

T.C.
YEDİTEPE UNIVERSITY
INSTITUTE OF HEALTH SCIENCES
DEPARTMENT OF PEDIATRIC DENTISTRY

**COMPARISON OF OBTURATION QUALITY OF
DIFFERENT ROOT CANAL FILLING MATERIALS
AVAILABLE FOR USE IN RETAINED PRIMARY
MOLARS: AN *IN VITRO* STUDY**

DOCTOR OF PHILOSOPHY THESIS

Ekin ÖZDEMİR, DENTIST

Istanbul-2025

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Istanbul-2025

THESIS APPROVAL FORM

Institute : Yeditepe University Institute of Health Sciences

Programme : Paediatric Dentistry

Title of the Thesis : Comparison of Obturation Quality of Different Root Canal Filling Materials Available for Use in Retained Primary Molars: An *in Vitro* Study

Owner of the Thesis : Ekin ÖZDEMİR

Examination Date : 08.07.2025

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This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated and numbered

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.



Ekin ÖZDEMİR

ACKNOWLEDGEMENTS

Çocuk diş hekimliğine adım atmama vesile olan hem klinik hem akademik bilgi ve tecrübelerini hayranlıkla örnek aldığım, bana yol gösteren değerli hocam Yeditepe Üniversitesi Diş Hekimliği Fakültesi Çocuk Diş Hekimliği Anabilim Dalı Başkanı ve aynı zamanda tez hocam olan Sayın **Prof. Dr. Senem SELVİ KUVVETLİ**'ye, en içten teşekkürlerimi sunarım.

Doktora eğitimim ve tez çalışmam süresince bilgi ve deneyimlerini güler yüzleri eksik olmadan bana aktaran, tüm sorularımı sabırla cevaplayan tez izleme komitesi üyesi olan çok değerli hocalarım Yeditepe Üniversitesi Diş Hekimliği Fakültesi Endodonti Anabilim Dalı öğretim üyesi **Prof. Dr. Meriç KARAPINAR KAZANDAĞ** ve İstanbul Üniversitesi Diş Hekimliği Fakültesi Pedodonti Anabilim Dalı öğretim üyesi **Prof.Dr. Elif Bahar TUNA İNCE** bu süreçte moral kaynağı oldular.

Mesleki kariyeri ve teorik bilgisi ile bana yol gösteren, sevgisiyle içimi ısıtan, Yeditepe Üniversitesi Diş Hekimliği Fakültesi Dekan Yardımcısı ve Çocuk Diş Hekimliği Anabilim Dalı öğretim üyesi sayın hocam **Prof.Dr. Elif SUNGURTEKİN EKÇİ** her sorunumda deneyimleri ve birikimiyle çözüm yolu buldu.

Öğrencisine sahip çıkan ve desteğini arkamızda hissettiren sevgili hocam **Prof.Dr. Didem ÖZDEMİR ÖZENEN**'e teşekkür ederim.

Çocuk Diş Hekimliğindeki gelişmeleri yakından takip etmemi sağlayan, bilgi ve yardımlarını hiçbir zaman esirgemeyen, desteklerini her zaman hissettiğim, anabilim dalımızın değerli öğretim üyeleri **Doç. Dr. Zerrin HATİPOĞLU, Dr. Öğr. Üyesi Gökçen Deniz BAYRAK ARSLANTAŞ, Dr. Öğr. Üyesi Elif YAMAN DOSDOĞRU, Dr. Feyza Nur GÖRKEN** bu süreçte hep yanımda oldular.

Doktora eğitimim sırasında tanışma şansına sahip olduğum, bilgisi ve sevgisi ile bu süreci destekleyen sevili hocam **Dr. Öğr. Üyesi Derya TABAKÇILAR**'a, arkadaşlığı ve samimiyeti için ayrıca teşekkür ederim.

Doktora tez çalışmamın Micro-CT görüntüleme ve analizi sürecinde bana olanak sağlayan, Ankara Üniversitesi Diş Hekimliği Fakültesi, Temel Tıp Bilimler Bölümü,

Anabilim Dalı öğretim üyesi **Dr.Öğr. Üys. Mert OCAK** hocam’a ölçümlemlerimi yapıp bu araştırmayı tamamlama katkısından dolayı teşekkür ederim.

Aramızdan melek olup ayrılan hocamız **Dr. Öğr. Üyesi Kübra ALTIN TONGUÇ**’u rahmetle anıyorum.

Çocuk diş hekimliği doktora eğitimimiz süresince güzel ve zor günleri paylaştığımız, birlikte gülüp birlikte ağladığımız, sevgili meslektaşlarım başta **Dr. Öğr. Üyesi Ayşe ÇELİK**, **Dr. Pırıl KIRMIZI**, **Dr. Reyhan GÜVEN**, **Dr. İpek Şimbil SAYGILI**, **Dr. Öğr. Üyesi İpek YÖREL**, **Dr. Öğr. Üyesi Ayşe Sultan AGİN**, **Dt. Ecem YILMAZ**, **Dr. Gülfem ÇAVUŞOĞLU ÇARPAR**, **Dr. Burcu AKSOY ÖZGÜVEN**, **Dr. Melis ÜNSAL ÇALIŞKANER**, **Dt. Melisa ALBAYRAK** ve **Dt. Berkay AKAY** olmak üzere tüm takım arkadaşlarıma hayat boyu başarılar dilerim.

Hem insan olarak hem de meslektaş olarak kendime örnek aldığım sevgili arkadaşım **Dt. Hülya SERÜK**’e tüm desteği için teşekkür ederim.

Tüm meslek yıllarımda iyi ki var dediğim **Uzm. Dt. Mine HELVACIOĞLU** beni bu süreçte de yalnız bırakmadığı için kendisine teşekkür ederim.

Bana her zaman destek olan, yuva olan sevgili teyzem **Prof. Dr. Ayça KURTOĞLU** olmasaydı tüm bu süreç yaşanamazdı. Doğru ve dürüst olmayı ilke edinmiş güçlü karakteri benim yolumu aydınlattı. Duyarlı ve uygar bakış açısı hayatıma değer kattı.

Onlarsız başlamamın devam etmemin mümkün olmadığı canım annem **Ayşe ÖZDEMİR** ve canım babam **Gürel ÖZDEMİR**’e ne kadar teşekkür etsem azdır.

Varlığından güç aldığım sevgili **Dr. Burak SAYDAM**’a yanımda olduğu için tüm kalbimle teşekkür ederim.

Bana aile olan **Dr. Ata SAYDAM** ve **İbrahim SAYDAM**’a, adını sayamadığım tüm değerli dostlarıma katkılarından dolayı teşekkür ederim.

Son olarak bilime değer vermeyi bize öğreten atamız **MUSTAFA KEMAL ATATÜRK**’e, teşekkürü bir borç bilirim.

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LIST OF ABBREVIATIONS

MTA	: Mineral Trioxide Aggregate
CT	: Computed Tomography
H0	: The null hypothesis
H1	: The alternative hypothesis
CI	: Confidence Interval
cGy	: Centigray
MSX1	: Muscle Segment Homeobox 1
PAX9	: Paired box gene 9
Axin2	: Axis inhibition protein 2
EDA	: Ectodysplasin A
Pitx2	: Paired-like Homeodomain Transcription Factor 2
ADAMTS2	: A disintegrin and metalloproteinase with thrombospondin motifs 2
NEMO	: NF-kappa-B essential modulator
TP63	: Tumour protein 63
Irf6	: Interferon regulatory factor 6
TGFB3	: Transforming growth factor beta 3
OTX2	: Orthodenticle homeobox 2
PLCD3	: Phospholipase C delta 3
MYT1	: Myelin transcription factor 1
CR	: Composite resin
Ni-Ti	: Nickel-Titanium

PTC	: Peroxide Tween Carbowax
AAPD	: American Association of Paediatric Dentistry
CHX	: Chlorhexidine
ZOE	: Zinc Oxide Eugenol
GI	: Glass Ionomer
MTA	: Mineral Trioxide Aggregate
ISO	: International Organization for Standardization
GP	: Gutta-percha
CLC	: Cold Lateral Condensation
WVC	: Warm Vertical Compaction
SEM	: Scanning Electron Microscopy
CT	: Computed Tomography
LAC	: Linear Attenuation Coefficient
CCD	: Charge-Coupled Device
M	: Magnification
HU	: Hounsfield Unit
RPM	: Rounds Per Minute
Ncm	: Newton centimetres
CEJ	: Cemento Enamel Junction
ROI	: Region of Interest
SD	: Standard Deviation
CEM	: Calcium Enriched Mixture

ABSTRACT

Özdemir E. 2025. Comparison of Obturation Quality of Different Root Canal Filling Materials Available for Use in Retained Primary Molars: An *In Vitro* Study. Yeditepe University, Institute of Health Sciences, Department of Pediatric Dentistry, PhD Thesis, Istanbul.

The purpose of this study was to evaluate and compare the obturation quality of three different root canal filling materials suitable for use in retained primary molars with missing permanent successors, using micro-computed tomography (micro-CT).

A total of 15 extracted human primary molars were selected and randomly divided into three groups (n=5 each): Group 1—ProRoot MTA (Dentsply®), Group 2—NeoSealer Flo (Avalon Biomed, USA) with gutta-percha (Diadent, Korea), and Group 3 (control)—AH Plus (Dentsply®) with gutta-percha. Root canal preparation was performed, followed by pre-obturation micro-CT scans (SkyScan 1275, Bruker micro-CT, Belgium). After obturation according to the assigned materials, post-obturation scans were performed. The parameters evaluated included filling percentage, total porosity, open pore percentage, and closed pore percentage within the filled canals.

Quantitative analysis revealed no statistically significant differences between the groups regarding filling percentage, total porosity, open porosity percentage, and closed porosity percentage values ($p>0.05$). All materials demonstrated acceptable filling quality under *in vitro* conditions.

Within the limitations of this *in vitro* study, ProRoot MTA, NeoSealer Flo with gutta-percha, and AH Plus with gutta-percha showed comparable obturation performance in primary molars requiring long-term retention. Further clinical studies are recommended to confirm these findings.

Keywords: Retained Primary Molar, Root Canal Filling Materials, Micro-CT

ÖZET

Özdemir E. 2025. Sürekli dişlenmede kalması gereken süt azı dişlerinde kullanım için uygun farklı kök kanal dolgu materyallerinin obturasyon kalitesinin karşılaştırılması: Bir *in vitro* çalışma. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü, Doktora Tezi, İstanbul.

Bu çalışmanın amacı, sürekli diş germinin gelişimsel olarak eksik olduğu ve bu sebeple ağızda uzun süre tutulması gereken süt azı dişlerinde kullanım için uygun olan üç farklı kök kanal dolgu materyalinin obturasyon (kanal dolumu) kalitesini mikro bilgisayarlı tomografi (mikro-BT) kullanarak değerlendirmek ve karşılaştırmaktır.

Toplam 15 adet çekilmiş insan süt azı dişi rastgele her biri 5 diştten oluşan üç gruba ayrıldı: Grup 1 — ProRoot MTA (Dentsply®), Grup 2 — NeoSealer Flo (Avalon Biomed, ABD) ile gutta-perka (Diadent, Kore) ve Grup 3 (kontrol grubu) — AH Plus (Dentsply®) ile gutta-perka. Kök kanallarının şekillendirilmesinin ardından, dolgu öncesi mikro-BT taramaları (SkyScan 1275, Bruker micro-CT, Belçika) yapıldı. Sonrasında, her grup için belirlenen materyallerle kök kanal dolgusu yapıldı ve dolgu sonrası tekrar taramalar gerçekleştirildi. Doldurulan kanallarda dolum yüzdesi, toplam porozite, açık boşluk yüzdesi ve kapalı boşluk yüzdesi parametreleri değerlendirildi.

Kantitatif analiz sonuçlarına göre, gruplar arasında dolum yüzdesi, toplam porozite, açık boşluk yüzdesi ve kapalı boşluk yüzdesi değerleri açısından istatistiksel olarak anlamlı bir fark bulunmamıştır ($p>0,05$). Tüm materyaller *in vitro* koşullarda kabul edilebilir dolum kalitesi göstermiştir.

Bu *in vitro* çalışmanın sınırlamaları dahilinde, ProRoot MTA, NeoSealer Flo ile gutta-perka ve AH Plus ile gutta-perka materyalleri, uzun süre ağızda tutulması gereken süt azı dişlerinde benzer dolum performansı sergilemiştir. Bulguların klinik çalışmalarla desteklenmesi önerilmektedir.

Anahtar Kelimeler: Persiste Süt Azı Dişi, Kanal Dolgu Materyalleri, Mikro-BT

1. INTRODUCTION AND PURPOSE

Absence of successor teeth or the presence of impacted permanent teeth may necessitate the retention of the corresponding primary teeth within the dental arches for an extensive period (1). Retaining these teeth will help to prevent discrepancies in arch length and maintain anteroposterior dimensions without the need for orthodontic or prosthodontic rehabilitation (2). Nevertheless, these teeth may be susceptible to dental caries due to prolonged residence in the oral cavity, incompatibility in interproximal contact with neighbouring permanent teeth, and sensitivity resulting from thinner enamel thickness (3, 4). In the event that endodontic treatment is necessary for these teeth due to deep dentin caries, it is essential that the obturation of the root canals should be carried out using a non-resorbable material. The clinical success of pulpectomy in primary molars which are anatomically distinct from the permanent ones is considerably affected by the quality of filling of the root canals (5). The objective of root canal treatment is to maintain the functionality of teeth that can be restored. In cases of multiple tooth deficiency, such as hypodontia, it is of paramount importance for patients to maintain the presence of primary teeth in the mouth (6).

In deep dentin caries, irreversible pulp inflammation may result, necessitating root canal treatment. Root canal treatment represents a potential treatment approach for primary teeth. Therefore it is valuable to provide data on the most appropriate material for filling in order to perform a success of pulpectomy.

Previous dental literature indicates a paucity of published information on the obturation quality of filling materials used for primary teeth. Further investigation is needed to compare the performance of obturation materials when utilised in the treatment of primary teeth. In conclusion, the filling quality of various obturation materials used for primary teeth requires further research. Ideally, the obturation material should be hermetic, biocompatible and non-discolouring, especially in anterior teeth (7, 8). This study will provide information for other scientific studies in this context. Although the clinical efficacy of endodontic treatments in retained primary teeth is limited, some studies reported successful results after filling with gutta-percha and a conventional sealer (9, 10).

An impervious filling of the root canal cavity of primary teeth, which are anatomically different from permanent teeth, while preserving the original anatomy, significantly affects the success of endodontic treatment (11). This study aimed to evaluate the efficacy of filling and the quality of obturation of three distinct protocols for filling root canals with non-resorbable materials in retained primary teeth. The first group consisted of Mineral Trioxide Aggregate (Proroot MTA, Dentsply®, Maillefer, Ballaigues, Switzerland), the second group consisted of a bioactive bioceramic-based root canal filling material (Neosealer Flo, Avalon Biomed, Houston, TX, USA), and Gutta-perka (Diadent, Cheongju, Korea). The control group, the third group, consisted of a resin-based root canal sealer (AH Plus, Dentsply®, DeTrey, Maillefer, Ballaigues, Switzerland) and Gutta-perka (Diadent, Cheongju, Korea). The filling efficacy and obturation quality of the materials in the primary root canals were evaluated and compared using micro-computed tomography (micro-CT) under in vitro conditions.

The null hypothesis of this study (H_0) was that there is no difference between the filling efficacy and obturation quality of different obturation protocols applied to primary molar teeth. The alternative hypothesis tested in this study (H_1) was that there is a difference between filling efficacy and the obturation success between different root canal filling protocols applied to primary molar teeth.

LITERATURE REVIEW

2.1. Congenital Dental Aplasia

Congenital tooth deficiency, also known as congenital dental aplasia, is one of the most prevalent dental anomalies (6, 12-15). It is attributed that it is caused by disorders during the early stages of development and is considered to be a mild dysplastic expression of the ectoderm (16, 17).

Where a primary tooth is congenitally missing, its permanent successor is also likely to be absent. Genetic predisposition is a key factor in congenital dental aplasia, as demonstrated by studies of genetically identical twins (18, 19, 20). The number of developmentally missing teeth is considered when defining the type of dental aplasia, permanent third molars are excluded from this evaluation (6).

Developmental absence of one to five teeth is classified as hypodontia, whereas oligodontia is determined as the absence of six or more teeth (21). Dental aplasia is more frequently observed in permanent than in primary dentition (21, 22). Various environmental and genetic factors are effective in dental aplasia (13, 23). The majority of reports consistently found a higher prevalence of tooth agenesis in females than in males. However, some researchers have found out in their studies that there was no significant difference based on sex (24, 25).

Dental aplasia can lead to major aesthetic, functional, and psychological issues, necessitating an interdisciplinary approach to management (6, 26-29).

2.1.1. The Diagnosis of Congenital Dental Aplasia

If a tooth has not erupted into the mouth within the expected time interval and is not evident on radiographs, it is suspected to be developmentally incomplete (30). The anticipated time interval for the eruption of teeth varies by country (31). Table 1 presents the comparative average eruption schedule of permanent teeth in individuals from Türkiye (32).

Table 1. Average eruption age of permanent teeth in Türkiye (32).

		TÜRKİYE	
		Female (age)	Male (age)
Maxilla	Central incisor	7	7
	Lateral incisor	8	9
	Canines	10	11
	First premolar	10	10
	Second premolar	10	10
	First molar	6.5	6
	Second molar	11	11
Mandible	Central incisor	6	6.5
	Lateral incisor	7	7
	Canines	9.5	10.5
	First premolar	9	10
	Second premolar	10	11
	First molar	6	7
	Second molar	11	11

Some clinical findings, such as the failure of the related tooth to erupt within four to six months after the eruption of the contralateral tooth, may suggest dental aplasia (31, 33).

Infraocclusion is defined as the lack of alignment between the primary tooth and the occlusal plane of the adjacent teeth (34). Individuals with missing premolars, infraocclusion of the corresponding primary molars has been found in approximately two-thirds of cases (35).

Radiographs can be helpful for a definitive diagnosis, but it should be noted that delayed development may be present on radiographs (36).

2.1.2. Prevalence of Dental Aplasia

The incidence of developmentally missing teeth during permanent dentition varies between populations. A meta-analysis study published in 2014 reported that hypodontia affects approximately 6.4% of individuals' permanent teeth. (95% Confidence Interval (CI): 5.7-7.2) (37).

It is estimated that 13.4% of the African population is affected by developmentally congenital dental aplasia, with the prevalence in Europe, North America and Latin America recorded at 7%, 5% and 4.4% respectively (37, 38). In Australia, the prevalence of dental aplasia was reported to be 6.3% of the Caucasian population (39, 40). In Türkiye, the prevalence of congenital dental aplasia and oligodontia was reported to be 3.12% and 0.07%, respectively. It was reported that females were more frequently affected than males, bilateral congenital dental aplasia was more common than unilateral congenital dental aplasia, and congenital dental aplasia was more common in the maxillae than in the mandible (41).

Class III malocclusion is a higher prevalence compared to other types of malocclusion (42, 43). The data obtained from the analysis of 145,848 subjects in 22 studies demonstrated that the incidence of missing teeth was most prevalent among mandibular second premolars, with a prevalence of 29.9% (37).

2.1.3. Aetiology of Dental Aplasia

Although the etiology of congenital dental aplasia is not fully understood, it is widely accepted that genetic, epigenetic and environmental factors play a role (44-46). There are evolutionary and anatomical theories (47).

The logic of evolutionary theories is that changes in the craniofacial region or tooth structure will result in a decrease in the number of teeth. Earlier, Dahlberg argued that the mesial members of incisors, canines, premolars, and molars were generally more resilient than their more distal neighbors (48). Subsequently, Clayton proposed that the more distal teeth were neither necessary for function nor subject to evolutionary development (49). Despite the existence of views proposing a correlation between the reduction in jaw size and the decrease in tooth number during human development, the extant evidence supporting this hypothesis is considered to be inadequate (50).

Anatomical theory posits that specific regions of the dental lamina are susceptible to external influences throughout the developmental process of teeth (50). Another hypothesis posits that dental aplasia is more prevalent in regions where innervation occurs subsequent to other developmental processes (51). In light of these theories, it is generally accepted that the complex interaction of genetic and environmental factors is an effective cause of the developmental absence of the tooth (50, 51).

Congenital dental aplasia is also observed when dysplasias and clefts are present in craniofacial anomalies (52). The use of drugs such as thalidomide by a pregnant woman may result in hypodontia (51). It has been hypothesised that rubella infection during pregnancy may be an etiological factor of tooth agenesis in the infant (53). Smoking during pregnancy has been linked to the development of craniofacial anomalies by negatively impacting the growth of neural crest cells, a process that may be further compounded by alcohol consumption (54).

Given that tooth agenesis and certain abnormalities in the craniofacial region share common signalling routes, there is a growing body of evidence suggesting a link between hypodontia and environmental factors. During cancer treatment in childhood, chemotherapy and radiation have been shown to have a range of adverse effects on dental development, including congenital dental aplasia (50).

Krasuska-Slawinska et al. demonstrated that increasing dosage of chemotherapeutic medications, including vincristine, cyclophosphamide and doxorubicin were associated with increased congenital dental aplasia (55).

Curative radiation dosage of 2000-4000 centigray (cGy) during the therapy of pediatric cancers have been shown to cause dental abnormalities, including congenital dental aplasia (56).

2.1.4. Genetic factors of Dental Aplasia

The evidence that trauma to the alveolar process, including the maturing tooth bud, can cause congenital absence of teeth is inconclusive (57). Given that X-linked (sex-linked) autosomal recessive and autosomal dominant mechanisms may be involved in the etiology of hypodontia, non-syndromic congenital absence of teeth may take place casually or may be acquired (Figure 1) (44).



Figure 1. Non-syndromic hypodontia; a: intraoral photograph of the first case, b: radiograph of the first case, c: intraoral photograph of the second case, d: radiograph of the second case, e: intraoral photograph of the third case, f: radiograph of the third case (44).

The observed ethnic diversity can be attributed to the difference between populations, the fact that it is seen as sexual dimorphism due to more congenital dental aplasia reported in females, which is more common among relatives. These observations support the effect of genetic factors (44, 58-60).

Congenital dental aplasia may occur due to disruption of particles that promote cellular attachment, malfunction of noncellular matrix particles, or faulty signalling routes (61). Teeth development is a multifaceted occurrence involving the action of more than 300 genes (52). Several key genes have been identified as playing a role in congenital absence of teeth. Mutations of the human homeobox MSX1 (muscle segment homeobox 1) gene have been associated with agenesis of teeth, while developmentally absent molars are thought to result from a change in the PAX9 (paired box gene 9) gene (62). Both the MSX1 and PAX9 genes encode transcription factor proteins that are crucial for dental maturation (45). The expression of the PAX9 gene, a member of the paired box family of transcription factors, plays a pivotal role in regulating tooth development at the bud stage, determining the sites of subsequent tooth formation (63).

In embryos lacking the PAX9 gene, tooth development stops at the bud stage, and the expression of this gene is mutated, causing congenital dental aplasia of most permanent molars (64). Wnt proteins are essential during embryonic development, including tooth development (45).

