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Jenni Ristaniemi

A REGISTER-BASED STUDY OF ERUPTION PATTERNS IN THE MAXILLARY PERMANENT CANINES AND DENTAL DEVELOPMENTAL ABNORMALITIES

FEATURES SEEN IN PANORAMIC RADIOGRAPHS AND TREATMENT NEEDS IN PERMANENT CANINES

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF MEDICINE;
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Academic dissertation to be presented with the assent of the Doctoral Programme Committee of Health and Biosciences of the University of Oulu for public defence in the Markku Larmas auditorium (H1091) in Dentopolis, on 3 November 2023, at 12 noon

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Abstract

Permanent maxillary canines have a long, complex eruption pathway with eruption disturbances and have been linked to other dental developmental abnormalities. Late treatment of a canine is a time-consuming and burdensome option for children and their families.

The aim of this research was to describe the variations in maxillary canine eruption patterns seen in panoramic radiographs (PTG) a couple of years before eruption into the oral cavity and to put these into perspective with regard to the treatment needed. A second aim was to describe the occurrence of dental developmental abnormalities and to investigate their relation to the features of maxillary canines. The material for this retrospective register-based research consisted of 1454 cross-sectional PTGs of the developing dentition of children in Eastern Finland and longitudinal treatment information on 1962 maxillary canines in the same children after PTG.

During natural eruption, overlapping and pronounced inclination of canines were more often seen in the earlier stages of development. Only a tenth of the canines needed treatment that included interceptive procedures. Overlapping and pronounced inclination, as well as incomplete lateral incisors, occurred more often in treated canines, and the children concerned more often had a delayed dental age. Overlapping and a large inclination angle of the canine were clearly associated with canine treatment needs.

Some kind of feature involved in Dental Anomaly Patterns (DAP) was detected in almost a third of the children examined, the most common feature being infraocclusion of the primary molars. Absent teeth, a peg-shaped maxillary lateral incisor and delayed dental age occurred more often together, and co-occurrence of transposition with absent teeth was also found. Early treatment for a canine had been carried out twice as often for children with DAP features than for those without any such features. Delayed dental age and absent teeth were associated with canine treatment needs.

Monitoring of the erupting canines in relation to dental development and the existing space conditions proved to be important after the first mixed dentition stage to make early treatment options available in time. If any dental developmental abnormality is diagnosed during the earlier stages of development, a precise follow-up is needed to diagnose conditions occurring later.

Keywords: canine, child, cross-sectional studies, dental developmental abnormality, diagnostics, early treatment, ectopic, longitudinal studies, permanent dentition, radiography, retrospective studies, tooth eruption

Ristaniemi, Jenni, Rekisteritutkimus pysyvien yläkulmahampaiden puhkeamisesta ja hampaiston kehityksellisistä poikkeamista. Piirteet panoraamaröntgenkuvissa sekä kulmahampaiden hoidon tarve
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta; Medical Research Center Oulu; Oulun yliopistollinen sairaala
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Tiivistelmä

Pysyvien yläkulmahampaiden puhkeaminen on monivaiheinen tapahtumasarja, jossa esiintyvät poikkeamat ovat merkittävä kliininen ongelma kehittyvässä hampaistossa. Yläkulmahampaiden puhkeamisongelmien ajatellaan liittyvän joukkoon hampaiston kehityksellisiä poikkeamia, jotka esiintyvät usein yhdessä. Yläkulmahampaan puhkeamispoikkeaman myöhäishoito on yleensä pitkä ja raskas hoitovaihtoehto lapselle ja hänen perheelleen.

Tämän tutkimuksen tarkoituksena oli kuvata yläkulmahampaan kehityksellisiä piirteitä panoraamaröntgenkuvasta (PTG) tarkasteltuna pari vuotta ennen sen puhkeamista suuonteloon ja suhteuttaa näkymää hampaan hoidon tarpeeseen. Tarkoituksena oli myös kuvata hampaiston kehityksellisten poikkeamien (DAP-piirteet) esiintymistä sekä niiden suhteutumista kulmahampaan piirteisiin. Tämä retrospektiivinen rekisteritutkimus koostui 1454 itäsuomalaislapsen PTG-kuvasta noin 9,5-vuotiaana sekä samojen lasten 1962 yläkulmahampaan myöhemmästä hoidontarve- ja hoitotiedosta.

Luonnollisen puhkeamisen aikana kulmahampaan ja toisen etuhampaan päällekkäisyys sekä kulmahampaan suurempi kallistuskulma PTG-kuvassa esiintyivät useammin hampaistokehityksen varhaisemmissa vaiheissa. Vain joka kymmenes kulmahammas tarvitsi hoitoa sisältäen ohjaavat varhaishoitovaihtoehdot. Hoidetuissa kulmahampaissa esiintyi useammin päällekkäisyyttä ja suurempi kallistuskulma kuin luonnollisesti puhjenneissa, ja nämä piirteet myös ennustivat merkittävimmin hoidon tarvetta. Hoidetuilla lapsilla oli useammin myös toisen etuhampaan kehitys vielä kesken ja hampaistoikä myöhäinen.

DAP-piirteitä havaittiin noin kolmanneksella lapsista ja yleisin tutkituista piirteistä oli maitoposkihampaiden infraokkluusio. Synnynnäisesti puuttuva hammas, tappimainen toinen yläetuhammas ja myöhäinen hampaistoikä esiintyivät merkittävästi useammin yhdessä. DAP-lapsille toteutettiin kulmahampaan varhaishoitoa lähes kaksi kertaa useammin kuin lapsille ilman DAP-piirteitä, ja myöhäinen hampaistoikä DAP-piirteenä oli yhteydessä erityisesti varhaishoitoon.

Puhkeavien yläkulmahampaiden seuranta suhteutettuna hampaiston kehitysvaiheeseen ja tilasuhteisiin on tärkeää heti ensimmäisen vaihdunnan päätyttyä, jotta varhaishoidon toteuttaminen ajallaan on mahdollista. Jos hampaistokehityksen varhaisvaiheissa ilmenee kehityksellinen poikkeama, on seuranta mahdollisten muiden poikkeamien varalta aiheellista.

Asiasanat: diagnostiikka, ektooppinen, hampaan puhkeaminen, hampaiston kehityksellinen poikkeama, kulmahammas, lapset, pitkittäistutkimukset, poikittaistutkimukset, pysyvät hampaat, retrospektiiviset tutkimukset, röntgenkuva, varhaishoito

To my family

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4th August 2023 Jenni Ristaniemi

Abbreviations

2D	Two-dimensional
3D	Three-dimensional
95% CI	95% confidence interval
ALARA	As low as reasonably achievable
CA	Chronological age
CBCT	Cone beam computed tomography
CI	Confidence interval
DA	Dental age
DAP	Dental Anomaly Patterns
e.g.	Exempli gratia
i.e.	Id est
ICC	Intra-class correlation coefficient
κ	Cohen's kappa coefficient
Mx	Maxilla
Mx.C.P1	Transposition of a maxillary canine and first premolar
MxC	Maxillary canine
MxI2	Maxillary lateral incisor
MxP1	Maxillary first premolar
MxP2	Maxillary second premolar
Mn	Mandible
Mn.I2.C	Transposition of a mandibular lateral incisor and canine
MnC	Mandibular canine
MnI	Mandibular incisor
MnM2	Mandibular second molar
MnP1	Mandibular first premolar
MnP2	Mandibular second premolar
N	Sample size
OR	Odds ratio
P	Probability value
PTG	Panoramic radiograph
SD	Standard deviation
X^2	Chi-Square
°	Degree

List of original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

I Ristaniemi, J., Rajala, W., Karjalainen, T., Melaluoto, E., Iivari, J., Pesonen, P., & Lähdesmäki, R. (2022) Eruption pattern of the maxillary canines: features of natural eruption seen in PTG at the late mixed stage—Part I. *European Archives of Paediatric Dentistry, 23*(2), 223–232. https://doi.org/10.1007/s40368-021-00650-1

II Ristaniemi, J., Karjalainen, T., Kujasalo, K., Rajala, W., Pesonen, P., & Lähdesmäki, R. (2022) Eruption pattern of the maxillary canines: features indicating treatment needs as seen in PTG at the late mixed stage—Part II. *European Archives of Paediatric Dentistry, 23*(4), 567–578. https://doi.org/10.1007/s40368-022-00719-5

III Ristaniemi, J., Kujasalo, K., Rytkönen, E., Melaluoto, E., Iivari, J., Pesonen, P., & Lähdesmäki, R. (2023) Features of Dental Anomaly Patterns in Finnish children as seen in panoramic radiographs at the late mixed stage. *Acta Odontologica Scandinavica*, 1–6. Epub ahead of print. https://doi.org/10.1080/00016357.2023.2232859

IV Ristaniemi, J., Karjalainen, T., Kujasalo, K., Rajala, W., Pesonen, P., & Lähdesmäki, R. Dental developmental abnormalities in relation to radiological features and treatment needs of erupting maxillary canines. *Manuscript*

Contents

1 Introduction

The permanent maxillary canines play an important role in creating a functional occlusion: they are strong teeth with long roots and are fashioned for guiding occlusal movements. Consequently, their eruption into the dental arch is a crucial matter. Maxillary canines have the longest and most complicated eruption pathway (Broadbent, 1941; Dewel, 1949), moving more than two centimetres in the process (Coulter & Richardson, 1997). Lateral incisor guidance (Becker et al., 1981; Brin et al., 1986; Broadbent, 1941), genetics (Baccetti, 1998; Peck, 2009; Peck et al., 1994) and the space available in the dental arch (Jacoby, 1983) are all factors that affect the eruption of a maxillary canine, which is one of the ordinary teeth that fail to erupt most frequently.

Failure of the eruption of a maxillary canine can be avoided with accurate monitoring, early diagnosis and interceptive treatment. Contiguously with clinical inspection and palpation, the basic radiographic examination for assessing erupting canines is a panoramic radiograph (PTG), which will enable the diagnosis of eruption disturbances from the age of 8–9 years onwards (Sajnani & King, 2012a) by means of geometric measurements, as first described by Ericson and Kurol (1988). At the earlier stages in the eruption pattern, overlapping of a canine with a lateral incisor root and mesial inclination are normal elements of eruption and should decrease with time if the eruption path is normal (Fernández et al., 1998; Sajnani & King, 2012a). Early treatment of a canine by extraction of the primary canine (Ericson & Kurol, 1988; Naoumova et al., 2015; Power & Short, 1993) or with early headgear (Hadler-Olsen et al., 2018; Silvola et al., 2009) have been shown to be effective, whereas late treatment for eruption disturbances of canines is usually a long-term undertaking and expensive for the patient and society (Bazargani et al., 2013) and thus should always be avoided.

The development of the human dentition is multistage and complex process that is prone to various developmental abnormalities, many of which have been reported to occur together more often than can be explained by chance alone (Baccetti, 1998; Peck, 2009). It was for these conditions that Peck (2009) first described the concept of Dental Anomaly Patterns (DAP). Some of these conditions can be detected during the earlier stages of dental development allowing for more accurate follow-up and the diagnosis of those abnormalities that occur later.

The present research was conducted to investigate features of erupting maxillary canines based on PTG evidence during the late mixed stage of the dentition and their relation to the treatment needs. Furthermore, this research describes the occurrence of dental developmental abnormalities in Finnish children at the late mixed stage of the dentition and the occurrence of features involved in DAP in relation to the radiological features and the need for treating the maxillary canines. One important aim of this study was to give diagnostic information to enable dentists to take clinical decisions when evaluating erupting maxillary canines. The clinical aspect of this research, consisting of estimating the early radiological features of erupting maxillary canines for a couple of years before their actual eruption into the oral cavity in relation to the need for treatment and the occurrence of dental developmental abnormalities, is new.

2 Review of the literature

2.1 Maxillary canines: normal development and eruption

Calcification of the permanent maxillary canines starts at the age of 4–5 months (Nelson, 2019) and the crowns of the canines being fully developed at the age of 4.5–7 years (Haavikko, 1970; Nolla, 1960). The development of the canines starts relatively early as the stage of crown development and the early stage of root development occur at very much the same time as those stages of the permanent maxillary lateral incisors (Haavikko, 1970; Nolla, 1960). The development of the maxillary canines slows down, however, and they finally achieve fully developed roots several years later than the lateral incisors (Haavikko, 1970; Nolla, 1960), being fully developed at the age of 13–15 years (Nelson, 2019) with several years' deviation (Haavikko, 1970; Nolla, 1960).

2.1.1 Eruption

Eruption of the permanent maxillary canines starts after the calcification of the crown is completed and root development has started (Koch et al., 2017). The maxillary canines have the longest and most complicated eruption pathway (Broadbent, 1941; Dewel, 1949), which means that they move more than two centimetres during their eruption (Coulter & Richardson, 1997).

The normal pattern of movement and alignment of the anterior maxillary teeth was described by Broadbent (1941) over 80 years ago. The early development of the canines occurs in the high subnasal maxillary bone above the first primary molar and on the palatal side of the primary dentition, and as the primary teeth erupt, the permanent canines migrate forward with the incisors to allow space for the development of the permanent premolars. In the "ugly duckling" stage, the canines are normally mesially angulated and high near the apical third of lateral incisor roots. As eruption towards the oral cavity proceeds, the lateral incisor roots guide the eruptive movement, and the canines will straighten out before erupting into the dental arch. (Broadbent, 1941) Significant movement of the canine in relation to the lateral incisor roots occurs in posterior and vertical directions first, whereas the canines show significant movement in a buccal direction only in the later stages of eruption (Coulter & Richardson, 1997).

The maxillary canines erupt into the oral cavity at 10–12 years, during the late stage of the mixed dentition (Koch et al., 2017; Nelson, 2019) with a normal deviation of several years (Eskeli et al., 1999; Haavikko, 1970; Hägg & Taranger, 1986; Hurme, 1949; Nyström et al., 2001). The maxillary canines erupt into the mouth with their root two-thirds complete and can erupt even if their root development is completed (Haavikko, 1970). The eruption path is influenced by genetic and local environmental factors (Marks & Schroeder, 1996). Since the development of a canine starts early and the tooth erupts relatively late (Haavikko, 1970; Nolla, 1960), it is susceptible to environmental influences for a long period of time.

2.1.2 Gender differences in development and eruption

Dental development and maturation vary but usually take place earlier in girls (Chaillet et al., 2004; Demirjian & Levesque, 1980; Eskeli et al., 1999; Haavikko, 1970; Hägg & Taranger, 1986; Hurme, 1949; Pahkala et al., 1991; Svanholt & Kjær, 2008), especially at the late mixed stage of the dentition (Pahkala et al., 1991). Variation is also seen among the decades, in the form of a secular trend for earlier eruption (Eskeli et al., 2016). In the matter of eruption, the difference between the genders especially involves the canines (Haavikko, 1970; Hurme, 1949). The early stages of dentition and tooth development proceed equally among girls and boys, but the girls are ahead during the later stages (Chaillet et al., 2004; Demirjian & Levesque, 1980; Haavikko, 1970) by approximately half a year (Haavikko, 1970). Girls' teeth erupt approximately six months ahead of boys' teeth, but with wide differences (Hurme, 1949). Considering the maxillary canines, crown is ready approximately at the same time in both genders, while root development is completed on average a year earlier in girls (Haavikko, 1970).

2.2 Maxillary canines: ectopic eruption

2.2.1 Definition

The terminology for the ectopic eruption of maxillary canines varies. Definitions that are mostly used are "ectopic", "displaced" and "impacted". The term "ectopic eruption" means an abnormal eruption path of a permanent tooth, which can lead to impaction (Proffit, 2019), while "impacted tooth" means that tooth fails to erupt into the oral cavity within expected developmental time and root development is complete (Becker, 2022). These terms and definitions for the ectopic eruption of maxillary canines nevertheless vary in the literature (Alessandri Bonetti et al., 2011; Baccetti, 1998; Bazargani et al., 2014; Benson et al., 2021; Ericson & Kurol, 1987a; Hadler-Olsen et al., 2020; Lindauer et al., 1992; Naoumova et al., 2015; Power & Short, 1993; Uribe et al., 2017).

2.2.2 Prevalence and classification

Permanent maxillary canines represent one of the ordinary teeth that most frequently fails to erupt, the prevalence of eruption disturbances varying from 0.8% to 2.8% (Bishara, 1992; Ericson & Kurol, 1986b, 1987a; Lövgren et al., 2019; McSherry, 1998; Thilander & Myrberg, 1973). Eruption disturbances in the maxillary canines more frequently affect girls (Becker & Chaushu, 2015; Bishara, 1992; Ericson & Kurol, 1987a; McSherry, 1998; Peck et al., 1994) and are distinctly more common than in the disturbances in the mandibular canines (Bishara, 1992; Dalessandri et al., 2017). Also, displacement of a canine occurs more often unilaterally than bilaterally (Bishara, 1992), prevalence of bilateral displacement varying in the range 17–45% (Peck et al., 1994).

