; ability to display bulk materials and provide the capacity to measure the composition and characteristics of the sample using various analytical methods.

Endodontically, this technology has been applied by numerous investigators to study the efficacy of various irrigation protocols and file systems in the removal of debris and smear layer or inspecting the root canal system accurately such as examining the apical region of the teeth; main apical foramen; accessory foramina; anastomosis (Hülsmann et al., 1997; Morfis et al., 1994; Peters and Barbakow, 2000).

### 2.7.6. Computed Tomography

The term computed tomography refers to a computerized X-ray imaging procedure in which a narrow beam of X-rays is aimed at the object to be studied, producing signals that are processed by the machine's computer to generate cross-sectional images or slices for the structure. These images are called tomographic images and contain more detailed information than conventional X-rays. Once a number of successive slices are collected by the machine's computer, they can be digitally stacked together to form a three dimensional resulted image.

In the year of 1990 the use of the CT scan in endodontics were firstly used by Tachibana and Matsumoto which reported that the computer scans provided the images necessary for 3 dimensional reconstruction of root canals, roots and teeth. However, radiation dose used at that time was large and the scanning procedure was time consuming in addition to the high cost (Tachibana and Matsumoto, 1990).

By taking into account the disadvantages mentioned earlier, improvements have been made in imaging software and scanning technology which create potential uses for it in endodontic research by considering it as a reproducible and noninvasive means of evaluating changes within the root canal system, dentin thickness, scan root canal before and after instrumentation (Gambill et al., 1996).

## 2.8. Micro Computed Tomography

In 1980s, the first micro CT scanners were developed (Elliott and Dover, 1982). Micro CT scanners capture images of the sample as a series of 2D projections, then the 2D images can be reconstructed and furtherly processed to enable the 3D visualization of the sample. The power of 3D micro CT systems can reveal the internal features inside the aimed sample.

Quantitative, qualitative and volumetric information about the microstructure for any object can be obtained from micro CT scanning without any destruction or change for the sample that allow using it in future studies or for obtaining further informations (Rhodes et al., 1999). On the other hand, a limitation of micro CT can be mentioned, it is impossible to use for in vivo studies due to the radiation level of exposure. Alternatively, cone beam computed tomography (CBCT) could be used for in vivo studies despite its lower resolution and failure to detect fine anatomical details. (Cotton et al., 2007; Ordinola- Zapata et al., 2017).

### 2.8.1. Basic Principles of Microtomography

The principle of micro CT is represented in using of a micro-focus X-ray source that illuminates the sample Figure (2.2). By rotating the sample, several views can be acquired from different angles. These multiple angular images are reconstructed to create a high resolution 3D image of the structur.

Previously, in conventional CT, the X-ray source and the detector turn around the object, that causes mechanical vibration and give a projection of the slice in its own plane, so that details at different parts of the slice will be superimposed. In order to resolve this superimposition in the calculation, it is necessary to have measurements of the projected X-ray with many different orientations about an axis perpendicular to the plane of the slice. This can be achieved if the specimen can be rotated about this axis. Later on, this idea was implemented by the technology of micro CT (Elliott and Dover, 1982). Other difference can be mentioned between the two techniques; where CT scans are limited to a resolution within millimeters, micro CT scanners can work at the level of microns which is a submillimeter scale.

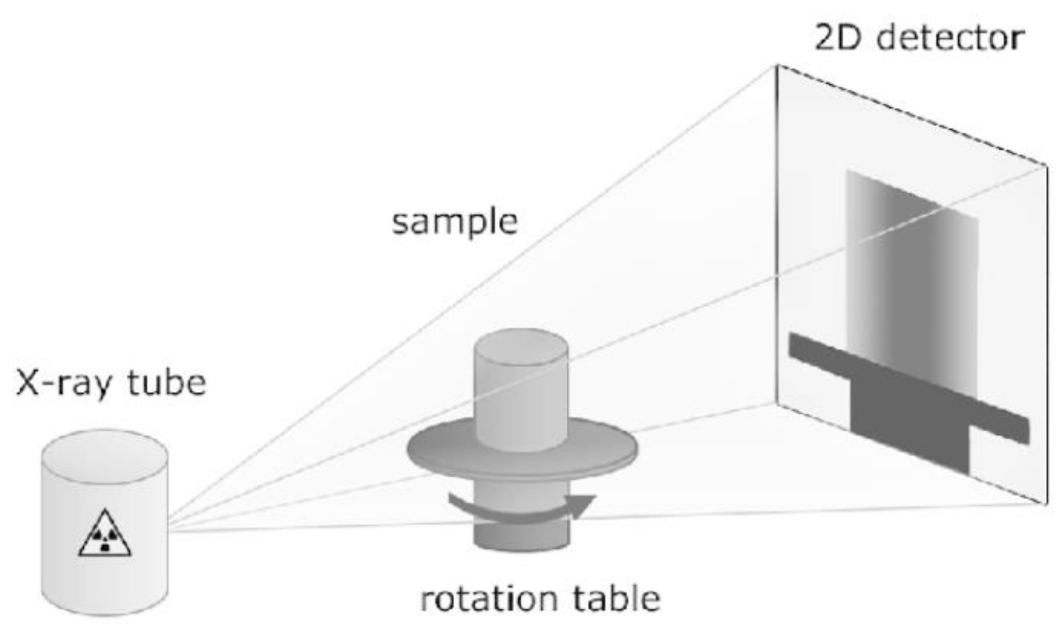


**Figure 2.2**. Principle of the micro computed tomography system (Leszczyński et al., 2014)

### 2.8.2. SkyScan-1172 System

The Skyscan 1172 is a desktop ex vivo micro CT scanner Figure (2.3). In this study, it was adopted for the scanning of the upper first maxillary teeth. This instrument has a 11Mp X-ray camera. The detail detectability is 1µm at highest resolution to 25µm. Also, has a PC windows based software for 2D/3D image analysis and realistic visualization. The specimen placement and variable specimen magnification can be automatically changed in which both the sample stage and the X-ray camera (detector), can be moved closer or farther from the source, as needed to obtain the suitable resolution and size requıred.

The Software of SkyScan 1172 system include some tools; CTAn (CT analyzer), CTVox (for volume rendering), Data Viewer, CTVol (3D animation) allows automatic or manual 3D rendering, animation, transparency, multiple color capacity, and making movies.

**Figure 2.3.** SkyScan-1172 System

## 2.9. Usage Areas of Micro CT in Endodontics Researches

According to the several advantages and properties of micro CT technology that make it very applicabale and widley used in different endodontics field of researches, like evaluate and analyze the internal anatomy of teeth (Briseño-Marroquín et al., 2015; Keles and Keskin, 2018), steps of endodontic treatment including instrumentation (Paqué and Peters, 2011), canal fillings (Somma et al., 2011), retreatment (Rödig et al., 2012), materials related to the endodontic treatment and its quality (Hammad et al., 2009), and also researches that study the volume and/or area using scanning pre and post endodontic treatment (Bergmans et al., 2001).

Numerous information can gained from micro CT technology because the samples used in this technology remain sound and intact.

### 2.10. Classifications of the Root Canal System

#### 2.10.1. Vertucci's Classification

Vertucci (1984) investigated thoroughly the anatomy of the root canals of extracted human teeth, number and type of root canals, number and location of lateral canals, apical foramina, and the frequency of apical deltas. According to his study the root canal configurations of human permanent teeth classified into eight types (Vertucci, 1984).

Type I: A single canal extends from the pulp chamber to the apex.

Type II: Two separate canals leave the pulp chamber and join short of the apex to form one canal.

Type III: One canal leaves the pulp chamber, divides into two within the root, and then merges to exit as one canal.

Type IV: Two separate and distinct canals extend from the pulp chamber to the apex.

Type V: One canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with separate apical foramina.

Type VI: Two separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex to exit as two distinct canals.

Type VII: One canal leaves the pulp chamber, divides and then rejoins within the body of the root, and tinally redivides into two distinct canals short of the apex.

Type VIII: Three separate and distinct canals extend from the pulp chamber to the apex.

#### 2.10.2. Gulabivala's Classification

Gulabivala et al. (2001) studied the root canal morphology of Burmese mandibular molars and one of the results of this study, seven additional canal configuration types were added to the Vertucci classification (Gulabivala et al., 2001):

Type 9: Three seperated canals leave the pulp chamber, then join to exit as one canal in the apical third.

Type 10: Two canals leave the pulp chamber then joined to form one canal then seperated again into two canals then rejoined again and exit as one canal.

Type 11: Four canals extend to apex to exit as two canals with two seperated apical foramina.

Type 12: Three seperated canals join apically to exit as two canals with two seperated apical foramina.

Type 13: Two seperated canals leave the pulp chamber diverged and exit as three canals.