AXIN2 (axis inhibition protein 2) is a negative regulator of the Wnt signalling pathway (65). AXIN2 is a crucial component of the Wnt/ β -catenin pathway (66). A nonsense mutation in the AXIN2 gene has been reported to cause hereditary oligodontia with a much more severe phenotype than MSX1 and PAX9 mutations. Mutations in AXIN2 may lead to the absence of multiple teeth groups such as permanent molars, premolars, lower incisors and upper lateral incisors (66). Mutations in the EDA (ectodysplasin A) and EDA receptor genes have been demonstrated to result in the absence of maxillary incisors (67).

2.1.5. The Syndromes Associated with Congenital Dental Aplasia

Although the majority of congenital dental aplasia is not syndromic, there are various syndromic conditions in which absence of teeth forms a phenotypic spectrum of genetic abnormalities (45, 68-77). The syndromes associated with congenital dental aplasia are illustrated in Table 2.

The panoramic radiography of a patient diagnosed with incontinentia pigmenti demonstrates a congenital tooth deficiency, as illustrated in Figure 2 (78).



Figure 2. The panoramic radiography of a patient diagnosed with incontinentia pigmenti reveals the congenital absence of multiple permanent teeth (78).

Patients presenting with congenitally missing teeth should undergo a comprehensive and systematic extraoral and intraoral examination to assess for other manifestations, which may be signs and symptoms of certain syndromes and/or other malformations (79). Factors to be considered in the evaluation include the age of the patient, the concerns and expectations of the patient and family, the general medical conditions, and the number, quality and positions of the present teeth. Timely and accurate diagnosis of developmentally missing teeth is of great importance for the evaluation of treatment strategies (80-87). Timely and accurate diagnosis of developmentally missing teeth is of great importance for the evaluation of treatment strategies (80-87).

Table 2. The syndrome associated with congenital dental aplasia (45, 68-79).

Anomaly	Prevalence	Author
Conical incisors	8.9%	Lai and Seow (1989) (35)
Hypoplastic enamel	11%	Baccetti (1998) (99)
Impaction of teeth (notably maxillary canines)	5.2–16%	Garib et al. (2009) Baccetti (1998) Garib et al. (2010) Al-Abdallah et al. (2015) (96, 99, 101)
Infra-occlusion of primary teeth (agenesis of permanent premolars)	15–65.7%	Baccetti (1998) (99)
Peg-shaped lateral incisors	18–46.7%	Baccetti (1998) Garib et al. (2010) Al-Abdallah et al. (2015) (99-101)
Retained primary teeth	Up to 60%	Al-Abdallah et al. (103)
Smaller crown and root size (microdontia)	20.6%	Garib et al. (2009) (96)
Transposition	4.7%	Al-Abdallah et al. (2015) (101)
Taurodontism	Up to 38%	Kim and Lai (102)

In cases of more severe hypodontia, it is particularly beneficial for the clinician to inform the patient or family that a medical examination is necessary to detect a previously undiagnosed syndrome (52).

An interdisciplinary approach may be required to establish an optimal treatment plan for these patients, with input and support from specialists working in the fields of pediatric dentistry, orthodontics, prosthodontics, periodontology, oral surgery, genetics, and psychology (88-90).

It is also important to consider the potential psychosocial impact of tooth loss on individuals (91-95). For instance, although Laing et al. asserted that there was no discernible discrepancy in the psychosocial impact of patients referring with hypodontia and those with "non-hypodontic" orthodontic treatment needs, in the same study they discovered that the loss of primary teeth with missing permanent successors had a negative impact on the participants' masticatory capacity (92).

In a cross-sectional study assessing hypodontia-related quality of life, 97 young participants with hypodontia, it was found that the problem of hypodontia negatively affected their social and emotional well-being. Additionally, more severe hypodontia was determined to be associated with greater adverse effects. The authors concluded that effective engagement which will be commenced as early as possible with a multidisciplinary approach is fundamental to minimise further unfavorable effects associated with agenesis (91).

2.1.6 Occlusal and Dental Disorders Associated with Congenital Tooth Agenesis

Another critical issue that clinicians taking care of young patients should be aware of about hypodontia is occlusal disorders. Table 3 illustrates the relationship between congenital dental anomalies and their effect on occlusion (35, 92-103).

Infraocclusion is defined as the failure of the eruption mechanism to align a tooth with the same occlusal plane of adjacent teeth. It was reported that individuals with missing second premolars were affected by infraocclusion of the corresponding primary molar in a ratio of approximately 65.7% (35, 92).

Table 3. The relationship between congenital dental anomalies and their effect on occlusion (35, 96, 99-102)

Anomaly	Prevalence	Author
Conical incisors	8.9%	Lai and Seow (1989) (35)
Hypoplastic enamel	11%	Baccetti (1998) (99)
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Smaller crown and root size (microdontia)	20.6%	Garib et al. (2009) (96)
Transposition	4.7%	Al-Abdallah et al. (2015) (101)
Taurodontism	Up to 38%	Kim and Lai (102)

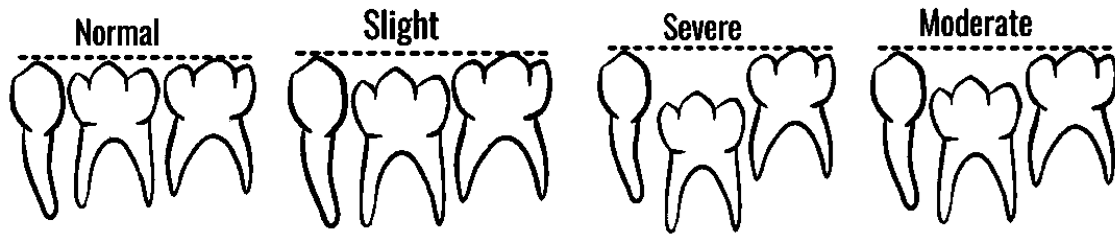


Figure 3. Classification of infraocclusion according to occlusal levels (104)

A variety of classification systems have been proposed for infraocclusion. Brearley has developed a straightforward classification system comprising three categories:

Slight: The occlusal plane is positioned precisely 1 mm beneath the anticipated occlusal surface of the tooth.

Moderate: The occlusal plane is positioned at a level that is approximately congruent with the point of contact between one or both neighboring tooth structures.

Severe: The occlusal planes are positioned at or beneath the level of the interdental gum mucosa of one or both neighboring tooth structures (104).

A tooth with mild infraocclusion is regarded as being situated beneath the occlusal surface of the neighbouring teeth, however not beneath the junction points. It should be stated that the minor discrepancy observed between an infraoccluded primary molar and neighbouring teeth can be attributed to variations in crown height rather than the infraocclusion itself.

Moderate infraocclusion is defined as an occlusal surface of the infraoccluded tooth situated between the junction points and bone, with the critically infraoccluded tooth positioned beneath the osseous crest (105).

The slight form of infraocclusion shows a decline in frequency with age, while the moderate and severe forms demonstrate a notable increase in prevalence, particularly among children aged 8- 10 and 11-13 years old, respectively (106).

Infraocclusion affects 2.5–8.3% of all infraoccluded primary molars (107). The prevalence of infraocclusion in children has been demonstrated to range from 1.3% to 8.9%, with a similar occurrence in both male and female subjects. However, the prevalence of this condition is reported to range from 18.1% to 44% in the siblings of affected children (108).

The lower primary second molars are the teeth most frequently affected. However, other studies have indicated an increased rate of infraocclusion in the lower primary first molars. The phenomenon exhibits no difference between either the left or right sides. The frequency of infraocclusion of lower primary molars is 10 times higher than that of the upper primary molars (106, 107). Furthermore, age-related variations have been observed, with infraocclusion being closely related with root resorption due to the eruption of premolars and the process of normal exfoliation. This is due to the fact that the number of infraoccluded primary first molars increases from three years of age, while the number of infraoccluded primary second molars increases from five years of age. The maximum prevalence of infraocclusion is observed in children between eight and nine years of age. The lower primary first molar is more frequently affected in children below the age of nine. Subsequently, infraocclusion of the primary second molar becomes the predominant phenomenon (109).

The term "submersion" is used in clinical contexts to describe a tooth that is depressed below the occlusal plane (110). Vertical tooth eruption seemed to be inhibited, resulting in the affected teeth appearing to "submerge" as surrounding teeth continue to develop around them (108).

Another anomaly that frequently occurs in conjunction with infraocclusion is known as ankylosis. Ankylosis refers to the fusion of cementum to alveolar bone and is observed in nearly all infraoccluded primary molars. Nevertheless, it can also occur following to infraocclusion. Such occurrences may transpire at any stage of the eruption process (111). Ankylosis of the primary molar to the alveolar bone typically occurs subsequent to the onset of root resorption. Should ankylosis occur at an earlier stage, the eruption of opposite teeth may develop substantially for the ankylosed tooth to be placed well below the normal plane of occlusion, and may even be partially covered with soft tissue (107).

The prevalence of ankylosis of primary molars has been reported to range from 1.3 to 38.5 percent (112). The term "tooth ankylosis" is used to describe a condition in which the teeth are unable to maintain their position at the same level as the neighboring teeth in a growing child. In some cases, there is no clinical or histological evidence to suggest that ankylosed teeth are located below the occlusal plane (109).

The management of an infraoccluded primary molar in the absence of a permanent successor is contingent upon a number of factors, including:

- Infraocclusion degree,
- Patient age,
- The possibility of progression of the infraocclusion,
- The prognosis of the infraoccluded tooth,
- The adverse effects of infraocclusion, such as a dental centerline shifting towards the infraoccluded tooth and adjacent teeth tipping into its space, should be considered (105).

In severe infraocclusion cases with adverse effects on the occlusion, early extraction could be considered (113). This can lead to some natural space closure, which might also prevent continued degradation of bone loss. Extracting upper primary second molars in a timely manner can be beneficial if there aren't permanent successors because permanent molars are likely to drift mesially and reduce the resulting space. However, achieving space closure after extracting lower primary second molars presents more difficulty, since permanent molars aren't as prone to mesial drift. Bjerklin et al. reported that retained primary molars demonstrate a long-term survival rate exceeding 90% (114).

2.1.6.1. The Management of Infraoccluded Primary Molars with Successors

In general, primary molars where premolars exist have been demonstrated to exfoliate normally by the erupting successor, which resorbs the roots of the submerged teeth. Nevertheless, the occurrence of extensive bony ankylosis may impede physiological exfoliation, potentially leading to forthcoming alignment issues. In the dental literature, a delay in exfoliation up to six-months has been described as tolerable,

with the degree of infraocclusion correlating with the duration of the delay. Consequently, a regular follow-up of patients in the mixed dentition is fundamental to ascertain the time of onset of delays in the eruption of permanent teeth. Kurol et al. recommend a policy of watchful waiting and patient observation for these types of cases (115).

In cases where exfoliation is delayed, the primary tooth is typically in slight infraocclusion. Consequently, the objective of treatment is to facilitate the exfoliation of the ankylosed tooth. Early onset cases can be further subdivided into those diagnosed at an early stage and those diagnosed later. Late diagnoses of early-onset conditions are likely to present with tipped adjacent teeth supra-eruption of the antagonist and thus indicate the necessity of orthodontic intervention followed by extraction (116). The use of a removable space maintainer can be required to compensate for the space loss between the teeth (117).

2.1.6.2. The Management of Infraoccluded Primary Molars in the Absence of a Successor

The management of infraocclusion of primary molars due to the absence of a permanent successor is a challenging endeavor. These teeth, because of their ankylosed state, do not undergo spontaneous exfoliation. Nevertheless, it is possible to observe a very slow process of root resorption in the case of tooth ankylosis (106).

A definite relationship between congenitally missing premolars and infraoccluded primary molars was reported to be in 17% of cases (118). In many cases, prophylactic removal is recommended at an early stage, following a determination of root resorption, loss of adjacent periodontal support, and the age of onset. In their 2001 study, Sidhu et al. proposed that patients presenting an infraocclusion along with agenesis of the permanent successor should be classified as noteworthy cases (107). Furthermore, severe infraocclusion is observed in only 2.5-8.3% of all infraoccluded primary molars, and has been specifically associated with a missing permanent successor. Therefore, these cases should be approached with particular caution, as aplasia has the potential to exacerbate the progression of infraocclusion. When making a therapeutic decision, the patient's age, occlusal status, and the development and condition of the affected tooth must be considered (115).



Figure 4. A primary tooth without a permanent successor in infraocclusion (119)

If the progression of infraocclusion and root resorption is exceedingly gradual and the primary molar is deemed beneficial, it may be retained within the dental arch and utilised as a natural space maintainer. The progression of infraocclusion and root resorption can be mitigated through the use of bonded materials to amplify the coronal height and approximal contacts, thereby preventing occlusal disturbances. However, it is essential to note that root resorption can ultimately result in tooth loss (107). Therefore, it is inadvisable to defer the therapeutic extraction of the tooth for an extended period, given the potential for additional loss of the alveolar bone. Conversely, following the extraction, an orthodontic intervention to close the gap or other means of closing the gap should be considered (115).

2.1.6.3. Treatment Options for Mandibular Second Premolar Tooth Agenesis

An ankylosed primary tooth with a missing successor may remain functional for over twenty years, particularly if it is slightly submerged. In such cases, the crown can be extended vertically by fabricating a stainless steel crown or the occlusal addition of posterior composite, thereby reestablishing acceptable occlusion until a more suitable prosthesis can be planned and constructed. Furthermore, the placement of a crown maintains the mesiodistal dimension (115).

2.1.6.4. Primary and (Early) Mixed Dentition

It is of the highest importance that clinicians are aware of the fact that delayed dental development is a common occurrence in individuals with congenital dental aplasia (98). In cases of severe dental agenesis, associated functional, aesthetic, and psychological problems may necessitate intervention in children (88). The evaluation of oro-facial functions related to mastication and speech should be included in the management plan (89, 90). Treatment alternatives involve the restoration of deformed teeth with composite resin (CR), and the application of removable dentures, which may resolve aesthetic and functional problems.

The patient intends to participate in scheduled evaluations and modifications of any fitted appliances throughout the duration of their growth and development. Routine interceptive orthodontic interventions, , can stimulate favourable dental development in milder forms of congenital dental aplasia. Extraction of primary teeth has been proposed to facilitate the favourable movement of permanent teeth. However, studies indicate that additional later intervention is typically more effective than complete space closure (90, 120, 121).

2.1.6.5. Late Mixed and Permanent Dentition

A significant number of congenital agenesis cases necessitate orthodontic intervention to facilitate optimal tooth positioning for effective management. It is frequently recommended that patients seek the guidance of an orthodontist at an early stage (122, 123).

A comprehensive orthodontic assessment should require evaluating the malocclusion's general features alongside concerns about tooth agenesis (6). The orthodontist will advise on whether the missing tooth or teeth can help resolve features of an existing malocclusion. During late mixed and permanent dentition, growth modification can be a valuable approach for managing skeletal discrepancies. Orthodontic fixed appliances effectively direct the teeth to their predetermined positions, ensuring the successful completion of the treatment plan (89). When the degree of tooth loss is significant, anchorage demands often present a substantial clinical obstacle (52). The advent and use of temporary anchorage devices have significantly advanced the

capacity for controlled tooth movement, thereby facilitating the solution of many clinical challenges (103).

Agenesis of the mandibular second premolars presents with several potential treatment options that need to be evaluated. One possible course of action is *in situ* retention of the primary molar, while the alternative is to extract it. Extracting the contralateral premolar and maxillary premolars in some cases can help facilitate spontaneous closure or closure achieved with fixed orthodontic appliances. (124). Autotransplantation of the maxillary third molar is another possibility (125). Further treatment choices may be implant-supported prostheses and tooth-supported bridges/pontics (126).

2.1.6.6. Treatment Options for Mandibular Second Premolar Tooth Agenesis with Orthodontic Approach

When developing an orthodontic treatment plan, it is essential to consider many variables. It is of significant importance to consider the skeletal and dentoalveolar classifications. Extracting the mandibular second primary molars to close spaces in a low-angle subject is contraindicated, particularly in cases where the dentition is not already crowded. It is also necessary to consider the condition of the second primary molar in question. In instances where the tooth is affected by caries, extensive restorations, or progressive root resorption and infra occlusion, the retention of the tooth may be contraindicated (127).

Various approaches have been proposed to manage the absence of mandibular second premolars (3). In subjects with hypodontia, Joondeph and McNeill proposed that the primary mandibular molar should be extracted at an early age, before 11 years of age, to allow spontaneous space closure (127).

A four-year follow-up study conducted by Mamopoulos et al. revealed that 80% of the extraction space was successfully closed in subjects with congenital agenesis of the second premolar, resulting in a mean residual space of 2 mm (128).

Lindqvist et al. likewise reported analogous findings. In 84% of the selected cases, the space was closed through mesial drift and tipping of the first molar and distal drift and tipping of the first premolar (120).

Following the conclusion of root development for the second molar and first premolar, the extraction of the primary molar is frequently linked to an elevated proclivity for these teeth to tip. Moreover, Lindqvist et al. observed a notable mandibular dental midline displacement towards the site of extraction (120).

One straightforward approach to extraction is hemisection or controlled slicing. The method is based on bisecting the second primary molar and removing the distal half. This will permit the mesial drift of the first permanent molar. Subsequently, the residual mesial root half is then removed once the movements have slowed. If the mechanisms are meticulously crafted and reinforced, the mandibular molar can be translocated mesially with diminished anterior tipping and loss of anchorage (129).

If an uncrowded arch is present, the second primary molar is at risk of progressive root resorption or pronounced infraocclusion. Mesial movement of the first permanent molar is challenging or inadvisable, and autotransplantation may be the optimal treatment option. The transplantation process serves to preserve the volume of the alveolar bone and replace a missing tooth in a manner that does not involve the adjacent teeth. This benefit distinguishes it from tooth-supported prosthetic treatments. The most appropriate tooth for transplantation is the maxillary third molar, which has a crown size similar to the mandibular second primary molar. The success rates for autotransplantation have been reported to range from 82 to 94 percent (126).

Fixed orthodontic treatment has been demonstrated to achieve space closure if the decision to extract the second primary molar is delayed beyond 11–12 years of age and/or if spontaneous space closure fails to occur (3). This approach may also be beneficial in addressing mandibular anterior crowding. The extraction of the mandibular second primary molar is contraindicated in subjects exhibiting no crowding, a pronounced deep bite, and a hypo-divergent vertical skeletal pattern; those with mandibular retrusion or generalized spacing of teeth; and those with no other indications for dental extractions. Obtaining satisfactory outcomes without incurring undesirable complications, such as

modifications to the patient's facial profile, is challenging. In such cases, the retention of the primary molar may be a feasible alternative.

Rune and Sarnäs reported that, at a mean age of 17 years, only 5% of the primary molars were extracted due to infraocclusion. Moreover, they found that root resorption levels remained unchanged in approximately 50% of cases. No correlation was identified between root resorption and infraocclusion (130).

Ith-Hansen and Kjær reported similar findings. The examination of a sample of 26-second primary molars revealed that in 23 cases, the degree of root resorption was unaltered (131).

Bjerklin and Bennett reported 59 retained mandibular second primary molars in subjects comprising a sample of 41 (132). The mean age at the final registration was 20 years and six months. Nearly a third of the subjects exhibited no change in root resorption levels from the initial registration, conducted when they were between 11 and 16 years old, to the third registration, conducted between 19 and 20 years later, with the latter registration also including data from the subjects' second primary molars. In several instances, root resorption of at least 50% was recorded at the initial registration, yet the subjects' second primary molars were still present at the time of the second registration.

The available literature comprises two studies of adult subjects, conducted by Sletten et al. and Nordqvist et al. (1, 133). In their 2003 study, Sletten et al. assessed root resorption and submergence of retained second primary molars in a sample of 20 adult patients selected from a larger cohort of over 6,000 subjects (1).

The prevalence of root resorption and submergence of retained second primary molars was examined in a cross-sectional study conducted in Sweden by Nordqvist et al. (133). The study included 20 adult patients. The results of the study supported the opinion that mandibular second primary molars have a favorable long-term prognosis, despite a significant correlation between root resorption and age. The study demonstrated a greater incidence of root resorption in the older subjects (133).

2.1.6.7. The management of Agenic Maxillary Lateral Incisors

In a recent study, Barber et al. observed that current research in the treatment of agenesis maxillary lateral incisors appears to primarily focus on clinician and researcher outcomes, rather than what is of the utmost importance to patients (134). It would appear that the current lack of patient-centricity has resulted in uncertainty regarding the effectiveness of space closure or space opening in these patients. This may be due to the lack of studies examining the effects of treatment duration, patient satisfaction, temporomandibular joint and periodontal outcomes. It might be helpful to consider the initial malocclusion when deciding what to do about the spacing of agenic maxillary lateral incisors. It may be helpful to consider the existing malocclusion, which appears to be a Class I incisor, canine, and molar with a "normal" overbite. It seems reasonable to suggest that the closer the relationship is to the ideal, the more likely prosthetic planning of the lateral incisor is.

In terms of prosthetic replacement for the agenic lateral incisor, there are a number of possible options that could be considered depending on the circumstances (126).

Several options are available, including a resin-bonded fixed partial denture, a traditional full-closure fixed partial denture, a cantilevered fixed partial denture, a removable partial denture or an implant (88, 122, 135-137).

Furthermore, periodontal and surgical procedures, such as alveolar ridge augmentation, may be compulsory to achieve successful biological, functional, and aesthetic outcomes.

In cases where the closure of a space is planned, the extraction of primary lateral incisors and primary canines may be an option to stimulate the eruption of permanent canines in proximity to the central incisors. This approach may facilitate the closure of the 'excess' space through a reduction of the overjet and/or protraction of the maxillary posterior teeth (135).

It was reported in a retrospective study with retrospective evaluation of patients who underwent treatment for agenesis of the maxillary lateral incisors that subsequent space closure exhibited greater satisfaction with their treatment compared to patients who underwent prosthodontic treatment and their had superior periodontal health were

exceptional compared to patients who underwent treatment for agenesis and space opening with prosthetic replacement (137).

It may be beneficial to consider rotating the premolar mesio-palatally to emulate the canine and thereby utilise the excess space, as well as abrasion of the palatal ridge of the first premolar to prevent its interference with the occlusion in excursive movements (136). Furthermore, the aesthetic outcome of the treatment must be considered when closing the cavity of a missing upper lateral incisor. It is frequently the case that patients have aesthetic expectations that necessitate some degree of remodelling and/or prosthetic treatment of the upper six anterior teeth.

Despite the advances in the prevention of caries with preventive applications in paediatric dentistry, caries formation can be seen in primary teeth and these caries also affect the pulp (1). Root canal treatment in primary teeth with irreversible pulpitis or necrotic pulp is a clinical application that provides long-term retention in the mouth until the successor erupts or in case of retention in primary teeth without successor (2).