Displacement of a maxillary canine is mainly classified as palatal and buccal, whereas horizontal displacement above the tooth roots and transpositions are rare. Approximately 70–77% of displaced maxillary canines are palatally positioned (Paatero & Kiminki, 1962; Peck et al., 1994), whereas the prevalence of buccal displacement has been stated to be 13–22% (Ericson & Kurol, 1987a; Jacoby, 1983; Paatero & Kiminki, 1962). In a 3D study, Hadler-Olsen and his co-workers (2015) reported ectopic erupting maxillary canines to be mainly located palatally (54.4%) or in line with the dental arch (41.3%), while a small minority (4.3%) were buccally displaced.

2.2.3 Aetiology

The reason for eruption disturbances in the permanent maxillary canines is not fully understood. The fact that the eruption process is long and multi-stage is part of the aetiology (Coulter & Richardson, 1997), but there are also potential local causes of displacement, including retention or early loss of the primary canine, displacement of the crypt, supernumerary teeth, odontoma, periapical granuloma, a cyst, an alveolar cleft, ankylosis (Becker & Chaushu, 2015; Bishara, 1992) and trauma

(Brin et al., 1993). Also, deviations in dental and skeletal morphological characteristics have been suggested as part of the aetiology (Al-Nimri & Gharaibeh, 2005; Arboleda-Ariza et al., 2018; Basdra, 2000; Kim et al., 2012; Larsen et al., 2010; Sacerdoti & Baccetti, 2004).

The consensus regarding the main aetiologies for maxillary canine eruption disturbances is that buccal and palatal displacements require different conditions with different aetiologies, since buccal displacement is closely associated with crowded dentition while palatal displacement has a multifactorial aetiology that includes the theory of lateral incisor guidance and genetic background. Concerning palatal displacement, it has been suggested that the guidance and genetic theories share aetiologies, and both might act at different stages during the eruption of a maxillary canine (sequential theory) (Sajnani & King, 2012c).

Guidance theory

In the theory of guidance, the eruption of a maxillary canine is influenced by lateral incisor root guidance (Broadbent, 1941) and an abnormal lateral incisor is unable to guide the erupting canine. According to earlier studies, a displaced maxillary canine is related to an absent, peg-shaped or small lateral incisor (Becker et al., 1981, 1999; Brin et al., 1986; Kolokitha et al., 2023; Leifert & Jonas, 2003; Mossey et al., 1994; Sacerdoti & Baccetti, 2004; Zilberman et al., 1990), and to a shorter root (Becker et al., 1984; Bertl et al., 2018; Kim et al., 2017, Melchor-Soto et al., 2022) or retarded development of a lateral incisor (Leifert & Jonas, 2003). Also, Melchor-Soto and his co-workers (2022) have been shown that there is difference in the root dilaceration and convergence angles of the lateral incisors between impacted and normally erupting maxillary canines.

Genetic theory

In the genetic theory, the eruption of a maxillary canine can be influenced by genetic factors. In particular, palatal displacement of a maxillary canine has been thought to have a genetic background. It runs in families (Camilleri, 2005; Peck et al., 1994; Svinhufvud et al., 2008; Zilberman et al., 1990) and has been associated with other dental developmental abnormalities (Baccetti, 1998; Peck, 2009). According to Peck and his co-workers (1994), other evidence supporting a genetic background for palatal displacement includes its bilateral occurrence, gender differences (occurring more frequently in girls) and variation in prevalence among different populations (occurring more frequently in European populations).

Space conditions

A permanent maxillary canine replaces one of the last primary teeth in the upper jaw, which means that it is sensitive to the influence of space conditions in the dental arch. Buccal displacement of a maxillary canine is linked to crowding (Sajnani, 2015; Thilander & Jakobsson, 1968), whereas in palatal displacement there is usually enough space in the dental arch (Al-Nimri & Gharaibeh, 2005; Dewel, 1949; Jacobs, 1994). Jacoby (1983) found that crowding is an aetiological factor for 85% of buccally displaced maxillary canines, whereas 85% of palatally displaced canines would have the required space in which to erupt. Larger tooth size has been proposed as affecting the possibility for buccal displacement (Chaushu et al., 2003).

2.3 Maxillary canines: diagnostics

When the clinician suspects deviation in the eruption of a permanent canine in view of the developmental stage of the occlusion during an oral examination, he needs to take a brief extra look. There are three main steps involved in locating an erupting maxillary permanent canine: clinical inspection, palpation and, if necessary, radiographic examination (Jacobs, 1999).

2.3.1 Inspection and palpation

During a children's oral examination the dentist should clinically inspect and routinely palpate the sites of erupting maxillary canines, possibly manifested in the clinical inspection as a bulge under the mucosa. During the early stage of normal canine eruption already erupted maxillary lateral incisor may be tilted distally into the "ugly duckling" position (Broadbent, 1941), although in the later stages the lateral incisor might be inclined because the crown of a displaced maxillary canine is pressing on its root (Jacobs, 1999). Mobility in a primary canine and resorption of its root is a good sign, but it still does not ensure a favourable position for the erupting permanent canine (Ericson & Kurol, 1987b; Power & Short, 1993).

The bulge caused by the emerging maxillary canine should be palpable in the labial sulcus on the alveolar process above the primary canine (Williams, 1981) approximately 1–1.5 years before eruption into the oral cavity (Ericson & Kurol, 1986a; Kurol, 2002). In the material studied by Ericson and Kurol (1986a), the maxillary canine was not palpable in 29% of cases at the age of 10 years, whereas the corresponding proportion at the age of 11 years was 5%. On the other hand, some canines in that same material were already palpable at the age of eight years, reflecting individual variations in development. A positive palpation of a labial sulcus on the alveolar process above the primary canine is the sign of a normally erupting canine, and according to the Chalakkal et al. (2011), a maxillary canine has a high probability of being palatally displaced if palpation is negative at the age of 10–12 years.

2.3.2 Radiographic examination

Radiographic examinations play an essential role in assessing the positions of maxillary canines and should be done whenever justifiable. Ericson and Kurol (1986a) state that a radiographic examination in mixed dentition is indicated if 1) there is asymmetry on palpation or otherwise a pronounced difference between the left and right side; 2) the canines cannot be palpated in a normal position and dental development is advanced, or 3) the lateral incisor is late in erupting or shows pronounced displacement or inclination.

The primary examination for assessing the developing dentition, erupting teeth and the need of orthodontic treatment is PTG, which is widely available in dental clinics. This is an extraoral technique that provides general information with a low radiation dose and is usually taken as an initial radiograph (Jacobs, 1999; White & Pharoah, 2014). The location of an erupting canine within the maxilla can also be determined by the parallax method (tube-shift technique, Clark's role), where two periapical or occlusal radiographs are taken from different projections (Jacobs, 1999; White & Pharoah, 2014).

Cone beam computer tomography (CBCT) is the primary 3D imaging technique employed in dentistry and can be used to locate a displaced tooth and observe the resorption state of an adjacent tooth for treatment planning purposes. CBCT enables highly accurate diagnosis of ectopic erupting maxillary canines and their surrounding structures and geometrical positions, but the radiation dose is higher than in traditional 2D imaging, so that CBCT should always be optimized (Pakbaznejad Esmaeili et al., 2020) and used only when justified (ALARA) (European Commission 2012).

Overlapping and inclination

In the late 1980s Ericson and Kurol studied the clinical features and radiographic diagnostics of eruption disturbances in maxillary canine (Ericson & Kurol, 1986a, 1986b, 1987a), leading to the publication in 1988 of a series of geometric measurements for PTGs to help in diagnosing cases of a palatally displaced canine (Ericson & Kurol, 1988). These geometric measurements have been widely used ever since (Alejos-Montante et al., 2019; Alqerban et al., 2016; Chalakkal et al., 2011; Fernández et al., 1998; Lindauer et al., 1992; Malik et al., 2019; Naoumova & Kjellberg, 2018; Power & Short, 1993; Sajnani & King, 2012a; Shin et al., 2022; Uribe et al., 2017; Warford et al., 2003).

The crown of a maxillary canine is often seen in PTG to overlap with the root of the lateral incisor in the early stages of eruption and development. This overlapping will diminish after the age of 8–9 years if eruption proceeds normally (Fernández et al., 1998; Sajnani & King, 2012a), but given abnormal eruption it may increase still further (Sajnani & King, 2012a). By the age of 12 years overlapping is usually a sign of displacement (Chalakkal et al., 2011; Lindauer et al., 1992; Warford et al., 2003). Thus, one early PTG sign of abnormal eruption may be the occurrence of overlapping with the completed root of the adjacent lateral incisor (Fernández et al., 1998).

Mesial inclination of a maxillary canine has been shown to increase up to the age of 8–9 years, after which the tooth progressively rights itself as eruption proceeds (Fernández et al., 1998; Sajnani & King, 2012a). In an ectopic eruption path, it will still be pronouncedly mesially inclined after the age of nine years (Chalakkal et al., 2011; Sajnani & King, 2012a).

According to Ericson and Kurol (1986b), radiological diagnosis of disturbances in the eruption of maxillary canines is not possible in children younger than 10 years because of the large fluctuation and high possibility of spontaneous pathway correction. However, Sajnani and King (2012a) showed later that early radiological diagnosis of maxillary canine displacements is possible from the age of 8–9 years onwards using geometric measurements, regardless of the labiopalatal position of the canine concerned.

Root development stage

The root development stage of a permanent tooth can be determined from dental radiographs by various methods (Haavikko, 1970, 1974; Moorrees et al., 1963;

Nolla, 1960), and it has been shown that there is no difference in root development between impacted and normally erupting maxillary canines (Sajnani & King, 2012a).

Dental age

The dental age of a child can be estimated clinically by the stage of emergence of the teeth (Eskeli et al., 1999) or radiologically by the stage of tooth formation (Demirjian et al., 1973; Demirjian & Goldstein, 1976; Haavikko, 1970, 1974; Moorrees et al., 1963). Determinations of dental age are used for forensic purposes as well as in clinical dentistry, for monitoring the development of teeth and the whole dentition.

The method of Demirjian (1973) is widely used for estimating age and in dentistry for describing the stages in tooth development (Koch et al., 2017), and Chaillet et al. (2004) modified the maturity curves for Finnish populations by reference to this method. Demirjian's method is more suitable for children with mixed dentition (Bagherpour et al., 2010) and is an accurate means of estimating of general dental development stages (Baghdadi & Pani, 2012; Chaillet et al., 2004).

2.3.3 Follow-up

A further observation period is needed when clinical inspection and palpation, alone or after examination by means of intraoral periapical radiographs or a cropped panoramic radiograph, give some sign of abnormal eruption of a maxillary canine. During this follow–up period consideration should be given to the space conditions (Jacoby, 1983) and to individual and gender differences in dental development (Eskeli et al., 1999; Haavikko, 1970; Hurme, 1949). A palatally erupting maxillary canine can usually be observed if it is overlapping with the adjacent lateral incisor under halfway and its angulation is only minor (Naoumova & Kjellberg, 2018).

2.4 Maxillary canines: treatment

Permanent maxillary canines have an important role in a functional occlusion: they are strong teeth with long roots and are intended to guide the occlusal movements. Thus, eruption into the dental arch in the right position is crucial. Treatment of an ectopic maxillary canine is also essential due to risk of impaction and complications such as root resorption in the adjacent teeth (Alemam et al., 2020; Ericson & Kurol, 2000; Hadler-Olsen et al., 2015; Simić et al., 2022).

2.4.1 Early treatment

Early interceptive treatment with simple appliances at an early stage in the mixed dentition is common in Finland (Kerosuo et al., 2008; Keski-Nisula et al., 2008; Pietilä et al., 1997; Silvola et al., 2009; Väkiparta et al., 2005). It has been reported that the average age for starting orthodontic treatment in children is 9.5 years (Pietilä et al., 1997) and almost a third of all children have had orthodontic treatment by the age of 12 years (Arpalahti et al., 2022). If an eruption disturbance in a maxillary canine can be diagnosed early, interceptive treatment is usually sufficient, the aim being to guide the aberrant development of the canine early enough to normalize its eruption path and at least make the orthodontic treatment easier and shorter.

Interceptive space opening

Interceptive space opening for permanent teeth can be carried out employing several treatment options. The use of a Quad Helix (Kerosuo et al., 2008; Väkiparta et al., 2005) or an eruption guidance appliance (Keski-Nisula et al., 2008) in the early mixed stage of the dentition will effectively create the necessary space for the dental arch.

Headgear can create additional space in the dental arch when distalizing the maxillary first molars with a low degree of force and expanding the dental arches (Pirttiniemi et al., 2005), and this is an effective interceptive treatment option at an early stage in the mixed dentition (Väkiparta et al., 2005). In young children (initially at a mean age of less than 8 years) with an Angle Class II occlusion, the eruption path of the maxillary canines has been shown to be significantly more vertical after early headgear treatment (Hadler-Olsen et al., 2018; Silvola et al., 2009). The use of headgear at the late stage of the mixed dentition (mean age of the children approximately 11 years) has been shown to have a positive effect on the eruption path of the maxillary canines (Armi et al., 2011; Baccetti et al., 2008), especially after extraction of the primary canines (Baccetti et al., 2008) or after rapid maxillary expansion treatment (Armi et al., 2011). Rapid maxillary expansion with or without transpalatal arch therapy, has been shown to be an interceptive treatment option for palatally displaced canines (Baccetti et al., 2011).

Extraction of a primary canine

Primary maxillary canine extraction at an age of 10–13 years is said to be an effective mode of interceptive treatment for a palatally displaced permanent canine (Baccetti et al., 2008; Bazargani et al., 2014; Ericson & Kurol, 1988; Habib et al., 2023; Naoumova et al., 2015; Power & Short, 1993), even if there is clear overlapping of the canine with the root of the lateral incisor is (Figure 1). Extraction of the maxillary primary canine as well as the primary first molar has also been tried (Alessandri Bonetti et al., 2011; Hadler-Olsen et al., 2020), but there is no evidence that double extraction is any more effective (Benson et al., 2021).

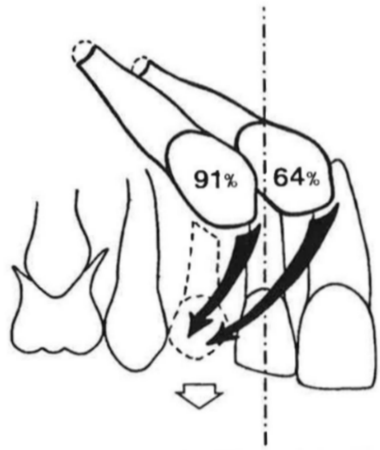

Fig. 1. Ericson and Kurol's (1988) schematic illustration of success rates of the normalization of the maxillary permanent canine eruption path at the control examination 18-month after extraction of the primary canines viewed in terms of the initial position of the canine relative to the lateral incisor root. Reprinted with permission from Ericson & Kurol, 1988 © Oxford University Press.

2.4.2 Late treatment

In the case of late diagnosis of ectopic eruption of a maxillary canine or unsuccessful interceptive treatment, later orthodontic treatment is needed. An orthodontic treatment plan for developmental and occlusal abnormalities is needed before embarking on such a late treatment option. The need for extracting permanent teeth must be evaluated and, if necessary, a CBCT image may be taken for treatment planning purposes, especially in order to diagnose possible root resorptions and decide on the option for surgical exposure.

Later treatment for crowding

If crowding exists in the dental arch, the maxillary canines will typically erupt on its buccal side (Jacoby, 1983), and in these cases any eruption disturbance should be treated by relieving the crowding. Opening the space with a fixed appliance is usually the optimum treatment, but extraction of the permanent maxillary premolars needs to be considered and this should be done at the right time in relation to the developmental stage of the dentition and the erupting canine. Extraction of the first premolars is typically needed for patients with recurrent crowding (already with incisors at the first stage), an Angle Class II relation or bimaxillary protrusion (Becker, 2022). When there is an absence of space in the dental arch and the canine is in a difficult position this may instead lead one to consider extraction of the permanent canine (Littlewood & Mitchell, 2019).

Surgical exposure and orthodontic treatment

The late treatment of a displaced maxillary canine is often a combination of surgical exposure and orthodontic procedures. Surgical exposure can be done by open or closed techniques (Becker et al., 2016; Kokich, 2004) followed by traction of the canine to the dental arch with fixed appliance. The geometric location of the canine will affect the duration of the orthodontic treatment (Arriola-Guillén et al., 2019; Bazargani et al., 2013; Crescini et al., 2007), and adequate diagnosis of the location is crucial in terms of treatment success (Becker et al., 2016). In the case of marked palatal displacement (Naoumova & Kjellberg, 2018) or a horizontal canine, surgical exposure is the primary treatment option.