Type 14: Four separated and distinct canals extend from the pulp chamber to the apex.

Type 15: Five canals leave the pulp chamber, exit as four canals in the apical third.

# 3. MATERIAL AND METHOD

This study was carried out under *in vitro* conditions at Ondokuz Mayıs University/ Faculty of Dentistry and micro CT Laboratory of Inonu University. It was approved by the Research Ethics Committee KAEK (2015/408) of Ondokuz Mayıs University.

## 3.1. Sample Selection and Preparation

Maxillary first molar teeth extracted with reasons nonrelated with this study were collected. The age and gender of the patients were unknown. Any tooth with extreme caries, root resorption, crack, fracture, or root fusion were excluded. Collected teeth surfaces were carefully cleaned with ultrasonic scaler and then a periapical radiographs were taken to exclude teeth with calcified canals or previously applied root canal treatment. Samples were differentiated as right or left, then stored in small plastic containers with saline at room temperature.

## 3.2. Micro Computed Tomography Scanning

A total of 198 were selected and mounted on a high-resolution desktop micro CT system (Skyscan1172; Bruker-microCT, Kontich, Belgium) in the micro CT laboratory of Inonu University. The teeth were scanned on a micro CT device (SkyScan 1172, Bruker-microCT, Kontich, Belgium) at 9 µm (pixel size), 100 kV, 100 µA, 180° rotation range and 0.6° step, camera exposure time of 2200 ms and frame average of 1 with aluminium copper filters.

## 3.3. Analysis of Data

Data reconstruction was performed by NRecon v.1.10.6. software (Bruker-microCT) with a beam hardening correction of 65%. After the reconstruction, approximately 1300 two-dimensional axial cross-sectional images of each sample were obtained at 0.01 mm intervals. Images were transferred to CTAn software in order to obtain three-dimensional models and to perform quantitative two-dimensional measurements.

In order to evaluate and define the mesiobuccal, distobuccal, and palatal root canal morphology of the upper first molar teeth in detail, images were examined with CTAn software. Both dentin and pulp / root canals were obtained using the CTAn program. Three dimensional models of dentin and root canals were created using automatic segmentation thresholding and surface models using CTAn software. In

CTVol (Bruker-mikro CT) software, dentin was made translucent and after the root canals were colored, root canal configuration was evaluated visually. Canal configurations were classified according to Vertucci (1984) and Gulabivala et al. (2001) classification systems, and specimens that could not be represented with these systems were also specified. Two evaluators together performed the classifications and recordings the root canal configuration types of the specimens (R. A. and A. K.).

While the configurations of the root canal were determined, the two-dimensional cross-sectional images of the roots and images created with the CTVol software were evaluated together.

For precise analysing and evaluating the morphology of the root canal related the maximum number of canals, sites of merging and splitting of canals through its pathway. each examined sample was divided into coronal, middle, and apical thirds by measuring the length of each root and divided it by three (Figure 3.1.).

In addition, the number of canal orifices and the number of major apical foramina were also examined.

### 3.4. Statistical Analysis

The obtained results of:

- Distribution of different root canal configuration types according to Vertucci and Gulabivala et al. Classifications.
- Maximum number of root canals in each third.
- Number of canal orifices and major apical foramina.
- Distribution of merging and diverging of canals according to each third.

were analysed with frequency analysis, and evaluated statistically with IBM SPSS Statistics 22.0 program.

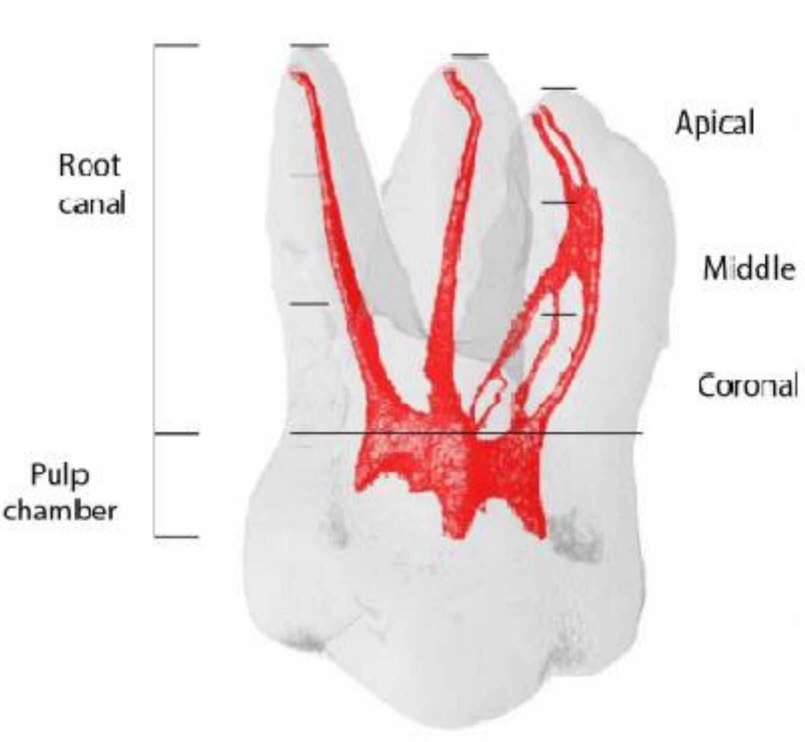


**Figure 3.1.** Hypothetical analogy for the three parts of each root

# 4. RESULTS

## 4.1. Root Canal Morphology

198 upper first molar teeth was examined using micro CT device. Three-dimensional analysis of root canal systems for each root was done seperately (mesiobuccal, distobuccal, palatal). As a result of that analysis, the most common canal configurations for the mesiobuccal roots are respectively found as; Type I (46, 23.2%), Type II (31, 15.7%), Type III (21, 10.6%), Type V (20, 10.1%), Type IV (16, 8.1%), Type VI (12, 6.1%), Type VII (9, 4.5%). 10 teeth could not encountered under Vertucci system while coincide with the system of Gulabivala in the following order respectively; Type XIII (4, 2%), Type IX, X, and XII in the same number and proportion as (2, 1%). Canal configurations for 33 teeth could not be included under Vertucci nor Gulabivala configuration systems.

For the distobuccal roots the most common canal configurations are respectively found as; Type I (174, 87.9%), Type II (9, 4.5%), Type V (8, 4%), Type III and Type VII (1, 0.5%). 2 teeth could not encountered under the Vertucci system, while they coincided with Gulabivala classification system represented by Type X and ratio (2, 1%).

The outcome for the canal configurations of the palatal roots are as the following respectively; Type I (194, 98%), Type V (2, 1%), Type II (1, 0.5%). 1 tooth ( 1, 0.5%) couldn't be classified according to Vertucci nor Gulabivala system regarding the configurations of it's root canal system.

Findings regarding the configurations of root canal systems for the mesiobuccal, distobuccal, and palatal roots are summarized in Table 4.1

Examples for the images created with the CTVol program are presented in (Figures 4.1-4.66).

**Table 4.1.** Distribution of Vertucci's Classification types among mesiobuccal, distobuccal, palatal roots and non classified root canal types

| Classification | Mesiobuccal Root | Distobuccal Root | Palatal Root |
|---|---|---|---|
| | **n (%)** | **n (%)** | **n (%)** |
| Type I (1-1 ) | 46 (23.2%) | 174 (87.9%) | 194 (98%) |
| Type II (2-1 ) | 31 (15.7%) | 10 (5.1%) | 1 (0.5%) |
| Type III (1-2-1) | 21 (10.6%) | 1(0.5%) | - |
| Type IV (2-2) | 16 (8.1%) | - | - |

| | | | |
|---|---|---|---|
| Type V (1-2) | 20 (10.1%) | 8 (4%) | 2 (1%) |
| Type VI (2-1-2) | 12 (6.1%) | - | - |
| Type VII (1-2-1-2) | 9 (4.5%) | 1 (0.5%) | - |
| 1-2-3-1-2 | 1 (0.5%) | - | - |
| 1-2-1-2-1 | 4 (2%) | 2 (1%) | - |
| 3-1-2 | 1 (0.5%) | - | - |
| 3-2-3-2 | 1 (0.5%) | - | - |
| 1-3-2 | 1 (0.5%) | - | - |
| 3-2-3 | 1 (0.5%) | - | - |
| 1-3-1 | 3 (1.5%) | - | - |
| 3-4-3 | 1 (0.5%) | - | - |
| 1-2-3 | 1 (0.5%) | - | - |
| 2-3-1 | 1 (0.5%) | - | - |
| 4-3-1-2 | 1 (0.5%) | - | - |
| 3-1-2 | 1 (0.5%) | 1 (0.5%) | - |
| 2-3-1-2 | 1 (0.5%) | - | - |
| 2-1-4 | 1 (0.5%) | - | - |
| 3-2-1-2 | 2 (1%) | - | - |
| 1-3 | 2 (1%) | - | - |
| 2-3-1-3 | 1 (0.5%) | - | - |
| 3-1-2-1 | 1 (0.5%) | - | - |
| 2-3-2-3 | 1 (0.5%) | - | - |
| 3-4-1-2-1 | 1 (0.5%) | - | - |
| 2-1-2-3 | 1 (0.5%) | - | - |
| 2-1-2-1-2 | 2 (1%) | - | - |
| 3-2-1 | 2 (1%) | - | - |
| 2-1-3 | 1 (0.5%) | - | - |
| 1-2 (end in the mesial root) -1 | - | - | 1 (0.5%) |
| Total number of teeth | 198 | | |

