UNIVERSITÀ DEGLI STUDI DI MILANO
Facoltà di Medicina e Chirurgia
Scuola di Dottorato in Scienze morfologiche, fisiologiche e dello sport

RELATIONSHIP BETWEEN DISPLACED MAXILLARY CANINES AND THE MORPHOLOGY OF THE MAXILLA: A 3D MODEL ANALYSIS

Tutor: Ch.ma Prof.ssa Chiarella SFORZA

Tesi di Dottorato di:
Giorgio CACCIATORE
Matricola: R10021

ANNO ACCADEMICO 2014/2015

CONTENTS

ABSTRACT

AIM: To examine whether there is a relationship between impacted maxillary canines, early diagnosed by using panoramic radiographs, and the morphology of the maxilla on 3D model casts. SUBJECTS AND METHODS: Subjects were divided into two groups: the displaced maxillary canines (DMC) group and the control group. The DMC group consisted of 24 patients, with a mean age of 9.1±1.1 years, while the control group consisted of 25 subjects, with a mean age of 8.7±0.9 years. Fourteen patients had bilateral maxillary canine impactions. Early prediction of maxillary canine impaction was made by using three geometric measurements on panoramic radiographs: the position (sector) of the displaced canine relative to the surrounding teeth, the angle made by the long axis of the tooth with the midline, and the distance from the occlusal plane. Seven measurements were calculated on the digital casts of each subject: intermolar width (IMW), arch length (AL), depth of the palatal vault (PVD), available arch space (AAS), the sum of the widths of the four maxillary incisors (SWI), the right/affected (R-Af) and left/unaffected (L-Un) available spaces. Differences between the DMC group and the control group were calculated by means of Student's t-test for independent samples. RESULTS: Both IMW and AL in the DMC group resulted statistically significant decreased relative to the control group ($P<0.01$). No statistically significant differences between the two groups were found in the PVD. Moreover, the values of the SWI and AAS were significantly decreased ($P<0.01$) in the DMC group relative to the controls. These findings are consistent with those found for AL and IMW. The right/affected and left/unaffected sides were shorter in the DMC group as well ($P<0.01$), although there were no statistically significant differences between the two sides (right/affected, left/unaffected) in both groups. CONCLUSION: The shape of the maxillary arch was narrower and shorter in the displaced maxillary canines group compared with the control group. Further researches are needed to investigate the differences between unilateral and bilateral impactions.

INTRODUCTION

The Maxillae (Upper Jaw)

The maxillae are the largest bones of the face, except for the mandible, and form, by their union, the whole of the upper jaw. Each assists in forming the boundaries of three cavities: the roof of the mouth, the floor and lateral wall of the nose and the floor of the orbit; it also enters into the formation of two fossae, the infratemporal and pterygopalatine, and two fissures, the inferior orbital and pterygomaxillary. Each bone consists of a body and four processes: zygomatic, frontal, alveolar, and palatine.

The body (corpus maxillae) is somewhat pyramidal in shape, and contains a large cavity, the maxillary sinus (antrum of Highmore). It has four surfaces: an anterior, a posterior or infratemporal, a superior or orbital, and a medial or nasal.

The anterior surface (Fig. 1) is directed forward and laterally. In its lower part it presents a series of eminences corresponding to the positions of the dental roots. Just above those of the incisor teeth there is a depression, the incisive fossa. Lateral to the incisive fossa there is another depression, the canine fossa; it is larger and deeper than the incisive fossa, and it is separated from it by a vertical ridge, the canine eminence, corresponding to the socket of the canine tooth. Above the fossa there is the infraorbital foramen, the end of the infraorbital canal. Medially, the anterior surface is limited by a deep concavity, the nasal notch, whose margin ends below in a pointed process, which together with the homologous contralateral formation composes the anterior nasal spine.

The infratemporal surface (Fig. 1) is directed backward and laterally, and forms part of the infratemporal fossa. It is separated from the anterior surface by the zygomatic process and by a strong ridge, extending upward from the socket of the first molar tooth. At the lower part of this surface is a rounded eminence, the maxillary tuberosity, especially prominent after the growth of the wisdom tooth; it is rough on its lateral side for articulation with the pyramidal process of the palatine bone.

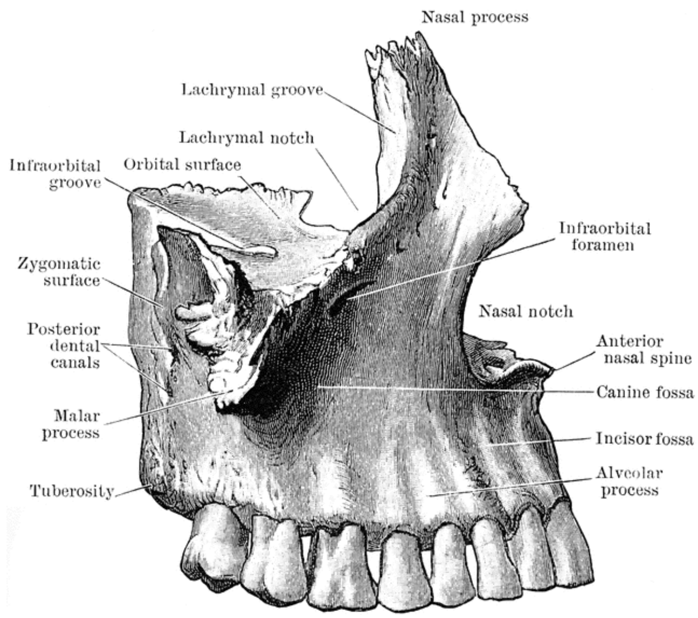


Fig. 1. Right maxilla. Outer surfaces (from Romanes, 1981 modified).

The orbital surface (Fig. 1) is triangular, and forms the greater part of the floor of the orbit. It is bounded medially by an irregular margin which in front presents a notch, the lacrimal notch. Near the middle of the posterior part of the orbital surface there is the infraorbital groove, which ends in a canal, subdivided into two branches. One of the canals, the infraorbital canal, opens just below the margin of the orbit.

The nasal surface (Fig. 2) presents a large, irregular opening leading into the maxillary sinus. Below the aperture there is a smooth concavity which forms part of the inferior meatus of the nasal cavity, and behind there is a rough surface for articulation with the perpendicular part of the palatine bone. This surface is traversed by a groove, commencing near the middle of the posterior border and running obliquely downward and forward; the groove is converted into a canal, the pterygopalatine canal, by the palatine bone.