2.5 Dental developmental abnormalities

2.5.1 Absent teeth

The absence of a permanent tooth is most common developmental abnormality in human dentition. The prevalence of absent teeth in Europe, is 5.5–8% (Grahnén, 1956; Haavikko, 1971; Khalaf et al., 2014; Polder et al., 2004; Rølling & Poulsen, 2009; Thilander & Myrberg, 1973), occurring more frequently in girls (Brook, 1984; Kenrad et al., 2013; Khalaf et al., 2014; Ojala-Alasuutari et al., 2022; Polder et al., 2004; Rølling & Poulsen, 2009). Usually 1–2 permanent teeth are affected, most commonly mandibular second premolars, followed by maxillary lateral incisors and maxillary second premolars (Khalaf et al., 2014; Ojala-Alasuutari et al., 2022; Polder et al., 2004). Absence of teeth usually occurs unilaterally, except for the absence of maxillary lateral incisors (Polder et al., 2004).

The aetiology of tooth agenesis is said to be multifactorial (Brook, 1984; Parkin et al., 2009), and substantially of genetic origin (Arte et al., 2001; Baccetti, 1998; Bailleul-Forestier et al., 2008; Matalova et al., 2008; Pinho et al., 2010; Svinhufvud et al., 2008; Vastardis, 2000). Children with absent teeth more frequently have generally smaller teeth (Brook, 1984; Brook et al., 2009; Garn & Lewis, 1970), peg-shaped maxillary lateral incisors (Al-Abdallah et al., 2015; Alvesalo & Portin, 1969; Baccetti, 1998; Choi et al., 2017; Marra et al., 2021), ectopic maxillary canines (Baccetti, 1998; Becker et al., 1981; Brin et al., 1986; Pirinen et al., 1996) and other teeth (Baccetti, 1998; Svinhufvud et al., 2008), delayed dental development (Choi et al., 2017; Daugaard et al., 2010; Gelbrich et al., 2015; Kan et al., 2009; Navarro et al., 2014; Ruiz-Mealin et al., 2012; Uslenghi et al., 2006), infraocclusion of the primary molars (Baccetti, 1998; Bjerklin et al., 1992), short-rooted teeth (Apajalahti et al., 1999), taurodontism (Arte et al., 2001) and enamel hypoplasia (Baccetti, 1998).

2.5.2 Small tooth size

The permanent teeth can be reduced in size either locally or generally, and in case of local reduction the tooth may be either in microform or mesiodistally narrow. The most common small tooth is a maxillary lateral incisor, as these can vary in anatomical shape more than any other teeth except the third molars (Nelson, 2019). Variations in maxillary lateral incisors can be manifested as mesiodistally narrow, "peg-shaped" or absent teeth, and different forms often occur together, with the same genetic origin (Alvesalo & Portin, 1969; Arte et al., 2001; Pinho et al., 2005, 2009). The prevalence of peg-shaped lateral incisors is approximately 1.8%, and these appear to be more likely in girls (Hua et al., 2013).

General microdontia, in which many teeth are smaller than average, can occur in both the primary and permanent dentition, prevalence for the permanent dentition being 2.5% (Brook, 1974). According to Brook (1984), in addition to the absence of certain teeth, girls more frequently manifest microdontia. General tooth size reduction is associated with hypodontia (Brook et al., 2009; Garn & Lewis, 1970), palatal displacement of a maxillary canine (Becker et al., 2002; Langberg & Peck, 2000; Naoumova & Kjellberg, 2018) and late dental development (Uslenghi et al., 2006).

2.5.3 Delayed dental development

In delayed dental development the timing of development and eruption is late relative to the expected chronological age standards, and this can be localized (Alexander-Abt, 1999; Haavikko, 1970; Hurme, 1949) or generalized (Demirjian et al., 1973; Hägg & Taranger, 1985). Local delay in dental development concerns individual teeth (Hurme, 1949), e.g. the mandibular second premolars may develop remarkably late (Alexander-Abt, 1999).

Generalized late timing in dental development has been related to many dental abnormalities, such as tooth agenesis (Daugaard et al., 2010; Gelbrich et al., 2015; Kan et al., 2009; Navarro et al., 2014; Ruiz-Mealin et al., 2012; Uslenghi et al., 2006) and distal angulation of unerupted mandibular second premolars (Wasserstein et al., 2004). Delayed dental age has also been associated in many studies with displacement of a maxillary canine (Lövgren et al., 2021; Rozylo-Kalinowska et al., 2011), especially palatal displacement (Becker & Chaushu, 2000; Naser et al., 2011). Such relations were not found, however, in the studies of Sajnani and King (2012b) and Latić-Hodžić et al. (2022).

2.5.4 Infraocclusion of primary molars

A disturbance in an ongoing tooth eruption process due to late ankylosis will cause infraocclusion, so that the tooth position will fall below the occlusion level in spite of having been in occlusion earlier. This progressive phenomenon is usually seen in the primary molars, with a prevalence varying according to age, reaching a maximum of 14.3% at 8–9 years (Kurol, 1981). Exfoliation of a primary molar usually occurs spontaneously, but might be delayed (Kurol & Koch, 1985; Kurol & Thilander, 1984b; Tieu et al., 2013). In the absence of a permanent successor the primary molar will persist and will not exfoliate spontaneously with time (Kurol & Thilander, 1984a). Infraocclusion of the primary molars has been associated with the occurrence of tooth agenesis (Baccetti, 1998; Choi et al., 2017; Küchler et al., 2008; Shalish et al., 2010), a peg-shaped lateral incisor (Baccetti, 1998; Odeh et al., 2015; Shalish et al., 2010), a displaced maxillary canine (Baccetti, 1998; Kolokitha et al., 2023; Odeh et al., 2015; Shalish et al., 2010), distal angulation of an unerupted mandibular second premolar (Shalish et al., 2010), enamel hypoplasia (Baccetti, 1998) and ectopic eruption of the first molars (Baccetti, 1998).

2.5.5 Transposition

In transposition two permanent teeth interchange positionally in the dental arch, the overall prevalence of this being 0.33% without any significant gender differences (Papadopoulos et al., 2010). Transposition most commonly affects the canines (Littlewood & Mitchell, 2019), with a prevalence of 0.2% (Thilander & Myrberg, 1973), and it more commonly occurs unilaterally in the maxilla (Ely et al., 2006; Papadopoulos et al., 2010; Shapira & Kuftinec, 1989). The most frequent form of transposition is between a canine and first premolar in the maxilla (Ely et al., 2006; Peck et al., 1993; Peck & Peck, 1995). Transpositions are rarer in the mandible, but it is lateral incisor and canine transposition that occurs here most often (Ely et al., 2006; Peck et al., 1998). These particular transpositions are associated with the displacement of a canine (Mercuri et al., 2013; Peck, 2009; Shapira & Kuftinec, 2001) or some other dental abnormality (Camilleri, 2005; Danielsen et al., 2015; Peck et al., 1993; Peck et al., 1998, 2002; Shapira & Kuftinec, 2001), and occur more frequently in girls (Peck et al., 1993; Peck et al., 1998; Shapira & Kuftinec, 2001).

2.5.6 Distal angulation of an unerupted mandibular second premolar

The mandibular second premolar is one of the last teeth to erupt into the lower dental arch, and it may become malposed during the eruption process, whereupon it usually tilts distally (Stemm, 1971; Wasserstein et al., 2004). Unerupted mandibular second premolars have been shown to be more distally inclined if there is agenesis of its antimere (Navarro et al., 2014; Shalish et al., 2002) or its development is late (Wasserstein et al., 2004). Palatal displacement of a maxillary canine is associated with the distal angulation of an unerupted mandibular second premolar (Baccetti et al., 2010; Shalish et al., 2009) and if the two abnormalities occur at the same time, the delay in dental development has been shown to be more profound (Shalish et al., 2009). Similarly, tooth agenesis (Choi et al., 2017; Garib et al., 2009, 2010) and infraocclusion of the primary molars (Shalish et al., 2010) are associated with distal angulation of an unerupted mandibular second premolar.

2.5.7 Dental Anomaly Patterns (DAP)

The development of the human dentition is multifactorial and complex entailing several abnormalities. As described, many developmental abnormalities in the dentition have been reported to occur together at a much higher frequency than can be explained by chance. Many of these conditions can be diagnosed during the early stages of dental development, providing an opportunity for more accurate follow-up and for the diagnosis those dental abnormalities that occur later. To describe these conditions, Peck (2009) first proposed the concept of Dental Anomaly Patterns (DAP).

Features that are related to the Dental Anomaly Patterns (DAP) of Peck (2009):

- Absent teeth
- Microform teeth (e.g. peg-shaped MxI2)
- Tooth-size reduction (generalized or localized)
- Delay in tooth formation and eruption (generalized or localized)
- Infraocclusion (most often of primary teeth)
- Palatal displacement of a canine
- Maxillary canine and first premolar transposition
- Mandibular lateral incisor and canine transposition
- Distal angulation of an unerupted mandibular second premolar

3 Aims of the research

The main objective was to describe the eruption pattern of the permanent maxillary canines as seen in PTG at the mixed stage of the dentition, the treatment needs regarding the maxillary canines, the occurrence of dental developmental abnormalities and their co-occurrence.

The more specific aims were:

1. To describe the variation in permanent maxillary canine eruption patterns as seen in PTG at the late mixed stage of the dentition when eruption into the oral cavity took place naturally (no treatment) (I) or needed treatment in order to ensure eruption (II).
2. To determine the prevalence of maxillary canine treatment needs in the mixed stage of the dentition (II).
3. To determine the prevalence of certain dental developmental abnormalities involved in Dental Anomaly Patterns (DAP) (Peck, 2009) and investigate their co-occurrence in the mixed stage of the dentition in Finnish children (III).
4. To investigate the radiological features of erupting maxillary canines and the treatment needed to ensure eruption of the canines into the oral cavity in relation to the occurrence of dental developmental abnormalities (IV).

4 Materials and methods

4.1 Materials

The cross-sectional part of this material included 1454 panoramic radiographs (PTGs) of the developing permanent dentition of children born between 1980 and 1996 in Lapinlahti, Eastern Finland. The children were mainly in the third year of primary school between the years 1987 and 2007. The PTGs had been taken in response to referrals during annual oral examinations when applicable, to examine the development of the dentition and to determine whether interceptive treatment would be appropriate. The PTGs were taken by the Health Centre's radiological department using Cranex DC 2 (Soredex) equipment until 15.3.2006 and a Planmeca Proline XC (Plandent) system after that. The longitudinal part of the material consisted of information on the treatment of 1962 permanent maxillary canines in the same children.

The PTGs constituting the material gathered from the municipal health centre in Lapinlahti were copied digitally and basic background information, including name, gender, date of birth and the date of the PTG, was gathered during the years 2006–2007 by Terhi Karjalainen (TK) and Raija Lähdesmäki (RL), Associate Professor, DDS, and specialist in orthodontics. To determine the treatment needs with regard to the maxillary canines, all available records from annual oral and dental examinations, including other PTGs and intraoral radiographs, were examined during the years 2016–2020 by Kati Kujasalo (KK), Jenni Ristaniemi (JR), Wille Rajala (WR) and RL. The study design and protocol for the formation of the subgroups used for Papers I–IV are presented in Figure 2.

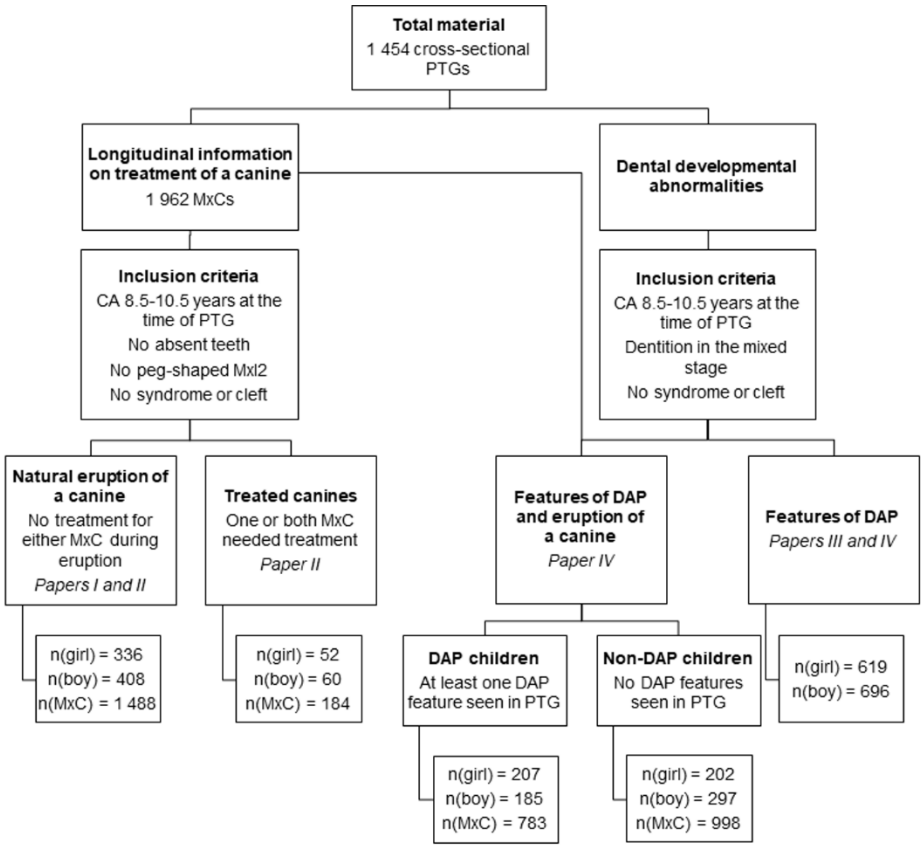

Fig. 2. Formation of subsamples used in Papers I–IV.

4.2 Methods

All determinations used in this thesis were conducted under the supervision of RL. Variables concerned with overlapping and inclination of maxillary canines (TK), the developmental stages of the maxillary canines and lateral incisors (WR), and also dental age (Eeva Melaluoto, EM and Jenni Iivari, JI), absent teeth (Eelis Rytkönen, ER), peg-shaped maxillary lateral incisors (ER, Papers I and II), transpositions (KK) and distal angulation of unerupted mandibular second premolars (KK) were originally ascertained as parts of theses for the degree of Licentiate in Dentistry at the University of Oulu, Finland. The variables relevant to the needs for the treatment of maxillary canines (KK, JR, RL), peg-shaped maxillary lateral incisors (JR, Papers III and IV) and infraocclusion of primary molars (JR) were elucidated for this research and variables determined previously were complemented and re-checked where necessary (JR) to ensure congruence of the results (e.g. regarding transpositions).

4.2.1 Features related to maxillary canines

Overlapping and inclination

The determinations of overlapping and inclination in the PTGs were carried out by TK using the neaView Radiology software (Neagen Oy), with geometrical measurements modified from Ericson and Kurol (1988). Overlapping of a canine crown with the lateral incisor root) was measured and classified into Grades 0–2 (Table 1, Figure 3), while the inclination of a canine was measured as the angle (α) between the midsagittal suture of the maxilla and the mid-axis of the canine (Figure 3), where the latter was defined by reference to the pulp chamber. The average tooth axis was adjusted by reference to the crown and root in cases of crooked roots and rotated teeth.

The exclusion criteria for this variable were an emerged canine, complete primary or permanent dentition, orthodontic treatment at the time of the PTG or poor quality of the PTG. Overlapping of a canine was not determined from dentition in which a maxillary lateral incisor was absent. The overlapping and inclination angle measurements were assessed for repeatability and reliability by measuring 31 PTGs twice.

Table 1. Grades of overlapping of the canine crown with the lateral incisor root, modified from the geometrical measurements of Ericson and Kurol (1988).

Grade	Definition
Grade 0 (G0)	No overlapping
Grade 1 (G1)	Crown of the canine covering half or less of the width of the lateral incisor root (some overlapping)
Grade 2 (G2)	Crown of the canine covering more than half of the width of the lateral incisor root (clear overlapping)

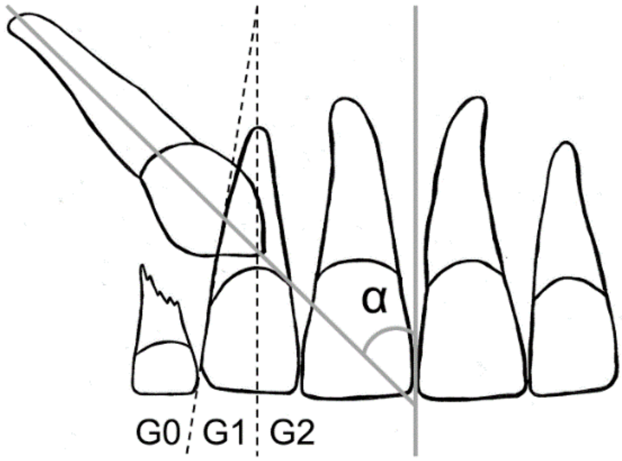

Fig. 3. The maxillary permanent canine in relation to adjacent teeth (modified from Ericson & Kurol, 1988). Reprinted under CC BY 4.0 licence from Paper I © 2021 Ristaniemi, Rajala, Karjalainen, Melaluoto, Iivari, Pesonen, Lähdesmäki.