**Table 4.2.** Distribution of Gulabivala′s Classification types between mesiobuccal, distobuccal, and palatal roots

| **Gulabivala classification** | **Mesiobuccal Root n (%)** | **Distobuccal Root n (%)** | **Palatal Root n (%)** |
|---|---|---|---|
| Type IX (3-1) | 2 (1%) | - | - |
| Type X (2-1-2-1) | 2 (1%) | 2 (1%) | - |
| Type XII (3-2) | 2 (1%) | - | - |
| Type XIII (2-3) | 4 (2%) | - | - |
| Total number of teeth | 198 | | |

### 4.2. Number of Canals

The number of canals observed in the coronal, middle and apical thirds for each root in the examined samples (198 teeth) is recorded and presented in Table 4.3. The majority of the two canals are observed in the coronal part of the mesiobuccal roots. One or two canals were probably often to seen in the middle and apical part of the mesiobuccal root. A single canal was predominantly seen in the coronal, middle and apical third of the distobuccal and palatal roots. A second canal was noticed in 6.6% in the coronal part, 3% in the middle part and 5.1% in the apical part of the distobuccal roots. Two canals were seen in 1.5% of the coronal third, 0.5% of the middle third, and 1% of the apical third of the palatal roots.

third of the palatal roots.

**Table 4.3**. Numbers of root canals in the coronal, middle, and apical thirds of each root

| | **Mesiobuccal Root** | | | **Distobuccal Root** | | | **Palatal Root** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **No. of canals** | **No. of roots (n)** | **%** | **No. of canals** | **No. of roots (n)** | **%** | **No. of canals** | **No. sof roots (n)** | **%** |
| Coronal third | 1 | 66 | 33.3 | 1 | 184 | 92.9 | 1 | 195 | 98.5 |
| | 2 | 109 | 55.1 | 2 | 13 | 6.6 | 2 | 3 | 1.5 |
| | 3 | 21 | 10.6 | 3 | 1 | 0.5 | - | - | - |
| | 4 | 2 | 1.0 | - | - | - | - | - | - |
| Middle third | 1 | 96 | 48 | 1 | 192 | 97 | 1 | 197 | 99.5 |
| | 2 | 83 | 41.9 | 2 | 6 | 3 | 2 | 1 | 0.5 |
| | 3 | 17 | 8.6 | - | - | - | - | - | - |
| | 4 | 2 | 1.0 | - | - | - | - | - | - |
| Apical third | 1 | 111 | 56.1 | 1 | 188 | 94.9 | 1 | 196 | 99 |
| | 2 | 72 | 36.4 | 2 | 10 | 5.1 | 2 | 2 | 1 |
| | 3 | 14 | 7.1 | - | - | - | - | - | - |
| | 4 | 1 | 0.5 | - | - | - | - | - | - |
| Total number of teeth | 198 | | | | | | | | |

### 4.3. Number of Major Apical Foramina

The majority of the teeth examined had a single major apical foramen for all roots. The presence of two major apical foramina was as follows: 33.3%, 5.1%, and 1% in the mesiobuccal, distobuccal, and palatal roots respectively. Three major apical foramina were not observed in the distobuccal and palatal roots, while they were present at 7.6% in the mesiobuccal roots. When the number of major apical foramina was greater than three it was reported also, and found mostly in the mesiobuccal roots (6.1%) followed by distobuccal roots (1.5%) followed by the palatal roots (1%). Table 4.4 summarizes the results for the number of major apical foramina in each root.

**Table 4.4**. Distribuation of the number of major apical foramina in mesiobuccal, distobuccal, and palatal roots of the maxillary first molar tooth

| | **Mesiobuccal** | **Distobuccal** | **Palatal** |
|---|---|---|---|
| | **n (%)** | **n (%)** | **n (%)** |
| 1 foramen | 105 (53%) | 185 (93.4%) | 194 (98%) |
| 2 foramina | 66 (33.3%) | 10 (5.1%) | 2 (1%) |
| 3 foramina | 15 (7.6%) | - | - |
| More than three | 12 (6.1%) | 3 (1.5 %) | 2 (1%) |
| Total number of teeth | 198 | | |

### 4.4. Number of Root Canal Orifices

The results from the present study showed that one orifice is the frequent case for the canals in the distobuccal and palatal roots of the first maxillary molar teeth. The highest degree of diversity was observed in the mesiobuccal root in which one orifice 105 (53%) , two orifices 77 (38.9%), three orifices 15 (7.6%), and four orifices 1 (0.5%) were seen. 1% of the palatal root were presented with 2 orifices. However, the majority of the canals at the distobuccal roots had a single orifice, but 5.6% of the canals had two orifices and 0.5% had three orifices. Table 4.5 shows the number of canal orifices in each root.

**Table 4.5.** Distribuation of the number of canal orifices in mesiobuccal, distobuccal, and palatal roots of the maxillary first molar tooth

| | **Mesiobuccal** | **Distobuccal** | **Palatal** |
|---|---|---|---|
| | **n (%)** | **n (%)** | **n (%)** |
| 1 orifice | 105 (53%) | 186 (93.9%) | 196 (99%) |
| 2 orifice | 77 (38.9%) | 11 (5.6 %) | 2 (1%) |
| 3 orifice | 15 (7.6 %) | 1 (0.5%) | - |
| 4 orifice | 1 (0.5%) | - | - |
| Total number of teeth | 198 | | |

### 4.5. Merging and Splitting in Canals

The positions or levels where canals merged or diverged during its course in the roots were identified. In most of the samples, mergence was concentrated in the coronal third of the roots. The palatal roots had no canal mergence in the middle and apical thirds.

Regarding the divergence in the root canal system of the examined first maxillary molars, the coronal third of the mesiobuccal roots showed the highest proportion followed by the middle and then the apical third. Figure 4.1. explain the distribution of mergerence and divergence of root canals in the mesiobuccal root over each third. The distobuccal roots showed the highest canal divergence apically, while the palatal roots only had canal divergence in the coronal third. Table 4.6 and Table 4.7 summarize the presence of canal mergence and divergence in the three thirds for each root of the upper first molar teeth. Table 4.8 summarizes the frequency of merging and diverging canals during their course according to the root thirds in the mesiobuccal root. While the root canals most frequently merged or diverged in the coronal and middle thirds, the numbers of mergence and divergence in the apical third were significantly lower than coronal and middle thirds ($p < .05$). The number of divergence was significanlty greater than the number of mergence in the apical third ($p < .05$). No significant difference was detected between merging and diverging frequency in the coronal and middle thirds ($p > .05$).

**Table 4.6.** Presence of canal mergence in the coronal, middle and apical thirds of the maxillary first molar roots

| **Level of canal mergence** | **Coronal third** | | **Middle third** | | **Apical third** | |
|---|---|---|---|---|---|---|
| | **With merge** | **Without merge** | **With merge** | **Witout merge** | **With merge** | **Without merge** |
| Mesiobuccal Root **n (%)** | 60 (30.3%) | 138 (69.7%) | 50 (25.3%) | 148 (74.7%) | 11 (5.6%) | 187 (94.4%) |
| Distobuccal Root **n (%)** | 13 (6.6%) | 185 (93.4%) | 4 (2%) | 194 (98%) | 1 (0.5%) | 197 (99.5%) |
| Palatal Root **n (%)** | 1 (0.5%) | 197 (99.5%) | - | 198 (100%) | - | 198 (100%) |
| Total number of teeth | 198 | | | | | |