The success of root canal therapy was originally based on three key components: debridement, meticulous disinfection, and proper obturation with an effective seal, where each aspect was considered equally important (138). However, in today's context, successful root canal treatment depends on a broader set of principles. These principles include accurate diagnosis and treatment planning, a thorough understanding of anatomy and morphology, the traditional concepts of debridement, meticulous disinfection, and obturation, appropriate coronal restoration, and the use of three-dimensional imaging to assess the healing of teeth with preexisting periapical pathosis (139).

2.2. Anatomy of Primary Molars Root Canal

2.2.1. Anatomy of Maxillary Primary Molars

The primary maxillary molars are considered predominantly three-rooted. It has also been documented that instances of two or four roots have been observed. The two-rooted form is the result of the fusion of the distobuccal root and the palatal root. It is more commonly observed in maxillary first molars (figure 5) (140).

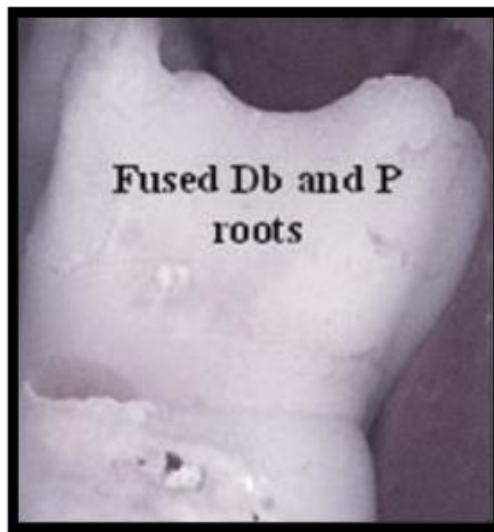


Figure 5. Palatal root fusion with distobuccal root in maxillary primary molar (143).

2.2.1.1.Mesial Canal Structure of Maxillary Primary Molars

The mesial canal structure of maxillary primary molars exhibits considerable variability. It has been reported that between 75% and 95% of mesiobuccal roots exhibit the presence of a second root canal (141). Furthermore, additional studies in the literature have indicated the potential for the presence of three canals in the mesiobuccal root (142).

In a separate analysis of maxillary molars, 6.67% of the mesial roots of maxillary first primary molars and 53.3% of maxillary second primary molars were found to have a second canal (143).

2.2.1.2.Distal Canal Structure of Maxillary Primary Molars

It is important to note that while maxillary primary molars are generally believed to have a single root canal, there are cases where a second canal has been observed. This occurrence has been reported in up to 27.8% of cases (144) . Similarly, although the palatal root typically contains a single canal, there have been instances where an additional palatal canal has been found in primary second molars. Additionally, it is not uncommon for the distobuccal and palatal roots to undergo diffusion, resulting in a combined structure that may form a ribbon-like or C-shaped canal extending to the apical portion (143).

2.2.2. Anatomy of Mandibular Primary Molars Root Canal

The double-rooted variant is the most prevalent variant in primary mandibular molars, though single-rooted and triple-rooted variants also exist (145). It has been documented that accessory roots have been observed, at least in some cases, to occur, particularly in second molars (146).

It is also noteworthy that the mesial root structure of mandibular primary molars is typically two-rooted, with two root canals reported as type IV according to the Vertucci classification (Table 4) (147).



Table 4. Vertucci's primary molar teeth root canal morphology classification (147).

	Mandibular				Maxillary					
Vertucci's Classification	First Molar		Second Molar		First Molar			Second Molar		
	Mesial	Distal	Mesial	Distal	Mesiovestibular	Distovestibular	Palatine	Mesiovestibular	Distovestibular	Palatine
	%	%	%	%	%	%	%	%	%	%
Class I	13	60	13	46.5	93	100	100	84	93	100
Class II	-	7	-	46.5	-	-	-	-	7	-
Class III	-	-	13	-	7	-	-	7	-	-
Class IV	40	33	20.5	7	-	-	-	-	-	-
Class V	40	-	46.5	-	-	-	-	7	-	-
Class VI	7	-	7	-	-	-	-	-	-	-

2.2.2.1.Mesial Canal Structure of Mandibular Primary Molars

Although two-canalchannel variation is prevalent, it is noteworthy that three-canalchannel variation has been observed with high frequency in the mesial roots of mandibular first molars. In addition to these variations, the presence of a single root canal has also been documented on rare occasions (140).

2.2.2.2.Distal Root Structure of Mandibular Primary Molars

The distal root structure of mandibular primary molars generally contains one or two canals. It is also noteworthy that all double canals have been classified as type IV according to the Vertucci classification system. Moreover, the presence of three canals in the distal root has also been documented (147).

Physiological root resorption in areas such as the apical foramen, lateral accessory canal, and furcation accessory canal may result in the exposure of dentin tubules (148). Consequently, the process may render the root surface more permeable to microbial toxins. Taking these factors into consideration, the possibility exists for interradicular bone lesions in primary molar teeth to occur at any point along the root or in the furcation area (149-151).

Various modern methods and equipment are being developed for use in pediatric endodontic applications. These techniques include the use of electronic apex locators and rotary nickel-titanium (Ni-Ti) files.

2.3.Determination of Working Length in Endodontic Treatment

It is of significant importance to ascertain the length of the root canal during the course of a root canal treatment in primary molars. The purpose of this step is to prevent damage to the permanent tooth bud when using chemical-mechanical instruments within the boundaries of the root canal (152).

Periapical radiography remains the most preferred method for measuring working length in primary teeth; however, it is believed that the disadvantages of two-dimensional

imaging can be overcome by using various types of apex locators as additional measurement tools.

It is noteworthy that the identification of the apex is of particular significance in roots that are undergoing irregular physiological resorption (153). Two-dimensional radiographs may be an inadequate method for determining the size of the root canal, as illustrated in the accompanying Figure 6 (133).

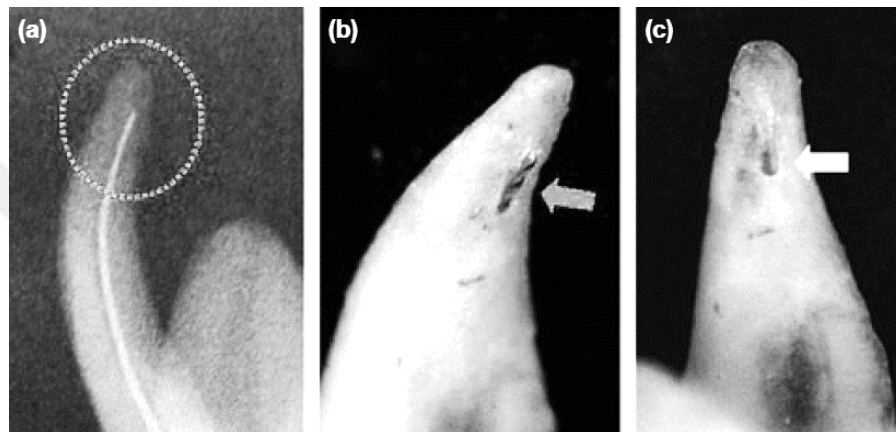


Figure 6. Apical radiography (a), File at the apex (b), Clinical apex (c) (133)

The high accuracy of the apex locator has been demonstrated *in vivo* in studies conducted with and without root resorption (154, 155). Kielbassa et al.(2003) reported an accuracy rate for their apex locators of 64%, while Odabaş et al. (2011) observed a rate of 86.4-95.8% for the same devices (156, 157). While both studies demonstrated accurate measurements within one millimeter of the visually determined lengths of the root canals, a lack of standardized measurement techniques may have led to conflicting results. In a pilot study conducted in 2008 by Leonardo et al., the results were based on the initial reading of "1" on the apex locator display (153). This reading indicated that a measurement of the actual root canal length 1 mm shorter than the root apex exhibited the strongest correlation with the visual method, as previously observed by Odabaş et al. (2011) (157).

2.4.Mechanical Instrumentation in Root Canal Treatment

The utilisation of NiTi rotational systems can be traced back to the early 21st century (158). In a study conducted by Silva et al. in 2004, no significant difference in cleaning efficacy was observed between K-scopes (Dentsply Maillefer, Ballaigues, Switzerland) and the ProFile system (Dentsply Tulsa Dental, Tulsa, OK, USA). Both systems demonstrated a significant reduction in preparation time, satisfactory consistency, and smooth walls (159).

In 2006, Kuo et al. presented a protocol that shortened the root canal treatment time of primary teeth in the clinic. In accordance with the stipulated treatment protocol, it is recommended to utilise a 10-size K-file as the primary instrument, followed by two files (SX and S2) of the ProTaper NiTi rotational system, and subsequently 25 or 30-size H-files for the final stage of preparation. As demonstrated by clinical and radiographic findings, a success rate of 96% was attained at the 12-month follow-up (160).

Azar et al.(2012) recommended a sequence of S1, S2 and F1 for ProTaper, and evaluated this in comparison with the Mtwo NiTi rotational system (VDW, Munich, Germany) and hand files. The study demonstrated acceptable cleaning ability with both systems (161).

In 2012, Pinheiro et al. conducted a comparative analysis of another ProTaper series with hand files. In the present study, the ProTaper group utilised S1 first, followed by S2, and finally F1 and F2 in sequence. A hybrid technique was also included in the comparison. Despite requiring a longer preparation time compared to manual and rotational systems, the hybrid technique provided the most significant reduction in *Enterococcus faecalis* (162).

In 2008, Kummer et al. demonstrated that the utilisation of Hero 642 (Micro-Mega, Besançon, France) resulted in a substantial reduction in the time required for treatment. Another finding was that iatrogenic perforations occurred in the middle third of resorbed roots in both rotational and manual systems (163).

2.5. Root Canal Irrigation of Primary Teeth

Root canal irrigation, particularly with Sodium Hypochlorite (NaOCl) at a concentration of 1%, appears to be the most commonly utilized irrigant in the treatment of first molars (159, 162, 163). Furthermore, the American Association of Paediatric Dentistry (AAPD, 2012) also recommends utilisation of NaOCl at a concentration of 1% (164).

The utilisation of saline is similarly pervasive, akin to sodium hypochlorite, and is endorsed by the United Kingdom National Guidelines for Paediatric Dentistry (161, 165).

In addition to these two solutions, other irrigation solutions such as hydrogen peroxide, Dakin's solution (0.5% NaOCl neutralized with boric acid), and chlorhexidine (CHX) can be used in paediatric endodontics (166-169).

Although the combination of chlorhexidine (CHX) and sodium hypochlorite (NaOCl) has been found to be effective in terms of tissue dissolution capacity and antimicrobial effect, a study conducted by Tirali et al. (2012) demonstrated that a solution containing 0.1% octenidine dihydrochloride exhibited superior in vitro antibacterial activity compared to a solution containing 2% CHX and 5.25% NaOCl. To enhance the antimicrobial efficacy of CHX, it is recommended that it is used in combination with 6% citric acid (170). Additionally, 6% citric acid has been reported to promote healing without damaging the root dentin of primary molars when used with NaOCl (170, 171). Using 17% ethylenediaminetetraacetic acid (EDTA) as the final irrigation solution has been shown to improve tubular penetration and obturation (172).

United Kingdom National Guidelines for Pediatric Dentistry recommend the use of normal saline (0.9%), CHX (0.4%), or NaOCl solution (0.1%) for root canal treatment procedures (165). American Academy of Pediatric Dentistry (AAPD, 2012), however, recommends a higher concentration, suggesting irrigants such as 1% NaOCl and/or CHX for optimal bacterial decontamination of root canals (164).

The optimal concentration of NaOCl is still a matter of debate in endodontics. Nevertheless, it is a widely used solution, with concentrations typically ranging from 0.5% to 5.25% or 6%. A review of the literature indicates that there is insufficient

evidence to support the claim that a 0.1% concentration exhibits effective tissue-dissolving and antimicrobial activity (173-175).

Furthermore, even at low concentrations, the interaction between NaOCl and CHX has been shown to produce a brown precipitate containing significant quantities of the carcinogen parachloroaniline, either within the precipitate itself or in one of the CHX breakdown products. Due to the relatively high likelihood of irrigant overflow, its use is not recommended for primary molar teeth with root resorption (176, 177).

Using a solution such as saline or sterile distilled water and then drying it carefully may help prevent the formation of a brown precipitate caused by the combination of NaOCl and CHX (178). In addition to demonstrating lower cytotoxicity compared to EDTA and higher efficacy in removing the smear layer, maleic acid has also been shown not to cause precipitation or color changes when combined with CHX (179).

In primary teeth where the permanent tooth is absent, if the tooth is planned to remain in the mouth and endodontic treatment is required, obturation can be performed using materials and methods preferred for permanent teeth (138).

2.5.1. Endodontic Materials Used to Fill Root Canals

Successful root canal obturation is of critical importance in ensuring the long-term efficacy of endodontic treatment. Two significant aspects of root canal filling are as follows: firstly, ensuring apical sealing and secondly, filling the root canal without leaving any voids in the filling material (7). The implementation of high-quality root canal obturation has been demonstrated to serve as an effective measure in preventing the penetration of substances, including both oral fluids such as saliva and biological contaminants such as bacteria, into the canal. This process effectively inhibits the proliferation of microorganisms (179).

For the subsequent root canal filling to be carried out effectively, it is imperative that the preceding cleaning and shaping procedures are executed in accordance with the requisite standard. The cleaning and preparation process involves mechanical and

chemical instrumentation to eliminate organic and inorganic components from the root canal. It is evident that inadequate cleaning and preparation of the canal is a primary indicator of treatment failure (177).

The root canals of primary teeth are three-dimensional structures with complicated and distinct anatomies. Achieving three-dimensional obturation with comprehensive coronal, lateral, and apical closure is crucial for the success of the treatment over the long term. Radiographs remain the primary imaging modality for visualising the root canal during both the diagnostic and treatment phases; however, they only provide two-dimensional information (7).

2.5.1.1.Root Canal Sealers

The role of the sealing material is to fill the space surrounding the dentin wall of the prepared root canal and the core filling material, thus ensuring that the root canal is sealed in a liquid-tight manner. Furthermore, the sealing material contributes to antimicrobial activity by reaching lateral canals and tubules that gutta-percha cones cannot penetrate (7).

Although sealing materials have been reported to cause infection in the periapical tissues to varying degrees, this phenomenon is generally temporary and does not impair tissue healing (180).

Sealers are available in a range of formulations and properties, representing a diverse array of options. According to their composition, they can be divided into five main groups: zinc oxide eugenol (ZOE) based, calcium hydroxide based, glass ionomer based, resin based, and bioceramic sealants.

The characteristics of an ideal sealer have been delineated in the literature. It is yet to be demonstrated that any single material is capable of completely eliminating leakage or fulfilling all the desired criteria. The characteristics of an ideal sealing material are as follows:

1. The ability to form a liquid-tight seal
2. Visibility on radiographs
3. Antimicrobial
4. Stability in size and lack of shrinkage upon adjustment
5. Lack of staining
6. Non-irritation of periapical tissues
7. Non-solubility in tissue fluid
8. Biocompatibility (7,8).

2.5.1.2. Zinc Oxide Eugenol Sealers

Zinc oxide-eugenol (ZOE) paste is the most commonly used material in clinical endodontics. ZOE pastes are available in two forms: as a powder-liquid combination or as a two-paste preparation. Although *ex vivo* laboratory studies have shown that ZOE paste possesses cytotoxic properties due to the presence of eugenol, it remains clinically valuable for both animal and human studies (182). Additionally, the anti-inflammatory and antimicrobial effects of ZOE paste have been well documented (183).

These sealants have remarkable properties. Despite their advantages, ZOE sealants become low strength and high porosity and porous after curing, making them susceptible to separation in the event of tissue fluid leakage (182, 183). In response to these disadvantages of eugenol, non-eugenol sealants are available as an alternative.

2.5.1.3. Calcium Hydroxide Sealers

Calcium hydroxide is a material with a wide range of applications in clinical dentistry, including procedures such as pulp coating and apexification (184). Its therapeutic properties are primarily based on its antimicrobial action and ability to promote healing of periapical tissues (8). The high alkalinity of calcium hydroxide (pH 12) has been postulated to stimulate restorative and remineralisation processes. Furthermore, studies have demonstrated the capacity of calcium hydroxide to denature

specific intra-canal proteins. In the context of external root resorption, calcium hydroxide has been shown to halt the process and promote healing (8, 182, 185).

A variety of calcium hydroxide-based sealers are currently available, exhibiting differences in antibacterial action, cytotoxicity, and solubility (185). In comparison to alternative sealing groups, calcium hydroxide-based sealers have been shown to exhibit reduced toxicity (8). However, the issue of solubility remains a concern, as their sealing capacity to provide a proper seal has been demonstrated to be similar to that of ZOE sealers (8, 186).

2.5.1.4. Glass Ionomer Sealers

Glass ionomer (GI) paste is frequently selected for root canal obturation due to its inherent ability to chemically bond with dentin. This bonding mechanism involves a reaction between the polyacrylic acid in the GI composition and the hydroxyapatite of the dentinal surface, resulting in a strong interface between the canal walls and the filling material (187, 188). This material has many advantageous properties, such as reliable apical sealing and minimal solubility in body fluids. In addition, its antibacterial properties and continuous release of fluoride ions contribute to its clinical efficacy (189, 190).

Despite these benefits, delivering the primer uniformly to the middle and apical portions of the canal can be problematic, which may affect the material's adhesion in these regions (191, 192). In addition, once the GI material sets and bonds to dentin, it forms a dense, uniform mass that can be challenging to remove during retreatment procedures (193, 194).

2.5.1.5. Resin Sealers

Eugenol-free resin sealers are valued for their adhesive properties to root canal walls and are typically categorized into two main types: epoxy resin-based and methacrylate resin-based sealers. The methacrylate-based sealers can be further divided into four subtypes, each with unique compositional characteristics, including differences

in primer systems and whether they utilize self-etching or non-etching mechanisms (182, 195).

These resin-based materials offer several clinical benefits, such as strong adhesion to dentin, effective sealing capability, and generally favorable biocompatibility with periapical tissues (191). Nonetheless, they have also been associated with an initial inflammatory response following application, and in some cases, potential allergic or mutagenic effects have been reported (196).

2.5.1.6. Bioceramic Sealers

Bioceramic sealers are known for their excellent biocompatibility and are primarily composed of calcium silicate or calcium phosphate compounds. Among these, mineral trioxide aggregate (MTA) has emerged as a widely used root canal filling material and plays a versatile role in various endodontic procedures (197).

MTA's composition includes tricalcium silicate combined with bismuth oxide, the latter providing radiopacity to ensure clear detection on radiographic images (198, 199). When mixed with water, MTA undergoes a hydration reaction, resulting in a highly alkaline environment (pH ~12) and the formation of calcium silicate hydrates. These hydrates contribute to MTA's sealing ability by precipitating around calcium silicate particles and gradually forming an intratubular barrier, thereby enhancing its performance as a root canal material (200-202).

Despite these advantages, one of the major limitations of bioceramic-based sealers is their strong bond to dentin, which can hinder retreatment procedures and complicate post-space preparation (203, 204).

2.5.2. Core Obturation Materials

Core materials function as a physical barrier within the root canal, occupying most of the canal space to prevent reinfection or the penetration of external contaminants. These materials typically occupy the majority of the space within the canal, filling gaps or irregular spaces between the canal and canal walls. Gutta-percha is currently the most widely adopted and clinically recognized core material used in root canal obturation.

The ideal core filling material should possess the following characteristics:

1. It should be easily manipulable.
2. It should demonstrate dimensional stability.
3. It should exhibit excellent sealing properties (apical and lateral).
4. It should not irritate periapical tissues.
5. It should be radiopaque (visible on radiographs).
6. It should not stain.
7. It should be antimicrobial.
8. It should be biocompatible (7).

2.5.2.1. Gutta-Percha

Gutta-percha (GP) is currently the most widely used core material in modern endodontic practice. It is primarily produced in the form of cones composed of zinc oxide and gutta-percha, often supplemented with plasticizers and radiopaque agents to enhance handling and visibility on radiographs. Derived from the latex of certain tropical trees native to Malaysia, gutta-percha is a naturally occurring thermoplastic substance (199).

Its effectiveness as an obturation material is closely linked to its unique chemical characteristics. Gutta-percha can exist in two crystalline forms—alpha and beta—which are interconvertible based on temperature changes. When heated, it enters the alpha phase, becoming more flowable and adaptable under pressure. In contrast, at room temperature, it stabilizes in the beta phase, forming a firm and compressible mass (7, 199).

Clinically, GP offers several benefits, such as ease of use, good radiopacity, low toxicity, and thermoplasticity. However, it also presents limitations, most notably its lack of adhesion to dentin and its tendency to shrink upon cooling (199). GP cones are available in both standardized sizes with a 0.02 taper and non-standardized variants, following ISO specifications. This standardization allows practitioners to match the GP cone to the canal preparation, which is typically shaped using rotary instrumentation

systems and corresponding file sizes. A cone that matches the final file size can then be placed to ensure proper fit within the canal (7, 199).

Gutta-percha has also been employed as a core obturation material in the pulpectomy of primary molars lacking permanent successors, a technique similarly applied in permanent teeth (Figure 7) (196).



Figure 7. Utilisation of gutta-percha in primary molars (200)

2.5.2.2. Bioceramic Materials

Mineral trioxide aggregate (MTA) is extensively utilized in endodontics and may also serve as a core obturation material (200). In addition to its chemical makeup, MTA offers several favorable characteristics, including a long setting time, relatively low compressive strength, enhanced resistance to fracture, and notable antibacterial and antifungal effects. Its excellent biocompatibility has been well-documented, largely attributed to its high pH and its ability to induce hydroxyapatite formation—a mineral compound that supports bone regeneration (201).

MTA is employed in a wide range of endodontic procedures, such as repairing root perforations, managing internal root resorption, performing apexogenesis, and conducting pulp capping treatments (202, 203). These properties make MTA particularly useful in root canal therapy for primary teeth, even in cases of root resorption and congenital absence of permanent successors. As shown in Figure 8, a primary molar

without a permanent successor was obturated with MTA, and radiographic evidence of healing was observed after a six-month follow-up period (204).



Figure 8. Utilisation of Neo MTA as root filling material. 6-month follow-up (a). 24 months follow-up (b) (204).

2.5.2.3. Other Core Materials

Numerous alternative core filling materials are commercially available, yet studies have not demonstrated a statistically significant improvement in leakage prevention compared to gutta-percha (199). Among these alternatives are glass ionomer-coated gutta-percha cones and various resin-based obturation systems (205). One proposed concept is that combining a resin core with a resin sealer could result in the creation of a “monoblock”—a unified, bonded mass within the root canal space. However, current materials have yet to fully realize this objective (206).

When selecting sealers and core filling materials, it is essential to evaluate several critical properties. One key concern is solubility; many sealers are prone to gradual dissolution upon exposure to tissue fluids (196). Additionally, extrusion of these materials beyond the apex often leads to periapical irritation, except in the case of bioceramic sealers, which are biocompatible and generally non-irritating (207, 208). Adhesion to dentinal walls also varies widely among materials; for example, zinc oxide-eugenol (ZOE) sealers show minimal adhesion, whereas resin-based sealers adhere more effectively (209). Another important factor is dimensional change during setting. Most

conventional sealers contract as they set, potentially leading to voids between the sealer and canal wall. In contrast, bioceramic sealers tend to expand slightly during the setting process, potentially enhancing their sealing ability (209).