Developmental stages of maxillary canines and lateral incisors

The root development stages of the canines (MxC root development) were assessed from the PTGs by WR using the method of Nolla (1960) and were divided into Stages 1–5 (Table 2, Figure 4). The exclusion criteria for this variable were oligodontia (> six absent teeth) or an unclear PTG.

The development stages of the lateral incisors in the maxilla (MxI2s development) were assessed from the PTGs and grouped by WR according to Nolla (1960) into incomplete (Nolla's value 8.7 or less) or complete (Nolla's value 9.0–10.0). The exclusion criteria for this variable were a peg-shaped lateral incisor, an absent maxillary lateral incisor, oligodontia (> six absent teeth) or an unclear PTG.

Calibration was performed before assessing the final measurements. The development stage of the canine was measured first from 655 PTGs and then from all 1454 PTGs, where repeatability was tested with 65 randomly selected PTGs.

Table 2. Stages of maxillary canine root development, grouped according to Nolla's method (Nolla, 1960).

Stage	Definition	Values in Nolla's method	Value given by Nolla	Explanation given by Nolla
Stage 1	Root formation started	< 7.0	6	Crown completed
Stage 2	One-third of the root length completed	7.0, 7.2	7	One-third of root completed
Stage 3	Half of the root length completed	7.5, 7.7		
Stage 4	At least two-thirds of the root length completed	8.0–8.7	8	Two-thirds of root completed
Stage 5	Root completed, apex open/closed	9.0–10.0	9	Root almost completed, open apex
			10	Apical end of root completed

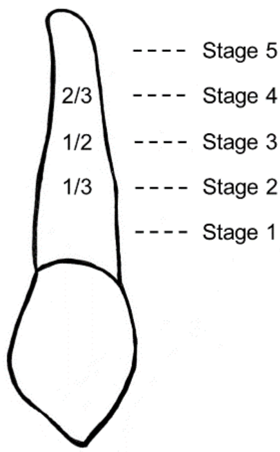

Fig. 4. Stages of maxillary canine root development. Reprinted under CC BY 4.0 licence from Paper I © 2021 Ristaniemi, Rajala, Karjalainen, Melaluoto, Iivari, Pesonen, Lähdesmäki.

Dental age

Dental age was analysed from the PTGs by EM and JI using Demirjian's dental maturity method (Demirjian et al., 1973; Demirjian & Goldstein, 1976). The developmental stages of seven individual teeth in the mandibular left quadrant were evaluated and scored in stages (0 and A–H). If an individual tooth was absent, its antimere was taken for assessment (Demirjian & Goldstein, 1976), as also if the developmental stage of an individual tooth deviated notably from the general line. After the stages had been scored, reference was made to the Finnish maturity curves (Chaillet et al., 2004). The exclusion criteria for this variable were an absent tooth (no antimere) or poor quality of the PTG. Each examiner assessed half of the material.

Calibration by reference to detached PTG material (n = 16) from children with differing stages of dentition was performed before recording the final measurements. The most challenging teeth evaluated were premolars between the development stages E and F, in which case the examiners' assessments were compared with each other and with the findings of an orthodontist familiar with the method. The examiners assessed 30 PTGs twice to assess the intra- and inter-reliability of the findings.

For the purposes of this study the child's dental age was considered normal with a mean ± 1SD (1SD = 1 year). Furthermore, dental age was grouped as either early/normal (> −1 year) or delayed (≤ −1 year) relative to the chronological age (Eskeli et al. 1999).

Treatment needs

Information on needs for treatment was collected manually in retrospect by JR, KK and RL from the dental records. Orthodontic treatments that were completed because of eruption of a maxillary canine were based on treatment plans given by a senior orthodontist. Each need for treatment was categorized after the time PTG had been taken until the canine had erupted in all cases for which patient records could be found in the health centre's paper archives or software data (Table 3). Orthodontic treatment before PTG or after the eruption of the canine concerned was not included.

The exclusion criteria for this variable were an emerged canine (based on PTG and/or dental records), oligodontia (> six absent teeth), poor quality of the PTG, odontoma or a cyst in the maxillary canine area or transposition of a maxillary canine and the first premolar.

Table 3. Maxillary canines categorized according to treatment need.

Treatment need	Definition
Natural eruption of a canine	
No treatment	
No treatment	No treatment for maxillary canine
Follow up	No treatment for maxillary canine, follow up carried out
Treated maxillary canines	
Early treatment	
Interceptive treatment	Extraction of a primary canine and/or interceptive slicing of a primary second molar and at the same time extraction of a primary first molar if needed due to eruption of a maxillary canine
Early headgear	Dental headgear applied with an Interlandi-setup during mixed dentition before or during eruption of the maxillary canines, may include other interceptive procedures
Late treatment	
Orthodontic treatment	Mainly surgical exposure of a maxillary canine and traction with a buccal bow (TMA .016x.018”) from the transpalatal arch and later alignment with a fixed appliance. Now and then, surgical exposure alone or only traction with a fixed appliance was enough.
Treatment for crowding	Extraction of a permanent first premolar and/or treatment with fixed appliance for relieving severe crowding especially for maxillary canine. In some cases the extracted tooth may be a permanent second premolar.

4.2.2 Features related to the DAP

Absent teeth

Absent teeth were assessed from the PTGs by ER. A permanent tooth was regarded as congenitally absent if the follicle was not visible in the PTG. The absence of third molars was excluded. In cases of rare absences (MnI, MnM2, MxC), absence was confirmed by JR.

Microform teeth

Peg-shaped maxillary lateral incisors were an exclusion criterion for the Papers I and II and were assessed from the PTGs by ER on the basis of a mesiodistally narrowed shape.

For Papers III and IV, peg-shaped maxillary lateral incisors (peg-shaped MxI2) were detected from the PTGs by JR, on the basis of the mesiodistal width of the crown being narrower than that of the cervical part of tooth (Grahnén, 1956), while the anatomical shape of the crown was pointed and the root possibly smaller (Nelson, 2019). The exclusion criterion for this variable was an unclear PTG. Calibration was performed by JR in the PTG material and by discussing selected borderline cases (n = 14) with a supervisor.

Delay in tooth formation and eruption (generalized)

Delays in tooth formation and eruption were ascribed to delayed dental age. Dental age was evaluated from the PTGs by EM and JI using Demirjian's dental maturity method (Chaillet et al., 2004; Demirjian et al., 1973; Demirjian & Goldstein, 1976), as presented earlier (see Dental age in 4.2.1.). Dental age was assessed as delayed if it was ≤ -1 year relative to the chronological age (Eskeli et al., 1999).

Infraocclusion of primary molars

Infraocclusion of primary molars was assessed visually from the PTGs by JR by comparing them with the occlusal plane and marginal ridges of the adjacent teeth. The PTGs were categorized as showing no visible infraocclusion or visible infraocclusion in at least one primary molar in the maxilla or mandible. The exclusion criteria for this variable were an absent primary molar and no infraocclusion in the others, failure to determine the occlusal plane, a significant loss of tooth morphology in the primary molars, an orthodontic appliance in the area or poor quality of the PTG. Calibration was carried out with a supervisor before recording the final measurements, and repeatability was estimated by measuring 146 PTGs twice.

Transpositions

Transpositions of a canine and a first premolar in the maxilla (Mx.C.P1) or a canine and a lateral incisor in the mandible (Mn.I2.C) were assessed on the PTGs by KK and confirmed in a second assessment by JR. Two adjacent teeth were classified as transposed if their crowns had crossed each other within the dental arch in the PTG despite the existence of adequate space.

Distal angulation of an unerupted mandibular second premolars

Distal angulation of an unerupted mandibular second premolar was determined from the PTGs by KK and classified as distally tilted if the long axis of the developing premolar bud intersected with the mesial border of the neighbouring mandibular first molar (modified from Baccetti et al., 2010). The exclusion criteria for this variable were an emerged mandibular second premolar, mandibular second premolar root development not started or the absence of a mandibular first molar (by JR).

4.2.3 Summary of the variables studied

A summary of the continuous and categorized variables is presented in Table 4.

Table 4. Summary of the variables studied.

Variable	Categories	Notes
Overlapping	Grade 0 (no overlapping) Grade 1 (≤ ½ overlapping) Grade 2 (> ½ overlapping)	Modified from Ericson & Kurol, 1988
Inclination	< 15 15–19.9 20–24.9 ≥ 25	Grade (°) towards the maxillary midline, modified from Ericson & Kurol, 1988
MxC root development	Stage 1 (root formation started) Stage 2 (1/3 completed) Stage 3 (1/2 completed) Stage 4 (2/3 completed) Stage 5 (root completed)	Modified from Nolla, 1960
MxI2s development	Incomplete Complete	Modified from Nolla, 1960

Variable	Categories	Notes
Dental age	Early/normal (> −1 year from CA) Delayed (≤ −1 year from CA)	Assessed by Demirjian's method (Chaillet et al., 2004; Demirjian et al., 1973; Demirjian & Goldstein, 1976)
Treatment need	Early (interceptive / headgear) Late (orthodontic / for crowding)	Determined from dental records from the time of PTG until the canine had erupted
Absent teeth	Yes/No by tooth	Third molars excluded
Peg-shaped MxI2	Yes/No by tooth	According to Grahnén, 1956; Nelson, 2019
Infraocclusion	Yes/No by PTG	Primary molars
Transposition	Yes/No by tooth	Mx.C.P1 and Mn.I2.C included
Distal angulation of MnP2	Yes/No by tooth	Modified from Baccetti et al., 2010

4.2.4 Statistics

The results were recorded using matrix software (Microsoft Excel) and the statistical analyses were performed using SPSS (version 26.0 and 28.0, IBM SPSS Statistics, Armonk, NY, USA) and SAS Enterprise guide version 7.1. P values < 0.05 were considered statistically significant.

The repeatability of the assessments of overlapping, MxC root development and infraocclusion was assessed using Cohen's kappa coefficient. To check the reliability of the assessments of inclination and dental age, the intra-class correlation coefficient was calculated. Cohen's kappa coefficient (Landis & Koch, 1977) and the intra-class correlation coefficient were interpreted as being substantial if the strength of the agreement was 0.61–0.80 and almost perfect if it was 0.81–1.00.

In Papers I–IV the normality of the continuous variables (angles, chronological and dental ages) was assessed visually using histograms or box plots. Gender-specific mean chronological and dental ages were analysed with the independent samples t-test. The distributions of the variables were described with frequencies and percentages, and categorial variables were compared by means of cross tabulation and the Pearson Chi-square test or Fisher's exact test.

The comparisons of the mean angles in Papers I and II were performed using one-way ANOVA and the comparisons of variables with more than two categories (overlapping Grades 0–2, MxC root development) between stages in the dentition using Tukey's post hoc test. The independent samples t test was used to compare the mean angles in variables with two categories (MxI2s development, dental age, overlapping yes/no, treatment need yes/no).

In the Paper II, the single associations of independent variables (overlapping, inclination, MxC root development, MxI2s, development, dental age) with the response variables (early treatment, late treatment, all treatments) were determined with unadjusted logistic regression models constructed separately for gender, while adjusted logistic regression models were used to check the associations of all the independent variables and gender with the response variables. Statistically significant two-way interaction terms were included in the final models.

In the Paper IV, the single associations of independent DAP features and gender with the response variables (no treatment, early treatment, late treatment, all treatments) were determined with unadjusted logistic regression models, while adjusted logistic regression models were used to check the associations of all DAP features and gender with the response variables in the material as a whole. Statistically significant two-way interaction terms were checked during the formation of the models.

In Papers II and IV, the strength of each association was illustrated with an odds ratio and 95% confidence interval. In addition, odds ratios and 95% confidence intervals in Paper II were described graphically using forest plots. The logistic regression models were constructed using the SAS glimmix procedure with random effect, to take account of children in the data who had two canines.

4.2.5 Ethical considerations

The data for this retrospective study were gathered from clinical dental records. The head of dental services gave permission for copying the PTGs in 2006, while permission for using the patient records and radiological images in the longitudinal approach was given first by the head of dental services in 2015 and later by the director of health services in 2019. The personal information gathered for this work was coded to prevent identification.

5 Results

5.1 Reliability

The intra-rater reliability showed almost perfect agreement for overlapping (d.13 κ = 0.917, d.23 κ = 0.849), inclination (d.13 ICC = 0.933, d.23 ICC = 0.922) and infraocclusion (κ = 0.837) and substantial agreement for MxC root development (Stages 1–5) (κ = 0.777). The inter-rater reliability for dental age showed almost perfect agreement (ICC = 0.871), while the intra-rater reliability showed substantial agreement for examiner 1 (ICC = 0.789) and almost perfect agreement for examiner 2 (ICC = 0.945).

5.2 Description of the basic results

The material included 1454 PTGs and 2907 permanent maxillary canines. The mean age of the children concerned at the time of PTG was 9.3 years (SD 0.6), without any difference between the genders (p = 0.067). Assessment of the need for treatment (n = 1962) showed that 11.6% of the canines needed treatment to ensure eruption into the oral cavity, again without any gender difference (Table 5). None of the canines remained unerupted or needed extraction, except for one canine when surgical exposure was suggested but refused. The frequencies and percentages of the variables related to the maxillary canines in the total material are presented in Table 6.

Table 5. Canine treatment needs in the total material.

Need for treatment	Girls n (%)	Boys n (%)	P value[1]	All n (%)
No treatment	805 (87.7)	929 (89.0)		1734 (88.4)
Early treatment				
Interceptive treatment	27 (2.9)	20 (1.9)	0.135	47 (2.4)
Early headgear	39 (4.2)	32 (3.1)	0.159	71 (3.6)
Late treatment				
Orthodontic treatment	10 (1.1)	8 (0.8)	0.440	18 (0.9)
Treatment for crowding	37 (4.0)	55 (5.3)	0.244	92 (4.7)

[1]Pearson's Chi-square test, significances are for the gender differences.

Table 6. Distribution of variables between the naturally erupting and treated canines in the total material of PTGs. Modified from Paper II © 2022 Ristaniemi, Karjalainen, Kujasalo, Rajala, Pesonen, Lähdesmäki.

Variable	Group	Total study material n (%)	Natural eruption of a canine n (%)	Treated canines n (%)	P value[2]
Overlapping	Grade 0	1239 (54.5)	798 (56.2)	62 (34.8)	
	Grade 1	964 (42.4)	594 (41.8)	94 (52.8)	
	Grade 2	72 (3.2)	28 (2.0)	22 (12.4)	< 0.001
Inclination (º)	< 15	1493 (65.0)	938 (65.9)	107 (59.8)	
	15–19.9	430 (18.7)	273 (19.2)	26 (14.5)	
	20–24.9	234 (10.2)	134 (9.4)	25 (14.0)	
	≥ 25	139 (6.1)	78 (5.5)	21 (11.7)	0.001
MxC root development	Stage 1	314 (10.8)	93 (6.3)	16 (8.7)	
	Stage 2	1558 (53.8)	856 (57.6)	115 (62.5)	
	Stage 3	630 (21.8)	396 (26.6)	41 (22.3)	
	Stage 4	393 (13.6)	142 (9.5)	12 (6.5)	0.172
MxI2s development	Incomplete	2196 (77.8)	1146 (78.5)	160 (88.4)	
	Complete	626 (22.2)	314 (21.5)	21 (11.6)	0.002
Dental age[1]	Early/Normal	1202 (92.5)	673 (95.2)	91 (90.1)	
	Delayed	97 (7.5)	34 (4.8)	10 (9.9)	0.035

[1]Dental age is presented for children; [2]Significances are of differences between naturally erupting and treated MxCs, Pearson's Chi-square test

5.3 Natural eruption of the maxillary canines (Paper I)

The distributions of children with natural eruption of a canine (n = 744) by chronological and dental age are presented in Figure 5. The mean chronological age was 9.4 years (SD 0.4) for the girls and 9.5 years (SD 0.4) for the boys (p = 0.001), while the dental age was 9.6 years (SD 0.8) for the girls and 10.0 years for the boys (SD 0.9) (p < 0.001).

5.3.1 Radiological features

The frequencies and percentages of the variables in the cases of natural eruption are presented in Table 6. The mean inclination of the canines was 12.4° (SD 7.4) and MxC root development, as obtained by Nolla's method (1960), varied in the range 6.2–8.7 and was more advanced in the girls, who also had more often complete their MxI2s development (p < 0.001) (Table 7).