**Tabel 4.7.** The existence of canals divergence in the coronal, middle, and apical thirds of maxillary first molar

| **Level of canal splitting** | **Coronal third** | | **Middle third** | | **Apical third** | |
|---|---|---|---|---|---|---|
| | **With split** | **Without split** | **With split** | **Witout split** | **With split** | **Without split** |
| Mesiobuccal Root **n (%)** | 50 (25.3%) | 148 (74.7%) | 33 (16.7%) | 164 (82.8%) | 26 (13.1%) | 172 (86.9%) |
| Distobuccal Root **n (%)** | 2 (1%) | 196 (99%) | 6 (3%) | 192 (97%) | 8 (4%) | 190 (96%) |
| Palatal Root **n (%)** | 3 (1.5%) | 195 (98.5%) | - | 198 (100%) | - | 198 (100%) |
| Total number of teeth | 198 | | | | | |

**Table 4.8.** The number of divergence and mergence in the coronal, middle, and apical thirds out of the total number the mesiobuccal root of the maxillary first molar

| Root third | Mergence | Divergence | Chi-Square p value |
|---|---|---|---|
| **Coronal third** | 60/198 (30.3%) | 50/198 (25.3%) | .30 |
| **Middle third** | 50/198 (25.3%) | 33/198 (16.2%) | .06 |
| **Apical third** | 11/198 (5.6%)* | 26/198 (13.1%)* | **.01** |
| **Chi-Square p value** | **.000** | **.015** | |

*indicates statistically significant difference in the frequency of mergence and divergence among root canal thirds ($p < .05$)

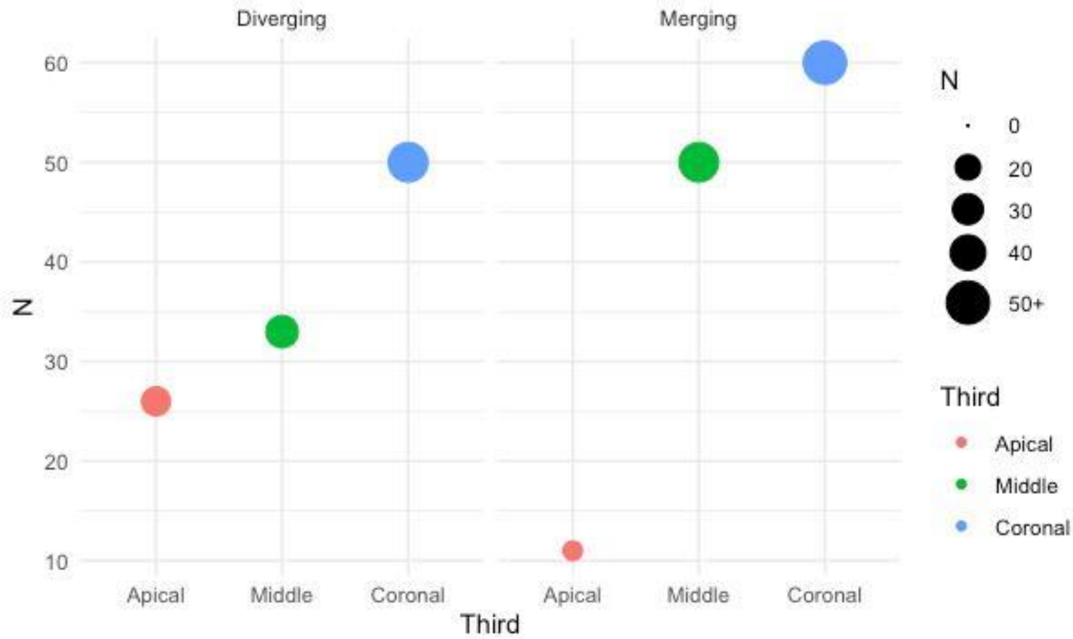


**Figure 4.1.** Distribution of mergerence and divergence of root canals in mesiobuccal root over each third


**Figure 4.2.** Type I (1-1)


**Figure 4.3.** Vertucci type I ends with apical delta Type I (1-1-delta)

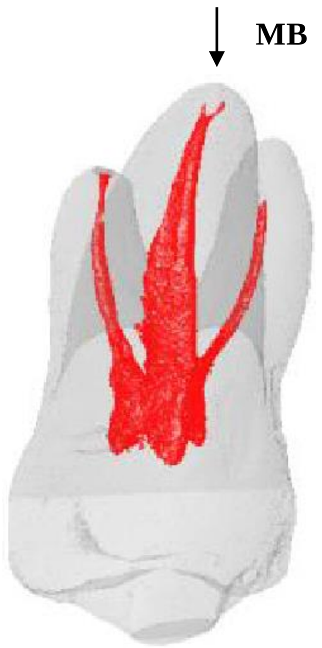


**Figure 4.4.** Type I (1-1)


**Figure 4.5.** Vertucci type I ends with apical delta Type I (1-1-delta)

**Figures 4.2.-4.37.** Examples of root canal configurations observed in mesiobuccal root of the first maxillary molar according to Vertucci and Gulabivala et al. classifications


**Figure 4.6.** Type II (2-1)


**Figure 4.7.** Vertucci type II ends with apical delta Type II (2-1-delta)

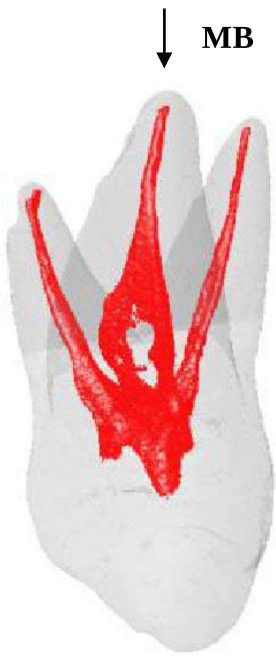


**Figure 4.8.** Type II (2-1)

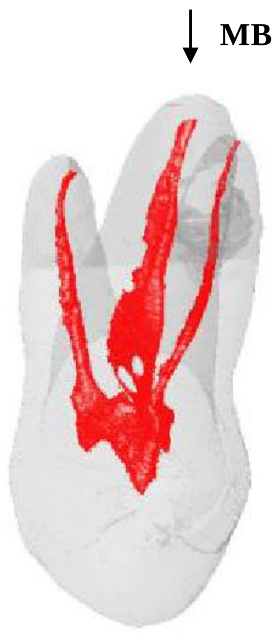


**Figure 4.9.** Type II (2-1)


**Figure 4.10.** Vertucci type III ends with apical delta Type III (1-2-1-delta)


**Figure 4.11.** Type III (1-2-1)


**Figure 4.12.** Type III (1-2-1)


**Figure 4.13.** Vertucci type III ends with apical delta Type III (1-2-1-delta)


**Figure 4.14.** Vertucci type IV ends with two apical deltas Type IV (2-2(2delta))


**Figure 4.15.** Type IV (2-2)


**Figure 4.16.** Type IV (2-2)

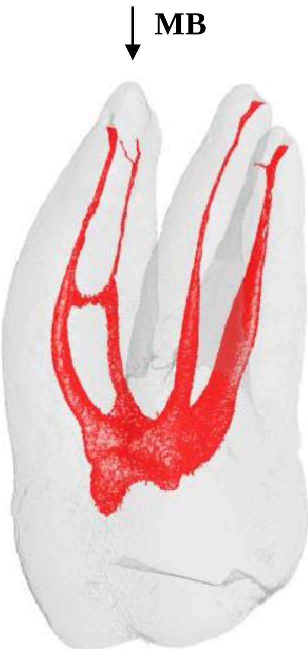


**Figure 4.17.** Type IV (2-2)


**Figure 4.18.** Vertucci type V ends with apical delta Type V (1-2(1delta))


**Figure 4.19.** Vertucci type V ends with one apical delta Type V (1-2(1delta))


**Figure 4.20.** Type V (1-2)


**Figure 4.21.** Type V (1-2)


**Figure 4.22.** Type VI (2-1-2)


**Figure 4.23.** Type VI (2-1-2)


**Figure 4.24.** Type VI (2-1-2)


**Figure 4.25.** Type VI (2-1-2(1delta))


**Figure 4.26.** Vertucci type VII
ends with apical delta
Type VII (1-2-1-2(1delta))


**Figure 4.27.** Type VII (1-2-1-2)


**Figure 4.28.** Type VII (1-2-1-2)

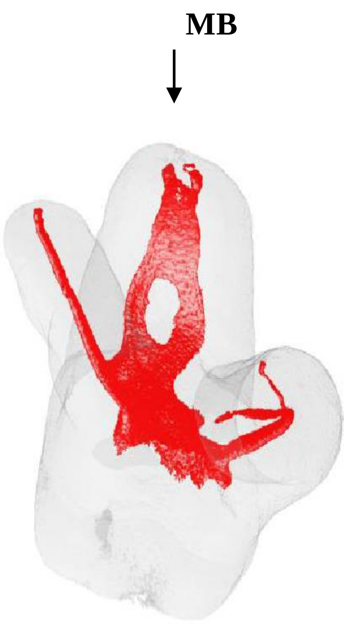


**Figure 4.29.** Type VII (1-2-1-2)


**Figure 4.30.** Type X (2-1-2-1)


**Figure 4.31.** Type X (2-1-2-1)


**Figure 4.32.** Type X (2-1-2-1)


**Figure 4.33.** Type XIII (2-3)


**Figure 4.34.** Type XIII (2-3)


**Figure 4.35.** Type XIII (2-3)


**Figure 4.36.** Type XII (3-2)


**Figure 4.37.** Type XII (3-2)


**Figure 4.38.** (2-1-3)


**Figure 4.39.** (2-1-2-3)


**Figure 4.40.** (2-3-2-3)


**Figure 4.41.** (3-1-2-1)

**Figures 4.38.-4.41.** Example of root canal configurations can't be classified by Vertucci nor Gulabivala et al. classification systems in mesiobuccal roots