2.5.3. Application Techniques of Root Canal Materials

2.5.3.1. Application of Root Canal Sealers

Several methods have been introduced to facilitate the placement of sealers into the root canal system and to promote uniform distribution along the prepared canal walls. One such approach utilises a device called the Lentulo spiral, a screw-shaped instrument attached to a slow-speed handpiece (210).

In this technique, the Lentulo spiral is coated with sealer and then placed into the canal. Once activated, the spiral rotates, dispersing the sealer along the canal walls through centrifugal force (211). Despite its effectiveness in distributing the material, the technique presents certain drawbacks. The Lentulo spiral is inherently delicate and susceptible to separation during use, posing a risk of instrument fracture within the canal (212, 213). Additionally, its use has been linked to the accelerated setting of resin-based sealers, likely due to the mechanical mixing or stirring effect generated during rotation (213).

An alternative and widely practiced method involves the use of gutta-percha (GP) cones. In this technique, the clinician coats either a GP cone or a pre-fitted paper point with sealer and places it into the canal using a pumping or twisting motion, which aids in spreading the sealer evenly throughout the canal walls (7).

2.5.3.2. Application of Core Obturation Materials

A wide range of obturation materials and techniques are available for root canal filling, with gutta-percha (GP) being the most commonly used core material. Among the techniques utilized for GP placement, two primary methods dominate clinical practice: cold lateral condensation (CLC) and warm vertical compaction (WVC) (214).

In the cold lateral condensation technique, the procedure begins with the selection of a main GP cone, which is shaped and sized to precisely fit the canal's apical portion at the established preparation length (215). The cone is placed into the canal, and its fit is confirmed by tactile resistance, often described as a “tug-back” sensation. Once the cone is properly fitted, the canal is irrigated, dried, and coated with a root canal sealer. A spreader—either finger or hand-operated—is then inserted into the canal to a depth approximately 1–2 mm short of the preparation length (214). Secondary cones, matching the diameter of the spreader, are subsequently introduced into the spaces created by the spreader. This process is repeated until no further space is available for spreader insertion beyond the coronal third of the canal. Finally, any excess GP is cut off using a heated instrument and compacted apically with a root canal plugger (214, 215).

The warm vertical compaction technique involves the use of a main GP cone, Schilder-type pluggers, and a controlled heat source (216). The main cone is slightly shorter than the preparation length and must provide mild resistance when pulled back. After confirming its placement radiographically, the canal is irrigated, dried, and coated with sealer (216). The cone is reintroduced, and the coronal portion is removed with a heat source. A heated plugger is then inserted to progressively remove and soften the GP in the coronal and middle thirds of the canal. The softened GP is then vertically compacted using a cold plugger, sealing it apically. This sequence continues until an apical plug of approximately 4 to 5 mm of well-adapted GP is formed. Thereafter, additional small GP segments are introduced, thermo softened with the heated plugger, and compacted with a non-heated plugger. This stepwise compaction continues until the entire canal is filled with plasticised gutta-percha (216).

2.5.4. MTA as an Orthograde Obturation Material

Mineral trioxide aggregate (MTA) offers multiple clinical benefits when used for root canal obturation. These include excellent sealing properties (140), enhanced resistance to fracture, structural reinforcement of periradicular tissues, and the ability to manage resorptive defects effectively (217). In addition, orthograde MTA obturation can be considered as a pre-surgical measure in cases where access to the apical region is limited, often reducing the need for surgical root-end procedures. Once fully set, MTA

becomes highly insoluble, providing resistance to coronal leakage and acting against microbial invasion and biofilm development within the canal (217).

Despite these advantages, handling MTA in its paste form can be technically challenging and often requires clinical familiarity (218-222). The narrow, restricted anatomy of the root canal system further complicates efforts to achieve a homogenous and void-free fill. Incomplete adaptation or the formation of voids within the MTA mass has been associated with microleakage and may compromise long-term success. To address this issue, several obturation techniques have been introduced to optimize the placement and condensation of MTA (224-228).

Among the proposed methods are hand compaction using endodontic pluggers and files (229-231), the canal projection technique (229), the MTA pellet method (230), application via a Lentulo spiral (231), and the use of ultrasonic agitation to enhance flow and adaptation (232). However, the most effective technique for ensuring void-free MTA obturation has yet to be definitively determined (233).



The following table 5 offers a comprehensive overview of the utilisation of orthograde fill in conjunction with an array of methodologies and assessment techniques by MTA.

Table 5. Comparison of the methodologies and findings of existing studies (225, 227, 231, 234).

Author	Sample model	Technique used	Method of measurement	Result
Aminoshariae et al. (227)	Polypropylene tubes with an inner diameter of 0.7 mm at the apical tip	Plugger direct Ultrasonic placement	Void scores using radiographs and light microscope	Pluggers resulted in better adaptation to the tube walls and fewer voids
Yeung et al. (225)	Acrylic blocks with 30-degree curved canals and straight canals prepared with K3 (%6 taper,size 45)	Plugger Ultrasonic Activated ultrasonic	Fill density using difference in mass	Plugger with ultrasonic activation resulted in an MTA fill that statistically significantly heavier
El-Ma'ita et al. (231)	Minimally curved single canal; anterior human teeth with crowns removed prepared with Protaper F5(size 50, variable taper)	Plugger Ultrasonic Activated ultrasonic	Micro-CT percentage of voids	Ultrasonic compaction produced significantly less-dence root fillings
Keleş et al. (234)	Modaretely curved (15-20 degrees) mesial roots from mandibular molars with a Vertucci type2 canal configuration prepared with Resiproc R25(size 25, variable taper)	Plugger Ultrasonically Activated ultrasonic	Micro-CT percentage of voids	No significant difference between tecniques at apical 3 mm;no significant difference between two tecniques at the coronal half of the isthmus

The objective of root canal obturation is to guarantee the complete burial of any residual microorganisms that may persist subsequent to canal cleaning and disinfection. This is imperative to prevent future proliferation and subsequent reinfection. Furthermore, effective obturation functions as a barrier, impeding the entry of bacteria or potential nutrients from the oral cavity and periodontal and periapical fluids into the root canal system (223).

2.6.Imaging Techniques Used in The Evaluation of Root Canal Filling

2.6.1. Optical Microscopy

The classification of optical microscopes is based on their operational mode. Brightfield microscopes transmit light through the object, while polarised light microscopes reflect light from the surface of the object (235).

The distinguishing feature of these microscopes is the manner in which they provide a three-dimensional view of the specimen, achieved by combining the two reflections of the sample as perceived by each eye. This configuration affords the operator a superior perspective on the geometry of the observed object (236).

The prevalence of light microscopy in the biological and medical sciences is due to its ability to examine the structure and function of a sample through direct observation and, in many cases, noninvasively (235-238). Despite the substantial advancements in this domain, it is crucial to recognize the inherent limitations of this method. Despite the technological sophistication of microscopes and stereoscopes, with their advanced optical systems capable of achieving resolutions as fine as a few micrometers, the integrity of the image can be compromised by the characteristics of the specimen. For example, the specimen's shape and texture have been shown to have a substantial impact on resolution, often resulting in unclear representations that impede analysis (237). Furthermore, the examination of samples through optical microscopy is inherently constrained to the surface (238).

2.6.2. Scanning Electron Microscopy

Scanning electron microscopy (SEM) was introduced as an advancement over conventional light microscopy, enhancing its core principles to achieve greater imaging capabilities (239). This method involves directing a focused beam of high-energy electrons onto the sample, enabling detailed two-dimensional and three-dimensional visualization of microstructural features with high spatial resolution (240). SEM allows for the analysis of surface features up to approximately 1 μm in depth, offering critical information about the sample's topography, crystalline structure, and electrical properties. Although light microscopy remains a fundamental tool in many scientific fields, its magnification limit of approximately 1000 $\times$ is significantly surpassed by SEM, which can achieve magnifications up to 1,000,000 $\times$ and resolutions down to 1 nanometer or less (241).

Despite its wide applicability and ability to generate high-resolution images efficiently, SEM does have methodological constraints. Traditional SEM systems require a high-vacuum environment, as the presence of gas molecules can interfere with both the electron beam and the detection of secondary or backscattered electrons. As a result, samples must be dry and free of contaminants, a requirement that poses difficulties, particularly for biological or biomedical specimens, which are prone to dimensional changes such as shrinkage during the drying process (242).

2.6.3. Radiographs

Radiographic techniques encompass a range of imaging modalities, with traditional X-ray absorption imaging being the most commonly used. In this method, an X-ray beam passes through the sample, and the amount of transmitted radiation is measured to produce an image based on attenuation contrast (243). In addition to this conventional approach, more advanced techniques such as fluorescence X-ray tomography, dual-energy X-ray tomography, and phase-contrast X-ray tomography are available (244, 245).

Phase-contrast imaging is particularly useful for visualizing low-density materials, where conventional attenuation-based imaging falls short due to the limited differences in absorption coefficients among substances. This approach typically requires a monochromatic X-ray beam and the ability to adjust the distance between the sample

and the detector. Moreover, X-ray diffraction methods can be employed to generate detailed three-dimensional compositional maps of the sample, offering valuable structural and material insights (246).

2.6.4. Computed Tomography

Computed tomography (CT) is a three-dimensional, sample-preserving imaging method that relies on the differential X-ray signal reduction of various materials. One of the key advantages of CT is its ability to capture time-lapsed data without altering the sample, which has led to the concept of “four-dimensional imaging,” where time serves as the fourth dimension. Because samples remain unaltered during scanning, they can undergo additional testing or be used for in-situ experiments. Moreover, CT generally requires minimal sample preparation, making it ideal for fragile specimens that might deform if physically sectioned (247).

In certain applications, contrast agents may be introduced to improve image clarity, though these typically do not compromise the integrity of the sample. CT is also a versatile multiscale technique, capable of imaging from the millimeter level using clinical or industrial systems, down to submicron resolution with nano-CT setups. This flexibility allows for high-resolution analysis of various materials, including biological tissues and microelectronic components. Additionally, the volumetric data obtained from CT scans can be used for numerical simulations or as the basis for three-dimensional models in additive manufacturing processes. A major limitation of CT lies in the need for sufficient atomic number (Z) contrast to ensure image quality (248).

It is widely acknowledged that improvements in resolution are generally associated with increased acquisition and operational costs. Although low-energy, non-ionizing radiation presents a more economical imaging option, it comes with trade-offs such as limited penetration and reduced resolution. Furthermore, as the size of the sample increases, spatial resolution often decreases. Conversely, achieving higher resolution typically requires extended scanning durations. The application of sample-preserving and non-invasive imaging modalities is especially valuable in materials science, while the use of non-ionizing radiation contributes to minimizing potential health risks (249).

2.6.4.1. Micro-Computed Tomography

Micro-computed tomography (micro-CT) is fundamentally an X-ray imaging method that utilises a cone-beam X-ray source along with a rotating sample stage to achieve sub-micron spatial resolution. The term “micro-CT” is essentially a shortened form of “high-resolution computed tomography.” Aside from resolution, one of the most notable differences between clinical CT systems and lab-based micro-CT systems lies in their scanning geometry. In clinical CT imaging, both the X-ray source and detector rotate around a stationary patient, whereas in laboratory micro-CT setups, the sample itself rotates while the X-ray source and detector remain fixed. Additionally, medical CT scanners typically use fan-beam geometry, while micro-CT systems rely predominantly on cone-beam geometry (250).

The basic operating concept of micro-CT involves acquiring a series of X-ray projection images by rotating the sample, positioned between a stable X-ray generator and a fixed detector. These projections are then reconstructed using specialized algorithms to produce detailed cross-sectional slices of the sample (251).

One of the key advantages of in vivo micro-CT systems is their ability to scan the same specimen at multiple time points, making them particularly useful in longitudinal studies. Micro-CT also enables comprehensive three-dimensional evaluation, including assessments of material density, porosity, structural thickness, and other morphometric parameters (252, 253).

While dense materials such as bone can be imaged with high clarity and minimal preparation, one limitation of micro-CT is its reduced capacity to distinguish soft tissues due to their low X-ray absorption properties. However, this limitation can be effectively addressed through the use of contrast-enhancing agents, as demonstrated in numerous experimental studies (254).

2.6.4.1.1. The Fundamental Principles of Micro-CT

Computed tomography (CT) is a sample-preserving imaging modality that exploits the differences in how various materials reduce X-ray signal intensity to generate cross-sectional representations of objects or biological tissues. The change in X-ray

intensity as it passes through a material is described mathematically by the Lambert–Beer law:

$$I = I_0 - \mu x$$

In this expression, I represents the transmitted X-ray intensity, I_0 is the initial or incident intensity, μ is the linear attenuation coefficient (LAC), and x corresponds to the thickness of the object. The LAC is influenced by the density and atomic number of the material, as well as the energy of the X-rays used during scanning (249).

As the X-ray beam passes through the material, a portion of its photons is absorbed, depending on the specific LAC. The unabsorbed photons that continue through the object are captured by a detector, often a high-resolution charge-coupled device (CCD), placed on the opposite side. These detected signals are used to construct a two-dimensional projection image that reflects variations in X-ray signal reduction—essentially a shadow image. The sample is then incrementally rotated, typically by 180° or 360°, to collect projection images from numerous angles. Hundreds or even thousands of such projections are acquired and subsequently processed using reconstruction algorithms to generate a detailed three-dimensional model. One widely used reconstruction method is a modified version of Feldkamp’s back-projection algorithm (252).

Following image reconstruction, post-processing is typically required to extract quantitative data. One of the standard procedures in this step is image segmentation, where grayscale attenuation images are transformed into binary or multi-bit datasets (e.g., 2-bit) to facilitate analysis. Often, this analytical phase is more time-intensive than the scanning process itself due to the large volume of image data involved (253).

In laboratory-based micro-CT systems, the X-ray source generally consists of a tube configured in a cone-beam geometry. This setup introduces geometric magnification, making the distances between the X-ray source and both the object and detector crucial for determining image scale. Magnification (M) can be computed as:

$$M = \frac{SDD}{SOD}$$

To allow for standardized comparison and reproducibility, the concept of the Hounsfield Unit (HU), or CT number, was introduced. In this scale, water is assigned a value of 0 HU, and air is set at −1000 HU (252). The HU value of a material can be calculated using the following formula:

$$HU = 100 \times \frac{\mu - \mu_{water}}{\mu_{water} - \mu_{air}}$$

In the equation above, μ is the LAC of the material being imaged, μ_{water} is the LAC of water, and μ_{air} is that of air. Image quality in CT imaging is influenced by multiple parameters, including the voltage and current settings of the X-ray tube. Additional factors such as sample rotation speed, exposure duration, and the inherent quality of the specimen must also be carefully controlled. Furthermore, both the type of detector and the reconstruction algorithms employed play a role in determining final image clarity. Even minor misalignments during sample mounting can result in significant imaging artifacts, emphasizing the need for precise and stable positioning (252).

2.6.4.1.2. The Resolution of Micro-CT

The resolution can be calculated using the following equation:

$$R = \frac{d}{M} + \left(1 - \frac{1}{M}\right) \times s$$

In micro-CT imaging, R denotes the voxel size, d represents the detector resolution, M refers to the system magnification, and s indicates the focal spot size of the X-ray source. The typical spatial resolution for medical and industrial CT scanners ranges from approximately 70 to 1000 μm , whereas micro-CT and nano-CT systems offer higher resolutions, typically between 5 and 150 μm .

As with many imaging and characterization techniques, there is an inverse relationship between spatial and temporal resolution in micro-CT applications. Achieving higher spatial resolution requires acquiring a large number of slices, which demands numerous incremental movements of the sample during rotation. To minimize motion-related artifacts, it is essential to introduce a stabilization delay following each rotational step. However, even high-intensity X-ray sources cannot fully compensate for the time

lost due to these delays. As a result, high-resolution scans may require extended acquisition times, often lasting several hours (252).

2.6.4.1.3. Imaging Artifacts in Micro-CT

The presence of imaging artifacts during micro-CT measurements can be attributed to a variety of factors. However, the majority of these artifacts can be corrected to some extent during the image reconstruction step. The inherent properties of the samples may result in errors during the imaging process. For example, the shape of wet samples may be altered during the imaging process due to the effects of drying. Such occurrences can be averted by ensuring that the samples are hermetically sealed (249).

The occurrence of imaging artifacts can be further exacerbated by increasing asymmetry in the sample. To ensure the accuracy of the reconstruction, it is imperative to define the rotation axis with precision. In the event that the reconstruction centre is not defined with precision, this can result in the appearance of a tail-like artifact (253).

2.6.4.1.4. The Data From The Micro-CT

The fundamental output obtained from micro-CT imaging is based on variations in X-ray signal reduction, which yields a quantitative absorption map in either two or three dimensions. This dataset can be further refined through post-processing techniques. Micro-CT enables the detection of pores, fractures, and structural anomalies, allowing for the visualization and assessment of the internal architecture of materials in three dimensions. In this capacity, micro-CT serves as a powerful qualitative diagnostic tool. Nonetheless, it is also capable of delivering detailed quantitative metrics such as porosity, pore size and shape, connectivity, orientation, spatial distribution, volume fraction, and local density variations (254).

3. MATERIALS and METHODS

3.1. Study Design & Sample Preparation

This study complied with the ethical norms of the institution in charge of human research as revised in 2008. In order to fulfil the objectives of this project, an *in vitro* study was designed and approved by the Yeditepe University Clinical Research Ethics Committee. Inclusion criteria for the samples and possible benefits to the subjects were described in the protocol submitted to the board of the clinical research ethics committee. In addition, informed consent processes and confidentiality procedures were also analysed (acceptance date: 19/10/2023, acceptance number: 2023/1794).

A power analysis was conducted using the G*Power (v3.1.9.2) program to determine the required sample size. With a 95% confidence interval ($1-\alpha$), and 95% test power ($1-\beta$), an effect size of $f=1.598$, and a minimum of 12 samples, (4 in each group), the study should include a minimum of 12 samples. In consideration of the potential for sample loss, the number of samples was increased by 20% to yield a total of 15 samples, with 5 in each group. Based on since each primary molar has three root canals, the total sample size corresponds to 45 canals.

The samples selected for this study were obtained from extracted primary molars of patients with various indications for extraction at Yeditepe University Faculty of Dentistry. Informed consent was obtained from the paediatric patients and their families. Although the study had no direct or indirect adverse effects on the patients and their families, only the teeth of volunteer families were included in the study (Appendix 1).

Inclusion criteria for the extracted primary molars:

1. Absence of root abnormalities,
2. Presence of a least 2/3 of the root length,
3. Absence of radiographic calcifications,
4. No fractures or cracks in the root canals,
5. Absence of internal/external root resorption

Exclusion criteria for the extracted primary molars:

1. Root abnormalities
2. Root resorption exceeding one-third of the root length
3. Radiographically confirmed calcifications
4. Fractures or cracks in the root canals
5. Internal resorption

The specimens utilised in the present study were obtained from primary molars that were indicated for extraction in the treatment of pediatric dental patients aged between 3 and 10 years who were referred to Yeditepe University Faculty of Dentistry , Department of Pediatric Dentistry. It was determined that patients should be at least three years old but not yet ten years old, as this is when primary molars typically reach adequate root length. Consequently, children between the ages of three and ten , along with their parents, were invited to participate in the study. While the extracting primary molars with intact roots was not the preferred option according to the prevailing treatment approach, this procedure was deemed more appropriate for patients undergoing treatment under general anaesthesia, where radical treatments were a priority. Consequently, the teeth of these patients were included in the study.

3.2.Storage Conditions of The Samples

The collected teeth were disinfected by cleaning the root surfaces in the Hard Tissue Laboratory of Yeditepe University Faculty of Dentistry for preparation and then stored in 5.25% sodium hypochlorite (NaOCl) solution for 2 hours. The specimens were maintained in distilled water at room temperature for one month before root canal preparation.

The teeth were maintained in distilled water at 4°C until the commencement of the experiments. The roots were then meticulously cleaned with a sponge in order to remove any extraneous matter that might have adhered to their surface.

3.3.Determination of the Working Length

Once a sufficient number of teeth had been obtained, an access cavity was opened for the specimens. The working length was then determined using a 10# K-type file (Dentsply®, Maillefer, Ballaigues, Switzerland), based on the root length as seen from the apex with a $\times 1.5$ dental loupe and headlight (Dr. Kim DKH-50, Gyeonggi-do, Korea) (Figure 9).

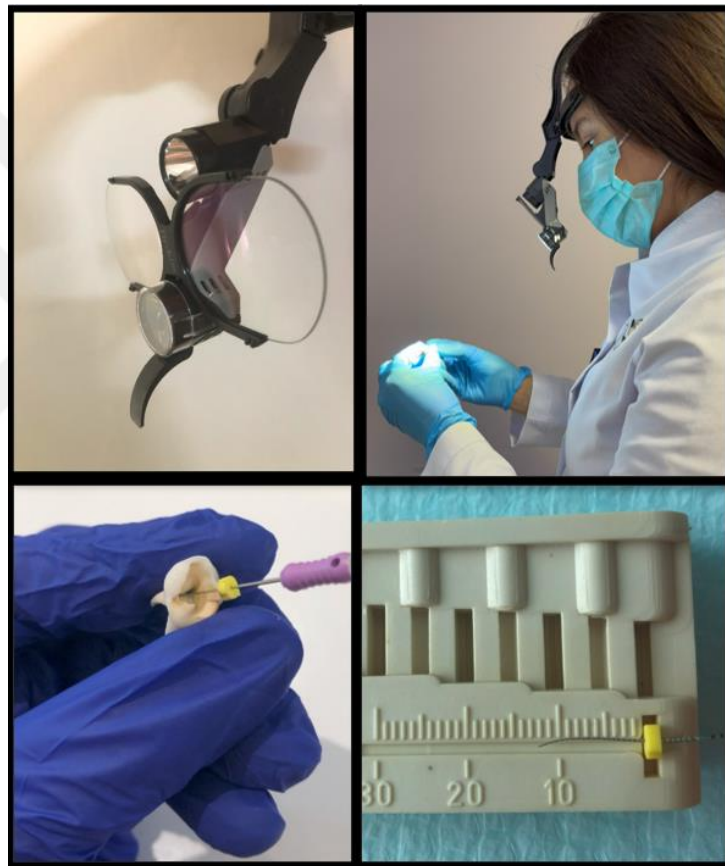


Figure 9. 10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland), dental loupe and headlight (Dr.Kim DKH-50, Gyeonggi-do, Korea) used in the research.

3.4.Preparation of Root Canals

All chemomechanical root canal preparations were conducted by a single trained operator, and the biomechanical preparation was performed according to manufacturer's

instructions. Each file was used on a maximum of five teeth, as recommended by the manufacturer.



Figure 10. EndoArt Pedo Blue File (EndoArt, İnci Dental, İstanbul, Turkey) used in the research

The EndoArt Pedo Blue Rotary files were utilised under the instructions provided by the manufacturer (Figure 10).