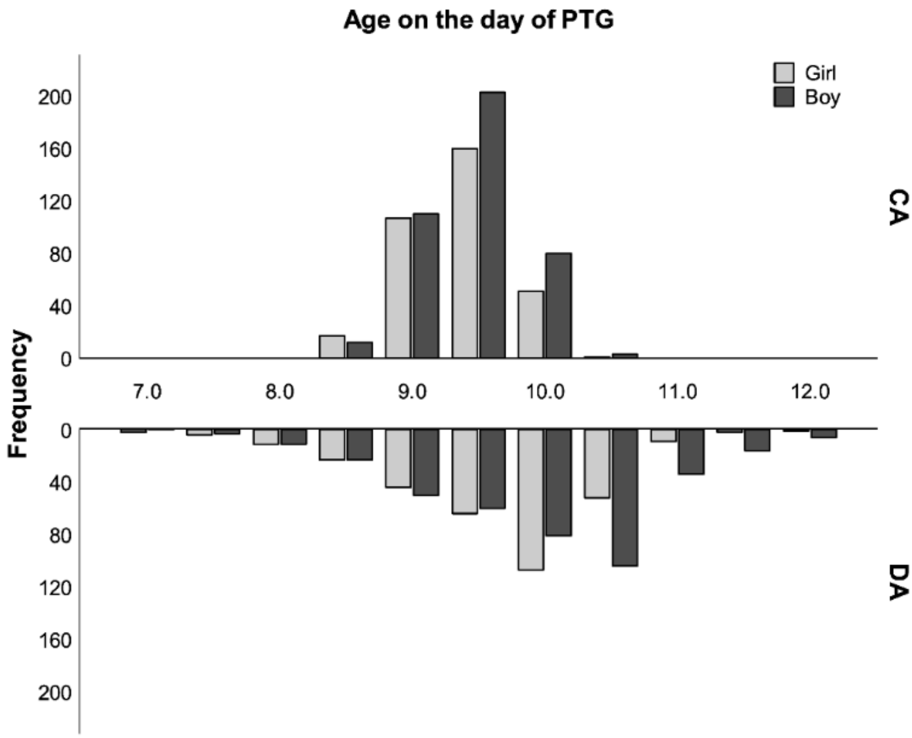

Fig. 5. Distribution of children with natural eruption of a canine by chronological age (CA, n = 744) and dental age (DA, n = 707) in years.

Table 7. MxC root development and MxI2s development by gender in the children with natural eruption of a canine.

Variable	Group	Girls n (%)	Boys n (%)	P value[1]
MxC root development	Stage 1	11 (1.6)	82 (10.1)	
	Stage 2	327 (48.7)	529 (64.9)	
	Stage 3	232 (34.5)	164 (20.1)	
	Stage 4	102 (15.2)	40 (4.9)	< 0.001
MxI2s development	Incomplete	462 (70.9)	684 (84.7)	
	Complete	190 (29.1)	124 (15.3)	< 0.001

[1]Pearson's Chi-square test

5.3.2 Comparisons between radiological features

Overlapping occurred more often when MxC root development had proceeded less than halfway, and clear overlapping was most often observed when the root length was less than a third ($p = 0.007$). Overlapping occurred more often if MxI2s development was incomplete ($p = 0.01$). (Table 8) The distribution by grouped dental age did not differ between the grades of overlapping ($p = 0.171$).

Table 8. MxC root development and MxI2s development vs. overlapping in the children with natural eruption of a canine. Modified from Paper I © 2021 Ristaniemi, Rajala, Karjalainen, Melaluoto, Iivari, Pesonen, Lähdesmäki.

Variable	Group	Grade 0 n (%)	Grade 1 n (%)	Grade 2 n (%)	P value[1]
MxC root development	Stage 1	52 (6.5)	37 (6.2)	4 (14.3)	
	Stage 2	436 (54.6)	379 (63.9)	18 (64.3)	
	Stage 3	234 (29.3)	138 (23.3)	5 (17.9)	
	Stage 4	76 (9.5)	39 (6.6)	1 (3.6)	0.007
MxI2s development	Incomplete	607 (77.1)	484 (83.2)	25 (89.3)	
	Complete	180 (22.9)	98 (16.8)	3 (10.7)	0.01

[1]Pearson's Chi-square test

Inclination angles ≥ 15° occurred more frequently in the cases of clear overlapping ($p = 0.033$, Table 9), and inclination was greater in the earlier stages of MxC root development and when the MxI2s were incomplete ($p < 0.001$, Table 9), regardless of overlapping ($p < 0.001$, Table 10). As root development in the canine progressed from a third to halfway the inclination decreased significantly ($p < 0.001$, Table 10). Overlapping seems to increase the inclination angle of the canine when the root reaches a third of its final length (Stage 2) and/or when MxI2s are incomplete ($p < 0.001$, Table 10).

The children with delayed dental age had a larger inclination in their developing canines ($p = 0.019$, Table 9) regardless of overlapping ($p = 0.002$ and $p = 0.034$, Table 10). Overlapping seems to increase the inclination angle only in cases of early/normal dental age ($p < 0.001$, Table 10)

Table 9. Overlapping, MxC root development, MxI2s development and dental age vs. inclination (°) in the natural eruption of a canine. Modified from Paper I © 2021 Ristaniemi, Rajala, Karjalainen, Melaluoto, Iivari, Pesonen, Lähdesmäki.

Variable	Group	< 15	15–19.9	20–24.9	≥ 25	P value[2]
		n (%)	n (%)	n (%)	n (%)	
Overlapping	Grade 0	547 (58.8)	136 (49.8)	73 (55.3)	34 (45.9)	
	Grade 1	370 (39.8)	129 (47.3)	55 (41.7)	37 (50.0)	
	Grade 2	13 (1.4)	8 (2.9)	4 (3.0)	3 (4.1)	0.033
MxC root development	Stage 1	55 (5.9)	19 (7.0)	13 (9.8)	6 (7.7)	
	Stage 2	492 (52.5)	189 (69.2)	96 (72.2)	63 (80.8)	
	Stage 3	301 (32.1)	53 (19.4)	15 (11.3)	7 (9.0)	
	Stage 4	90 (9.6)	12 (4.4)	9 (6.8)	2 (2.6)	< 0.001
MxI2s development	Incomplete	692 (74.9)	240 (90.2)	118 (88.7)	69 (92.0)	
	Complete	232 (25.1)	26 (9.8)	15 (11.3)	6 (8.0)	< 0.001
Dental age[1]	Early/normal	860 (96.3)	241 (92.3)	116 (92.1)	67 (93.1)	
	Delayed	33 (3.7)	20 (7.7)	10 (7.0)	5 (6.9)	0.019

[1]Dental age was assessed for children, and was same for both MxCs; [2]Pearson's Chi-square test

Table 10. Mean inclination (°) as a function of overlapping, root development of MxC, development of MxI2s and dental age in the children with natural eruption of a canine. Reprinted [adapted] under CC BY 4.0 licence from Paper I © 2021 Ristaniemi, Rajala, Karjalainen, Melaluoto, Iivari, Pesonen, Lähdesmäki.

Variable	Group	No overlapping (Grade 0)			Overlapping (Grade 1 or 2)			P value[3]
		n	Mean angle	SD	n	Mean angle	SD	
MxC root development	Stage 1	52	13.8	8.0	41	13.3	7.7	0.776
	Stage 2	432	13.0	7.4	396	14.8	6.9	< 0.001
	Stage 3	231	9.5	6.8	143	10.4	6.4	0.210
	Stage 4	75	8.0	7.1	38	10.6	8.0	0.081
P value[2]			< 0.001			< 0.001		
MxI2s development	Incomplete	600	12.4	7.4	508	14.3	6.9	< 0.001
	Complete	179	8.8	7.4	99	9.3	6.6	0.597
P value[3]			< 0.001			< 0.001		
Dental age[1]	Early/normal	712	11.3	7.5	558	13.3	7.0	< 0.001
	Delayed	32	15.4	6.1	36	15.9	7.9	0.788
P value[3]			0.002			0.034		

[1]Dental age was assessed for children, and was same for both MxCs; [2]One-way ANOVA; Independent-samples t-test

5.4 Treated maxillary canines (Paper II)

The distributions of children with treated maxillary canines (n = 112) by chronological and dental age are presented in Figure 6. The mean age of the treated children at the time of PTG was 9.4 years (SD 0.4), without any gender difference (p = 0.996). The dental age yielded values in the range 7.1–11.9 years, giving a mean age of 9.4 years (SD 0.8) for girls and 9.8 years (SD 1.0) for boys (p = 0.021). The grouped dental age did not differ between the genders (p = 0.186).

The most common treatment need in the cases of treated canines was for crowding (40.2%), and this more often affected the boys (boys 59.5% vs. girls 40.5%). A third of the canines (n = 58) were treated with early headgear and a fifth with interceptive treatment (n = 38). The need for treatment did not differ statistically between the genders (p = 0.481).

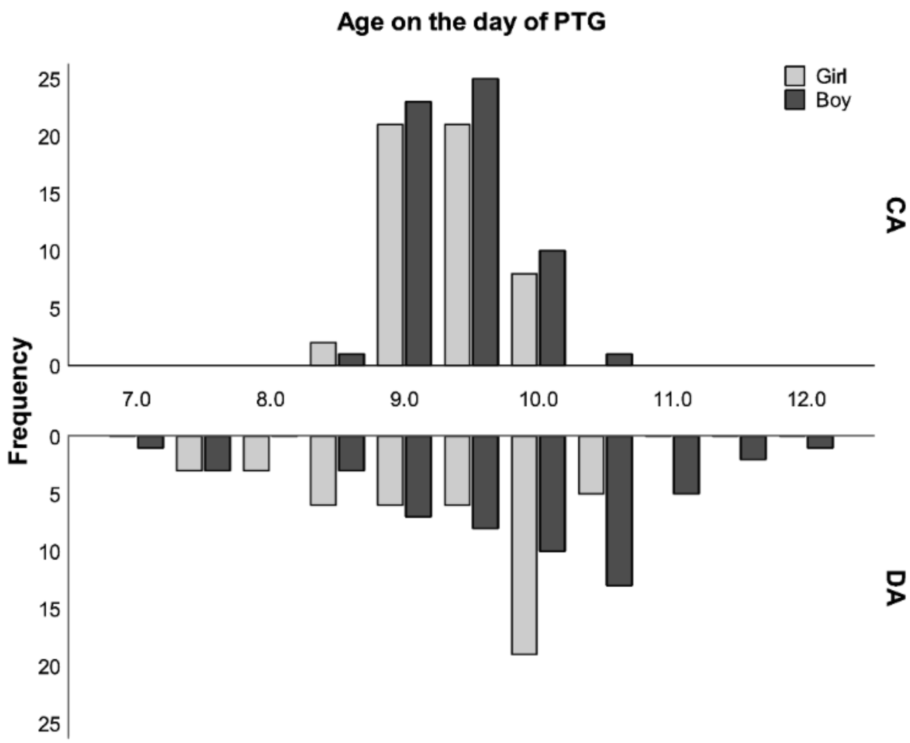

Fig. 6. Distribution of children with treated maxillary canine(s) by chronological age (CA, n = 112) and dental age (DA, n = 101) in years.

5.4.1 Radiological features

The frequencies and percentages of the variables in the cases of treated canines are presented in Table 6. The mean inclination of the treated canines was 14.4° (SD 9.0). MxC root development yielded Nolla's values (1960) in the range 6.5–8.2, being more advanced in the girls ($p < 0.001$, Table 11), while the development of MxI2s did not differ between the genders ($p = 0.294$, Table 11).

Table 11. MxC root development and MxI2s development by gender in cases of treated canines.

Variable	Group	Girls n (%)	Boys n (%)	P value[1]
MxC root development	Stage 1	0 (0.0)	16 (16.5)	
	Stage 2	49 (56.3)	66 (68.0)	
	Stage 3	30 (34.5)	11 (11.3)	
	Stage 4	8 (9.2)	4 (4.1)	< 0.001
MxI2s development	Incomplete	72 (85.7)	88 (90.7)	
	Complete	12 (14.3)	9 (9.3)	0.294

[1]Pearson's Chi-square test.

No statistical differences were detected between the grades of overlapping and inclination ($p = 0.053$), MxC root development ($p = 0.558$), MxI2s development ($p = 0.656$) or grouped dental age ($p = 0.109$), nor between the inclination and MxC root development ($p = 0.609$), MxI2s development ($p = 0.086$) or grouped dental age ($p = 0.067$) in the cases of treated canines.

Almost all the MxI2s were incomplete in the groups receiving interceptive treatment (97.4%) and treatment for crowding (93.0%), whereas a fifth of the MxI2s were complete in the groups receiving early headgear or orthodontic treatment ($p = 0.013$) (Table 12). As many as a third of the children in the interceptive treatment group ($n = 11$) had a delayed dental age ($p < 0.001$) (Table 12), but differences of this kind were not seen between the treatment groups in overlapping ($p = 0.555$), inclination ($p = 0.168$) or MxC root development ($p = 0.310$).

Table 12. MxI2s development and dental age vs. need for treating maxillary canines. Modified from Paper II © 2022 Ristaniemi, Karjalainen, Kujasalo, Rajala, Pesonen, Lähdesmäki.

Variable	Group	Interceptive treatment n (%)	Early headgear n (%)	Orthodontic treatment n (%)	Treatment for crowding n (%)	P value[2]
MxI2s development	Incomplete	37 (97.4)	46 (79.3)	11 (78.6)	66 (93.0)	
	Complete	1 (2.6)	12 (20.7)	3 (21.4)	5 (7.0)	0.013
Dental age[1]	Early/normal	24 (68.6)	46 (95.8)	14 (100.0)	63 (94.0)	
	Delayed	11 (31.4)	2 (4.2)	0 (0.0)	4 (6.0)	< 0.001

[1]Dental age was assessed for children, and was same for both MxCs; [2]Fisher's Exact test

5.4.2 Comparisons between naturally erupting and treated canines

Comparisons between the distributions of the naturally erupting and treated canines in terms of the variables studied here are presented in Table 6. The treated canines more often had overlapping ($p < 0.001$) and a large inclination ($p = 0.001$) than did the naturally erupting canines. Root development of MxC did not differ between the naturally erupting and treated canine groups ($p = 0.172$), but the latter had incomplete MxI2s more often than did the former ($p = 0.002$) (Table 6). The dental age of the treated children (n =101, 9.6 years, SD 1.0) was later compared with those whose canines had erupted naturally (n = 707, 9.8 years, SD 0.8) by the time of the PTG ($p = 0.039$). A delayed dental age was detected more often in the children with treated canine(s) ($p = 0.035$, Table 6).

The mean inclination of naturally erupted canines was greater in the higher grades of overlapping ($p < 0.001$), while the inclination significantly decreased as the MxC root development, MxI2s development and dental age proceeded ($p < 0.001$), but no corresponding significant reduction was seen in the case of overlapping, MxC root development or dental age in the children with treated canines. Only in MxI2s development was the mean inclination significantly larger if the MxI2s were incomplete ($p = 0.001$). (Table 13)

Table 13. Mean inclination (°) as a function of treatment need, overlapping, MxC root development, development of MxI2s and dental age.

Variable	Group	Natural eruption of canine			Treated canines			P value[3]
		n	Mean angle	SD	n	Mean angle	SD	
Overlapping	Grade 0	790	11.6	7.5	62	12.7	8.6	0.246
	Grade 1	591	13.3	7.2	93	14.7	8.8	0.164
	Grade 2	28	16.2	6.3	22	16.3	6.6	0.958
P value[2]			< 0.001			0.173		
MxC root development	Stage 1	93	13.5	7.8	16	16.0	12.3	0.296
	Stage 2	840	13.9	7.3	112	15.2	8.7	0.140
	Stage 3	376	9.8	6.7	39	12.9	8.3	0.008
	Stage 4	113	8.9	7.5	12	10.0	7.2	0.618
P value[2]			< 0.001			0.146		
MxI2s development	Incomplete	1119	13.3	7.2	156	15.3	9.0	0.009
	Complete	279	9.0	7.1	20	8.5	7.0	0.773
P value[3]			< 0.001			0.001		
Dental age[1]	Early/normal	1284	12.2	7.4	142	14.1	9.4	0.018
	Delayed	68	15.6	7.1	17	17.4	6.4	0.352
P value[3]			< 0.001			0.164		

[1]Dental age is assessed for children, and was same for both MxCs; [2]One-way ANOVA; [3]Independent-samples t-test

5.4.3 Associations of radiological features with treatment needs

Unadjusted associations with treatment needs

The associations between the independent variables and all treatments by gender are illustrated in Figure 7 and those between the independent variables and early and late treatment by gender in Figure 8.

Clear overlapping (OR = 8.10, 95% CI = 3.94–16.47) and some overlapping (OR = 1.91, 95% CI = 1.32–2.78) were associated with treated canines regardless of gender (Figure 7), but only clear overlapping was associated with early treatment (OR = 6.13, 95% CI = 2.45–15.33), whereas both some overlapping (OR = 2.65, 95% CI = 1.58–4.45) and clear overlapping (OR = 10.30, 95% CI = 4.23–25.12) were associated with late treatment (Figure 8).

A large inclination angle (≥ 25°) was associated with treated canines (OR = 2.41, 95% CI = 1.31–4.44), especially in girls (OR = 3.73, 95% CI = 1.67–8.34) (Figure 7). A large inclination was associated with early treatment only in the girls (OR = 3.12, 95% CI = 1.19–8.18) (Figure 8). A large inclination was associated with late canine treatment (OR = 2.86, 95% CI = 1.33–6.16), especially in the girls (OR = 4.14, 95% CI = 1.42–12.03) (Figure 8).