The zygomatic process (processus zygomaticus; malar process) is a rough triangular eminence, situated at the angle of separation of the anterior, zygomatic, and orbital surfaces. In front it forms part of the anterior surface; behind, it forms part of the infratemporal fossa; above, it is rough and serrated for articulation with the zygomatic bone.

The frontal process (processus frontalis; nasal process) is a strong plate, which projects upward, medially, and backward, by the side of the nose, forming part of its lateral boundary.

The upper border articulates with the frontal bone and the anterior with the nasal; the posterior border articulates with the lacrimal bone.

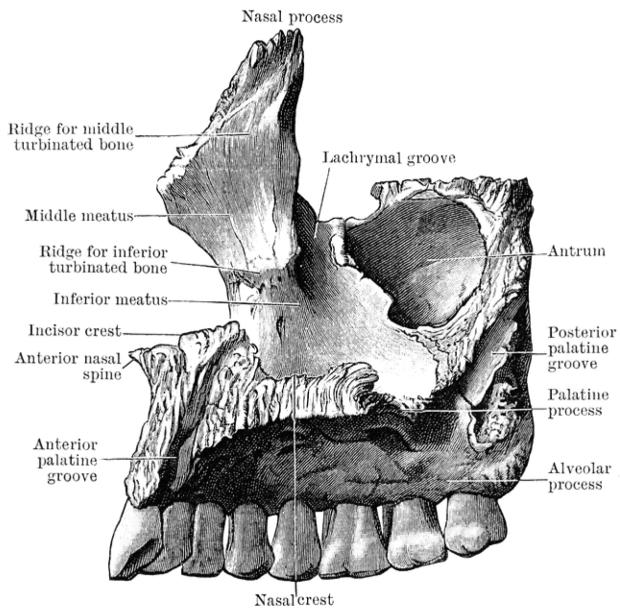


Fig. 2. Right maxilla. Nasal surface (from Romanes, 1981 modified).

The alveolar process (processus alveolaris) is the thickest and most spongy part of the bone. It is broader behind than in front, and excavated into deep cavities for the reception of the teeth. These cavities are five (deciduous dentition) or eight (permanent dentition) in number, and vary in size and depth according to the teeth they contain. That for the canine tooth is the deepest; those for the molars are the widest, and are subdivided into minor cavities by septa; those for the incisors are single, but deep and narrow. When the maxillae are articulated with each other, their alveolar processes together form the alveolar arch.

The palatine process (processus palatinus; palatal process), thick and strong, is horizontal and projects medially from the nasal surface of the bone. It forms a considerable part of the floor of the nose and the roof of the mouth and is much thicker in front than behind. Its inferior surface (Fig. 3) is concave, rough and uneven, and forms, with the palatine process of the opposite bone, the anterior three-fourths of the hard plate. The posterior border is serrated for articulation with the horizontal part of the palatine bone. When the two maxillae are articulated, a funnel-shaped opening, the incisive foramen, is seen in the middle line, immediately behind the incisor teeth. Occasionally two additional canals are present in the middle line; they are termed the foramina of Scarpa. The upper surface of the palatine process is concave from side to side, smooth, and forms the greater part of the floor of the nasal cavity (Drake et al., 2015).

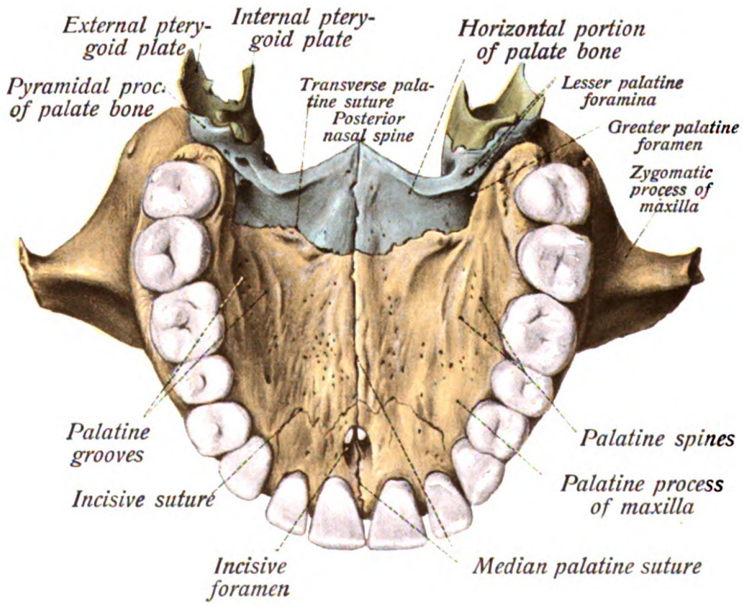


Fig. 3. The bony palate and alveolar arch (from Paulsen and Waschke, 2013 modified).

The Mandible (Lower Jaw)

The mandible, the largest and strongest bone of the face, consists of a horizontal portion, the body, and two perpendicular portions, the rami, which continue posteriorly to the body nearly at right angles.

The body (corpus mandibulae) is curved somewhat like a horseshoe and has two surfaces and two borders. The external surface (Fig. 4) is marked in the median line by a faint ridge, indicating the symphysis or line of junction of the two original pieces composing the bone at an early period of life. This ridge divides below and encloses a triangular eminence, the mental protuberance. Below the second premolar tooth, on either side, midway between the upper and lower borders of the body, there is the mental foramen, for the passage of the mental vessels and nerve. The internal surface presents spines and depressions, which give origin to the extrinsic muscles of the tongue and supra-hyoid ones. The superior or alveolar border, wider behind than in front, is hollowed into cavities, for the reception of the teeth; these cavities are sixteen (permanent dentition) or ten (deciduous dentition) in number, and vary in depth and size according to the teeth which they contain.

The ramus (ramus mandibulae; perpendicular portion) is quadrilateral in shape, and has two processes, separated by the mandibular notch. The Coronoid Process (processus coronoideus) is a thin, triangular eminence, which affords insertion to the Temporalis muscle.