1. Before commencing preparation with rotary instruments, the glide path was prepared with #10 and #15 K-files.
2. Initial preparation was performed using an EndoArt Pedo Blue File (EndoArt, İnci Dental, Istanbul, Turkey), specifically, #15.06 blue file, followed by #20.04 and then #25.04. Each set of instruments was utilised to prepare up to five canals with the aid of a Motopex endodontic motor (Woodpecker, Guangxi, China). The files were meticulously monitored for any deterioration between procedures.
3. The identical irrigation protocol was employed in all study groups. During the biomechanical preparation, the root canals were irrigated with 1% NaOCl (2 ml) and sterile saline solution (2 ml) using a 27-gauge needle (Ayset, Adana, Türkiye). Finally, all canals were dried with paper points (size 25.04) (DentPlus, DiaDent, Cheongju-si, South Korea).

The endomotor speed was set at 300 revolutions per minute (rpm), while the torque value was set to 2.0 Newton-centimetres (Ncm). No alteration in either speed or torque was observed during operation at these designated values.



Figure 11. Motopex endodontic motor (Woodpecker, Guangxi, China) used in the research

The specimens that had undergone root canal preparation were then preserved in distilled water.

3.5.The Root Canal Filling Materials in the Study and Control Groups

A computer and a basic random number generator program (Python software foundation, USA) were employed to divide the samples into three groups of five teeth each. The teeth were allocated to the study and control groups using simple randomisation.

Table 6. The brand names and manufacturers of the root canal filling materials in the study and control groups and number of specimens

Group	1	2	3
Material	Proroot MTA (Dentsply®, Maillefer, Ballaigues, Switzerland)	Neosealer Flo (Avalon Biomed, Houston, TX, USA) and gutta percha (Diadent, Cheongju, Korea)	AH Plus (Dentsply®, DeTrey, Maillefer, Ballaigues, Switzerland) and gutta percha (Diadent, Cheongju, Korea)
n	5	5	5

Once the teeth had been numbered, they were placed in a storage container for transfer to the Micro-CT Laboratory of Ankara University Faculty of Dentistry where the Micro-CT analyses were carried out (Figure 12).



Figure 12. The preparation and enumeration of 15 human primary molars was conducted before imaging.

Table 7. The general properties and composition of the root canal filling materials used in the study

Materials	Manufacturer	LOT	Composition
ProRoot MTA White	Dentsply Tulsa Dental, Hohnson City, Germany	359788	Powder: Portland cement, bismuth oxide, calcium sulfate dihydrate, tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite Liquid: Water
Neoseal Flo MTA	Avalon Biomed, Bradenton, Florida, USA	2022042604	Tantalite (< 50%), Tricalcium Silicate(< 25%), Calcium Aluminate(< 25%), Dicalcium Silicate (< 10%), Grossite (< 6%), Tricalcium Aluminate(< 1%), Calcium Sulfate (< 1%)
AH Plus Sealer	Dentsply, De-Trey Konstanz, Germany	2401000828	Zirconium dioxide (50–75%), tricalcium silicate (5–15%), dimethyl sulfoxide (10–30%), lithium carbonate (< 0.5%), thickening agent (< 6%)
Gutta Percha	Diadent, Cheongju, Korea	010324	Zinc Oxide (66%), Barium sulphate (11%), Stearic Acid (3%), Gutta Percha (20%)

3.6. Scanning of the Samples with Micro-CT and Analysis of Images

The specimens were placed in the holder of the micro-CT device for stabilization during the scanning procedure and scanned with a desktop micro-CT scanner (SkyScan1275; Bruker micro-CT, Kontich, Belgium) to generate three-dimensional images. Projection images were acquired at 80 kV, 125 uA, 16,001 um pixel size, 360 degrees rotation, and 0.2 degrees rotation. The duration of the scans was 60 minutes. The teeth were then randomly distributed to three different groups. Once the filling procedures had been completed for each group, micro-CT scans were performed again using the same parameters. The specimens were positioned on the identical micro-CT holder stand and scanned with the same settings used for the initial scanning procedure. The micro-CT device utilised for scanning is illustrated in the Figure 13 below.

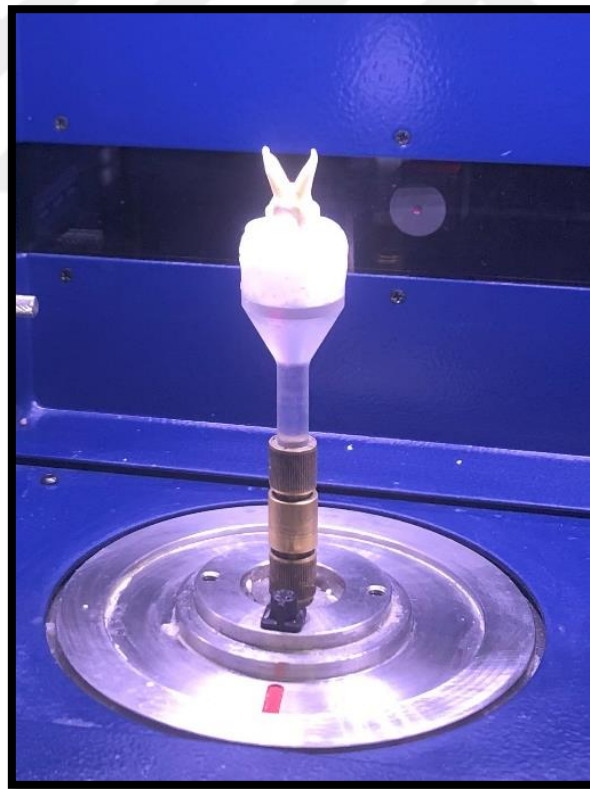


Figure 13. The specimens were fixed in the tomograph with the help of a carrier and a paraffin wax holder.

The obtained three-dimensional reconstruction data were created using post-threshold based segmentation using a special software, NRecon version 1.6.9.4; Skyscan, and then imaged using Dataviewer Programme version 1.5.2.4; Bruker Micro-CT (Figure 14).



Figure 14. Dataviewer Programme version 1.5.2.4; Bruker Micro-CT used in the research.

3.7.Root Canals Filling Procedures

Following the scanning procedure, the root canals of the specimens were filled according to the manufacturers' instructions in each group. The root canals in the first study group were filled with Proroot MTA (Dentsply®, Maillefer, Ballaigues, Switzerland), those in the second study group were filled with Neosealer Flo (Avalon Biomed, Houston, TX, USA) and gutta-percha (Diadent, Cheongju, Korea). The root canals in the control group were filled with AH Plus sealer (Dentsply®, DeTrey, Maillefer, Ballaigues, Switzerland) and gutta-percha (Diadent, Cheongju, Korea).

Proroot MTA, which is manufactured as a package containing the powder part and a liquid micro-dose ampule, was designated for administration in the first group (Figure 15). In this group, the powder and liquid components were combined according to manufacturer's instructions, forming a paste.

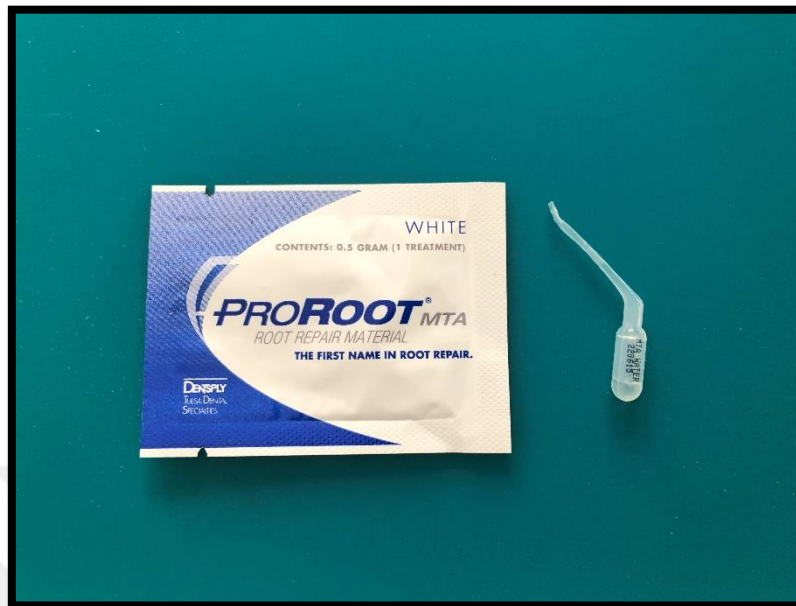


Figure 15. ProRoot MTA White (Dentsply Tulsa Dental, Hohnson City, Germany) used in the research

1. ProRoot® MTA powder was dispensed onto a mixing pad, and ProRoot® liquid was gradually added to the powder from a microdose ampule. Subsequently, the material was stirred with the liquid for approximately one minute to ensure complete hydration of the powder particles.
2. Subsequent to the placement of the MTA in the designated endodontic cavity, it was carefully guided into the canal utilising a plugger. Initially, pluggers (Fanta Dental Materials Co., Ltd., Shanghai, China) were used to insert the MTA into the root canal. Spreaders numbered #40, #35, #30 and #25 and paper points with the same number were used to deliver the material to the root tip.



Figure 16. Pluggers (Fanta Dental Materials Co., Ltd., Shanghai, China) used in the research.

Neoseal Flo MTA is formulated as a ready-made paste in a single tube (Figure 17). In the second study group that employed the Neoseal Flo technique, the canal was filled with sealer from the apex to the coronal at a slow speed. The sealer was efficiently delivered to the root tip by means of a flexible flo tip. During filling, the flexible tip exhibited a tendency to rise up coronally, allowing for pressure-free filling. The main cone of #25 0.4 gutta-percha was placed in each canal. The gutta-percha was trimmed at the orifice with a heated ball burnisher.



Figure 17. Neosealer Flo (Avalon Biomed, Houston, TX, USA) used in the research.



Figure 18. Gutta Percha #25,.04 taper (Diadent, Cheongju, Korea) used in the research.

The teeth in the control group were filled with AH Plus and gutta-percha using the cold lateral compaction technique. The master cone was number #25 with 0.4 taper gutta-percha, while spreaders number #20 and number #15 and gutta with the same were used as the secondary cones. The number 0.2 taper was selected as the preferred secondary cone.



Figure 19. AH Plus Bioceramic Sealer (Dentsply, De-Trey Konstanz, Germany) used in the research.

3.8.The Storage Conditions of the Samples After Filling

The teeth were filled with a flowable composite resin (G-ænial™ Universal Injectable Universal Light-Cured Radiopaque Injectable Composite; GC, Tokyo, Japan) (Figure 21).



Figure 20. G-ænial™ Universal Injectable Universal Light-Cured Radiopaque Injectable Composite used in the research.

The samples were stored in a humidified incubator (Memmert INE 400, Germany) at 37°C with 100% humidity for a period of seven days in the Hard Tissue Laboratory at Yeditepe University Faculty of Dentistry. This procedure was performed to ensure the paste hardened completely (Figure 22).



Figure 21. Memmert Oven (Memmert INE 400, Germany) used in the research.

3.9. Scanning of Samples with Micro-CT and Analysis of Images

The scan was then transferred to CTan software (version 1.13.5.1) for image analysis. It was hypothesised that the inflexion point of the micro-CT absorption histogram between the dentin and filling material compartments might serve as an applicable segmentation threshold to delineate the boundaries of the tissues. The volumes of the filling materials before and after filling were calculated in mm³, and the mean values were then determined for each sample. The average percentage of residual filling material was colour coded. The change in the filled and empty volume of the canal was also examined.

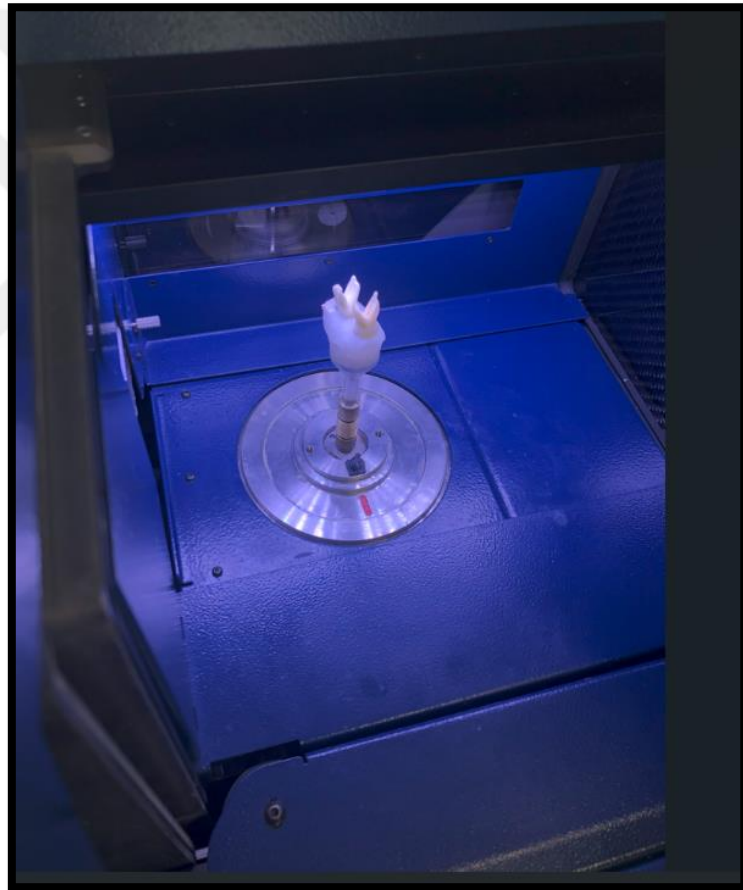


Figure 22. Subsequent micro-CT imaging of the specimens was performed following the completion of root canal treatment.

The micro-CT images were analysed and the parameters related to root canal filling quality were evaluated. The 2-dimensional images obtained from the initial and subsequent scans were saved on the computer as pre- and post-instrumentation folders, respectively.

The images were then imported into the CTvox program for three-dimensional analysis. The pre and post-filling images were repositioned in all three planes using DataViewer software (version 1.5.6.2, Bruker), with the pre and post-filling images overlaid on the software to ensure standardization of position (Figure 24).

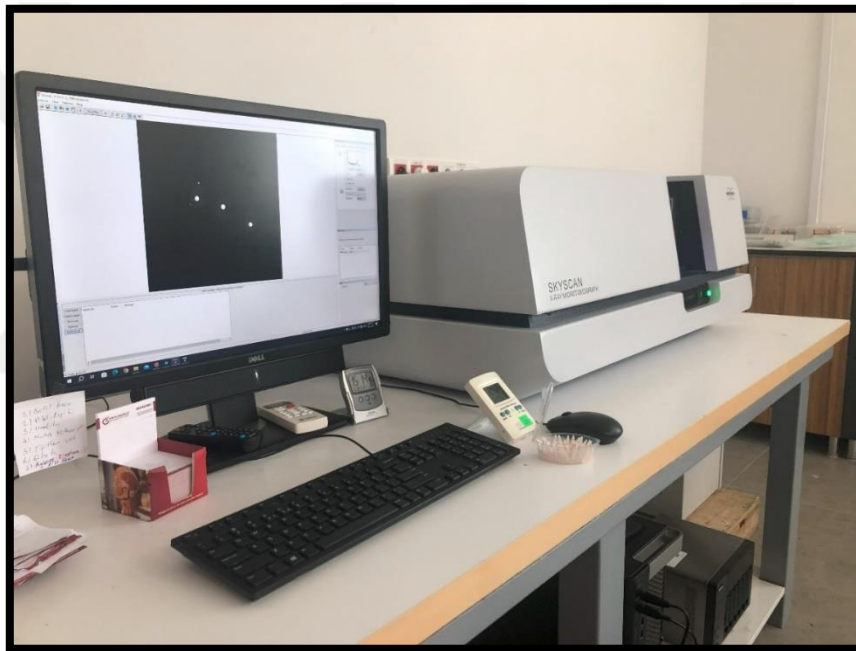


Figure 23. DataViewer software (version 1.5.6.2, Bruker).

The precise positioning of the pre- and post-filling images was achieved by mounting them on a custom-made fixed block and employing a software-controlled iterative overlay. The grayscale images permitted a quantitative comparison of the matched root canals before and after filling. The images were imported into CTAn software (version 1.20.3.0; Bruker) to calculate the change in canal volume in the unfilled space.

3.10. Volume Change Calculations

The volume change was determined by subtracting the values before and after filling using the CTAn program. The software allows the user to obtain the desired sections from the 3D image. Furthermore, adjusting the brightness and opacity values allows the removal of "unwanted" voxels before calculating the final pulp and root canal cavity volume. It allows thresholds to be set for teeth to standardize volume measurements. The shortest distance between the cemento enamel junction (CEJ) and the point 0.5 mm above the apex was determined in matched sections before and after filling by overlapping the canal models in accordance with the previously described methodology.

The threshold permitted the delineation of shades of gray, thereby facilitating the determination of empty canal volume and the identification of areas filled with material. To ensure consistency in measurement, the region of interest was selected in the images. The pre- and post-filling images were then superimposed in DataViewer software. Subsequently, the data were imported into CTAn software for analysis of the aforementioned parameters. The threshold was set, and the software was instructed to calculate the volume of the pre and post-filling 3D images.

Meanwhile, the region of interest (ROI) of the images was employed to guarantee that the appropriate and identical regions were selected for each set of images of pre- and post-filling teeth. Consequently, the measurements were also standardized. The change in volume was determined by calculating the difference between the post-filling volume of a root canal and the prepared root canal volume.

The measurement boundaries were established for the pre- and post-filling images from the CEJ to the apex.

After taking the micro-CT scans of the teeth with completed root canal filling, the following parameters were measured by comparing them with the previous images.

1. Filling Percentage %

- Shows how much of the canal is filled with filling material.

2. Closed Pore Percentage %

- It refers to the voids that are trapped in the canal filling and have no connection to the outside environment.

3. Open Pore Percentage %

- Refers to the spaces (pores) within the root canal filling that are connected to the external environment.

4. Total porosity Percentage %

- Refers to all pores (open + closed pores) within the canal filling.

3.11. Statistical Analysis

The data and measurement evaluation criteria information were given to a statistician and analyzed. Data were analyzed using the *R programming language (version 4.4.1)*. Normality of data distribution was assessed using the Shapiro-Wilk test. Shapiro-Wilk test was preferred due to the small sample size.

Comparisons between three or more groups were made as follows:

- One-way ANOVA test was preferred for normally distributed data.
- Kruskal-Wallis test was used for non-normally distributed data.

This methodological approach aims to increase the reliability of statistical results by selecting analyses appropriate to the distributional characteristics of the data.

4. RESULTS

This study evaluated the filling percentage, total porosity percentage, open porosity percentage, and closed porosity percentage of different sealers (ProRoot MTA, AH Plus + Gutta-Percha and NeoSeal Flo + Gutta-Percha). A total of 15 primary molars were utilised, with five teeth allocated to each group. Each molar had three root canals, and due to anatomical variations, the outcomes were quantified on a per-tooth basis.

4.1. Filling Percentage (%)

The pre-filling and post-filling volumes of the teeth were measured to determine the filling percentage. The results showed variation across groups:

- ProRoot MTA White Group: Filling percentages ranged from 81% to 87%, with the highest value observed in sample 5 (87%) and the lowest in sample 1 (81%). The mean filling percentage was $84.72 \pm 2.07\%$, with a median of 85 (81.6 - 87).

- NeoSealer Flo Group: Values ranged from 75% to 98%, with sample 15 showing the highest filling percentage (98%) and sample 13 the lowest (75%). The mean value was $90 \pm 9.33\%$, with a median of 95 (75 - 98).

- AH Plus Group: The filling percentages ranged between 73% and 99%, with the lowest observed in sample 6 (73%) and the highest in samples 8 and 9 (99%). The mean value was $91.6 \pm 10.9\%$, with a median of 96 (73 - 99).

A One-Way ANOVA test indicated no statistically significant difference among the groups ($p = 0.423$). The mean filling percentage value was 84.72 for ProRoot White MTA, 91.6 for AH Plus and gutta-percha, and 90 for Neosealer Flo and gutta-percha.

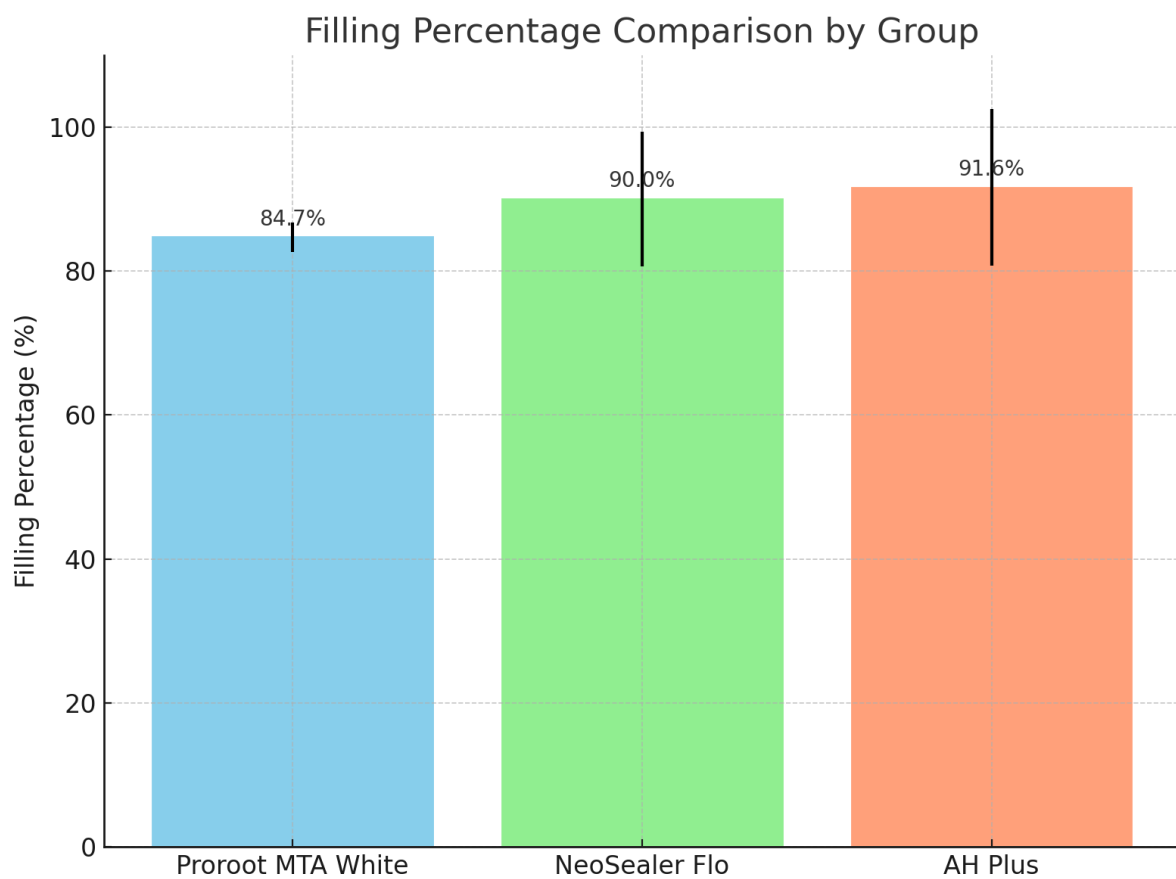
Comparison of filling percentage values among the material groups is given in Table 8, and Graph 1 presents the distribution of filling percentages in the material groups.