Incomplete MxI2s were associated with treated canines (OR = 2.05, 95% CI = 1.18–3.56), especially in the girls (OR = 2.51, 95% CI = 1.18–5.37) (Figure 7) and in the case of early treatment (OR = 2.10, 95% CI = 1.01–4.39) (Figure 8). Delayed dental age was associated with treated canines (OR = 2.29, 95% CI = 1.09–4.78) (Figure 7), especially in the cases of girls receiving early treatment (OR = 3.48, 95% CI = 1.17–10.34) (Figure 8).

Adjusted associations with treatment needs

The associations between all the variables and treatment need groups are illustrated in Figure 9. Treated canines had an association with clear overlapping (OR = 7.18, 95% CI = 3.26–15.82), some overlapping (OR = 1.69, 95% CI = 1.12–2.55) and a large inclination (≥ 25°) (OR = 2.27, 95% CI = 1.12–4.58). Late treatment was associated with clear overlapping (OR = 10.43, 95% CI = 3.81–28.58) and some overlapping (OR = 2.43, 95% CI = 1.37–4.31), and also with a large inclination angle (OR = 3.40, 95% CI = 1.44–8.02), while early treatment was associated only with clear overlapping (OR = 5.41, 95% CI = 1.96–14.97). In adjusted logistic regression an early stage of MxC root development (root formation started, Stage 1) showed a significant inverse association with late treatment (OR = 0.15, 95% CI = 0.03–0.87).

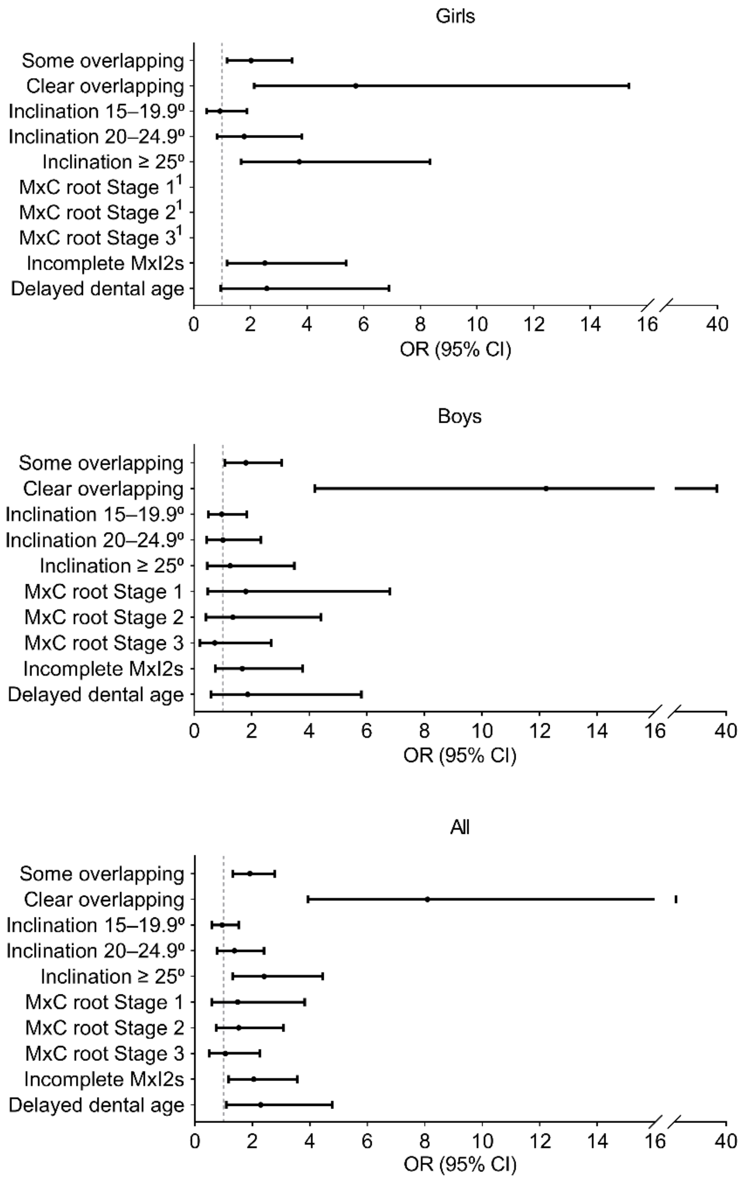

Fig. 7. Unadjusted logistic regression analysis of associations between the independent variables and all treatments in the treated canines, by gender (Overlapping ref. No overlapping; Inclination ref. < 15º; MxC root development ref. Stage 4; MxI2s development ref. Complete; Dental age ref. Early/normal, Dental age is assessed for children and was same for both MxCs; [1]frequency too low).

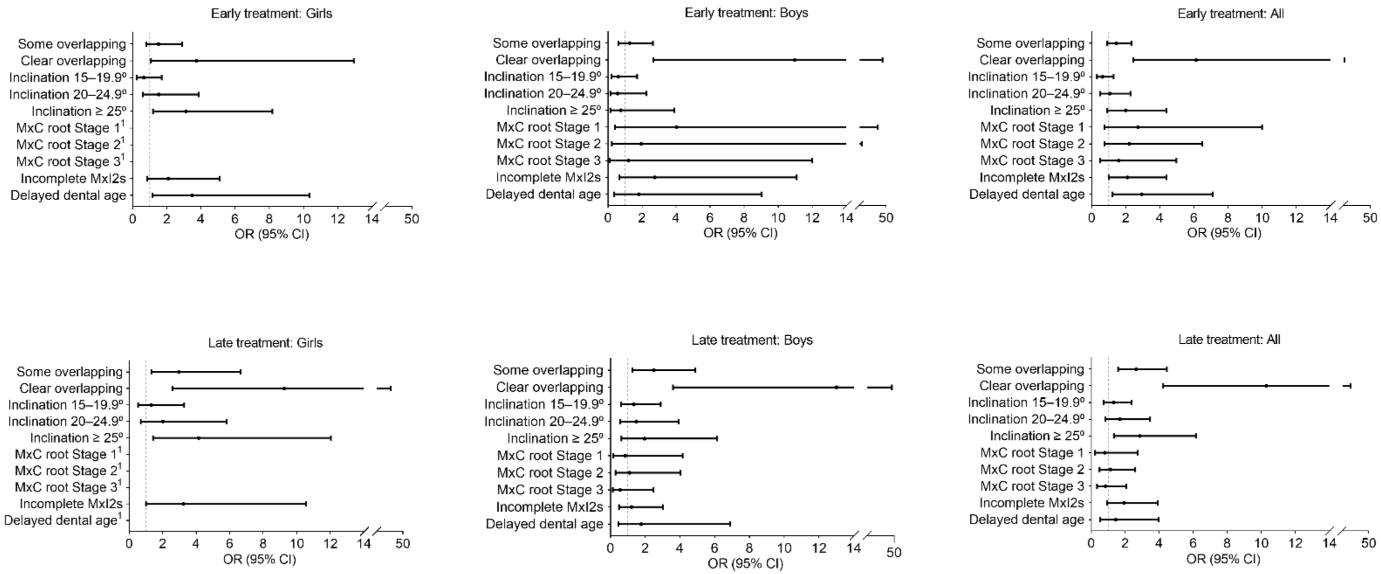

Fig. 8. Unadjusted logistic regression analysis of associations between the independent variables and early and late treatment in the treated canines, by gender (Overlapping ref. No overlapping; Inclination ref. < 15º; MxC root development ref. Stage 4; MxI2s development ref. Complete; Dental age ref. Early/normal, Dental age is assessed for children and was same for both MxCs; [1]frequency too low).

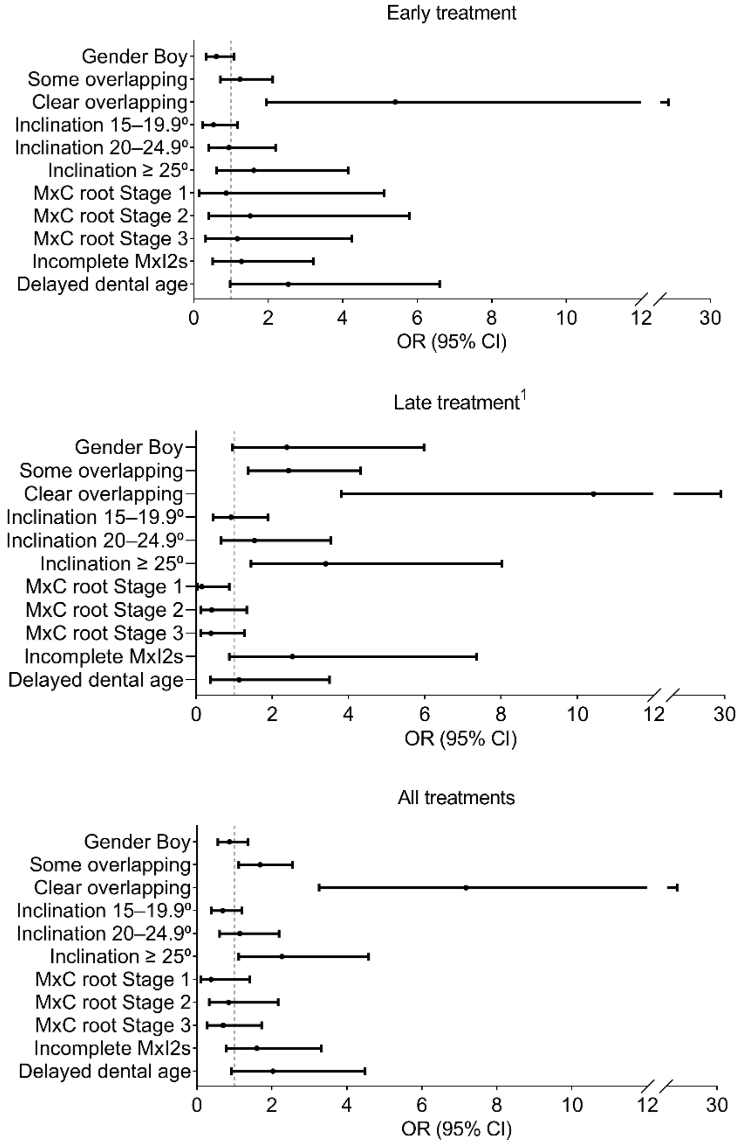

Fig. 9. Adjusted logistic regression analysis of associations between all the independent variables and treatment need groups in the treated canines (Gender ref. Girl; Overlapping ref. No overlapping; Inclination ref. < 15º; MxC root development ref. Stage 4; MxI2s development ref. Complete; Dental age ref. Early/normal, Dental age is assessed for children and was same for both MxCs; [1]Adjusted by interaction effect Gender * MxI2s development).

5.5 Features of DAP (Paper III)

The mean age of the children (n = 1315) concerned at the time of the PTG was 9.4 years (SD 0.4), a figure which did not differ between the genders ($p = 0.052$). Dental age could be assessed for 1176 children and varied between 6.5 and 13.2 years. The mean dental age was 9.6 years (SD 0.8) for girls and 9.8 years (SD 1.0) for boys ($p < 0.001$).

5.5.1 Prevalence of DAP features

At least one feature involved in DAP was detected in 29.8% (n = 392) of the children. The prevalences of the DAP features studied here are presented in Table 14. Infraocclusion was detected in 17.5%, being more frequent in girls ($p = 0.040$). One or two peg-shaped MxI2 were detected in 2.4% of the children, and these more often occurred unilaterally (1.7% vs. 0.7%). Distal angulation of MnP2 was detected in 7.3%, and this, too, more often occurred unilaterally (6.0% vs. 1.0%).

Table 14. Prevalences of DAP features in the subsample aged 8.5–10.5 years. Modified from Paper III © 2023 Acta Odontologica Scandinavica Society.

Variable		Total material	Girls	Boys	P value[1]
		n (%)	n (%)	n (%)	
Infraocclusion	Yes	154 (17.5)	80 (20.4)	74 (15.1)	
	No	727 (82.5)	312 (79.6)	415 (84.9)	0.040[2]
Absent teeth	Yes	110 (8.4)	68 (11.0)	42 (6.0)	
	No	1205 (91.6)	551 (89.0)	654 (94.0)	0.001[2]
Delayed dental age	Yes	89 (7.6)	44 (8.0)	45 (7.2)	
	No	1087 (89.4)	503 (92.0)	584 (92.8)	0.565[2]
Distal angulation of MnP2	Yes	81 (7.3)	43 (8.4)	38 (6.3)	
	No	1035 (92.7)	466 (91.6)	569 (93.7)	0.161[2]
Peg-shaped or absent MxI2	Yes	42 (3.2)	20 (3.2)	22 (3.2)	
	No	1269 (96.8)	599 (96.8)	670 (96.8)	0.958[2]
Peg-shaped MxI2	Yes	31 (2.4)	12 (1.9)	19 (2.7)	
	No	1280 (97.6)	607 (98.1)	673 (97.3)	0.337[2]
Transposition	Yes	7 (0.5)	3 (0.5)	4 (0.6)	
	No	1308 (99.5)	616 (99.5)	692 (99.4)	> 0.999[3]

[1]Statistically significant differences are between boys and girls; [2]Pearson's Chi-square test; [3]Fisher's exact test

Absences of permanent teeth varied from 1 to 8, occurring in 8.4% (n = 110) of the children and more often in girls (p = 0.001) (Table 14). Most of the children (7.0%) had 1 or 2 teeth absent, the most common absent tooth being MnP2 (Table 15), more often unilaterally (2.9%), while the absence of MxP2 occurred more often bilaterally (1.4%). At least one premolar was absent in 6.5% of the children, and more often in girls (7.9%, p = 0.043). MxI2 was absent in 1.1%, again more often unilaterally (0.8%).

Table 15. Prevalences of congenitally absent teeth in the subsample aged 8.5–10.5 years. Modified from Paper III © 2023 Acta Odontologica Scandinavica Society.

Children (n = 1315)	n (%)
MnP2	70 (5.3)
MxP2	31 (2.4)
MxI2	14 (1.1)
MnM2	10 (0.8)
MxP1	7 (0.5)
MnP1	5 (0.4)
MnI	5 (0.4)
MnC	2 (0.2)
MxC	1 (0.1)

5.5.2 Co-occurrence of DAP features

One feature involved in DAP occurred in 24.4% of children, while two occurred in 4.7% and three in 0.7%. Significant differences in distribution among the features are presented in Table 16. Three children (0.2%) had both MxI2 phenotypic variations, and these more often occurred together (p = 0.004) (Table 16). If MnP2 was absent, the antimere was not distally angulated any more often (right MnP2 absent vs. left MnP2 distally angulated p = 0.397, left MnP2 absent vs. right MnP2 distally angulated p = 0.470). A peg-shaped MxI2 was found more often with delayed dental age (p = 0.007) and absent teeth (p < 0.001) (Table 16). Delayed dental age and absent teeth occurred together more often (p = 0.008), especially in the case of an absent MxP2 (p = 0.009) or MnP2 (p = 0.049) (Table 16). Transposition was found more often with absence of teeth (p = 0.016), especially in the case of an absent MnP2 (p = 0.049) (Table 16).

Table 16. Distributions of absent teeth in subgroups among the features involved in DAP. Modified from Paper III © 2023 Acta Odontologica Scandinavica Society.

Variable		Delayed dental age		P value[1]	Peg-shaped MxI2		P value[1]	Transposition		P value[1]
		Yes	No		Yes	No		Yes	No	
		n (%)	n (%)		n (%)	n (%)		n (%)	n (%)	
Absent teeth	Yes	9 (10.1)	39 (3.6)		11 (35.5)	99 (7.7)		3 (42.9)	107 (8.2)	
	No	80 (89.9)	1048 (96.4)	0.008	20 (64.5)	1181 (92.3)	< 0.001	4 (57.1)	1201 (91.8)	0.016
Absent MnP2	Yes	4 (4.5)	15 (1.4)		7 (22.6)	63 (4.9)		2 (28.6)	68 (5.2)	
	No	85 (95.5)	1072 (98.6)	0.049	24 (77.4)	1217 (95.1)	< 0.001	5 (71.4)	1240 (94.8)	0.049
Absent MxP2	Yes	5 (5.6)	13 (1.2)		4 (12.9)	27 (2.1)				
	No	84 (94.4)	1074 (98.8)	0.009	27 (87.1)	1253 (97.9)	0.005			
Absent MxP1 or MnP1	Yes				2 (6.5)	7 (0.5)				
	No				29 (93.5)	1273 (99.5)	0.018			
Absent MxI2	Yes				3 (9.7)	11 (0.9)				
	No				28 (90.3)	1269 (99.1)	0.004			
Absent MnI	Yes				2 (6.5)	3 (0.2)				
	No				29 (93.5)	1277 (99.8)	0.005			
Peg-shaped MxI2	Yes	6 (6.8)	18 (1.7)							
	No	82 (93.2)	1066 (98.3)	0.007						

[1]Fisher's exact test

5.6 Features of DAP and maxillary canines (Paper IV)

The mean chronological age of the DAP children (n = 392) at the time of the PTGs was 9.4 years (SD 0.4), with no gender difference (p = 0.980), while the mean chronological age of the non-DAP children (n = 499) was 9.3 years (SD 0.3), again with no difference between the genders (p = 0.070). The mean chronological age did not differ between the DAP and non-DAP children (p = 0.881).