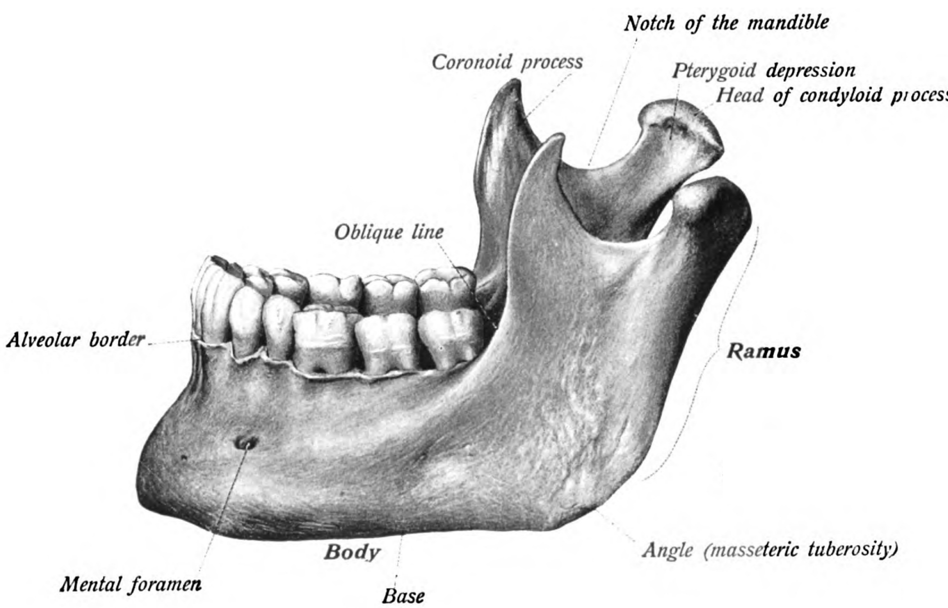


Fig. 4. Mandible. Outer surface (from Paulsen and Waschke, 2013 modified).

The Condyloid Process (processus condyloideus) is thicker than the coronoid, and consists of two portions: the condyle, and the constricted portion which supports it, the neck. The condyle presents an articular surface for articulation with the articular disk of the temporomandibular joint. Its long axis is directed medially and slightly backward, and if prolonged to the middle line will meet that of the opposite condyle near the anterior margin of the foramen magnum (Drake et al., 2015).

Teeth

Teeth are the small hard tissue structures of the upper and lower jaws for biting and chewing of food; they also help in the shaping of sounds and forming of words in speech. The part above the gum is the clinical crown, and that below the gum is the clinical root. The anatomical crown is covered by enamel, which shares the same embryological origin of the epithelial tissue of the skin and it is the hardest substance in the human body (Fig. 5). The surface of the anatomical root is composed of a bonelike tissue called cementum. Underneath the surface enamel and cementum there is a calcified substance called dentin, which makes up the main body of the tooth. Within the dentin, in a space in the centre of the tooth, there is the dental pulp, a soft, sensitive tissue that contains nerves, blood vessels, and lymph vessels. The root of the tooth sits in an alveolus (socket) in the jawbone.

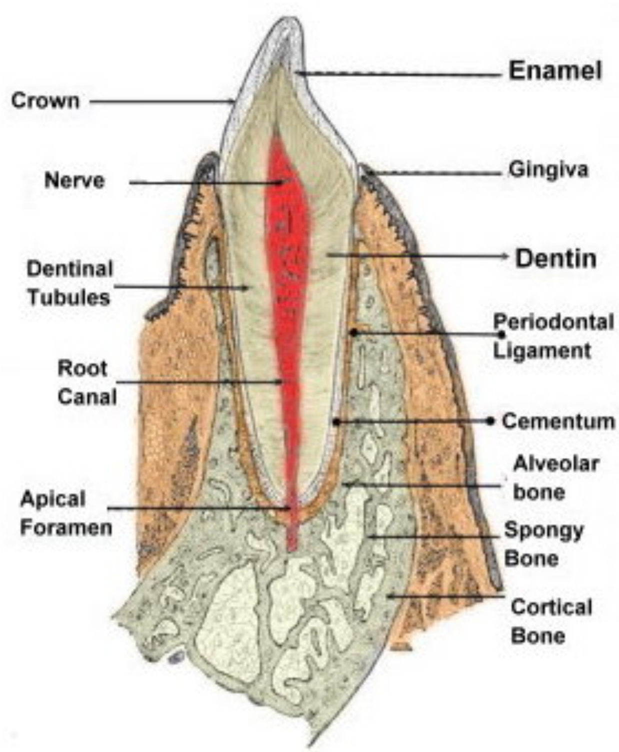


Fig. 5. Tooth anatomy (from Romanes, 1981 modified).

The tooth is supported in bone by an attachment apparatus, known as the periodontium, which interacts with its root. The periodontium consists of the cementum, periodontal ligaments, alveolar bone, and gingiva. Of these, cementum is the only dental component. Periodontal ligaments connect the alveolar bone to the cementum. Alveolar bone surrounds the roots of teeth to provide support and creates what is commonly called an alveolus, or "socket". Lying over the bone there is the gingiva or gum, which is readily visible in the mouth.

Humans, like other mammals, are diphyodont, meaning that they develop two sets of teeth: the “baby”, “milk”, “primary”, or “deciduous” teeth and the permanent teeth. There are 20 primary teeth, which are later replaced by 32 permanent teeth, evenly divided between the upper and lower jaws. In the primary set of teeth, there are two types of incisors, central and lateral, the canines and two types of molars, first and second; the permanent teeth are the central incisors, lateral incisors, canines, first and second premolars or bicuspids, first, second and third molars. Third molars are commonly called "wisdom teeth" and may never erupt into the mouth or form at all.

Most teeth have identifiable features that distinguish them from others. Canines have one cusp. Maxillary and mandibular premolars usually have two cusps. Maxillary molars have two buccal cusps and two lingual cusps. A fifth cusp that may form on the maxillary first molar is known as the cusp of Carabelli. Mandibular molars may have five or four cusps (two or three buccal and two lingual). Canines and premolars, except for maxillary first premolars, usually have one root. Normally, maxillary first premolars have two roots, one buccal and other one lingual. Maxillary molars usually have three roots (two buccal and one lingual), whereas mandibular molars have two roots (one mesial and the other one distal) (Nelson, 2015).

Tooth eruption

Although tooth eruption occurs at different times for different people, a general eruption timeline exists. The dentition goes through three stages. The first, known as primary dentition stage, occurs when only primary teeth are visible. Once the first permanent tooth erupts into the mouth, the teeth that are visible are in the mixed (or transitional) dentition stage. After the last primary tooth is shed or exfoliates out of the mouth, the teeth are in the permanent dentition stage.