Table 8. Comparison of filling percentage values according to groups

Grup	Mean $\pm$ SD	Median (min-max)	Test Statistic	p
Proroot MTA White	84,72 $\pm$ 2,07	85 (81,6 - 87)	0,926	0,423 ^x
NeoSealer Flo	90 $\pm$ 9,33	95 (75 - 98)		
AH Plus	91,6 $\pm$ 10,9	96 (73 - 99)		

^x One- Way ANOVA

SD: Standart Deviation



Graphic 1. Filling Percentage by group in primary teeth

4.2.Total Porosity Percentage (%)

The total porosity percentage varied between groups:

- ProRoot MTA White Group: Ranged from 0.3011% to 0.6233%, with a mean of $0.4297 \pm 0.1477\%$ and a median of 0.3585 (0.3011 - 0.6233).
- NeoSealer Flo Group: Total porosity ranged between 0.1683% and 0.4337%, with a mean of $0.2851 \pm 0.1049\%$ and a median of 0.2851 (0.1683 - 0.4337).
- AH Plus Group: The highest porosity was observed in sample 8 (0.8836%), while the lowest was in sample 7 (0.0115%). The mean value was $0.2957 \pm 0.3657\%$, with a median of 0.1279 (0.0115 - 0.8836).

A One-Way ANOVA test showed no statistically significant difference among the groups ($p = 0.290$).

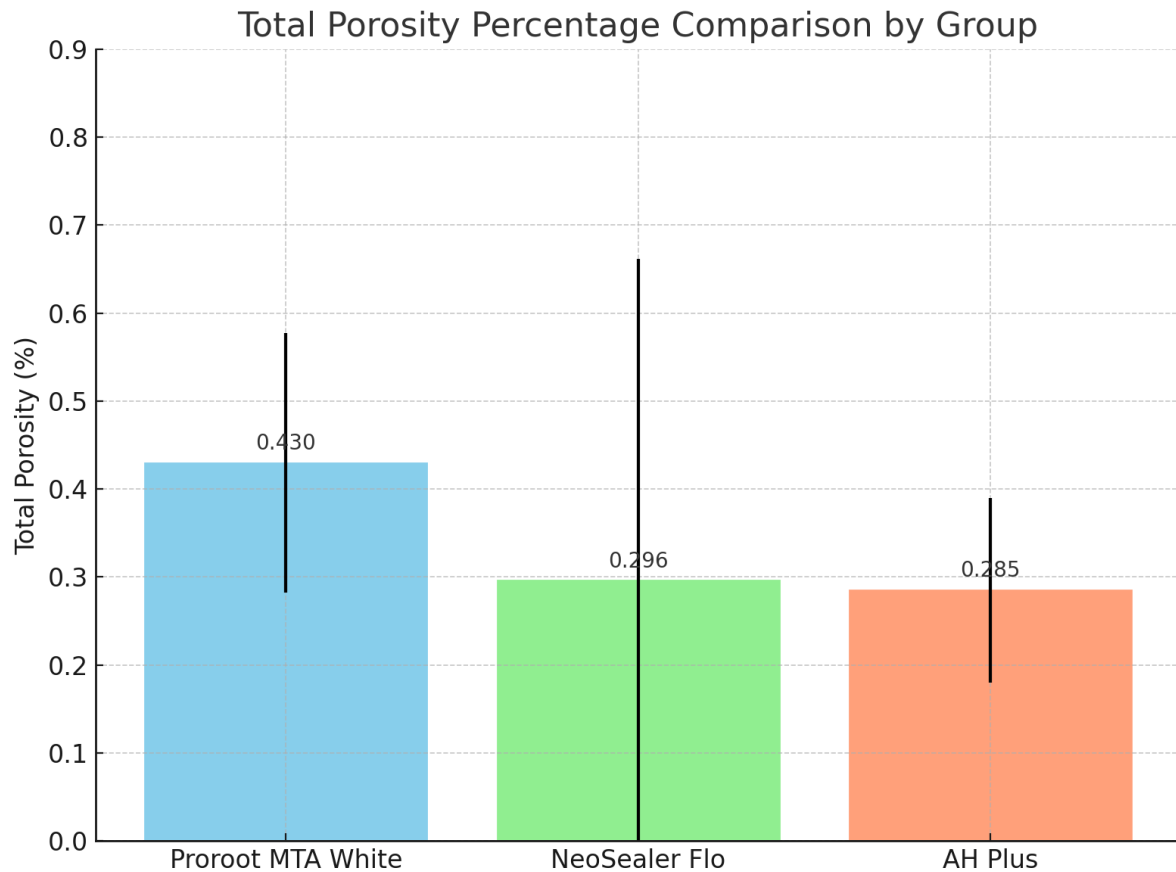
Table 9 compares the total porosity percentage among the material groups, and Graph 2 shows the distribution of total porosity percentage .

Table 9. Comparison of total porosity percentage according to groups

Group	Mean $\pm$ SD	Median (min-max)	Test Statistic	p
Proroot MTA White	0,4297 $\pm$ 0,1477	0,3585 (0,3011 - 0,6233)	1,480	0,290 ^x
NeoSealer Flo	0,2957 $\pm$ 0,3657	0,1279 (0,0115 - 0,8836)		
AH Plus	0,2851 $\pm$ 0,1049	0,2851 (0,1683 - 0,4337)		

^x One-Way ANOVA

In the analysis, revealed no statistically significant differences in mean total porosity percentage values among the study groups ($p=0.290$). The mean value was 0.4297 for ProRoot MTA, 0.2957 for AH Plus and gutta-percha, and 0.2851 for Neosealer Flo and gutta-percha.



Graphic 2. Distribution of total porosity% between the material groups.

4.3.Open Pore Percentage (%)

The open pore percentage was generally low across all groups:

- ProRoot MTA White Group: Ranged from 0.0001% to 0.0057%, with a mean of $0.0014 \pm 0.0024\%$ and a median of 0.0003 (0.0001 - 0.0057).
- NeoSealer Flo Group: Open pore percentage ranged from 0.00006% to 0.0321%, with a mean of $0.0082 \pm 0.0138\%$ and a median of 0.0006 (0 - 0.0321).
- AH Plus Group: Sample 10 had the highest open porosity (0.1191%), while some samples (6, 9, 12) showed no measurable open pore percentage. The mean value was $0.0424 \pm 0.0493\%$, with a median of 0.0362 (0 - 0.1191).

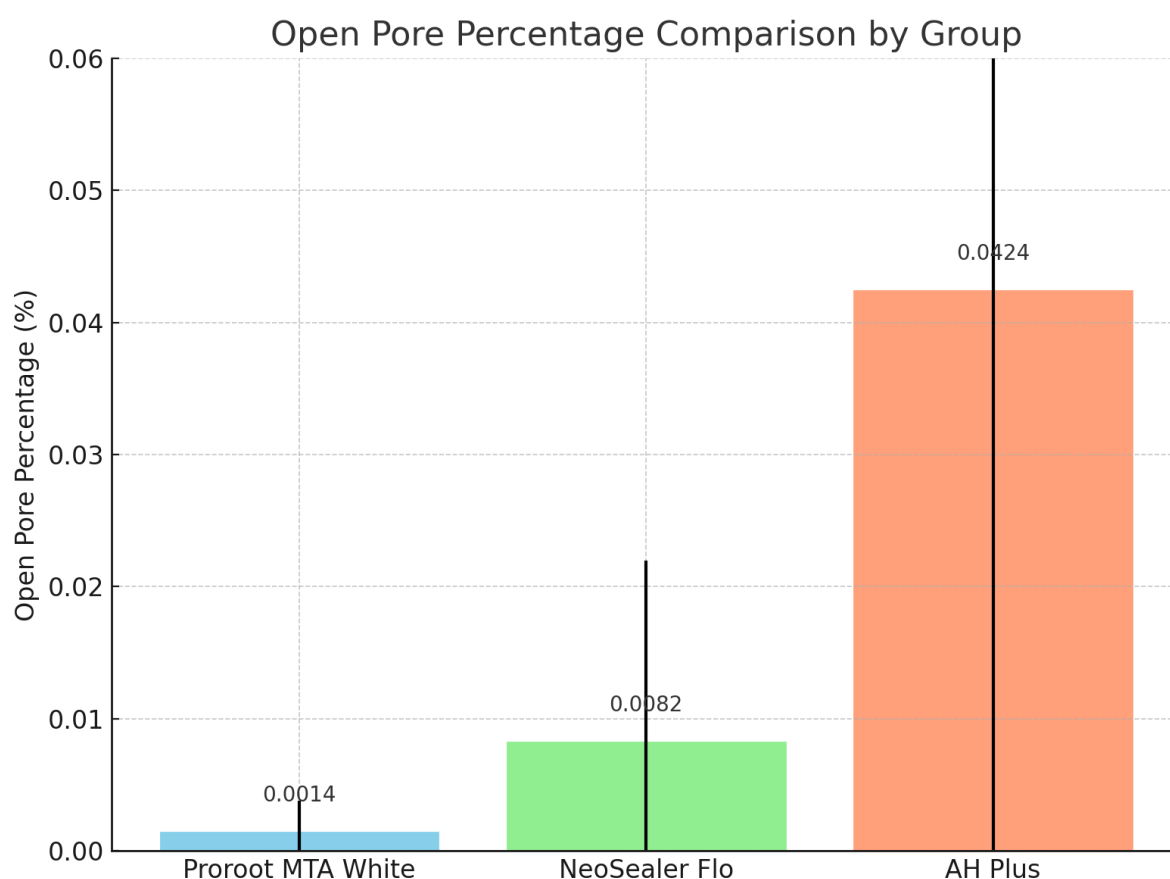
A Kruskal-Wallis H test indicated no statistically significant differences among the median open pore percentage values of the three material groups ($p = 0.762$). The median values

were recorded as 0.0003 for ProRoot MTA, 0.0362 for AH Plus and gutta-percha, and 0.0006 for Neosealer MTA and gutta-percha. Table 10 and Graph 3 presents the comparison of the percentage of open pores by group.

Table 10 . Comparison of the percentage of open pores by groups

Group	Mean $\pm$ SD	Median (min-max)	Test Statistic	p
Proroot MTA White	0,0014 $\pm$ 0,0024	0,0003 (0,0001 - 0,0057)	0,544	0,762 ^x
NeoSealer Flo	0,0082 $\pm$ 0,0138	0,0006 (0 - 0,0321)		
AH Plus	0,0424 $\pm$ 0,0493	0,0362 (0 - 0,1191)		

^x Kruskal Wallis H Test



Graphic 3. Comparison of open pore percentage etween groups

4.4. Closed Pore Percentage (%)

The values for closed pore space volume and closed pore percentage are presented in the following table 11.

The closed pore percentage varied significantly:

- ProRoot MTA White Group: Ranged from 0.3008% to 0.6232%, with a mean of $0.4284 \pm 0.1486\%$ and a median of 0.3528 (0.3008 - 0.6232).
- NeoSealer Flo Group: Values ranged between 0.1677% and 0.4017%, with a mean of $0.2766 \pm 0.0941\%$ and a median of 0.2753 (0.1677 - 0.4017).
- AH Plus Group: Sample 8 exhibited the highest closed pore percentage (0.8272%), whereas the lowest was in sample 7 (0.0029%). The mean value was $0.2535 \pm 0.3422\%$, with a median of 0.1279 (0.0029 - 0.8272). A One-Way ANOVA test showed no statistically significant difference among the groups ($p = 0.427$).

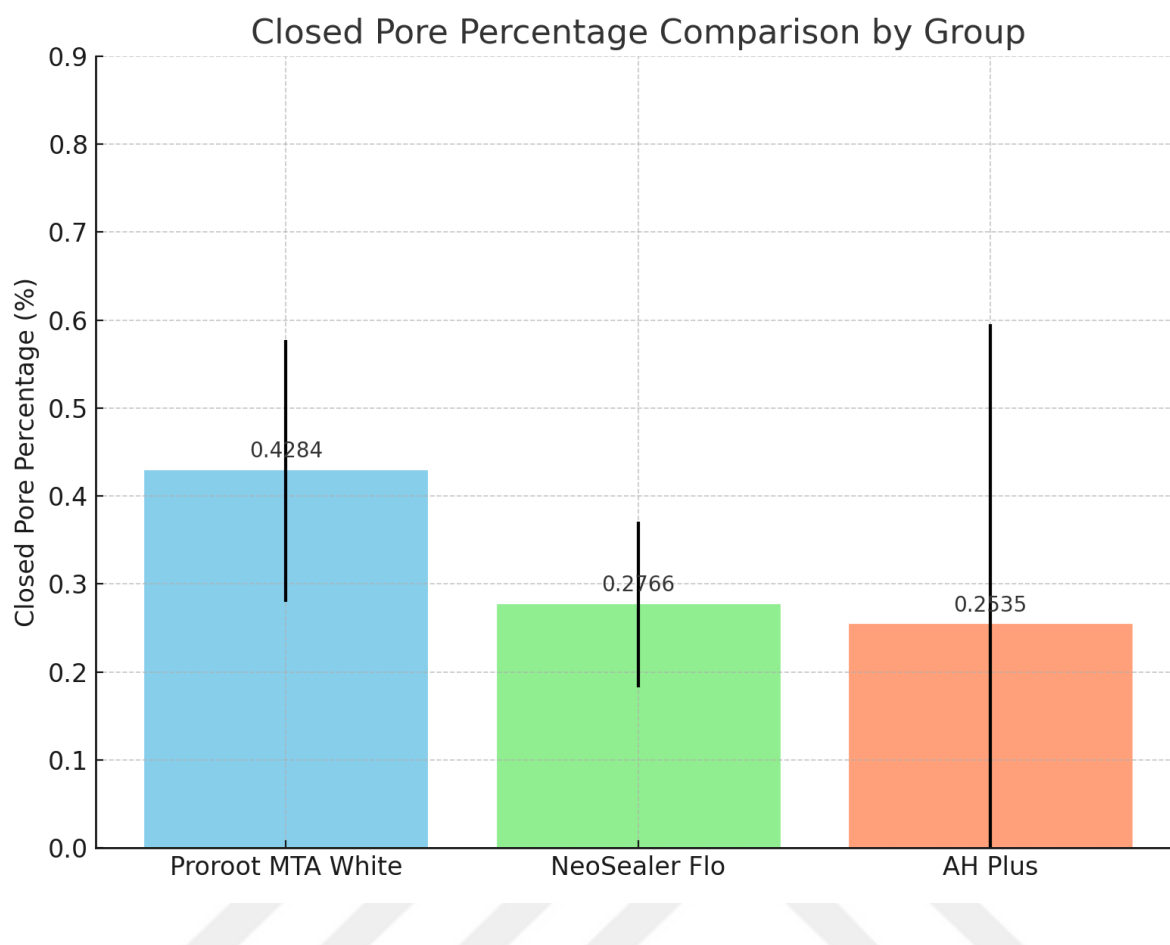
The following table 15 and graphic 4 present a comparison of the percentage of closed pores by group.

Table 11. Comparison of closed pore percentage by groups

Grup	Mean $\pm$ SD	Median (min-max)	Test Statistic	p
Proroot MTA White	$0,4284 \pm 0,1486$	0,3528 (0,3008 - 0,6232)	0,915	0,427 ^x
NeoSealer Flo	$0,2766 \pm 0,0941$	0,2753 (0,1677 - 0,4017)		
AH Plus	$0,2535 \pm 0,3422$	0,1279 (0,0029 - 0,8272)		

^x One-Way ANOVA

The mean value was 0.4284 for ProRoot MTA, 0.2535 for AH Plus and gutta-percha, and 0.2766 for Neosealer Flo and gutta-percha.



Graphic 4. Comparison of closed pore percentage between groups

The images of the specimens after root canal preparation, before filling, and micro-CT images obtained after root canal filling are presented in tables 12-14. Furthermore, colorized versions illustrating the diverse angles and textures of the filled canals are also presented in the table.

Table 12. Proroot MTA White material group post-filling micro-CT images showing the filling, dentin, and example boundaries, and comparison of these images with pre-filling micro-CT images

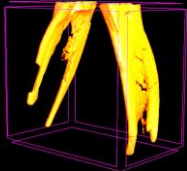
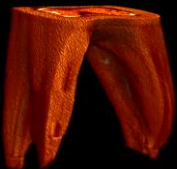
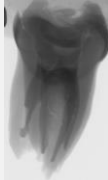
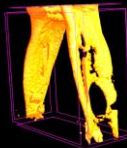
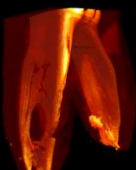
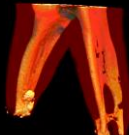
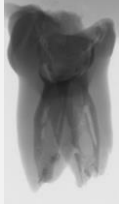
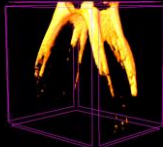
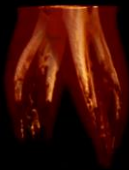
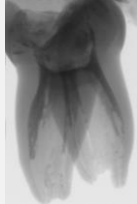
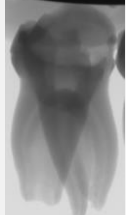
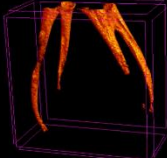
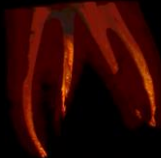
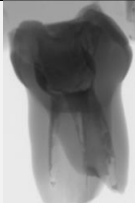
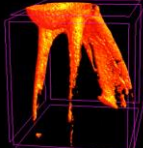
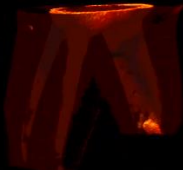
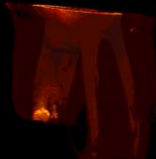
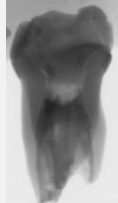
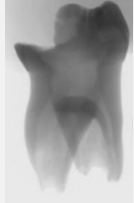
Proroot MTA White Filling Materials	Samples Outer Limits	Thickness of Dentin Surrounding the Filling	Post-Filling	Pre-Filling
				
				
				
				
				

Table 13. Neosealer Flo MTA and gutta-percha material group post-filling micro-CT images showing the filling, dentin, and example boundaries, and comparison of these images with pre-filling micro-CT images

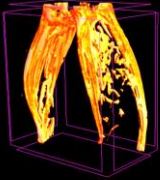
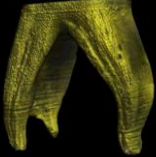
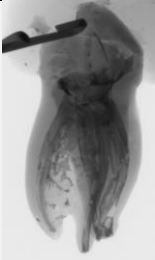
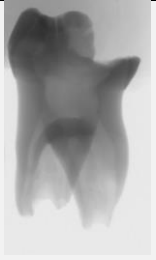
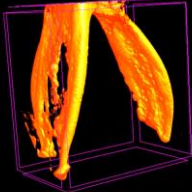
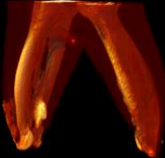
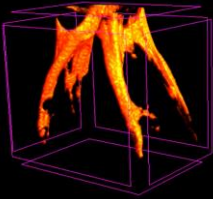
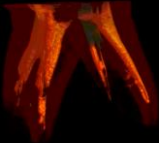
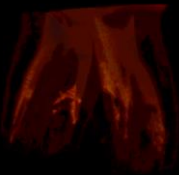
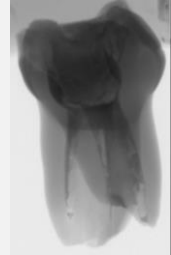
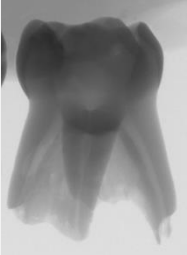
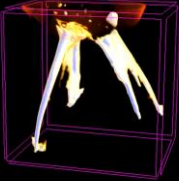
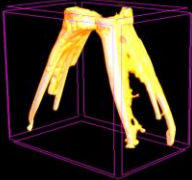
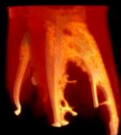
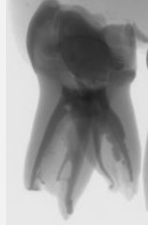
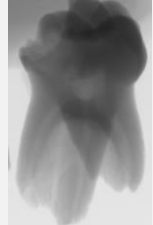
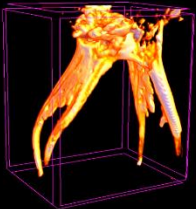
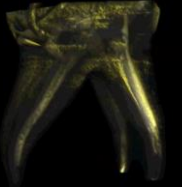
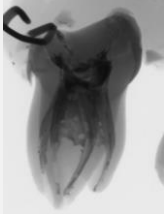
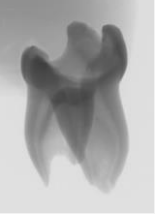
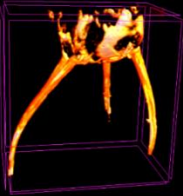
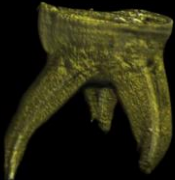
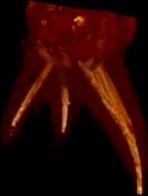
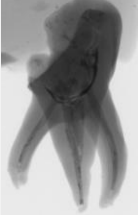
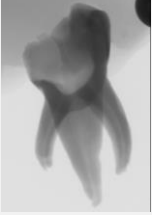
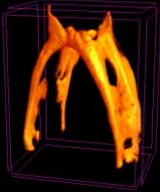
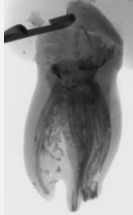
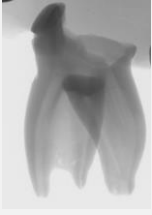
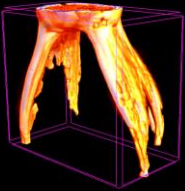
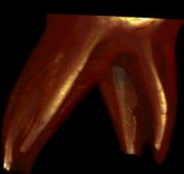
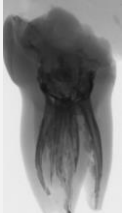
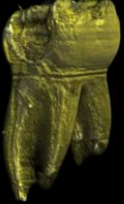
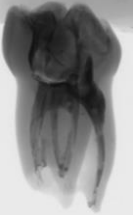
Neosealer Flo MTA and gutta-percha Filling Materials	Samples Outer Limits	Thickness of Dentin Surrounding the Filling	Post-Filling	Pre-Filling
				
				
				
				
				

Table 14. AH Plus and gutta-percha material group post-filling micro-CT images showing the filling, dentin, and example boundaries, and comparison of these images with pre-filling micro-CT images.