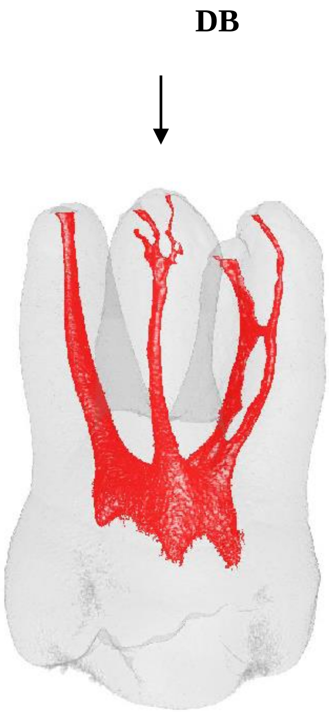


**Figure 4.42.** Vertucci Type I
ends with apical delta
Type 1 (1-1delta)


**Figure 4.43.** Type I (1-1)

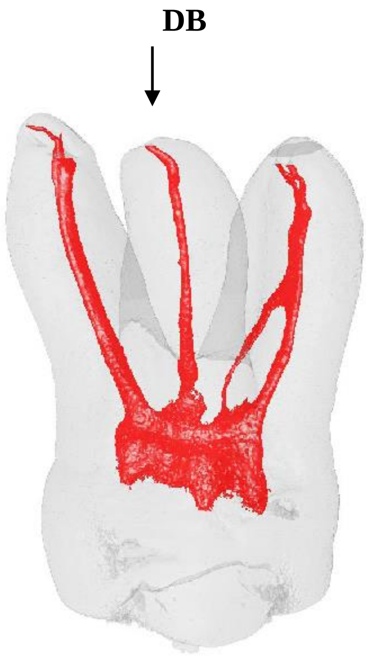


**Figure 4.44.** Type I (1-1)

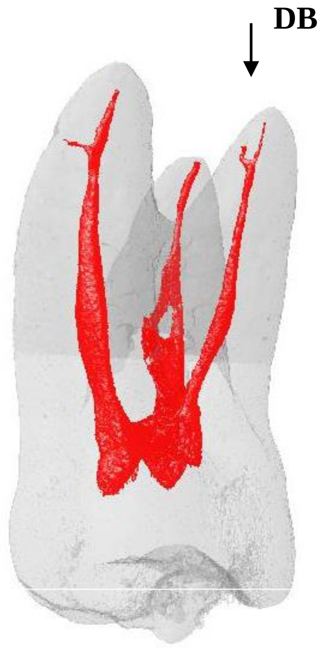


**Figure 4.45.** Type I (1-1)

**Figures 4.42.-4.57.** Example of root canal configurations observed in distobuccal root of the first maxillary molar according to Vertucci and Gulabivala et al. classifications

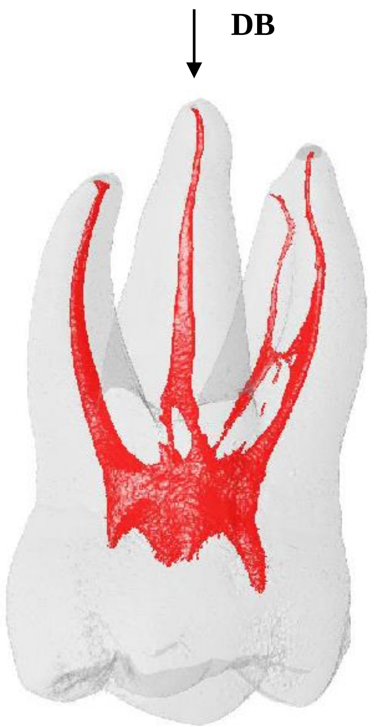


**Figure 4.46.** Type II (2-1)


**Figure 4.47.** Type II (2-1)


**Figure 4.48.** Type II (2-1)


**Figure 4.49.** Type II (2-1)


**Figure 4.50.** Type III (1-2-1)


**Figure 4.51.** Type V (1-2)

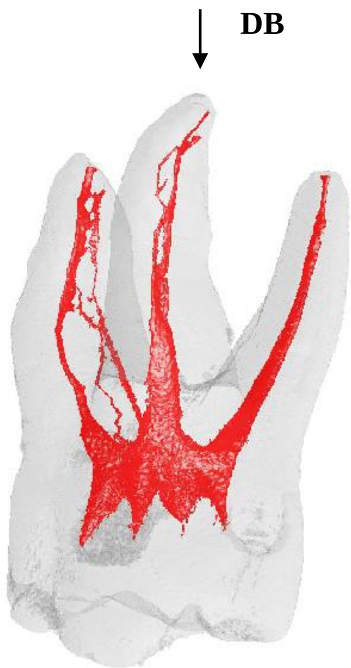


**Figure 4.52.** Type V (1-2)


**Figure 4.53.** Type V (1-2)

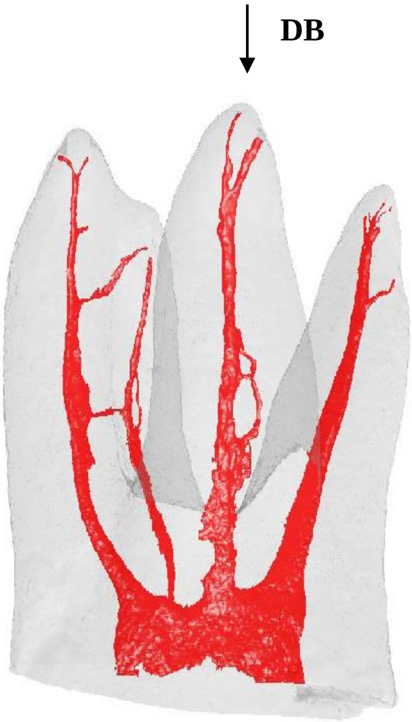


**Figure 4.54.** Type VII (1-2-1-2)


**Figure 4.55.** Type X (2-1-2-1-delta) ends with apical delta

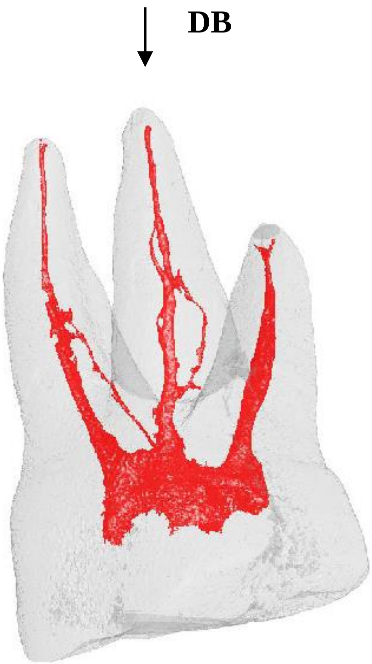


**Figure 4.56**. Configuration of root canal can’t be classified according to Vertucci nor Gulabivala in distobuccal root
(1-2-1-2-1)


**Figure 4.57.** Configuration of root canal can’t be classified according to Vertucci nor Gulabivala in distobuccal root
(3-1-2 (1delta))


**Figure 4.58**. Vertucci type I
ends with apical delta
Type I (1-1-delta)

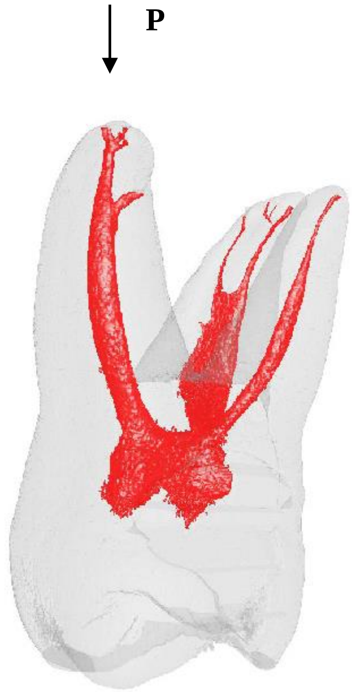


**Figure 4.59**. Vertucci type I
ends with apical delta
Type I (1-1-delta)


**Figure 4.60**. Type I (1-1)


**Figure 4.61**. Type I (1-1)

**Figures 4.58.- 4.64.** Examples of root canal configurations observed in palatal root of the first maxillary molar according to Vertucci's classification system