Primary dentition stage starts on the arrival of the mandibular central incisors, typically from around six months, and lasts until the first permanent molars appear in the mouth, usually at six years. As a general rule, four teeth erupt for every six months of life, mandibular teeth erupt before maxillary teeth, and teeth erupt sooner in females than males. The primary teeth typically erupt in the following order: (1) central incisors, (2) lateral incisors, (3) first molars, (4) canines, and (5) second molars.

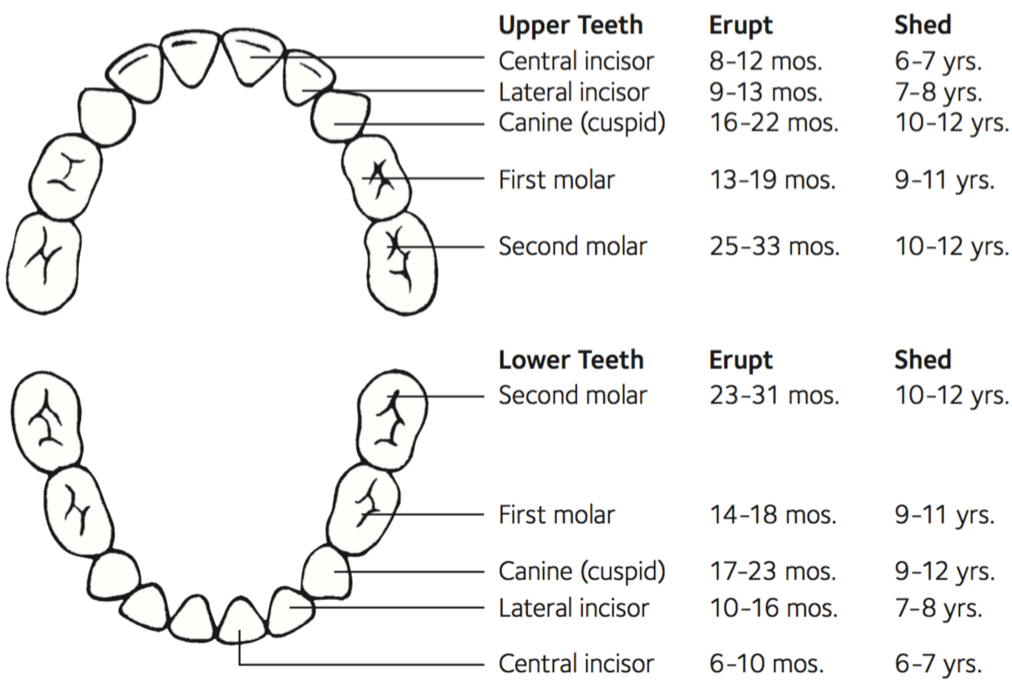


Fig. 6. Primary teeth eruption chart (from http://www.mouthhealthy.org/en/az-topics/e/eruption-charts).

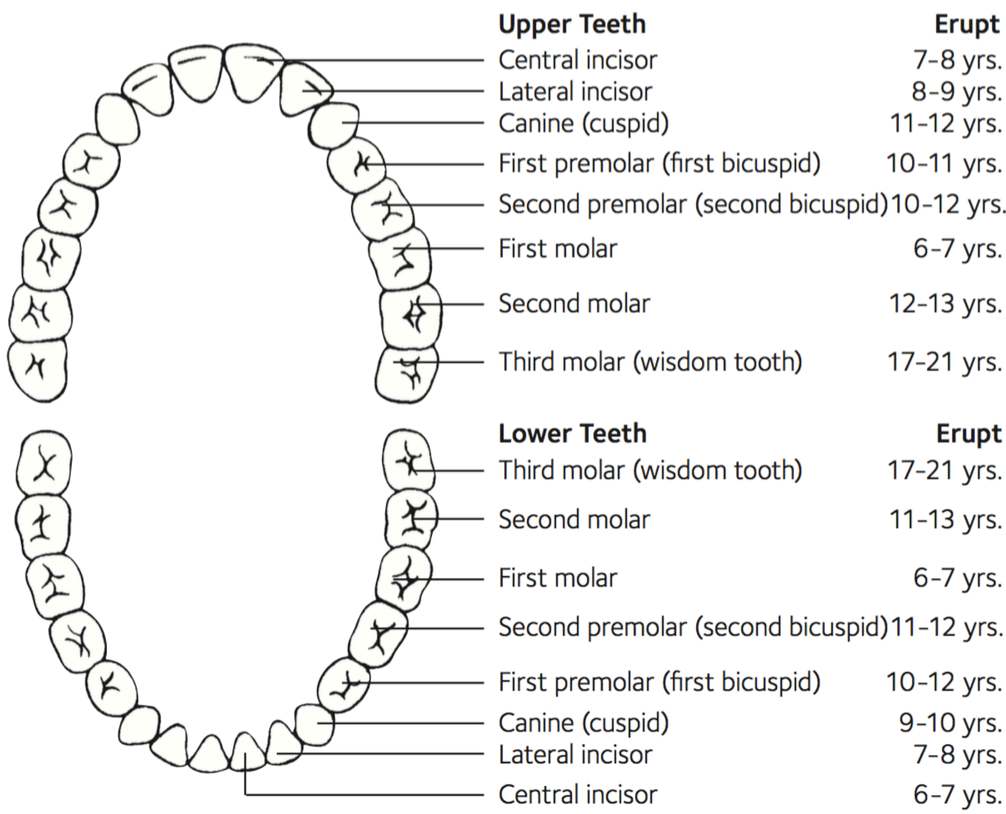


Fig. 7. Permanent teeth eruption chart (from http://www.mouthhealthy.org/en/az-topics/e/eruption-charts).

Mixed dentition stage starts when the first permanent molar appears in the mouth, usually at six years, and lasts until the last primary tooth is lost, usually at twelve years. Permanent teeth in the maxillae erupt in a different order from permanent teeth on the mandible. Mandibular teeth erupt in the following order: (1) first molars (2) central incisors, (3) lateral incisors, (4) canines, (5) first premolars, (6) second premolars, (7) second molars, and (8) third molars. Maxillary teeth erupt in the following order: (1) first molars (2) central incisors, (3) lateral incisors, (4) first premolars, (5) second premolars, (6) canines, (7) second molars, and (8) third molars (Nelson, 2015).