AH Plus and gutta-percha Filling Materials	Samples Outer Limits	Thickness of Dentin Surrounding the Filling	Post-Filling	Pre-Filling
				
				
				
				
				

5. DISCUSSION

It is imperative to recognise that primary teeth should not be regarded as mere transient structures; they fulfil critical functions in a child's growth and development. In addition to facilitating proper mastication, supporting correct speech, and contributing to facial development from an aesthetic perspective, these teeth also function as guides for permanent teeth (255). However, in certain instances, the formation of permanent tooth germs may be compromised during the developmental period of the child, leading to conditions such as hypodontia or, in more severe cases, oligodontia. In such cases of developmental anomalies, given the absence of permanent teeth to replace the primary teeth, it may be necessary to retain these teeth in the oral cavity for as long as possible (256).

In the case of primary exhibiting congenital dental aplasia, endodontic treatment is frequently recommended as a preferred alternative to extraction, with the objective of prolonging the functional lifespan of the tooth. The efficacy of this treatment is contingent upon the thorough cleaning, shaping, and sealing of the root canal system (131). Obturation is imperative for impeding bacterial penetration and fostering periapical tissue healing. However, the anatomical characteristics of primary teeth, such as thin dentin walls, physiological root resorption tendency, and variable root morphology, render this procedure complicated (257).

In recent years, the advent of sophisticated imaging technologies, most notably micro-CT, has yielded substantial advances in the evaluation of root canal treatments. This system, capable of three-dimensional analysis at the micrometer level, provides an objective and precise method for evaluating obturation quality. Its capacity to furnish significantly more detailed information than conventional radiographic methods has firmly established it as the gold standard in such *in vitro* studies (254).

In this study, three distinct obturation systems available for use in the root canal treatment in retained human primary teeth with congenitally missing permanent successors were evaluated and compared with regard to obturation qualities, employing the micro-CT imaging method. One of the materials selected for analysis, ProRoot MTA,

is a bioceramic material that has been the subject of considerable clinical research, with a strong record of success (197, 198). In contrast, NeoSEALER Flo, a recently developed bioceramic sealer, has demonstrated faster obturation when utilised with a single-cone technique (258). AH Plus represents a popular choice in the field of endodontics, specifically within conventional root canal treatments that involve the lateral condensation technique in conjunction with gutta-percha (199). A comparative analysis of these three systems was aimed to provide valuable insights to guide clinical practice and demonstrate the impact of material selection on endodontic approaches specific to primary teeth.

In the contemporary era, dental professionals are at the disposal of a plethora of materials and techniques for root canal treatment of primary teeth. Nevertheless, the extant literature offers few information regarding the performance of these materials and techniques in exceptional cases, such as those involving congenital dental aplasia. The phenomenon of congenital dental aplasia has been shown to induce an outcome wherein the primary dentition is compelled to persist within the oral cavity for a duration that exceeds its physiological limit. Endodontic interventions conducted within this study are required to guarantee not only immediate but also long-term functional outcomes. Consequently, the filling material must not only be biocompatible but also of high quality in terms of sealing ability, longevity, durability, and physical strength.

ProRoot MTA is widely regarded as the gold standard, particularly concerning its efficacy in apical sealing. However, the substance's high viscosity impedes its application and necessitates expertise for achieving uniform saturation (259). NeoSEALER Flo, due to its low viscosity, readily penetrates irregular canal surfaces. This novel root canal filling material has yielded a more homogeneous filling and reduced porosity (258). The instrument can be utilised in conjunction with a solitary cone gutta-percha. AH Plus has been demonstrated to provide adequate sealing when utilised in conjunction with the gutta-percha using lateral condensation technique. However, its epoxy-based composition and inherent shrinkage over time increase the risk of microleakage relative to bioceramics (200, 260). With respect to apical sealing, NeoSEALER Flo has the potential to offer certain advantages, including its capacity to adapt to the canal wall and its uniformity.

Nevertheless, ProRoot MTA continues to demonstrate the highest apical sealability values.

In this study, data concerning filling percentage and total porosity, including open and closed pore percentages, were also analysed. The employment of micro-CT technology facilitated the analysis of details that are imperceptible in three dimensions and at high resolution. Specifically, the evaluation of volumetric changes and porosity distribution before and after filling objectively demonstrated the materials' ability to adapt to canal morphology. The evaluation of these parameters is directly related to the long-term success of the material and the risk of infection (254).

In this regard, the study provides the first direct comparative information on the performance of three prominent filling systems. These systems are commonly used in clinical practice but have not yet been sufficiently compared in the pediatric patient group, particularly in primary molars.

The selection of obturation material plays a critical role in the success of root canal fillings. The material used must adapt to the dentin surface, provide a seal against bacterial penetration, be resistant to resorption, and be biocompatible, which is particularly important in primary teeth. The three distinct materials examined in this study—ProRoot MTA, NeoSEALER Flo with single-cone technique, and AH Plus with lateral condensation technique—demonstrate marked variations in terms of composition and application methodologies.

ProRoot MTA is a calcium silicate-based bioceramic material. Its hardening process occurs through a hydration process that utilises the moisture present in the environment. During this process, calcium hydroxyl ions are released, and the formation of hydroxyapatite, which facilitates biological bonding with tissues, is supported (260).

NeoSEALER Flo is a calcium silicate-based, flowable bioceramic sealant. The substance exhibits hydrophilic properties, enabling self-curing in a moist environment. In comparison with conventional MTA, it exhibits enhanced flowability, rendering it well-suited for utilisation in conjunction with the single-cone technique (261).

AH Plus is a two-component, epoxy resin-based, classic resin-based sealant. The curing process is achieved through chemical, which results in the formation of mechanical and partial chemical bonds to the surface of the dentin (262).

With respect to their chemical structure, both ProRoot MTA and NeoSEALER Flo demonstrate a higher degree of compatibility with the biological environment. The polymer-based composition of AH Plus has been observed to induce irritation in certain instances. It has been reported that AH Plus may cause tissue irritation and inflammation if it migrates to the periapical tissues (263-265). This phenomenon may contribute to the acceleration of resorptive processes. Furthermore, it has been observed that AH Plus demonstrates volumetric shrinkage during the hardening process, which may result in microleakage. It has been demonstrated that microleakage has the potential to increase bacterial penetration, thereby elevating the risk of resorption (266).

Numerous studies have highlighted ProRoot MTA's high biocompatibility and lack of toxicity. Research has demonstrated that, under certain conditions, the substance in question has the capacity to stimulate regeneration rather than inflammation when it comes into contact with apical tissue (258-260).

NeoSEALER Flo has been demonstrated to be biocompatible and non-cytotoxic, exhibiting comparable properties to ProRoot MTA. It has been demonstrated to possess a high antibacterial effect and has been shown to be compatible with root resorption (259).

It is noteworthy that AH Plus may exhibit a certain level of cytotoxic effect during the period preceding hardening subsequent to application. While it is generally well tolerated after hardening, there is a risk of reaction when in direct contact with the periapical region (263-265). In light of the aforementioned characteristics, MTA and NeoSEALER Flo are safer options in comparison to AH Plus with regard to biological tolerance. The utilisation of bioceramic materials is particularly recommended in primary teeth and structures that are susceptible to resorption.

It has been demonstrated that AH Plus is incompatible with physiological resorption due to the epoxy-based structure of the substance. It is imperative to exercise caution in order to avoid the potential occurrence of residual substances within the root

canal, as this may result in the initiation of pathological root resorption (265). ProRoot MTA is a material that has been safely used in endodontics for many years in terms of root tip sealing and biological compatibility (263). NeoSEALER Flo, while exhibiting analogous biological properties, offers distinct advantages in pediatric cases due to its simplified application and homogeneous filling. AH Plus has demonstrated consistent efficacy in the treatment of permanent teeth; nevertheless, its use in primary teeth should be approached with caution due to its incompatibility with resorption and the possibility of toxicity (256).

ProRoot MTA merits particular attention due to its apical sealing and biological compatibility. Its particle size is minuscule, enabling its penetration of dentinal tubules. Furthermore, the substance's alkaline pH has been shown to possess antimicrobial properties (202, 207).

In this study, ProRoot MTA was condensed into the canal using a plugger, paper point, and spreaders. This method facilitates the material's adaptation to the apical region, while ensuring stability during the setting process. However, the complexity inherent in the manipulation of MTA engenders a heightened reliance on the operator's experiential expertise. This is particularly evident in primary teeth, where the intricate structure of the root canals can impede the uniform distribution of MTA within the apical region (260).

NeoSEALER Flo is a novel bioceramic sealer that is distinguished by its high flowability and chemical bonding with dentin. The sealer's low solubility and high pH level have been demonstrated to be effective in preventing bacterial invasion. The self-curing formulation of NeoSEALER Flo obviates the necessity for additional drying in the canal (258, 261).

In this study, NeoSEALER Flo was applied using the Single Cone technique. In this technique, a single main cone of gutta-percha was utilised, meticulously shaped to conform to the internal dimensions of the canal. This method offers a practical application that can be preferred in primary teeth. The utilisation of a singular cone gutta-percha compatible with rotary systems in enlarged canals has been demonstrated to be a time-efficient approach. Nevertheless, the risk of excessive extrusion of the flowable sealer necessitates the meticulous implementation of this technique (261).

AH Plus is a conventional sealing agent derived from epoxy resin. The substance under consideration has a protracted setting time, commendable sealing properties, and minimal solubility. This substance has been observed to penetrate deeply into dentin tubules, forming a hard structure over time that effectively provides sealing. However, the biological tolerance and resorption behavior of epoxy-based materials are controversial, especially for primary teeth (256).

In this study, AH Plus was applied using the lateral condensation technique. In this technique, auxiliary cones are placed around the main gutta-percha cone, and compression is achieved with the help of a spreader. This method has gained significant traction, particularly in the context of permanent dentition (267). However, the narrow and inclined canals of primary teeth may limit the applicability of this technique. Furthermore, the pressure exerted during the process of lateral condensation has the potential to compromise teeth with thin root structures.

ProRoot MTA requires a prolonged preparation period and is challenging to apply due to its viscous consistency and extended setting time, which may present logistical difficulties in clinical settings (260, 268). The duration of the application process may be extended, particularly in cases involving pediatric patients. ProRoot MTA is the preferred material for applications such as apicalization and root tip filling (257). However, its utilisation as a root canal filling material necessitates expertise.

The injectable, premixed composition of NeoSEALER Flo, in conjunction with its rapid setting time, renders it a potentially optimal choice for pediatric patients. NeoSEALER Flo has been demonstrated to be compatible with rotary systems, thereby reducing the time required for completion of the process. Its flowability allows it to adapt well to canal walls. Furthermore, the single-cone technique has been demonstrated to be a time-efficient method (261, 269). This approach may be particularly well-suited for pediatric patients.

AH Plus is a material that is simple to mix and can be applied using conventional techniques. However, the application of lateral condensation can pose significant challenges in the context of primary teeth. Although AH Plus is a material with which most dentists are familiar due to its wide use in clinical practice, NeoSEALER Flo is the

most practical option among the groups in terms of ease of application. This approach is of particular benefit in pediatric cases, where the constraints of time and patient cooperation are significant.

In the contemporary context, micro-CT has been acknowledged as a technique that offers high precision and reproducibility in assessing the efficacy of root canal treatments (254). In this study, the quality of the filling was evaluated using pre- and post-filling micro-CT scans for each tooth. A comprehensive examination encompassed four primary parameters: filling percentage, open pore percentage, closed pore percentage, and total porosity percentage.

The filling percentage is defined as the ratio between the original volume of the canal and the volume of the filling material. It has been demonstrated that an elevated ratio corresponds to greater homogeneity and completeness in the canal filling. Clinically, this signifies enhanced protection against microbial infiltration (265).

Open pore percentage is defined as spaces where the filling material does not make full contact with the canal wall and is connected to the external environment. These areas are of particular concern regarding leakage risk and bacterial contamination.

Closed pore percentage is defined as the presence of air pockets or irregularities within the filling material. Despite their lack of direct connection to the external environment, these factors have the capacity to influence the material's mechanical strength and biological stability. Over time, closed pores may undergo a process of resorption, resulting in the formation of areas susceptible to bacterial adhesion, which can potentially lead to leakage (266).

Total porosity, defined as the sum of open and closed pores, has been identified as a reliable indicator of overall filling quality.

The present study revealed no statistically significant differences between the parameters measured in all groups. This finding suggests that the utilisation of diverse materials and application techniques resulted in comparable outcomes with regard to filling quality (267-269). When evaluated in terms of clinical applications, this finding provides dentists with greater flexibility in material selection. The data obtained from the

study indicated that the three distinct obturation systems that were evaluated (ProRoot MTA, NeoSEALER Flo + single cone technique with gutta-percha, and AH Plus + lateral condensation technique with gutta-percha) demonstrated comparable performance with regard to filling and pore percentage parameters. The findings of the present study demonstrate both congruence with and discrepancies from existing literature in certain aspects.

ProRoot MTA has demonstrated its reliability over time, particularly with regard to its efficacy in establishing an apical seal. Torabinejad et al. (1995) demonstrated in their initial clinical studies that MTA exhibited superior performance in terms of sealing and tissue compatibility as a root-end obturation material (257). In their 2014 study, Yildiz and Tosun reported that MTA was successful as a root canal obturation material for primary molars (270). However, the methods employed in these studies were predominantly rooted in radiographic and subjective evaluations. In this particular context, the objective comparison facilitated by micro-CT supports the conclusion that MTA is not only biocompatible but also sufficient in terms of physical filling quality.

NeoSEALER Flo can be used with the single cone technique thanks to its high flowability and chemical bonding property with dentin. When compared to AH Plus sealer, NeoSEALER Flo did not show a statistically significant difference in push-out bond strength (271).

In a subsequent comparison between NeoSEALER and AH Plus, when applied using the single-cone technique, NeoSEALER Flo demonstrated higher bond strength in the apical region (272).

In this study, we demonstrated that this result is applicable even in systems with a more challenging morphology, such as primary teeth. However, according to Radwanski et al (2024), the excessive flowability of this material increases the risk of extrusion, which should be carefully evaluated, especially in resorptive primary teeth (269).

AH Plus, an epoxy-based sealer, has been utilised in endodontic treatments for a considerable duration. Its efficacy, particularly in conjunction with lateral condensation,

has been well-documented. However, the applicability of lateral condensation in primary teeth is limited. Omran et al. (2019) reported that the application of the AH Plus + lateral condensation system in primary teeth was challenging, but a successful filling percentage could be achieved due to the physical properties of the sealer (273). The present study lends further support to these findings, demonstrating that filling quality remains comparable despite the presence of technical challenges.

In the case report documented by Ansari and Mirkarimi (2008), the 12-month clinical and radiographic follow-up of root canal filling using gutta-percha and ZOE sealer in second primary molars without permanent successors was presented (274). In this study, gutta-percha was identified as the material of choice for root canal filling due to its ability to preserve teeth over an extended period. This determination was influenced by the material's non-absorbable characteristic, which is crucial for long-term dental maintenance. The extant literature supports the utilisation of permanent materials, such as gutta-percha, in cases where permanent teeth are not present (274).

Zinc oxide eugenol (ZOE)-based preparations have been among the most commonly used materials in primary tooth root canal treatments for many years. Nevertheless, the utilisation of ZOE in such cases is accompanied by significant drawbacks. Firstly, ZOE is a resorbable material. When employed in the context of wide root canals, it may undergo resorption over time, resulting in the formation of voids within the canal space and subsequent bacterial contamination (275).

Asgary & Fazlyab (2017) described the use of Calcium Enriched Mixture (CEM) cement in a single-session pulpectomy procedure in a case report on a mandibular second primary molar tooth with necrotic pulp and an apical lesion. The 12-month follow-up revealed that the tooth remained symptom-free, functionally present in the mouth, and exhibited interradicular bone healing (10). These findings indicate that CEM cement can yield successful outcomes due to its biocompatible structure and properties that support apical healing.

A comparison of CEM Cement and ProRoot MTA reveals that they are fundamentally based on the same chemical composition, as both are calcium silicate-based bioceramic materials. While materials such as ProRoot MTA have decades of use

and multi-centre clinical study data, CEM Cement is supported by a limited number of long-term clinical studies.

Jeevanandan (2017) documented the use of Biodentine™ as a root canal obturation material in a maxillary second primary molar tooth devoid of a permanent successor in a case report. In this case, the tooth remained functional during the two-year follow-up period, and no pain or periapical changes were detected in the patient. The efficacy of this approach is attributed to the biocompatible structure of Biodentine™, its high dentin-like mechanical properties, and its compatibility with the process of root resorption (276).

The primary distinctions between the Biodentine™ study and our own study are evident in the study design and evaluation methods employed. The Jeevanandan (2017)'s study is predicated on a case report, and the results are evaluated using clinical and radiographic follow-up (276). In contrast, the present study involves a larger sample group and utilises micro-CT analyses to objectively measure the volumetric quality and porosity levels of the filling. This method provides more detailed information about the penetration of the filling materials into the dentinal tubules and the presence of microscopic voids within the material.

However, the findings of both studies indicate that the utilisation of materials exhibiting high biocompatibility in primary teeth devoid of permanent successors is imperative for ensuring long-term functional success. Calcium silicate-based materials, including Biodentine™ and MTA-derived or bioceramic-containing materials such as ProRoot MTA and NeoSealer Flo, exhibit minimal tissue irritation, osteogenic potential, and appropriate resorption profiles, rendering them optimal choices for such clinical scenarios.

In summary, the case report on Biodentine™, as well as the findings of the present study, support the utilisation of biocompatible materials in the endodontic treatment of primary teeth devoid of permanent successors (276).

In a case report Zarekar et al. (2025), patients of pulpectomy performed using gutta-percha and bioceramic MTA Putty in two primary molars without permanent

successors were presented. The 12-month follow-up period revealed the efficacy of both materials, with the bioceramic MTA Putty receiving particular recognition for its biocompatibility and superior sealing properties (277). These results underscore the significance of endodontic treatment materials in terms of long-term biological compatibility and tissue response.

The findings of Jeevanandan (2017) and Zarekar et al. (2025) have demonstrated the potential efficacy of biomaterial-containing materials in primary tooth endodontics (276, 277). Zarekar et al. (2025) defined the 12-month success rate of bioceramic MTA Putty as the absence of clinical symptoms and radiographic healing (277). In contrast, it was determined in our study that ProRoot MTA demonstrated superior filling quality due to its low porosity and high filling rates. These findings support the potential advantages of bioceramic-based materials in primary tooth treatments in terms of both biological compatibility and physical filling properties. Conversely, the characteristics of the gutta-percha material utilised in the case report by Zarekar et al. (2025) or the techniques employed were not thoroughly delineated (277). The present study systematically evaluated both the single-cone technique combined with NeoSealer Flo and the lateral condensation technique applied with AH Plus. The effects of different filling methods on filling quality were compared. Our study revealed the application difficulties and negative effects of lateral condensation on filling homogeneity in teeth with complex canal anatomy, such as primary teeth.

The findings of this study are consistent with existing data in the literature. A study conducted in Türkiye by Bezgin et al. (2016) compared the efficacy of ProRoot MTA and gutta-percha/AH-Plus root canal treatments. The study reported that after a three-year follow-up period, 80% of patients treated with MTA experienced successful outcomes, while only 30% of those treated with gutta-percha/AH-Plus achieved success (9). The findings indicate that MTA facilitates more efficacious clinical outcomes due to its biocompatibility, tissue-healing properties, and superior sealing capacity. Although ProRoot MTA White had the lowest filling percentage and the highest total and closed porosity compared to the other groups, there was no statistically significant difference compared to the other materials. Based on the clinical results of Bezgin et al., ProRoot MTA is a preferable and successful clinical material (9).

The low porosity and high filling rates of bioceramic-based materials, such as ProRoot MTA and Neosealer Flo, suggest that these materials may be suitable alternatives for long-term use in primary teeth where no permanent replacement is available. These findings support the American Academy of Pediatric Dentistry'(AAPD) recommendation that non-resorbable or slowly resorbable materials should be preferred in teeth without permanent successors (278).

In a case report by Ansari and Mirkarimi (2021), a second primary molar tooth without a permanent successor was treated using gutta-percha, and it was reported that the tooth remained functional in the mouth for a 1-year follow-up period, the infection healed, and no adverse effects were observed. These findings suggest that gutta-percha may be a biocompatible option for primary teeth and may demonstrate long-term clinical performance (274). A similar finding was reported in a 2022 case series showing that root canal fillings with gutta-percha in infected primary molar teeth preserved tooth function and successfully resolved infection after one year (279).

However, given its inert nature, gutta-percha is incapable of forming chemical bonds with the root canal walls. Consequently, the efficacy of preventing apical and lateral leakage is contingent on the sealer utilised and the technique of application (180, 181, 186). Furthermore, in the context of physiological root resorption in primary teeth, the non-biodegradability of gutta-percha has the potential to result in adverse long-term effects. However, these effects were not observed in the case report by Ansari and Mirkarimi's one-year follow-up study (274).

Nagani et al. (2022) posits that gutta-percha's short-term clinical success is substantiated (279). However, our study provides more detailed information by analysing micromorphological factors that may be related to the long-term success of filling materials. In particular, bioceramic-based materials such as ProRoot MTA and Neosealer Flo, which have lower porosity, may offer significant advantages in terms of infection control and long-term sealing. In summary, the present study has yielded results consistent with the general trends reported in the extant literature. When applied appropriately, the utilisation of these materials ensures comparable obturation quality. Nevertheless, this does not negate the necessity to deliberate on technical challenges and

biological compatibility. It has been observed that new-generation materials such as NeoSEALER Flo may require formulations optimised for primary teeth.

In the context of endodontic treatment for primary teeth exhibiting germ deficiency, the primary objective should be to ensure long-term survival within the oral cavity, rather than merely achieving immediate success. This necessitates a multifaceted evaluation of the material's capacity to adapt to the canal's configuration, its resistance to dissolution in the biological environment, its resistance to resorption, its lack of toxicity, and its ease of clinical application when necessary (7,187).

This study is the only one to examine the quality of three different obturation systems used in primary teeth with germ deficiency using micro-CT. However, it is imperative to acknowledge the study's limitations, which should be taken into account when evaluating its scientific value.

5.1.The Limitations of the Study

Fistly, the study was conducted under *in vitro* conditions. The teeth were meticulously extracted from the oral environment and subsequently analysed under stringent sterile conditions. However, in a real clinical setting, factors such as saliva, mucosal contact, and the level of cooperation of pediatric patients can directly affect treatment success. Furthermore, factors such as pressure changes in occlusion and functional stresses can influence the behaviour of filling materials over time. Consequently, the findings of this study cannot be directly applied to clinical practice; however, they provide substantial guidance.

Secondly, the sample size is limited. A total of 15 teeth were evaluated, with 5 teeth in each group having 3 root canals. Due to variations between root canals, they were not evaluated separately; instead, calculations were based on the total volume of the root canals of each tooth. While this number is sufficient for statistical analysis, larger sample groups are required to better explain variations. The procurement of teeth, particularly the ethical considerations associated with the extraction of primary teeth with sound roots and germ deficiency, constitutes the most significant limiting factor in such studies.

In the event that replica teeth had been utilised in the design of our study, as opposed to original human teeth, it would have resulted in greater access to a more abundant array of samples and the attainment of a superior degree of standardisation. However, the group under examination did not consist of single-rooted teeth. In the study by Kooanantkul et al., volume measurements were made on both natural teeth and replica teeth, and the two sets of measurements were then compared. The volume measurements of the replica teeth exhibited analogous results to those of the natural teeth in the incisor group; however, this phenomenon was not observed in the molar teeth. This finding suggests that replicas are only suitable for the evaluation of obturation quality in uncomplicated root canal systems (280).