**Figure 4.62.** Type II (2-1)


**Figure 4.63.** Type V (1-2)


**Figure 4.64**. Type V (1-2)


**Figure 4.65**. An interesting palatal root canal system in which a second canal separates from the first root canal in the palatal root and continues towards the mesiobuccal root

## 5. DISCUSSION

One of the most important factors for a successful root canal treatment is a comprehensive knowledge of root anatomy and canal morphology. The diversity and complexity of root canal system can be a suitable harbor for microbial flora that are not easily accessible (Vertucci, 2005). Weine (2003) explained the fact that although the apical foramen is plugged well by a good sealed material, contact still exists between the root canal system and the periapical tissue. This gives the microorganisms the opportunity to disrupt the endodontic treatment and form a possible apical lesion if it remains within the canal. Multiple major apical foramina, apical deltas, multiple canals, multiple orifices, inter-canal communication, merging and splitting of canals during their pathway are examples of structures that add to the complexity of the canal system. This makes locating, accessing, cleaning shaping, and filling operations more difficult. In order to prevent tissue remnants, hard tissue debris and microorganisms accumulating in these hard-to-reach areas of the root canals from adversely affecting the success of the treatment, it is necessary to work with a magnifying tools, microscope, take advantage of internal canal medicaments with antibacterial properties, and use devices that provide better penetration and distribution for irrigation (Nair et al., 2005; Siqueira et al., 2013). Therefore, in order to perform a root canal treatment and achieve the desired result, it needs an up-to-date and knowledgeable clinician about root canal morphology and associated anatomical variations ( Cantatore et al., 2006; Vertucci, 2005).

In 1987, Burns described the permenant first maxillary molar teeth as "probably the most treated and least understood posterior teeth" (Burns, 1987). This tooth also shows different anatomical variations which, in turn, add to the complexity of the root and root canal system, thus increasing the difficulty during treatment (Vertucci et al., 2006).

Various methods have been used for investigating the root canal anatomy that include routine radiography, clearing technique, resin injection, histology, sectioning, scanning electron microscopy, and cone-beam computed tomography (Domark et al., 2013). The use of these techniques accompained by some challenges. Such as the destruction of the sample after its use, inability to use it again, giving a two dimensional images for a three dimensional objects, and not clarifying some anatomical details (Ordinola- Zapata et al., 2017). All these led to the need to use a new technology that overcomes these limitations.

From the early attempts to examine the first maxillary molar from an anatomical point of view was the study conducted by Barrett (1925). When he studied 32 teeth using the sectioning technique, and determined that the dominance was for teeth with 3 roots (90.60%) and (6.30%) with two roots. This was followed by two studies in which the clearing technique was used to examine the number of canals in the three roots of the first maxillary molar teeth. Hess (1925) after examining 513 samples, showed that the examined mesiobuccal roots contained 46.4% single canal and 53.6% had more than one canal, while 100% single canal was observed in the distobuccal and palatal roots. The other study conducted by Zürcher (1925) when examining 40 teeth, and stated that the mesiobuccal roots contained 57% single canal and 42.5% multiple canals, while the single canal system was the only system observed in the distobuccal and palatal roots. Studies and research continued after that, up to the present day, in a trial to overcome all the obstacles and challenges that were mentioned previously.

Micro CT imaging technology is a 3D imaging technique that appeared later and is considered as the most accurate method for revealing the actual internal root canal anatomy (Marceliano- Alves et al., 2019; Wolf et al., 2017). Micro term is derived from the the pixel size of the cross sectional images provided by this device which is in the micrometer unit. The areas that can be seen with this technique can be 1.000.000 times smaller than those that can be seen with the CT technology. This is due to the better spatial resolution that attained (5–10 µm3) voxel size scan, compared to 1 mm3 voxel size scan provided by CT. All that supports the ability of this technique to be useful in the study of fine details (Feldkamp et al., 1989; Kuhn et al., 1990).

″FOV‶ is another term which indicates the ability of choosing different fields of views with the micro CT according to the dimensions of the examined area. That makes it very utilized in many fields with obtaining a high resolution images (Guldberg et al., 2004).

To get the final appearance of a 3D image, several stages must pass through the main components of the micro CT device that include the X-ray source, a motor that intermittently spins the attached sample above it, an image intensifier that exposes the beams on the camera sensor, the CCD camera that translate the received X-rays into a form of image data, the image collector, and a computer that organizes the work of all these parts (Feldkamp et al., 1989; Kuhn et al., 1990).

The high-resolution images gained from the micro CT technique give the researcher an opportunity to make qualitative and quantitative measurements for the root canal system without destroying the samples (Marceliano- Alves et al., 2019; Nielsen et al., 1995).

Despite all the advantages of this technology, researchers may suffer from some challenges, such as the high costs of the device and software used, the long time spent during scanning and reconstruction processes, and the inability to use it for in vivo studies (Park et al., 2009).

In the present study, based on the aforementioned, the micro CT technique was used to investigate the morphology of the root canal system of 198 extracted first maxillary molars collected from the Turkish population.

### 5.1. Root Canal Morphology

Over time, the study of the root canal morphology has taken a wide area in the literature. Studies on this subject differ according to the technique used, the teeth examined, the standards adopted and the race where the samples were taken.

For the Turkish population, several studies concerned with evaluating root canal morphology in different teeth have been carried out. Some of these studies; Ok et al. (2014), Bulut et al. (2015), Demirbuga et al. (2013) , Nur et al. (2014), Celikten et al. (2016), Miloglu et al. (2013), Altunsoy et al (2015) that used the CBCT technique for the study of the root canal morphology in premolars, mandibular molars, anterior teeth of the maxilla and mandible, respectively. Sert et al. (2004b) depended on the use of clearing technique for studying the root canal morphology of the mandibular permanent teeth. Kartal et al. (1998) also used the clearing technique for discussed the root canal morphology of the maxillary premolars. While, Keleş and Keskin (2017) adopted the same technique used in our current study (micro CT) to examine the root canal morphology of the mesial roots of the mandibular first molar teeth within the apical portion of it.

The anatomy of root canals is diverse and complex. Accordingly, a classification system is needed to organize it. The first attempt was made by Weine et al. (1969) when they divided the canal shapes into four types according to their path, starting from the pulp chamber and ending with the root apex. Subsequently, a more sophisticated classification system was take placed based on the efforts of Vettucci (1974) in his study of 200 upper second premolars using a clearing technique. As a result, eight types of canal configuration have been described.

Efforts continued to develop the system of classifiying the root canals. An additional seven types of canal configuration were added to the Vertucci classification system by Gulabivala et al. (2001). In their study, 331 mandibular molars were collected from Burmese residents using a clearing technique.

Ahmed et al. (2016) developed a new classification system that can define both the canal configurations and the roots. Codes include characterizing the tooth number, root number and their configuration, and root canal configuration. Ahmet et al. system's is a proposed coding system to describe each tooth individually, but it is difficult to use for classify into groups.

Weine et al. (1969) while examining the morphology of the root canal in the mesiobuccal root of the first maxillary tooth as the specimen contained 208 extracted teeth, they found that the classifications of the canal configurations were 48.5% type I, 37.5% type II and 14.0% type III. Vertucci (2005) discussed the mesiobuccal root for 100 teeth, and the most common canal configurations were found to be 45% type I, 37% type II and 18% type IV. The present study determined the canal configurations of the mesiobuccal root of the first maxillary molar as 23.2% type I, 15.7% type II, 10.6% type III, 10.1% type V, 8.1% type IV, 6.1% type VI, 4.5% type VII, 2% type XIII, 1% type IX, 1% type X, and 1% type XII respectively. This demonstrates the consistency of our study with the two previous studies in that the most common canal configurations in the mesiobuccal root of the first maxillary molars are type 1 and type II respectively.

Two studies have been conducted investigating the root canal configuration of the mesiobuccal root of the first maxillary molars in the Turkish population using the clearing technique. Sert et al. reported that type II, type I, type IV and type III, respectively, were the most common canal configurations (Sert et al., 2011). Çalışkan et al. observed types II, I, IV, VI, V, respectively (Çalişkan et al., 1995). In another study conducted by Altunsoy et al. (2015) using the CBCT technique among the Southeast Turkish population, it was noted that the root canal of the mesiobuccal roots in the maxillary first molars had a high tendency to take the configuration of type II. The differences between the results of previous studies and the results of our study can be attributed to differences in the technique used, number of teeth collected or the population groups from which teeth are collected.