The permanent dentition begins when the last primary tooth is shed, usually at 12 years, and lasts for the rest of a person's life or until all of the teeth are lost (edentulism). The ranges of eruption of primary and permanent teeth are shown in figures 6 and 7, respectively.

Abnormalities of the teeth

Tooth abnormalities may be categorized according to whether they have environmental or developmental causes. While environmental abnormalities may appear to have an obvious cause, there may not appear to be any known cause for some developmental abnormalities. Environmental forces may affect teeth during development, destroy tooth structure after development, discolour teeth at any stage of development, or alter the course of tooth eruption. Developmental abnormalities most commonly affect the number, size, shape, and structure of teeth.

Abnormality in number

- Anodontia is the total lack of tooth development;
- Hyperdontia is the presence of a higher-than-normal number of teeth;
- Hypodontia is the lack of some teeth. Usually:
  Hypodontia refers to the lack of development of one or more teeth;
  Oligodontia may be used to describe the absence of 6 or more teeth.

Abnormality in size

- Microdontia is a condition where teeth are smaller than the usual size;
- Macrodontia is where teeth are larger than the usual size.

Microdontia of a single tooth is more likely to occur in a maxillary lateral incisor. The second most likely tooth to have microdontia are third molars. Macrodontia of all the teeth is known to occur in pituitary gigantism and pineal hyperplasia. It may also occur on one side of the face in cases of hemifacial hyperplasia.

Abnormality in shape

- Gemination occurs when a developing tooth incompletely splits into the formation of two teeth;
- Fusion is the union of two adjacent teeth during development;
- Concrescence is the fusion of two separate teeth only in their cementum;
- Accessory cusps are additional cusps on a tooth and may manifest as a Talon cusp, Cusp of Carabelli, or Dens evaginatus;
- Dens invaginatus, also called Dens in dente, is a deep invagination in a tooth causing the appearance of a tooth within a tooth;
- Ectopic enamel is enamel found in an unusual location, such as the root of a tooth;
- Taurodontism is a condition where the body of the tooth and pulp chamber is enlarged, and is associated with Klinefelter syndrome, Tricho-dento-osseous syndrome, Triple X syndrome, and XYY syndrome;
- Hypercementosis is excessive formation of cementum, which may result from trauma, inflammation, acromegaly, rheumatic fever, and Paget's disease of bone;
- A dilaceration is a bend in the root which may have been caused by trauma to the tooth during formation;

Abnormality in structure

- Amelogenesis imperfecta is a condition in which enamel does not form properly or at all.
- Dentinogenesis imperfecta is a condition in which dentin does not form properly and is sometimes associated with osteogenesis imperfecta.
- Dentin dysplasia is a disorder in which the roots and pulp of teeth may be affected.
- Regional odontodysplasia is a disorder affecting enamel, dentin, and pulp and causes the teeth to appear "ghostly" on radiographs (Neville et al., 2009).

AIM OF THE STUDY

Definitions and physiology

Displacement of maxillary canines can be defined as the "developmental dislocation […] often resulting in tooth impaction requiring surgical and orthodontic treatments" (Peck et al., 1996).

The term "malposed" or "displaced" maxillary canine (DMC) is generally referred to an anomalous position of the tooth recognised at an "early" stage of development. "Early" in biology is often considered as occurring before the usual or physiological time (Ricketts, 1998). From a physiological point of view, between 5 and 9 years of age the maxillary canine tends to move palatally, with substantial movement in a buccal direction between 10 and 12 years (McSherry and Richardson, 1999). Consequently, in the early stage of development it is not possible to differentiate palatally displaced canines (PDC) from buccally displaced canines (BDC). The average age when an upper canine should erupt is 12 years and 3 months in girls and 13 years in boys (Hurme, 1949).

The diagnostic criteria of evident "impacted" canine are as follows: (1) eruption difference of more than 1 year compared with the canine on the opposite side, (2) unerupted canine more than 1 year after all permanent teeth had erupted (Kim et al., 2012) (Fig. 8).

Epidemiology

Archaeological discovery of ancient human skulls has shown the presence of PDC since the sixth century BC (Baccetti et al., 1995).

The maxillary canine is second only to the mandibular third molar in its frequency of impaction, with a rate that varies from 0.8% to 2.8% (Chu et al., 2003; Ericson and Kurol, 1987). It is estimated that patients with bilateral impaction ranges from 17% to 45% of all patients with maxillary impacted canines. The ratios of female to male prevalence rate varies from 1.3:1 to 3.2:1 (Bishara, 1998; Peck et al., 1994). A dichotomy in DMC prevalence seems to exist between people of European ancestry and those of African or Asian ancestry. The preponderance of published cases of canine impaction are of European origin (Peck et al., 1994). Canine impaction has been found on the palate in 85% of the cases and to the buccal in 15% (Bishara, 1998; Ericson and Kurol, 1987; Rayne, 1969; Hitchin, 1956).

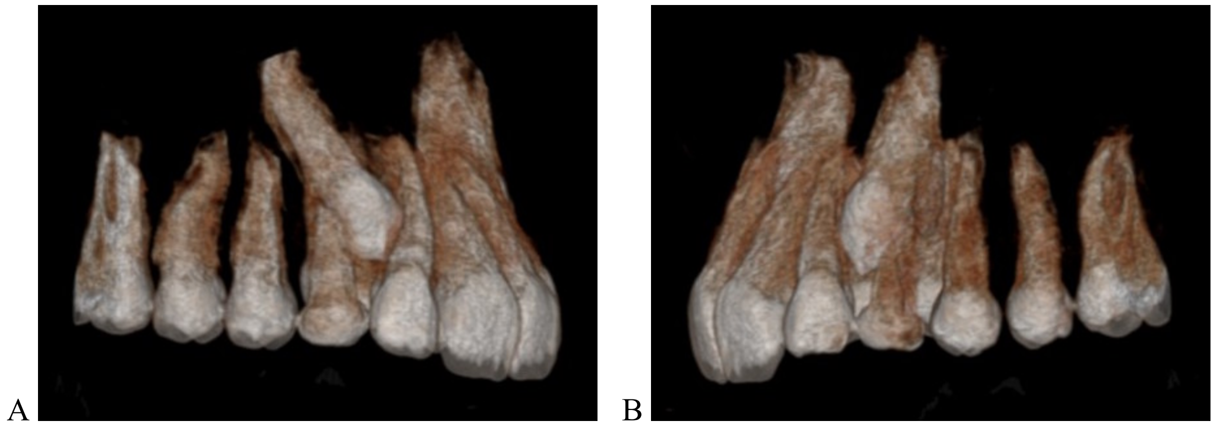


Fig. 8. A three-dimensional CBCT reconstruction of the maxilla of a 16 years old patient, with both impacted maxillary canines. **A**, The right impacted canine. **B**, The left impacted canine.