As the root volumes of natural tooth root canals cannot be standardized and can vary greatly, the measurements were calculated based on the percentage change in tooth volume pre-filling and post-filling. Although volume and area values were also provided, percentage measurements were used for statistical evaluation.

Thirdly, ultrasonic irrigation was not used in the study. Some recent studies suggest that ultrasonic irrigation may enhance sealer penetration by more effectively cleaning dentinal tubules (281).

Success in endodontic treatment depends not only on the mechanical shaping of the root canal but also on the effectiveness of chemical irrigation. Ultrasonic irrigation, which has replaced classic manual irrigation methods, offers significant advantages in terms of more effective liquid penetration into the canal system and debris removal (281). However, the use of this method in primary teeth, especially in roots that are physiologically prone to resorption, should be carefully evaluated.

Primary teeth have thinner dentin walls and narrower root canals compared to permanent teeth (282). Additionally, due to the physiological resorption process, root tips may be enlarged, the apical foramen may be open, and the walls may be irregular (283). These conditions increase the risk of microfractures in dentin walls or weakening of root structure during ultrasonic activation due to high-frequency vibrations.

Ultrasonic devices use vibration energy to facilitate deeper penetration of irrigation solutions. Dentinal tissue with limited thickness is low-tolerant to this vibration. According to Peters et al., 2012, these vibrations may lead to microscopic cracks or dentinal detachment, particularly in the apical region (254).

The process of physiological root resorption, which is present in primary teeth, can be accelerated or become uncontrolled through the use of ultrasonic irrigation. Vibration-induced mechanical and thermal effects have been demonstrated to elicit an inflammatory response in periodontal tissues or increase healing (281). In primary teeth intended to be retained in the oral cavity for an extended period due to germ deficiency, this risk may result in clinical failure.

The apical foramen of primary teeth may undergo physiological enlargement. The robust flow induced by ultrasonic activation has the potential to leak irrigation solutions through these open apices. This can result in severe soft tissue damage, especially when using solutions toxic to tissue, such as sodium hypochlorite.

The morphology of primary tooth roots is typified by a curved, short, and narrow configuration. The absence of adequate alignment between the tips of ultrasonic devices and the aforementioned structures has the potential to elevate the risk of contact with canal walls and consequent excessive dentin removal during the application process. Furthermore, given the reduced tolerance of pediatric patients for protracted treatment regimens, time-consuming techniques such as ultrasonic irrigation may present significant challenges in terms of implementation.

Despite the substantial body of positive data on the effectiveness of ultrasonic irrigation in permanent teeth, studies on primary teeth remain limited. Silva et al. (2010) found that manual irrigation provided comparable cleaning for primary tooth roots, with ultrasonic systems offering no additional benefits (284). This prompts further inquiry into the effectiveness of ultrasonic irrigation in primary tooth roots.

In the absence of ultrasonic irrigation, a smear layer may persist on the canal wall, potentially compromising the bonding capability of bioceramic sealants. However, given the objective of this study, which was to evaluate the materials utilised in accordance with

technical standards, control was ensured by processing each group with the same irrigation protocol.

Furthermore, the present study exclusively evaluated filling quality based on volume. It is imperative to note that other salient parameters, including but not limited to bacterial leakage, biological tissue response, and post-filling marginal adaptation, were excluded from the evaluation. Consequently, subsequent studies should encompass designs integrating bacterial leakage tests with micro-CT, histological analyses, and prolonged clinical follow-ups.

Notwithstanding these limitations, the present study offers significant data that illuminates the clinical applications of obturation materials and techniques for primary teeth exhibiting germ deficiency. Consequently, subsequent studies should employ multidisciplinary approaches, encompass larger sample sizes, and be supported by *in vivo* clinical observations and biological parameters.

6. CONCLUSIONS

Based on the findings of this *in vitro* study, no statistically significant differences were found among the three root canal filling materials ProRoot MTA, NeoSealer Flo with gutta-percha and AH Plus with gutta-percha in terms of filling quality or porosity characteristics ($p > 0.05$). The results are summarized below:

1. The highest mean filling percentage was observed in the AH Plus group ($91.6 \pm 10.9\%$), and the lowest in the ProRoot MTA group ($84.72 \pm 2.07\%$). However, the difference was not statistically significant ($p = 0.423$).
2. The highest total porosity was observed in the ProRoot MTA group ($0.4297 \pm 0.1477\%$), while the lowest was in the NeoSeal Flo group ($0.2851 \pm 0.1049\%$). The difference among groups was not statistically significant ($p = 0.290$).
3. The AH Plus group exhibited the highest open porosity ($0.0424 \pm 0.0493\%$), whereas the ProRoot MTA group showed the lowest ($0.0014 \pm 0.0024\%$). The differences among the groups was also not statistically significant ($p = 0.762$).
4. The ProRoot MTA group showed the highest closed porosity ($0.4284 \pm 0.1486\%$), followed by the NeoSeal Flo ($0.2766 \pm 0.0941\%$) and AH Plus ($0.2535 \pm 0.3422\%$) groups. No statistically significant difference was detected among the groups ($p = 0.427$).

The success of endodontic treatment in primary teeth depends on the selection of appropriate filling materials and techniques. In this study, the quality of filling in primary molars was evaluated *in vitro* using micro-CT, and three different obturation materials and techniques were used. This study is one of the limited number of studies that comparatively evaluates the filling quality of different obturation systems available for use in retained primary teeth with missing successors undergoing pulpectomy. Additionally, micro-CT was employed to analyse the adaptation of filling materials to canal walls and the resulting voids in detail.

In the context of endodontic treatment of primary teeth, the selection of obturation material and technique is extremely important. Treatment selection will vary depending on the root structure of the tooth, the duration of treatment, and the child's cooperation.

The findings of this study indicate that the obturation quality is comparable between different materials and techniques. In conclusion, within the limitations and given the findings of this *in vitro* study, novel bioceramic materials can be used besides conventional root canal filling materials in the filling procedures of retained primary molars with missing successors; however the results should be confirmed with further *in vitro* studies evaluating the antibacterial and sealing abilities. Additionally, evidence based clinical data obtained by prospective randomised clinical investigations is essential.

The results of this study were obtained by comparing the root canal filling quality of three different material groups - namely ProRoot MTA (Dentsply®), NeoSealer Flo (Avalon Biomed, USA) with gutta-percha (Diadent, Korea), and AH Plus (Dentsply®) with gutta-percha (control) - applied to the root canals of primary molars according to their clinical use. The null hypothesis (H_0) “there is no difference between the filling efficiency and obturation quality of different obturation protocols applied to primary molars” was confirmed; whereas the alternative hypothesis (H_1) “there is a difference in filling efficiency and obturation success between different root canal filling protocols applied to primary molars” was rejected.

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8. APPENDICES

8.1. APPENDIX A



Sayı: 37068608-6100-15- 2580
Konu: Klinik Araştırmalar
Etik Kurul Başvurusu hk.

19.Ekim.2023

Sorumlu Araştırmacı Prof. Dr. Senem Selvi Kuvvetli
(Yeditepe Üniversitesi, Diş Hekimliği Fakültesi Çocuk Diş Hekimliği AD., İSTANBUL)

Klinik Araştırma başvurunuz ve ek belgeleriniz Yeditepe Üniversitesi Klinik Araştırmaları Etik Kurulu (KA EK) tarafından incelendi. Etik Kurulumuz tarafından, başvurunuzun ve ek bilgilerinizin değerlendirilmesinin ardından, **18 Ekim 2023** tarihli toplantısında “**Sürekli Dişlenmede Kalması Gereken Süt Azı Dişlerinde Kullanım İçin Uygun Farklı Kök Kanalı Dolgu Materyallerinin Obturasyon Kalitesinin Karşılaştırılması: İn Vitro Çalışma**” başlıklı klinik araştırma protokolünüz ve başvurunuz uygun bulunmuştur.

Onay bilgileri:

Referans No : 2023/1794
Onay Süresi : Ekim 2023 -Ekim 2024
Yetkili Personel : Prof. Dr. Senem Selvi Kuvvetli

Yeditepe Üniversitesi Klinik Araştırmalarda Etik Kurulu Sağlık Bakanlığı, TİTCK Başkanlığın onayı ile oluşturulmuştur. Söz konusu projeniz, “İlaç ve Biyolojik Ürünlerin Klinik Araştırmaları Hakkında Yönetmeliği, Tıbbi Cihaz Yönetmeliği ve uluslararası etik ilkeler çerçevesinde değerlendirilmiş ve onaylanmıştır. Bu araştırma projenizle ilişkili raporların, onay tarihinden itibaren her 12 ayda bir sunulması ve klinik araştırma belgelerinin 14 (ondört) yıl süreyle saklanması gerekmektedir. Proje ile ilgili raporların bir yılın sonunda sunulmaması, projenin devam etmediğinin onayı olarak değerlendirilecektir. Bilginize sunulur.

Saygılarımla,

Prof. Dr. Turgay Çelik

Klinik Araştırmaları Etik Kurul Başkanı

8.2. APPENDIX B

	KLİNİK ARAŞTIRMALAR ETİK KURULU BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU	TARİH: VERSİYON: 2.0
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ÇOCUKLAR İÇİN BİLGİLENDİRİLMİŞ OLUR FORMU

Araştırmanın Adı: Sürekli Dişlenmede Kalması Gereken Süt Azı Dişlerinde Kullanım İçin Uygun Farklı Kök Kanalı Dolgu Materyallerinin Obiturasyon Kalitesinin Karşılaştırılması: Bir *In Vitro* Çalışma

Sevgili,

Benim adım Diş Hekimi Ekin ÖZDEMİR. "Tedavisi gereği çekilmiş süt dişleri üzerinde bir araştırma yapıyoruz. Amacımız bu dişlerde gerektiğinde kökünün tedavisi yapıldığında en başarılı şekilde iyileşmesini sağlayan malzemeyi bulmak. Araştırma ile yeni bilgiler öğreneceğiz. Bu yeni bilgiler, senin gibi hasta olan çocukların iyileşmesinde yardımcı olabilir, senin de bu araştırmaya katılmayı öneriyoruz. Araştırmayı ben ve başka bazı doktorlar birlikte yapıyoruz. Bu araştırmaya katılacak olursan; senden tedavi için çekilmiş olan dişini isteyeceğiz. Bu katılımanın seni hiçbir şekilde seni etkilemeyecek. Bu araştırmanın sonuçları başka doktorlarla da paylaşacağız; ama senin adını söylemeyeceğiz. Bu araştırmada aramızda olmak için, karar vermeden önce; anne ve babanla da konuşmalı, onlara danışmalıydın. Biz zaten anne ve babana bu araştırmadan bahsedeceğiz; onların izinlerini alacağız. Anne ve baban "tamam" deseler bile; önemli olan, senin kararın. Sen, araştırmaya katılmayı kabul etmeyebilirsin. Bu araştırmaya katılmak senin isteğine bağlı ve istemezsen katılmazsın. Bu nedenle hiç kimse sana kızmaz ya da küsmez. Önce katılmayı kabul etsen bile, sonradan vazgeçebilirsiniz; bu tamamen sana bağlı. Kabul etmediğin durumda da doktor abi/ablalar, muayene ve diğer işlemlerde, önceden olduğu gibi, sana gene çok iyi davranacaklar. Aklına şimdi gelen veya daha sonra gelecek olan soruları günün her saatinde, istediğin zaman (hatta gece bile), beni cep telefonumdan arayıp sorabilirsin. Telefon numaram ve adresim bu kâğıtta yazıyor. Bu araştırmaya katılmayı kabul ediyorsan aşağıya lütfen adını ve soyadını yaz ve imzalam. İmzalıdıktan sonra sana ve ailene bu formun bir kopyası verilecektir.

Çocuğun Adı, Soyadı:

Çocuğun imzası ve tarih:

Velisinin Adı, Soyadı:

Velisinin imzası ve tarih:

Açıklamaları Yapan Hekimin Adı, Soyadı, unvanı: Diş Hekimi Ekin ÖZDEMİR

cep tel: (

İmza

Sorumlu Araştırmacı: Prof.Dr.Senem SELVİ KUVVETLİ

 T.C. YEDİTEPE ÜNİVERSİTESİ	KLİNİK ARAŞTIRMALAR ETİK KURULU BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU	TARİH: VERSİYON: 2.0
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Araştırmanın Adı: Sürekli Dişlenmede Kalması Gereken Süt Azı Dişlerinde Kullanım İçin Uygun Farklı Kök Kanalı Dolgu Materyallerinin Obtürasyon Kalitesinin Karşılaştırılması: Bir *In Vitro* Çalışma

Çalışma *in-vitro* bir araştırma olup siz gönüllülerin çocuklarının yalnızca geri dönüşümsüz pulpa iltihabı veya diş absesi olan süt dişlerinin tedavisi gereğince çekimi yapılmış süt azı dişleri kullanılacaktır.

Araştırmanın amacı: Çalışmamızın amacı, ilgili süt dişlerinin altından sürekli dişlerin gelişimi olmadığı durumda kanal tedavisi gerektiren bir enfeksiyon gelişirse süt dişinin iyileşmesi için en uygun materyale karar vermek adına kök kanal dolgu materyallerinin karşılaştırılmasıdır. Araştırmada kullanılacak materyaller çekimi yapılmış süt azı dişlerinde uygulanacaktır.

Araştırmaya devam etmeniz için öngörülen bir süre bulunmamaktadır. Tedavi amaçlı olarak çocuğunuzun süt azı dişlerinin çekiminin ardından bu araştırmaya başka bir katkınızın bulunması beklenmemektedir.

Araştırmaya katılması beklenen tahmini gönüllü sayısı en az 15'tir.

Araştırmada uygulanacak tedavi bulunmamaktadır. Çocuğunuzun tedavisi gereği çekilen süt azı dişleri araştırmaya dâhil edilecektir. Yalnızca çekilmiş dişin araştırmaya dâhil edilmesi, çocuğunuzun üzerinde bir uygulama yapılmayacak olması herhangi bir riske maruz kalmayacağınızın kanıtıdır.

Araştırma ileri dönemde altındaki kalıcı diş mevcut olmayan süt dişlerinde gereksinim duyulabilecek olası kanal tedavilerinde kullanacağımız materyallerin seçimine karar vermek açısından klinik yarar sağlayacaktır.

Araştırmanın kapsamında herhangi bir sorumluluğunuz bulunmamaktadır.

Araştırmaya çekilmesi gereken süt azı dişlerinin kullanılması konusunda verdiğiniz izinle katılımınız isteğe bağlıdır ve istediğiniz zaman, herhangi bir cezaya veya yaptırıma maruz kalmaksızın, hiçbir hakkınızı kaybetmeksizin araştırmaya katılmayı reddedebilir veya araştırmadan çekilebilirsiniz.

Kimliğinizi ortaya çıkaracak kayıtlar gizli tutulacak, kamuoyuna açıklanmayacaktır. Araştırma sonuçlarının yayımlanması halinde dahi kimliğiniz gizli tutulacaktır. İzleyiciler, yoklama yapan kişiler, etik kurul, kurum ve diğer ilgili sağlık otoritelerinin gönüllünün orijinal tıbbi kayıtlarına doğrudan erişimleri bulunabilir, ancak bu bilgiler gizli tutulacaktır. Yazılı bilgilendirilmiş gönüllü olur formunu imzalamakla birlikte siz veya kanuni temsilciniz söz konusu erişime izin vermiş olacaksınız.

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Araştırma, kendi haklarınız veya araştırmayla ilgili herhangi bir olay hakkında daha fazla bilgi temin edebilmeniz için temasa geçebileceğiniz kişi ile bu kişiye ait günün 24 saatinde erişebileceğiniz telefon numarası,

Dt. Ekin Özdemir –

Sizden çocuğunuzun tedavisi için çekimi yapılan süt azı dişleri alınacak ve araştırma için biyolojik materyal olarak kullanılacaktır. Planlanan araştırma Yeditepe Üniversitesi Diş Hekimliği Fakültesi'nde yapılacaktır.

“Bilgilendirilmiş gönüllü olur formundaki tüm açıklamaları okudum. Bana yukarıda konusu ve amacı belirtilen araştırma ile ilgili yazılı ve sözlü açıklama aşağıda adı belirtilen hekim tarafından yapıldı. Araştırmaya gönüllü olarak katıldığımı, istediğim zaman gerekçeli veya gerekçesiz olarak araştırmadan ayrılabileceğimi biliyorum”

“Söz konusu araştırmaya, hiçbir baskı ve zorlama olmaksızın kendi rızamla katılmayı kabul ediyorum”

Gönüllünün yasal temsilcisinin

Adı- Soyadı:

İmzası:

Sorumlu Araştırmacının

Adı- Soyadı: Prof. Dr. Senem SELVİ KUVVETLİ

İmzası:

Sorumlu Araştırmacı: Prof.Dr.Senem SELVİ KUVVETLİ

8.3. APPENDIX C

	KLİNİK ARAŞTIRMALAR ETİK KURULU OLGU RAPOR FORMU	TARİH:
		VERSİYON: 2.0

ÇALIŞMANI ADI:

Sürekli Dişlenmede Kalması Gereken Süt Azı Dişlerinde Kullanım İçin Uygun Farklı Kök Kanalı Dolgu Materyallerinin Obturasyon Kalitesinin Karşılaştırılması: Bir *In Vitro* Çalışma

Sizden Yeditepe Üniversitesi Diş Hekimliği Fakültesi Çocuk Diş Hekimliği Anabilim Dalı'nda yürütülmekte olan ' Sürekli Dişlenmede Kalması Gereken Süt Azı Dişlerinde Kullanım İçin Uygun Farklı Kök Kanalı Dolgu Malzemelerinin Obturasyon Kalitesinin Karşılaştırılması: Bir *In Vitro* Çalışma ' konulu araştırmaya katılmanız istenmektedir.

Bu çalışma sizinki de dahil olmak üzere 15 adet daha önceden çekim onamı alınmış 3-10 yaş arası çocuk hastaların çekilmiş süt azı dişlerinde planlanmaktadır.

Çalışmanın amacı: Kalıcı dişlerin germ eksikliği durumunda süt dişlerinin diş çürüklerinden kaynaklı pulpa iltihabı durumlarında çekim yerine bu dişleri ağızda tutmak hastaya daha faydalı ve konforlu bir seçenek olacaktır. Böyle bir durumda ilgili süt dişine kök kanal tedavisi uygulamak gerekecektir ve tedavinin başarısı kaliteli bir kök kanal dolumu ile mümkündür. Bu çalışmanın amacı, farklı kök kanal dolgu malzemeleri kullanılarak süt dişlerinin köklerinin dolgu kalitesini değerlendirmektir.

Çalışmanın yöntemi:

Hasta ve velisinden çekim için onamı alınmış süt azı dişleri çalışmamızda kullanılacaktır. Çalışmanın prelinik olarak *in vitro* koşullarda yürütülmesi planlanmaktadır. Çalışmanın hastaya veya hasta yakınlarına herhangi bir advers olay durumu bulunmamaktadır. Diş çekiminden sonra hastanın tekrar kliniği çalışma ile ilgili ziyaret etmesine gerek yoktur.

Çalışmada farklı kök kanal dolum materyalleri karşılaştırılacaktır. Hastadan gönüllü olarak çalışmaya dahil olması amacıyla çekilmiş dişin alınması konusunda onam formu doldurulacaktır. Alman örneklerin kök kanalları şekillendirilip doluma hazır hale geldikten sonra mikro bilgisayarlı tomografi (mikro-BT) ile taranacaktır. Örnekler tarandıktan sonra kök kanalları doldurulup tekrar mikro-BT ile taranacaktır. Dolum için Gutta Perka, AH-Plus, ProRoot MTA ve Neosealer MTA isimli malzemeler kullanılacaktır. İkinci tarama da yapıldıktan sonra görüntüler karşılaştırılarak dolum kaliteleri hakkında bilgi elde edilmesi planlanmaktadır. Tarama tamamlandı analizler de yapıldığında çalışma sona erecektir.

Sizin ve çocuğunuzun da onamını alarak bu çalışmaya katılımınızı rica ederiz.

Dahil edilme kriterleri

1. Kök anomalilerinin olmaması,
2. Kökün boyunun en az 2/3'si kadar uzunluğunun olması
3. Radyografik olarak doğrulanmış kalsifikasyonların olmaması,
4. Kök kanallarında kırık veya çatlak olmaması,
5. İç kök rezorpsiyonunun olmaması.

Dahil edilmeme kriterleri

1. Kök anomalilerinin olması
2. Kök boyunun üçte birini geçen kök rezorpsiyonu,
3. Radyografik olarak doğrulanmış kalsifikasyonların olması,
4. Kök kanallarında kırık veya çatlak olması,
5. İç rezorpsiyonunun olması.

1. Örnek alınan hastanın bilgileri

Protokol:	Hasta adı soyadı:
Tarih:	Örnek numarası:
Yaş:	Cinsiyet:

Hasta şikâyeti:

Özel açıklamalar:

2. Alınan örneğin anatomik bilgileri

Diş numarası:

Diş durumu	Var	Yok
Kök anomalilerinin olmaması		
Kök boyunun üçte birini geçmeyen kök rezorpsiyonu		
Radyografik olarak doğrulanmış kalsifikasyonların olmaması		
Kök kanallarında kırık veya çatlak olmaması		
İç kök rezorpsiyonunun olmaması		
Kanal içinde tıkanıklık durumu		
Aksesuar kanal		

Kanal girişinden itibaren kanal boyu:

8.4. APPENDIX D: Curriculum Vitae (CV)

Özgeçmiş

Kişisel Bilgiler

Adı	Ekin	Soyadı	Özdemir
Doğum Yeri		Doğum Tarihi	
Uyruğu		Tc Kimlik No	
E- mail		Tel	

Öğrenim Durumu

Derece	Alan	Mezun Olduğu Kurumun Adı	Mezuniyet Yılı
Doktora			
Yüksek lisans	Diş Hekimliği	Hacettepe Üniversitesi	2015
Lisans	Diş Hekimliği	Hacettepe Üniversitesi	2015
Lise			

Yabancı Dil

Bildiği Yabancı Diller	Yabancı Dil Sınav Notu
İngilizce	

İş Deneyimi (Sondan geçmişe doğru sıralayın)

Görevi	Kurum	Süre
Çocuk Diş Hekimliği	Yeditepe Üniversitesi	

Bilgisayar Bilgisi

Program	Kullanım Becerisi
Microsoft programları	İyi

Bilimsel Çalışmaları

SCI, SSCI, AHCI indekslerine giren dergilerde yayınlanan makaleler

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Diğer dergilerde yayınlanan makaleler

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Uluslararası bilimsel toplantılarda sunulan ve bildiri kitabında (Proceedings) basılan bildiriler Hakemli konferans/sempozyumların bildiri kitaplarında yer alan yayınlar

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Diğer (Görev Aldığı Projeler/Sertifikalari/Ödülleri)

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