This study revealed that the mesiobuccal root is the most versatile root in the types of canal configuration that exist, which adding to the complexity of the root canal system. Palatal root is the least root in terms of types of canal classifications, while the distobuccal root has been observed to have six classifications of the canal's configuration. Briseño-Marroquín et al. (2015) in a micro CT study examining 179 maxillary first molars teeth reported results similar to ours. Thomas et al. (1993) also matches the same results.

The prevelance of types II, III, IV, V,VI, VII according to Vertucci classification with percentage of 55.1% and types IX, X, XII, XIII as classified by Gulabivala with percentage of 5% in the mesiobuccal roots, reflects the high probability of encountering two or more canals during the application of endodontics treameant for the mesiobuccal roots of the maxillary first molars. This result is in harmony with several studies in this field (Lee et al., 2011; Kartal et al., 1998; Vandenberghe et al., 2010; Hammad et al., 2009; Park et al., 2009; Sert et al., 2011; Altunsoy et al., 2015). Cleghorn et al. (2006) after reviewing 34 studies concerning the anatomy of the mesiobuccal root of the upper first molars, showed that 57% of the mesiobuccal roots have more than one canal which is in line with the findings of our study.

Vertucci type I is the dominant canal configuration of the canal in the palatal and distobuccal roots, a common finding in many studies and ours as well (Briseño-Marroquín et al., 2015; Cleghorn et al. (2006); Kim et al., 2012; Marceliano-Alves et al., 2016; Neelakantan et al., 2010; Thomas et al., 1993).

### 5.2. Number of Major Apical Foramina

A precise knowledge of the anatomy of the apical region of the root has an important influence on the prognosis of endodontic therapy. One of the reasons for its importance is its contribution to the ability to accurately determine the working length, which is one of the foundations of all applied steps in endodontic treatment (Morfis et al., 1994). Cleaning and shaping is one of these steps that creates an apical stop for the subsequent obturation process. Previously, opinions tended to end the steps of canal treatment at the point of apical constriction. However, according to some studies, this constriction may not be present (Coolidge, 1929; Simon, 1994), so the major apical foramen may be a more beneficial and important term (Wu et al., 2000). Which can be defined as the most apical opening of the root canal with greater diameter (Gutmann and Leonard, 1995). Therefore the present study highlight on the number of major apical foramina.

Hess and Zurcher were proactive in their research efforts in assessing the complexity of the anatomy of the root canal system, stating that the general rule is to anticipate difficulty rather than simplicity in the root canal system during its course. A single tapered canal that ends in a single hole is not the dominant image of the root canal system (Hess and Zurcher, 1925). Later, other studies shed light on many examples that agree and confirm the validity of this theory, such as the presence of more than one foramen, additional canals, delta, isthmus and other variations.

The greater the number of major foramen, the more complex the shape of the apical system of the root and canal system, which may adversely affect endodontic treatments (Morfis et al., 1994).

Cleghorn et al. (2006) concluded in a literature review for previous studies on the morphology of root and root canal systems in the first molar of the maxilla, that the canal system in the mesiobuccal root tends to end with a single major foramen even if there are two canal systems. Then Briseño-Marroquín et al. (2015) in a micro CT study for evaluating the configuration and the morphology of the root canal in the maxillary first molar teeth, it was found that the predominant form of the root canal system in the mesiobuccal roots was Vertucci type 1 accompained with single major foramen. In 2018, Tomaszewska et al. (2018) through a micro CT study and a meta analysis investigating the anatomy of the upper molars, it was reported that the appearance of a single apical foramen in the mesiobuccal root of the first upper molars was 55.1%. Our study matches these results as the percentage of single major foramen in the mesiobuccal roots was 53%. This also confirms our results on the most common root canal configurations found in the mesiobuccal root (Vertucci types I (1-1) and II (2-1)).

On the other hand, the mesiobuccal roots of the teeth examined in this study showed a 47% probability of having more than one major foramen (two major foramina 33.3%, three major foramina 7.6% and more than three 6.1%), which corresponds to Morfis's et al. study (1994) about apices of human permanent teeth.

It has been discussed in the literature that the incidence of having a single major foramen in the distobuccal and palatal roots of the upper first molars is high (Cleghorn et al., 2006). Morphis et al. (1994) approved the same result. This study showed similar findings from previous studies with a single major foramen in 93.4% and 98% of the distobuccal and palatal roots, respectively. On the other hand, the presence of two major foramina in the distobuccal and palatal roots was 5.1% and 1%, respectively. While three major foramina were not seen in the distobuccal and palatal roots, more than three were observed in the distobuccal and palatal roots ranging between 1.5% and 1%, respectively.

### 5.3. Number of Root Canal Orifices

In order to increase the success rate of endodontically treated teeth, it is necessary to know, identify and find all the root canal orifices in the pulp chamber (Krasner et al., 2010). It has been demonstrated that the root canal system is a variable structure and does not exhibit a single form which makes the determination of the number of canal orifices and complete examination of the pulpal floor necessary (Beatty and Interian, 1985).

Previous researches have recommended multiple approaches both at the clinical application level or at the scientific research level, to aid in examining the pulp cavity and identifying the root canal orifices such as; dental operating microscopy, selective dentin removal, CBCT, and microcomputed tomography techniques. For example, De Carvalho and Zuolo (2000) evaluated the effectiveness of using dental operating microscope in identifying root canal orifices in the examined teeth, and reported an increase in the number of root canal orifices accompanied by the use of a microscope compared to the naked eye. Manigandan et al. (2020) in a study of the upper molars, they discussed the application of selective dentin removal with the help of a dental operating microscope, followed by further investigation using CBCT technique improves the identification of root canal orifices. While Dowker et al. (1997), Bjørndal et al. (1999), and Peters et al. (2001) studied the pulp cavity using micro CT.

In the literature, the issue of the number of orifices of the root canal in the first maxillary molar has been adressed in a number of studies, especially the studies concerned with the mesiobuccal root.

Verma and Love (2011) and Dos Santos et al. (2020) were used the same technique used in our study during evaluating the morphology of the mesiobuccal root canal in the first maxillary molars. In the present study, while the mesiobuccal root canal was seen with one orifice (53%), the possibility of seeing more than one orifice was also high; two orifices (38.9%), three orifices (7,6%) and four orifices (0.5%) were seen. Verma and Love (2011) documented the existence of three possibilities for the number of canal orifices with 40% one orifice, 50% two orifices, 10% three orifices. Whereas, in the study carried out by Dos Santos et al. (2020), the highest percentage was the presence of one orifice, followed by the ratio of two orifices which matching our study.

Some studies differed with our study in the results (Seidberg et al., 1973; Thomas et al., 1993), this may be due to the difference in gender, age, and race from the sample taken or even the diffrerence in the method used in the study.

1% of the palatal root were presented with 2 orifices. 5.6% of the canals in the distobuccal root had two orifices, 0.5% had three orifices.

### 5.4. Merging and Splitting in Canals

Identifying the influences that increase the morphological complexity of the root canal system, improve the outcome of the endodontic treatment process and reduce the range of errors or problems that may be encountered by the clinician during treatment. And since the the percentage and location of the merging or splitting in the root canals affect the complexity of the root canal morphology. Therefore, it is necessary and important to know the method of distributing the mergence or divergence in the root canals along the canal pathway (Martins et al., 2017).

Failure to perceive the splitting of canal in the apical third, if present, may be one of the reasons for the inability to obtain the desired results from endodontic treatment and the formation of a periapical lesion later on. While the sudden splitting in the canal that may ocur in the middle third may be an important factor for the instrument breakage inside the canal due to the increase in the instrument′s stress (Günday et al., 2005; Pruett et al., 1997). However, divergence or canal splitting may be considered to be the simplest if it occurs at the coronal third of the canal, as it can be easily noticeable and therefore easier in terms of applying the treatment.

The literature is not very rich in information regarding the topic of merging and splitting in the root canals and its location during the canal pathway in the first maxillary molars. A previous studies of Zhang et al. (2014), Martins et al. (2016), and Mashyakhy et al. (2019) were dealt with a topic of the mergence of the root canals in the maxillary molars but with fused roots. In 2017, Martin et al. reported the first study concerned with the sites and distribuation of merging and splitting in the root canal in non-fused roots, among the Caucasian population using CBCT technique. In that study, it was shown that the merging occupies a larger area than the split in the root canals of the first maxillary molar teeth, and their distribution is concentrated in the middle third of the canals (Martins et al., 2017).