Aetiology

Crowding may play a role as an environmental cause of impaction, although arch length deficiency is associated primarily with buccal canine impaction (Langberg and Peck, 2000-Aug).

Two major theories have been delineated to explain the occurrence of PDC, i.e., the "guidance" theory and the "genetic" theory (Leonardi et al., 2003; Peck et al., 2002; Becker et al., 2002; Langberg and Peck, 2000-Aug; Vastardis, 2000; Baccetti, 1998-Dec; McSherry, 1998; Jacobs, 1998; Pirinen et al., 1996; Peck et al., 1996; Becker, 1995; Peck et al., 1995; Becker, 1993; Bishara, 1992; Becker, 1984; Jacoby, 1983). The guidance theory (Becker and Chaushu, 2015; Becker et al., 2002; Becker, 1995; Becker, 1993; Becker, 1984) refers to excess of space in the apical region of the maxillary bone during the eruption pathway of the permanent canine, due to either hypoplasia or aplasia of the upper lateral incisors. The displaced canine lacks the "guide" represented by the roots of the neighbouring teeth, thus suggesting the predominance of local reasons for the anomaly in the position of the tooth bud. According to the genetic theory, PDC are assigned to a complex of genetically determined tooth anomalies resulting from a developmental disturbance of the dental lamina (Leonardi et al., 2003; Peck et al., 2002; Vastardis, 2000; Baccetti, 1998-Dec; Pirinen et al., 1996; Peck et al., 1996; Peck et al., 1995). The associated dental features (aplasia and small size of lateral incisors included) allow for an early clinical diagnosis of the eruption disturbance (Stahl and Grabowski, 2003; Leifert and Jonas, 2003; Langberg and Peck, 2000-Apr; Baccetti, 1998-Jun; Brenchley and Oliver, 1997; Mossey et al., 1994; Oliver et al., 1989). Familial recurrences of PDC have been reported as well (Zilberman et al., 1990; Svinhufvud et al., 1988).

A different aetiology was discussed by McConnell et al. (1996), who implicated a deficiency in maxillary width as a local mechanical cause for palatally impacted canines. However, the relationship between displaced/impacted maxillary canines and the morphology of the maxilla remains controversial. A literature review about this relationship was conducted before starting the current study. The results of this review are presented in Table I. Some Authors stated that an association between PDC and transverse discrepancies could be present (Kim et al., 2012; Schindel and Duffy, 2007), most of the Authors didn't find differences in intermolar width of PDC and control groups (Hong et al., 2015; Yan et al., 2013; Saiar et al., 2006; Langberg and Peck, 2000-Aug; McConnell et al., 1996), one found that the width at maxillary first molar was greater in patients with PDC (Al-Nimri and Gharaibeh, 2005). Only two Authors evaluated patients aged under 10 years (Hong et al., 2015; Schindel and Duffy, 2007); the sample ages of the remaining Authors ranged between 10 and 30 years (Yan et al., 2013; Kim et al., 2012; Saiar et al., 2007; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug; McConnell et al., 1996). Moreover, different methods of measurement were used: cone-beam computed tomography (Hong et al., 2015; Yan et al., 2013) and dental casts (Kim et al., 2012; Schindel and Duffy, 2007; Saiar et al., 2006; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug; McConnell et al., 1996).

Diagnosis

One of the fundamental aspects in the diagnosis and treatment planning of a complex tooth anomaly such as the impaction of the permanent maxillary canine is the ability to diagnose and treat the tooth displacement early.

The main diagnostic tools that have been proposed to assess the probability of canine impaction in the individual patient relate both to spatial relationships of the tooth to the surrounding dentofacial structures, and to the associated features of the dentition, with special regard to concurrent dental anomalies. Baccetti (1998-Jun) demonstrated that palatal displacement of maxillary canines is associated with the early recognition of other tooth disturbances in the individual patient, such as small size of the upper lateral incisors, enamel hypoplasia, aplasia of second premolars, and infraocclusion of primary molars.

The early diagnosis of canine displacement in relation to the surrounding structures is based primarily on radiographic examination. Ericson and Kurol (1988-Nov; 1987) studied a sample of children aged 10–13 years and proposed the diagnosis on the panoramic film, which can be defined as “moderately” early. Lindauer et al. (1992) used a control group to propose a method to predict canine impaction with a precision of 78% through a modification of the procedure by Ericson and Kurol (1988-Nov). According to Fernandez et al. (1998) the overlapping of the canine and the lateral incisor in panoramic radiographs when the incisor has completed its development can be considered as a sign of a possible eruptive anomaly of the canine at an early stage. Warford et al. (2003) investigated angulations of unerupted canines in relation to the bicondylar plane measured from panoramic radiographs in addition to sector location of the tooth (in relation to overlapping of the lateral incisor) and concluded that sector location was a significantly better predictor of impaction than tooth angulation. A recent study stated that diagnosis of maxillary canine impaction is possible really early (8-9 years of age) by using geometric measurements on panoramic radiographs (sector locations of impacted maxillary canines, angulations formed by the long axis of the impacted canine with the midline, the distance of the cuspal tip of the impacted canine and the unaffected antimere from the occlusal plane) (Sajani et al., 2012).

Other radiographic techniques that are routinely used for orthodontic diagnosis such as lateral (Orton et al., 1995) and frontal cephalograms (Sambataro et al., 2005; McSherry and Richardson, 1999; Williams, 1981; Ricketts et al., 1972) can offer additional information for evaluation of upper canine displacement and, eventually, for prediction of canine impaction.

Treatment

Several treatment procedures (or associations of them) have been proposed for impacted maxillary canines, i.e., surgical exposure of the crown of the canine, either performed alone (Fig. 9.A-D) or followed by orthodontic traction of the impacted tooth (Fig. 9.E-H) (Burden et al., 1999; McSherry, 1998; Usiskin, 1991); extraction of the canine and replacement with implants (Mazor et al., 1999); and reimplantation of the displaced tooth (Berglund et al., 1996; Sagne et al., 1986; Moss, 1968).