The distributions of DAP and non-DAP children by dental age are presented in Figure 10. The dental ages of the DAP children varied from 6.5 to 11.9 years, with a mean of 9.2 years (SD 1.1), but no gender difference (p = 0.447), whereas the dental ages of the non-DAP children varied from 7.7 to 12.0 years, with a mean of 9.6 years (SD 0.6) for the girls and 9.8 years (SD 0.8) for the boys (p < 0.001). The mean dental age of the DAP children was significantly later than that of the non-DAP children (p < 0.001).

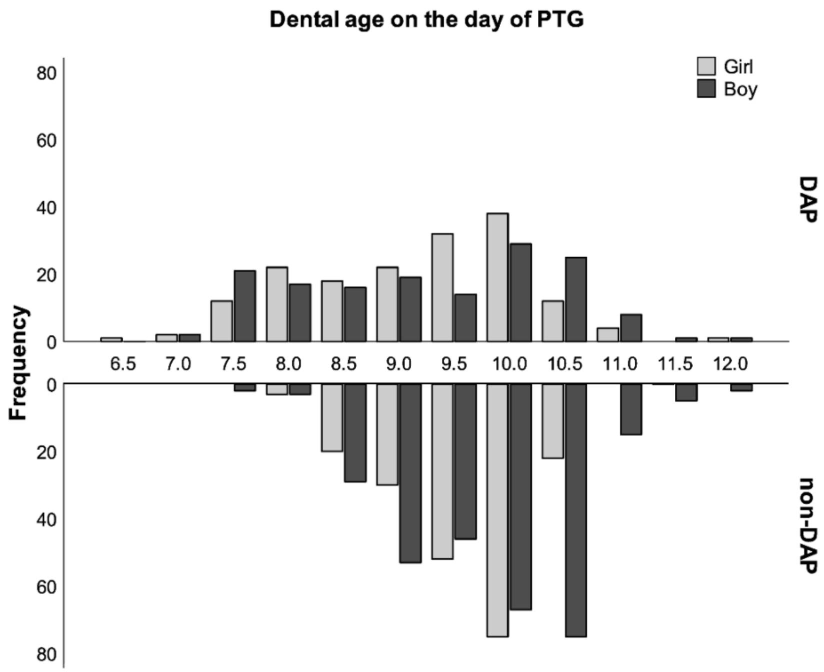

Fig. 10. Distribution of DAP children (n = 392) and non-DAP children (n = 499) by dental age in years.

5.6.1 Comparisons between the features of canines in DAP and non-DAP children

The need for treatment for the maxillary canines did not differ between the genders ($p = 0.355$), but the DAP children more often had early treatment ($p = 0.014$) (Table 17), whereas interceptive treatment was carried out more often for the DAP girls ($p = 0.004$) and early headgear treatment for the DAP boys ($p = 0.022$). Orthodontic treatment was more often needed by the non-DAP children (1.6% vs. 0.6%), but this difference was not statistically significant ($p = 0.134$).

The maxillary canines of the DAP children more often showed clear overlapping, but no overlapping also occurred more often ($p = 0.006$). Some or clear overlapping occurred more often in the maxillary canines of the non-DAP boys than in the DAP boys ($p = 0.023$), whereas same difference was not found among the girls ($p = 0.078$). The mean inclination was 13.4° (SD 7.5), but there was no difference in grouped inclination between the genders ($p = 0.051$) or between the DAP and non-DAP children ($p = 0.724$). (Table 18)

MxC root development varied between the DAP and non-DAP children, with the DAP children’s canines more often at either an early (Stage 1) or late stage (Stage 4–5), whereas those of the non-DAP children were mainly at Stage 2 or 3 ($p < 0.001$). MxI2s development were more often incomplete in the DAP boys ($p = 0.043$), but no difference was seen among the girls ($p = 0.750$). (Table 18)

Table 17. Distribution of maxillary canine treatment needs in the DAP and non-DAP children by gender.

Treatment need	Girls			Boys			All		
	DAP n (%)	non-DAP n (%)	P value[1]	DAP n (%)	non-DAP n (%)	P value[1]	DAP n (%)	non-DAP n (%)	P value[1]
No treatment	235 (88.3)	286 (89.4)		210 (88.6)	411 (92.2)		445 (88.5)	697 (91.0)	
Early treatment	22	16	0.127[2]	18	19	0.065[2]	40	35	0.014[2]
Interceptive treatment	15 (5.6)	4 (1.3)	0.004[2]	4 (1.7)	8 (1.8)	> 0.999[3]	19 (3.8)	12 (1.6)	0.012[2]
Early headgear	7 (2.6)	12 (3.8)	0.477[2]	14 (5.9)	11 (2.5)	0.022[2]	21 (4.2)	23 (3.0)	0.243[2]
Late treatment	9	18	0.230[2]	9	16	0.821[2]	18	34	0.529[2]
Orthodontic treatment	2 (0.8)	7 (2.2)	0.198[3]	1 (0.4)	5 (1.1)	0.669[3]	3 (0.6)	12 (1.6)	0.134[2]
Treatment for crowding	7 (2.6)	11 (3.4)	0.602[2]	8 (3.4)	11 (2.5)	0.453[2]	15 (3.0)	22 (2.9)	0.847[2]

[1]Significances of differences between no treatment and the treatment subgroups; [2]Pearson's Chi-square test; [3]Fisher's exact test

Table 18. Distribution of radiological features related to erupting maxillary canines in the DAP and non-DAP children by gender.

Variable	Group	Girls		Boys		All	
		DAP	non-DAP	DAP	non-DAP	DAP	non-DAP
		n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Overlapping	Grade 0	174 (52.7)	175 (45.7)	166 (61.3)	271 (51.0)	340 (56.6)	446 (48.8)
	Grade 1	137 (41.5)	191 (49.9)	98 (36.2)	243 (45.8)	235 (39.1)	434 (47.5)
	Grade 2	19 (5.8)	17 (4.4)	7 (2.6)	17 (3.2)	26 (4.3)	34 (3.7)
	P value[1]	0.078		0.023		0.006	
Inclination (°)	< 15	198 (58.9)	229 (59.5)	168 (60.2)	347 (64.4)	336 (59.5)	576 (62.3)
	15–19.9	73 (21.7)	81 (21.0)	63 (22.6)	107 (19.9)	136 (22.1)	188 (20.3)
	20–24.9	34 (10.1)	44 (11.4)	35 (12.5)	56 (10.4)	69 (11.2)	100 (10.8)
	≥ 25	31 (9.2)	31 (8.1)	13 (4.7)	29 (5.4)	44 (7.2)	60 (6.5)
	P value[1]	0.892		0.548		0.724	
MxC root development	Stage 1	21 (5.1)	4 (1.0)	73 (20.9)	67 (11.3)	94 (12.3)	71 (7.1)
	Stage 2	224 (54.4)	223 (57.7)	225 (64.3)	423 (71.5)	449 (58.9)	656 (65.9)
	Stage 3	112 (27.2)	140 (34.7)	40 (11.4)	85 (14.4)	152 (19.9)	225 (22.6)
	Stage 4	52 (12.6)	27 (6.7)	12 (3.4)	17 (2.9)	64 (8.4)	44 (4.4)
	Stage 5	3 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.4)	0 (0.0)
	P value[1]	< 0.001		< 0.001		< 0.001	
MxI2s development	Incomplete	324 (80.6)	314 (79.7)	320 (92.0)	514 (87.7)	644 (85.9)	828 (84.5)
	Complete	78 (19.4)	80 (20.3)	28 (8.0)	72 (12.3)	106 (14.1)	152 (15.5)
	P value[1]	0.750		0.043		0.426	

[1]Pearson's Chi-square test

5.6.2 Associations of the DAP features with canine treatment needs

The unadjusted and adjusted logistic regression analyses of associations between independent DAP features and treatment need groups in the children's maxillary canines are presented in Table 19. As independent variables, absence of teeth (OR = 2.09, 95% CI = 1.01–4.35) and delayed dental age (OR = 2.39, 95% CI = 1.04–5.49) were associated with a need for treatment, among which delayed dental age was associated especially with early treatment (OR = 3.29, 95% CI = 1.08–9.99). Unadjusted logistic regression for the maxillary canines of the DAP children did not give any associations between the DAP features and the treatment need groups.

Table 19. Unadjusted and adjusted logistic regression analyses of associations between DAP features and treatment need groups in the children's maxillary canines.

Variable	Early treatment[3]				Late treatment[3]				All treatments[3]			
	Unadjusted		Adjusted		Unadjusted		Adjusted		Unadjusted		Adjusted	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Gender Boy (ref. Girl)	0.83	0.47–1.47	0.89	0.44–1.81	1.03	0.59–1.80	0.72	0.33–1.56	0.93	0.62–1.41	0.81	0.46–1.41
Absent teeth (ref. no)	2.57	0.98–6.80	3.49	0.93–13.09	1.52	0.53–4.32	2.25	0.40–12.56	2.09[4]	1.01–4.35	2.93	0.94–9.12
Peg-shaped MxI2 (ref. no)[1]	4.03	0.68–23.75	2.27	0.29–17.54	0.83	0.07–10.28			2.50	0.61–10.20	1.41	0.21–9.53
Delayed dental age (ref. early/normal)	3.29[4]	1.08–9.99	2.53	0.83–7.69	1.53	0.46–5.10	0.74	0.14–3.92	2.39[4]	1.04–5.49	1.89	0.72–4.95
Infraocclusion (ref. no)	1.15	0.53–2.50	1.39	0.583.31	0.36	0.11–1.14	0.35	0.10–1.27	0.78	0.41–1.48	0.87	0.41–1.84
Distal angulation of MnP2 (ref. no)	1.09	0.34–3.55	0.62	0.10–3.94	1.04	0.31–3.52	2.10	0.51–8.74	1.07	0.45–2.55	1.21	0.38–3.82
DAP feature (ref. no)[2]	1.81	0.96–3.42			0.84	0.40–1.76			1.32	0.81–2.16		

[1]Peg-shaped MxI2 was excluded from the adjusted analysis of late treatment; [2]Transposition was excluded from the analysis; [3]Results are illustrated for the MxCs, so that the DAP feature was the same for both MxCs; [4]Statistically significant value

6 Discussion

Panoramic radiography is a basic examination to assess the developing dentition and observe the eruption of the permanent maxillary canines. A panoramic radiograph taken a couple of years before the eruption of the maxillary canines into the oral cavity is valuable when evaluating their eruption paths. Since most previous descriptive studies on this topic have been based on impacted maxillary permanent canines, the present research based on early features of erupting maxillary canines and later treatment need offers a new perspective on this dental developmental disorder. On average, the maxillary canines erupt into the mouth between the ages of 10–12 years during the late stage of mixed dentition (Koch et al., 2017; Nelson, 2019). A dentist can predict the path of maxillary canine eruption by clinical examination and palpation, and if necessary, by performing a radiographic examination.

One aim here was to describe the radiological features of maxillary canine eruption and to put these into perspective with regard to the treatment needed. Another aim was to report the occurrence of dental developmental abnormalities and to investigate their co-occurrence and relation to the features of maxillary canines.

6.1 Natural eruption of a maxillary canine (Paper I)

6.1.1 Dental development

At the age concerned (8.5–10.5 years), most roots of the naturally erupting canines had developed to between one-third and a half of their final length, while only a fifth of the lateral incisors were developmentally complete. These results differed from earlier findings, where root development in the canines have been reported to be mainly a half to three-quarters of the final length (Sajnani & King, 2012a) and more than half of the lateral incisors were completed (Fernández et al., 1998). According to the maturation norms quoted by Nolla (1960) development of the lateral incisor may still be incomplete at the above age.

In the present age cohort of children formation of the roots of the maxillary canines and lateral incisors was more advanced in the girls, confirming the general understanding regarding gender differences (Eskeli et al., 1999; Haavikko, 1970; Hägg & Taranger, 1986; Hurme, 1949; Nolla, 1960). The dental age of the girls concerned was nevertheless later than that of the boys, in contrast to earlier studies (Chaillet et al., 2004; Demirjian & Levesque, 1980). This may reflect the nature of root development between latent and growth periods, and the role of these growth periods during the eruption of individual teeth (Haavikko, 1970).

6.1.2 Overlapping and inclination

Almost half of the naturally erupting maxillary canines showed some degree of overlapping with the root of the adjacent lateral incisor in the PTG. This finding differed slightly from earlier reports that considered overlapping to be a normal eruption path feature up to 8–9 years of age (Fernández et al., 1998; Sajnani & King, 2012a) but a sign of displacement from the age of nine years onwards (Sajnani & King, 2012a). In the present study overlapping was more likely to occur when the root development in the maxillary canine had proceeded less than halfway or the lateral incisor was incomplete. Thus, some degree of overlapping at this age can be considered a feature of the normal eruption pattern if root development in the canine and the lateral incisor is at an early stage.

Little is known about the stage of lateral incisor root development in relation to the features of the erupting maxillary canines. Fernández and co-workers (1998) observed that overlapping with a fully developed lateral incisor in a PTG is rare and hence may be evidence of an abnormal canine eruption path. In their material overlapping occurred in only 7% of children over the age of nine years in whom the lateral incisor was complete. In the present children aged 8.5–10.5 years, however, overlapping occurred in more than a third of the cases in which the lateral incisor was complete, indicating that overlapping can occur during normal eruption even if development of the lateral incisor is complete.

The mean inclination of a naturally erupted canine at the age concerned, 12.4°, was convergent with the findings of Sajnani and King (2012a). In the present research it was found that the inclination of a canine was larger at the earlier stages of development when defined in terms that included dental age and root development in both the canine and the lateral incisor, and the inclination decreased significantly as root development continued from one-third to halfway. This can be considered one of the cut-off points in the canine eruption path and is in line with earlier findings that canines right themselves in time (Fernández et al., 1998; Sajnani & King, 2012a). Overlapping seems to increase the inclination angle significantly when root development in the canine is at an early stage (one–third) and/or the lateral incisor is incomplete. These findings verify the suggestion that larger inclination angles in a maxillary canine occur more frequently at the earlier stages of dental development.

6.2 Treated maxillary canines (Paper II)

6.2.1 Early radiological features

The maxillary canines that received treatment showed overlapping more often and had larger inclination angles than did those canines that erupted naturally, which is in line with the results of Sajnani and King (2012a) regarding ectopic canines. The results confirmed the findings that clear overlapping occurred six times more often and a large inclination (≥ 25°) twice as often than in the case of naturally erupting canines. It has been stated that overlapping is a better predictive factor than inclination when evaluating the possible impaction of a canine (Warford et al., 2003). Present findings regarding treated canines support this. Nevertheless, a large inclination angle of canine here has also been found to be an important predictive feature for its treatment, which confirms earlier findings of an abnormal maxillary canine eruption path in such instances (Chalakkal et al., 2011; Sajnani & King, 2012a).

In the age cohort studied here (8.5–10.5 years), the stage of maxillary canine root development did not differ between the treated and naturally erupting maxillary canines, agreeing with the results of Sajnani and King (2012a). Root development in the treated canines was nevertheless more advanced in the girls, whereas no difference was seen in lateral incisor development. In contrast, these children with treated maxillary canines had incomplete lateral incisors more often than did the children with naturally erupting canines, and only a minority of the treated children had a complete lateral incisor at the age concerned.

The fact that the children with treated canines had delayed dental development more often is in line with earlier findings that late timing of dental development and the displacement of a maxillary canine are related (Naser et al., 2011; Peck, 2009; Rozylo-Kalinowska et al., 2011). The dental age of the present boys with treated maxillary canines was earlier than in the corresponding girls (Papers I and II).

6.2.2 Early treatment

The perspective adopted here for early radiological features of maxillary canines and their later treatment needs is a novel one. Delayed dental age and incomplete lateral incisors were associated with the need for treatment, especially for early treatment. One interesting finding was that as many as a third of the children in the interceptive treatment group had a delayed dental age, differing clearly from the other treatment groups, where almost all of the children had an early or normal dental age. Moreover, it was interesting that the early stage of canine root development (Stage 1) had an inverse association with a late need for treatment, indicating a reduction in the need for late treatment. These results regarding dental age and root development in the canines and lateral incisors reflect the importance of the stage in dental development and differences among children of the same chronological age.

Treatment with early headgear between the early and late mixed stages of the dentition was enough to allow a third of the canines to erupt into the oral cavity. This drew attention to the ability of the types of headgear used here during the mixed stage to improve the eruption path, as suggested earlier (Hadler-Olsen et al., 2018; Silvola et al., 2009). Early headgear treatment can create the proper space conditions to allow the maxillary canines to erupt.