The current study is the first to investigate the level of merging and splitting of root canals during of its passage inside the roots among the Turkish population. The results showed that the highest incidence in the merging distribution was in the mesiobuccal roots as it was 30.3% in the coronal third, 25.3% in the middle third and 5.6% in the apical third. It is followed by the distbuccal roots in which the merging was found as follows: 6.6%, 2%, 0.5%, respectively, in coronal, middle, and apical thirds. The least rate of merging was observed in the palatal root. The sites of splitting in the root canal differed in distribution from the merging pattern. Although it was observed that mergence and splitting could be seen at any level of the root canal in the mesiobuccal and distobuccal roots, in the palatal root, mergence and divergence were seen only in the coronal third of the root canal. The results of the present study showed also that diverging canals were significantly more frequent than the merging canals in the apical third of the mesiobuccal root which increases the complexity of the root canal system.

### 5.5. Number of Canals

The first molar in the upper jaw generally has three roots and can have three or more root canals distributed over them (Walton and Torabinejad, 1996). It is also one of the most complex teeth in terms of the internal root canal system and anatomical features. Especially the mesiobuccal roots which have been emphasized in a wide range of studies (Cleghorn et al., 2006).

Any root that has two or more root canals has the ability to contain contact between the canals which may act as a reservoir for bacteria due to the retention of the pulp or tissues derived from the pulp (Vertucci, 2005). This increases the complexity of the root canal anatomical system and challenges during the treatment process.

In the current study, the number of canals in each root of the first upper molar tooth was examined over the three parts of the root; coronal, middle and apical. This aids in understanding and expecting the difficulty of the root canal system during its course and assisting the clinician in developing the treatment plan for surgical or non surgical procedures. In addition, it reduces the possibility of missing any canal along the root canal pathway and at all root levels.

In literature studies that focused on studying the morphology of the root canal of the first upper molar by dividing each root into three sections and discussing the canals and their number in each section are limited. Briseño-Marroquín et al. (2015) examined the root canal morphology of the first upper molars using micro CT technology. Their study divided each root of the first upper molar into thirds and described configuration and number of canals using 4 numbers. The first three digits show the number of canals in the coronal level of the three sections of each root, while the fourth digit reflects the number of major foramina. Our study agrees with the results of this study in terms of that the single canal was the predominant case in the coronal, middle and apical third of the distobuccal and palatal roots. The probability of having two canals in the coronal third of the mesiobuccal root was higher in our study with 55.1%, while Marroquin et al. reported it as 42.5%. Although there is a difference in the availability of two canals in the coronal section of the mesiobuccal root compared to the Marroquin et al.'s study, it is similar to the results obtained by Vertucci (1984) as 55% and Weine et al. (1969) as 51.5%.

Availability of more than one canal in the middle and apical sections due to canal division may require greater precision during endodontic treatment (Vertucci, 1984). The present study showed that the mesiobuccal root contains the largest number of canals in all three sections of the root compared to other roots of maxillary first molar, ranging from one to four canals. The apical third of the examined mesiobuccal roots, showed the presence of two canals at a rate of 36.4%, which corresponds to the study of Briseño-Marroquín et al. (2015) as 33.6%, and higher than that indicated by Vertucci in his study of 18% (Vertucci, 1984) . The palatal roots showed the possibility of having two canals in the coronal, middle, and apical thirds as (1.5%, 0.5%, 1%), respectively. The distobuccal root showed higher rates with a 3% opportunity of having two canals in the middle section and 5.1% of having two canals in the apical third.

# 6. CONCLUSION AND RECOMMENDATIONS

Within the limits of this study, which one hundred ninty eight human permanent maxillary first teeth were examined using micro CT technology for evaluating the morphology of the root canals system, the following results were obtained:

- The necessity to search for the third orifice of the root canal in the mesiobuccal root during the application of root canal treatment in the Turkish population as the probability of its presence is 7.6% , and the probability of a third canal is about 10.6% in the coronal third of the root, 8.6% in the middle third and 7.1% in the apical third.
- With the predominance of the first and second Vertucci types, the mesiobuccal root of the first maxillary molar is the most variable in terms of root canal configuration.
- The distobuccal root includes six types of canal configuration, and the palatal root is the least diverse in the canal's configuration.
- Vertucci type I is the most common canal configuration in the palatal and distobuccal roots.
- The splitting in the root canal is greater than the merging in the apical third of the mesiobuccal roots of the first maxillary molar, which increases the complexity of the root canal morphology in such teeth.
- Palatal root had the most uncomplicated root canal morphology between all the roots of the first upper molar, as splitting in the root canal was found in the coronal third with a low rate of 1.5%, no merging was observed in the middle and apical thirds, majority of one major apical foramen.
- Since the presence of the second canal was 6.6%, 3%, 5.1% in the coronal, middle, and apical thirds respectively of the distobuccal roots. And observed also in the examined palatal roots, It should not be forgotten that multiplicity of root canals is not limited to the mesiobuccal roots of the first maxillary molars, but can also be encountered in the distobuccal and palatal roots along the root canal pathway.
- In the 198 examined samples, apical delta was observed in all roots of the first upper molar with a higher incidence in the mesiobuccal root compared to the distobuccal and palatal root. This should be taken into account while planning

a non-surgical endodontic treatment or surgical endotontic treatment such as the apical section of the root end.

- More studies are needed to evaluate precisely the root canal system of the maxillary molars in Turkish population.

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T.C.
**ONDOKUZ MAYIS ÜNİVERSİTESİ**
**KLİNİK ARAŞTIRMALAR ETİK KURULU KARARLARI**

| TOPLANTI SAYISI | KARAR SAYISI | KARAR TARİHİ |
| --- | --- | --- |
| 49 | 2015/403-426-(2015-330) | 19.11.2015 |

Klinik Araştırmalar Etik Kurulu 19.11.2015 tarihinde Prof.Dr Dursun AYGÜN Başkanlığında toplandı

Prof.Dr Dursun AYGÜN
Başkan

Prof.Dr.Hulusi ATMACA
Üye
Toplantıya Katılmadı

Doç.Dr.Ayhan SÖĞÜT
Üye

Prof.Dr.Cafer POLAT
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Doç.Dr. Aydın HİM
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Prof. Dr.Sevgi CANBAZ
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ONDOKUZ MAYIS ÜNİVERSİTESİ

KLİNİK ARAŞTIRMALAR ETİK KURULU

Sayı: B.30.2.ODM.0.20.08/2065 20.11.2015

Sayın Doç. Dr. Ali Keleş

Etik Kurulumuza sunmuş olduğunuz **Kök Kanal Konfigürasyonunun Belirlenmesinde Endoskop ve Mikro Bilgisayarlı Tomografi Kullanımının Karşılaştırmalı Değerlendirilmes**başlıklı OMÜ KAEK 2015/ 408 Karar nolu Radyoloji çalışması nitelikli araştırma projeniz amaç, gerekçe, yaklaşım ve yöntemle ilgili açıklamaları, Klinik Araştırmalar Etik kurulu yönergesine göre 19.11.2015 tarihli Etik Kurulumuzda incelenmiş etik açıdan uygun bulunmuştur. Ancak araştırma bütçesinin maddi desteği henüz sağlanamadığından projeye bütçe desteği sağlanıp, tarafımıza bildirilmesinden sonra başlanmasına oy birliği ile karar verilmiştir.

Bilgilerinize arz/rica ederim.

Prof.Dr.Dursun AYGÜN

Klinik Araştırmalar Etik Kurulu Başkanı

## CURRICULUM VITAE

Fotoğraf

Rawan A.A ALQAWASMI, was born in Hebron. After finishing high school from Wedad Naser Idden's school, graduated from the Faculty of dentistry from Arab American University in 2010. She worked in her clinic in Palestine since her graduation until 2013, then worked in Ram Dental Clinics in Saudi Arabia as a general dentist from 2013-2015. She speaks and writes English excellently.

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### Published Articles:

**1.** Evaluation of dentine thickness of middle mesial canals of mandibular molars prepared with rotary instruments: a micro-CT study, Int Endod J.

**2.** Micro-computed tomographic analysis of the mesial root of mandibular first molars with bifid apex, Archives of Oral Biology. 2020, 117: 104792.

**3.** Accuracy of an endoscope to detect root canal anastomoses in mandibular molar teeth: a comparative study with micro-computed tomography, Acta Odontologica Scandinavica. 2020, 78.6: 433-437.

**4.** Diagnostic accuracy of endoscopy for the detection of isthmuses of mandibular molar teeth using micro-CT as reference, Eur Oral Res. 2021;55(1):34-38.

### Awards, Incentives and Scholarships Earned

**1**. Since 07/05/2018 until 30/09/2019 worked with a scholar with TUBITAK in the project numbered '117S139'.

**2.** Since 15/10/2019 until now worked with a scholar with TUBITAK in the project numbered '119S119'.