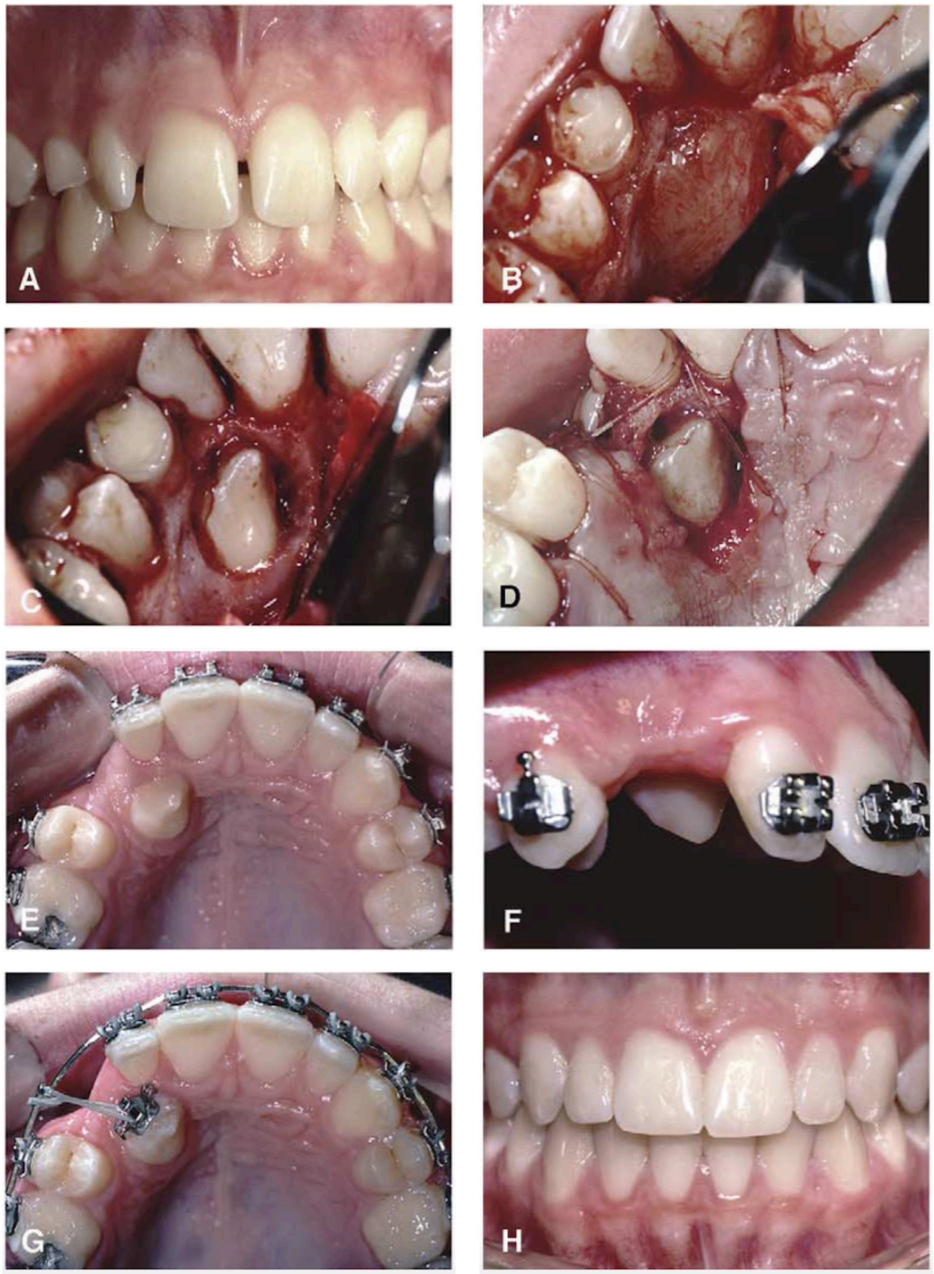


Fig. 9.A, Patient had palatally impacted maxillary right canine. Impacted tooth was uncovered before orthodontic treatment. **B**, Mucoperiosteal flap was elevated, and it was determined that crown was still covered with bone. **C**, All palatal bone down to cementoenamel junction was removed so that tooth could erupt unimpeded. **D**, Hole was placed in flap, and it was repositioned and sutured over crown of impacted canine. **E** and **F**, Canine erupted without orthodontic forces. **G**, When cusp tip was at level of occlusal plane, bracket was placed on crown and root was moved labially. **H**, After orthodontic treatment, it is difficult to identify differences between previously impacted right canine and contralateral nonimpacted canine (from Kokich 2003, modified).

Meanwhile, interceptive protocols proposed for PDC included extraction of the corresponding primary teeth (EC), orthodontic procedures to maintain or increase maxillary arch length or perimeter such as rapid maxillary expander (RME) (Fig. 10.A), transpalatal arch (TPA) and cervical-pull headgear (HG) (Fig. 10.B) or a combination of these modalities (TPA+EC, RME+TPA+EC, RME+HG, EC+HG). There was no evidence of the effects of EC in children with palatally displaced permanent canines (Parkin et al., 2009), while the prevalence of canine eruption was 65.7% for RME (Baccetti et al., 2009), 79.0% for TPA+EC (Baccetti et al., 2011), 80.0% for RME+TPA+EC (Baccetti et al., 2011), 82.3% for HG (Armi et al., 2011) and 85.7% for RME+HG (Armi et al., 2011) versus 13.6% for no treatment (Baccetti et al., 2009).