6.2.3 Late treatment

Given that every tenth maxillary canine in the entire sample from this homogeneous age cohort of Finnish children needed some treatment, including early treatment procedures to create more space in the dental arch for their eruption. Thus it can be concluded that only a small number of children eventually needed late orthodontic treatment, including surgical exposure of a maxillary canine.

One of the most common malocclusions to occur during the development of the permanent dentition in Finnish dental patients (Hannuksela, 1977; Heikinheimo et al., 1987; Kerosuo et al., 1991; Myllärniemi, 1970), patients in other Nordic countries (Helm, 1968; Thilander & Myrberg, 1973) and Caucasians (Littlewood & Mitchell, 2019) is crowding, and correspondingly the most common treatment option for the maxillary canines in the present cohort was treatment for crowding. This underlines the importance of monitoring the space conditions and, if necessary, creating space for the developing dentition and erupting maxillary canines early enough.

6.2.4 Follow-up

Sajnani and King (2012a) have shown that early differences in erupted and impacted maxillary canines as far as overlapping and inclination are concerned can be detected from the age of nine onwards. The present results were congruent with this finding, since overlapping, especially clear overlapping, and a large inclination at the age of 8.5–10.5 years was associated with a possible need for treatment (Paper II) and ought to be monitored. However, results also show that a maxillary canine can erupt naturally despite overlapping and a large inclination angle at this chronological age (Paper I). These findings agree with the observations of Ericson and Kurol (1986b), who recommend that disturbances in maxillary canine eruption shouldn't be diagnosed in children while they are younger than 10 years, due to the large variation and the possibility of spontaneous correction in the eruption path. Monitoring the eruption of the canine at the individual level during the latent period after the first mixed dentition provides a possibility for early treatment and can be expected to influence the space conditions in the dental arch.

6.3 Dental developmental abnormalities (Paper III)

6.3.1 Occurrence of DAP features

Dental developmental abnormalities of the kind involved in DAP, as seen in PTG, were detected in almost a third of the children. The most common feature involved in DAP in children with mixed dentition was infraocclusion in the primary molars, which was seen in almost a fifth of the children. Kurol (Kurol, 1981) reported the prevalence of primary molar infraocclusion to be at its maximum, about 14%, at the age of eight to nine. Also, infraocclusion occurred more often in girls, in contrast to earlier findings (Kurol, 1981; Odeh et al., 2016).

Congenitally absent permanent teeth were detected in 8.4% of the children, making them the second most common DAP feature. The occurrence of absent teeth was compatible with figures reported earlier in Finland (Haavikko, 1971) and Denmark (Rølling & Poulsen, 2009) and in a meta-analysis covering Europeans populations in general (Khalaf et al., 2014), whereas the present results are slightly higher than those reported for other European populations (Polder et al., 2004; Thilander & Myrberg, 1973). Absent teeth occurred more often in girls and mostly involved 1–2 teeth, the most affected tooth being the mandibular second premolar, all observations which are in line with earlier findings (Haavikko, 1971; Khalaf et al., 2014; Ojala-Alasuutari et al., 2022; Polder et al., 2004). On the other hand, the fact that bilateral occurrence of an absent maxillary second premolar was more common marked a difference relative to the earlier meta-analysis (Polder et al., 2004). One interesting finding to emerge from the present material was that the mandibular second molar was absent in 0.8% of cases, placing it in fourth place among the absent teeth. The prevalence reported in an earlier study of Finnish children (Haavikko, 1971) was lower (0.1%).

Maxillary lateral incisors are among the most varied teeth in terms of their anatomical shape (Nelson, 2019). Admittedly at least one other lateral incisor was detected as peg-shaped in slightly more than 2% of the children, being in line with the findings in an earlier meta-analysis (Hua et al., 2013). One the other hand, peg-shaped lateral incisor was detected more often unilaterally and without any gender difference, in contrast to the observations of Hua et al. (2013). A maxillary lateral incisor was absent in one percent of cases, which is lower than has been reported earlier, and such absences occurred more often unilaterally, also differing from the results of the earlier meta-analysis of Polder et al. (2004).

Distal angulation of unerupted mandibular second premolar was detected in 7.3% of the PTGs being in line with earlier report of Baccetti and co-workers (2010) (8.2%). In the present material, distal angulation occurred more often unilaterally.

The fact that the occurrence of transpositions (Mx.C.P1 or Mn.C.I2) was less than half a percent was in line with an earlier report (Thilander & Myrberg, 1973), but in this sample transposition occurred equally in the genders, which differed from earlier findings (Peck et al., 1993; Peck et al., 1998; Shapira & Kuftinec, 2001). Transposition in the maxilla was more common, as reported earlier (Ely et al., 2006; Papadopoulos et al., 2010; Shapira & Kuftinec, 1989).

Dental age varied by almost seven years (6.5 to 13.2 years) in this cohort of children aged 8.5–10.5 years, and delayed dental age was detected in 7.6% of cases. The occlusal development in these children varied between the end of the first mixed stage and an almost complete ordinary permanent dentition. The dental age of the boys was earlier in this cohort, in contrast to previous observations that girls are ahead in dental development (Chaillet et al., 2004; Demirjian & Levesque, 1980;

Eskeli et al., 1999; Haavikko, 1970; Hägg & Taranger, 1986; Hurme, 1949; Pahkala et al., 1991; Svanholt & Kjær, 2008).

6.3.2 Co-occurrence of DAP features

Absent teeth, peg-shaped maxillary lateral incisors and delayed dental age were more often found together in this cohort. A relation between absent teeth and a delay in dental development has been suggested earlier by many authors (Choi et al., 2017; Daugaard et al., 2010; Gelbrich et al., 2015; Kan et al., 2009; Navarro et al., 2014; Ruiz-Mealin et al., 2012; Uslenghi et al., 2006), and the absence of a second premolar occurring more often in children with delayed dental age confirmed the earlier findings of Navarro et al. (2014). In addition, a relation has been reported between any absent teeth and a peg-shaped maxillary lateral incisor (Al-Abdallah et al., 2015; Baccetti, 1998; Choi et al., 2017; Marra et al., 2021), especially in the case of absent and peg-shaped maxillary lateral incisors (Alvesalo & Portin, 1969; Arte et al., 2001). Likewise, an absent and a peg-shaped maxillary lateral incisor more often occurred together in the present research, but it should be noted that both phenotypes were seen only in three children. A congenitally absent or peg-shaped maxillary lateral incisor is one of the first visible features involved in DAP (Peck, 2009) to become apparent during an early stage in the mixed dentition and is an important indication for a follow-up with regard to other dental developmental abnormalities. The observation that transpositions occurred more often in conjunction with absent teeth is in line with earlier reports (Camilleri, 2005; Danielsen et al., 2015; Peck et al., 1993; Peck et al., 1998).

On the other hand, the children with primary molar infraocclusion, did not have other DAP features any more often, thus differing from earlier findings related genetically to other dental abnormalities (Baccetti, 1998; Choi et al., 2017; Küchler et al., 2008; Odeh et al., 2015; Peck, 2009; Shalish et al., 2010). Distal angulation of an unerupted mandibular second premolar was not found any more often in conjunction with the absence of its antimere, as has been suggested (Shalish et al., 2002), nor with any of the other DAP features studied here (Choi et al., 2017; Garib et al., 2009, 2010).

6.4 Dental developmental abnormalities and dental development (Paper IV)

6.4.1 DAP and features of the maxillary canines

This research suggested that overlapping of maxillary canines varied significantly more in the children with DAP features (Peck, 2009), and these more often had either clear overlapping or no overlapping at all. Surprisingly, the non-DAP boys had some or clear overlapping significantly more often than did the DAP boys indicating earlier dental development in the former. This is in line with the observation of an earlier dental age for non-DAP boys relative to non-DAP girls and the late dental development of DAP children. The inclination angle of the erupting maxillary canines did not differ between the children with and without DAP features. This finding differed from that expected.

The stage of canine root development in the children with DAP was more often either just at the beginning or well advanced (at least two-thirds completed), whereas in the non-DAP children the stage of development was mainly from one third to halfway regardless of gender. Earlier results have shown that canine root development does not differ between normal and ectopic erupting canines (Sajnani & King, 2012a) nor between naturally erupting and treated canines (Paper II). The early stage of canine root development in DAP children can be explained by their late dental age, but it was interesting to find that an advanced root development stage also occurred more often in the DAP children than in the non-DAP children. Lateral incisor development differed between the DAP and non-DAP boys, the former more often having incomplete lateral incisors, in line with their dental age.

6.4.2 DAP and dental age

Dental age was significantly later in the children with DAP features, as expected, and varied by as much as five and a half years (6.5 to 11.9 years), whereas the dental age of the children without DAP features varied by four and a half years (7.7 to 12.0 years). Delayed dental age has been related to eruption disturbances in the maxillary canines (Becker & Chaushu, 2000; Naser et al., 2011; Peck, 2009; Rozylo-Kalinowska et al., 2011), and the present results are compatible with this, as an association was found between delayed dental age and treatment needs of the maxillary canines. A delay in dental age was especially associated with early treatment.

6.4.3 DAP and the timing of treatment

The canines of the children with DAP features received early treatment significantly more often than those of the children without DAP features, almost twice as often, in fact. Interceptive treatment was carried out significantly more often on the DAP girls, while the DAP boys tended to receive early headgear treatment. Concerning the dental developmental stage, properly timed extraction of a primary maxillary canine in case of palatal eruption path (Bazargani et al., 2014; Ericson & Kurol, 1988; Naoumova et al., 2015; Power & Short, 1993) and early enough adoption of headgear (Hadler-Olsen et al., 2018; Silvola et al., 2009) are effective treatment options for managing abnormally erupting permanent canines.

It was surprising that late treatment was less closely related to the occurrence of DAP features. Orthodontic treatment, including surgical exposure, occurred more than twice as often (1.6% vs. 0.6%) in the children without DAP features, although the difference was not statistically significant. The canine treatment need was only slightly associated with delayed dental age and absent teeth.

Findings regarding treatment needs point to a successful follow-up and early treatment of the maxillary canines, especially in DAP children. This may suggest that early treatment was completed in time, as dental development was later in the DAP children. The results underline the importance of monitoring the erupting maxillary canines in children with and without dental developmental abnormalities. It is noticeable that dental age varied markedly even though the oral examinations were all carried out at the same primary school level.

6.5 Strengths and limitations

The major strength of this research is that it is based on PTGs from a representative age cohort of third-year primary school children. PTG gives a good general view of the maxillary canines a couple of years before their expected eruption into the oral cavity and yield important information about the dental developmental abnormalities that should be considered when planning follow-up or treatment. Furthermore, the material and the information on the treatment provided for the maxillary canines was all gathered from one public health centre, where orthodontic treatment and consulting was carried out by same dentists and senior orthodontist. Thus, the planning and implementation of the treatment can be considered to have been congruent throughout.

The clinical aspect adopted in this research is new. The material is of a considerable size compared with other descriptive studies (Alqerban et al., 2016; Fernández et al., 1998; Sajnani & King, 2012a), and the longitudinal view provided of the treatment needs of the maxillary canines means that the perspective is different from that adopted in earlier similar descriptive studies of erupting maxillary canines (Alqerban et al., 2016; Lindauer et al., 1992; Sajnani & King, 2012a; Warford et al., 2003).

The limitations of this work can be seen to lie in the study design, which is retrospective. The material was collected retrospectively from clinical dental records, which were not all complete in the archives. The cross-sectional PTGs represent the situation at one moment in the development of the subject's dentition, so that, due to variation in dental development, some features of DAP (e.g., infraocclusion and distal angulation of an unerupted mandibular second premolar) might have been visible before or after the PTG was taken.

The fact that the vertical distance of the canine tip from the occlusal plane (Ericson & Kurol, 1988) was not analysed can be seen as a limitation of this research, particularly as some earlier studies have suggested that this may be an important predictor of impaction of a maxillary canine (Alqerban et al., 2016; Sajnani & King, 2012a). It would be interesting to include this variable in the analysis in the future studies.

The treatment provided for the developing dentition and its occlusion is always individual, and for the purposes of this research the treatment need was categorized and considered from the time of taking the PTG to the eruption of the maxillary canines. Some children had received orthodontic treatment for the primary dentition or during the early mixed stage of the dentition (before the PTG), probably in the form of a Quad Helix for posterior cross-bite, braces on the upper incisors to close a large medial diastema, slicing of the primary canines mesially in the case of minimum space deficiency during the eruption of the lateral incisors, or elastics prescribed for a first molar cross-bite based on senior orthodontist treatment plans.

In addition, the subsamples for assessing the need for treatment with respect to the maxillary canines and the numbers of children with rare abnormalities (e.g., transposition) were markedly small. Also, the chronological age of the children was

8.5–10.5 years, and in rare cases a permanent second premolar might develop notably later than this.

6.6 Clinical implications and future research

To enable effective early treatment of maxillary canines, this should be carried out at a time that reflects the developmental stage of the dentition and existing space conditions. This would be cost-effective for society and save the child from long, demanding late treatment. The dental developmental stage in this age group of children varied markedly and was seen to extend between the end of first mixed stage and an almost complete ordinary permanent dentition. It is important to consider the dental developmental stage as a part of any dental examination.

The earlier study of Heikinheimo and co-workers (1987) showed that the longitudinally orthodontic treatment needs of the mixed dentition vary and require some follow–up, as the present findings also show. Attention needs to be paid to the eruption of the maxillary canines from the age of eight years onwards in view of the dental developmental stage.

The material for this work was derived from annual oral examinations, which was at that time the national standard for school children. Nowadays, according to Finnish legislation (Health Care Act 2:23 §; Government Decree 2:10 §), oral check-ups for school children should be done at least in the 1st, 5th and 8th grades by a dentist, dental hygienist, or specially trained dental nurse. There may therefore be only one oral examination performed by a dentist at primary school age, although emphasis is placed on the screening of occlusal development for those who need it. Only adequate monitoring based on the developmental stage of the dentition will enable early treatment to be provided for maxillary canine eruption problems.

This study showed a less marked association between late maxillary canine treatment and the occurrence of other dental developmental abnormalities. Although children with dental developmental abnormalities were prominent in the group receiving early treatment for their maxillary canines, it is important to monitor eruption in all children.

Several dental developmental abnormalities were seen in this research to have occurred together, which indicates the importance of an intensified follow-up for later occurring dental developmental abnormalities once some such conditions have been diagnosed during the earlier stages of dental development. The occurrence of dental developmental abnormalities in families, on the other hand, offers one possibility for screening dental developmental abnormalities and research for identifying similarities in genetic background. The pleiotropic effect was not investigated here and would need more research in the future.

The findings that have emerged from this thesis can help a dentist to make clinical decisions when evaluating the eruption of maxillary canines and dental developmental abnormalities in children with a late mixed dentition. Similar studies will be needed to verify our results and thereby support such clinical decision-making.

7 Conclusions

The findings reported here are compatible with a multistage eruption pattern for the maxillary canines. It is important to monitor the eruption of the canines after the first mixed dentition stage to enable early treatment to be started in time. The findings underline the importance of evaluating the existing space conditions and dental developmental stage as part of an examination of the developing dentition in addition to inspection and palpation of the canines. If any dental developmental abnormality is diagnosed during the earlier stages of development, an intensified follow-up will be needed to pre-empt conditions that might occur later.

The more specific findings are:

1. During the natural eruption of a canine, overlapping with the root of the lateral incisor and a larger inclination angle in the canine was seen at an early stage of development. The mean inclination angle of the canine was then seen to decrease as the root develops from one-third to halfway. Treated canines more often had overlapping, a larger inclination angle and incomplete lateral incisors than did naturally erupting canines, and these children generally had delayed dental age more often.
2. Only one in ten of the canines in the total material needed treatment. The most common option for treated canines was treatment for crowding (40.2%), while early headgear was sufficient in a third of the treated cases and interceptive treatment in a fifth. An association with treatment need was found, especially in cases of overlapping and a large inclination angle of the canine.
3. A feature involved in DAP of some kind was detected in almost a third of the children, the most common being infraocclusion of the primary molars, followed by absent teeth and delayed dental age. Mostly (24.4%) one feature occurred in a child. A delay in dental age, a peg-shaped lateral incisor and absent teeth more often occurred together, as did transposition and absent teeth.
4. The canines of the DAP children more often showed evidence of early treatment need, among which the DAP girls had more commonly received interceptive treatment and the DAP boys early headgear. Absent teeth and delayed dental age were associated with a treatment need. The canines of the DAP children had either no overlapping or clear overlapping and the development stage of the root was more often either at the beginning or well advanced.

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I Ristaniemi, J., Rajala, W., Karjalainen, T., Melaluoto, E., Iivari, J., Pesonen, P., & Lähdesmäki, R. (2022) Eruption pattern of the maxillary canines: features of natural eruption seen in PTG at the late mixed stage—Part I. *European Archives of Paediatric Dentistry, 23*(2), 223–232. https://doi.org/10.1007/s40368-021-00650-1

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