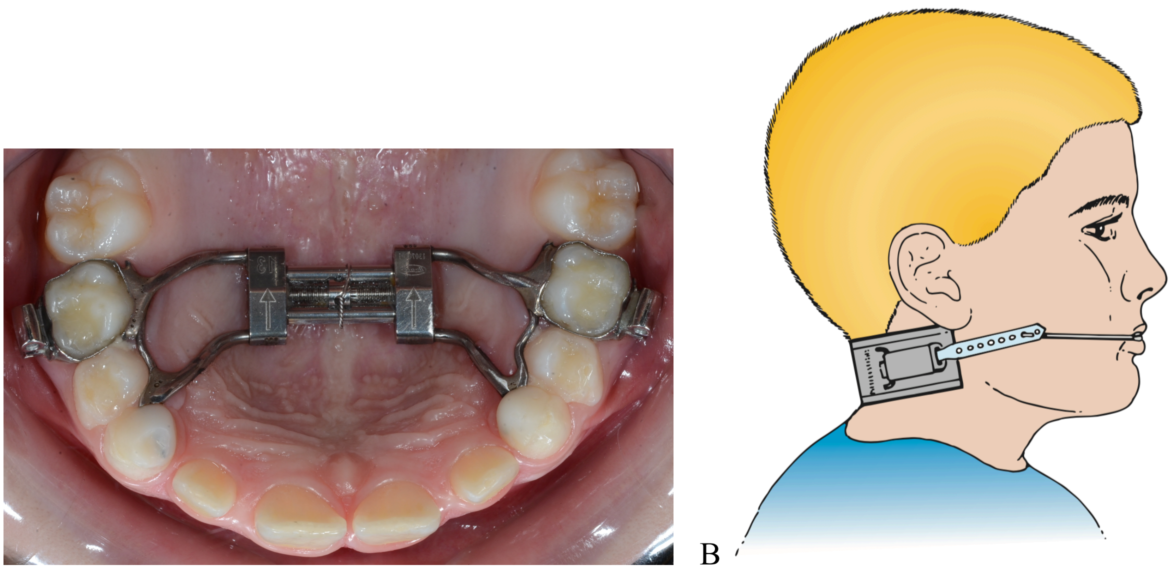
A  B

Fig. 10.A, Rapid maxillary expander. **B**, Cervical-pull headgear with safety connector (from Graber et al., 2012 modified).

If orthodontic treatment is not started in PDC cases, some other possible sequelae may occur, such as resorption of the roots of the neighbouring permanent teeth (Hadler-Olsen, 2015; Ericson et al., 2002; Ericson and Kurol, 2000; Rimes et al., 1997; Ericson and Kurol, 1988-Dec) and cysts (McSherry, 1998; Bishara, 1992; Ericson and Kurol, 1987).

Aim of the study

No previous studies evaluated the relationship between displaced maxillary canines and the morphology of the maxilla on digital casts. The aim of this study was to examine whether there is a relationship between impacted maxillary canines, early diagnosed by using panoramic radiographs, and the morphology of the maxilla on 3D model casts. If an association between some characteristics of the palate and displaced maxillary canines was demonstrated early, orthodontists could change them with their treatments.

Table I. Literature review about the relationship between impacted maxillary canines and the morphology of the maxilla

Authors **year of publication**	**Partecipants;** **mean age±SD, range (years)**	**Controls;** **mean age±SD, range (years)**	**Methods of measurement**	**Outcomes**	**Relationship between IMW and PDC**	**Other results**
Hong et al.; 2015	33 PDC: 22 F, 11 M; 18.2, 10-42 (pretreatment CBCT were taken when all patients were at least 10 years old)	66 not-PDC: 44 F, 22 M: 18.1, 10-42	Pretreatment CBCT	IMW, IPW1, IPW2, measured at central fossae; skeletal width at maxillary first molar, second premolar, and first premolar; the presence of permanent tooth agenesis and the mesiodistal width of maxillary anterior teeth	No differences of IMW in both groups	The maxillary transverse dimension, both skeletally and dentally, had no effect on the occurrence of PDC. The higher prevalence of permanent tooth agenesis was found in the PDC group. Moreover, the mean mesiodistal width of maxillary lateral incisors in the PDC group was significantly smaller than in the control group.
Yan et al.; 2013	101 PDC-69 BDC; -, 12-30	170 not-PDC or non-BDC: matched according to age (rounded to the whole year) and gender with the PDC-BDC group	Pretreatment CBCT	IMW, IP1, measured at central fossae; the mesiodistal width of maxillary anterior teeth; some CBCT measurements; some factors associated with palatally and buccally impacted canines	No differences of IMW in both groups	Anterior transverse (dental and skeletal) deficiency is a major etiologic factor for buccal canine impaction. Small (especially peg-shaped) or missing lateral incisors are a major etiologic factor for palatal canine impaction.
Kim et al.; 2012	45 PDC: 27 F, 18 M; 12.8±2.1	45 BDC; 26 F, 19 M; 12.1±1.3	Dental casts	IMW, measured at the mesio-buccal cusp tips; AL, PVD, SWI, AAS; width of NC, width of nostrils	IMW smaller in the PDC group	The shape of the maxillary arch was longer in the PDC group compared with the BDC group, and the PDC group had a deeper palatal vault than did the BDC group. There were no statistically significant differences in the widths of the NC and the nostrils between the 2 groups.
Schindel and Duffy; 2007	84 PXB: 42 F, 42 M; 9.5, -	100 not-PXB: 54 F, 46 M; 9.9, -	Dental casts	IMW, measured at the mesio-lingual cusp tips; sector location of the tip of an unerupted canine by using a panoramic radiograph, type of impaction (unilateral or bilateral)	An association between PDC and transverse discrepancies seems to be present	Patients with a transverse discrepancy do not have a greater likelihood of having a bilateral impaction compared with patients without a transverse discrepancy. However, this may be due to the small sample size of patients with bilateral impaction.

Saiar et al., 2006	79 PDC: 58 F, 21 M; 12.2±1.8, 9-16	79 not-PDC: 58 F, 21 M; 12.2±1.8, 9-16	Dental casts, occlusograms, posterio-anterior cephalograms	IMW, measured at central fossae; alveolar width at maxillary molars, premolars, canines; some cephalometric measurements	No differences of IMW in both groups	The additional finding in this study that the eruptive status of canines significantly affects maxillary alveolar arch width in this area suggests that maxillary intercanine alveolar arch width as measured in this or other studies is not a good predictor of PDC.
Al-Nimri and Gharaibeh; 2005	34 PDC: 27 F, 7 M; 17.7±4.6, 13-27	34 not-PDC: matched according to age (rounded to the whole year), gender and type of malocclusion, based on incisor classification with the PDC group	Dental casts	IMW, IPW1, measured at central fossae; SWI, AAS; dentoalveolar arch relationship, missing or anomalous teeth, the mesiodistal width of each maxillary tooth	IMW greater in the PDC group	PDC occurred most frequently in subjects with a Class II division 2 malocclusion. There was an association between PDC and anomalous lateral incisors. There were no other statistically significant differences between the PDC group and their matched comparisons.
Langberg and Peck; 2000	31: 21 F, 10 M; 13.6; 11-17 (ages of pretreatment dental casts were not reported)	31 not-PDC: matched according to age (rounded to the whole year) and gender with the PDC group	Pretreatment dental casts	IMW, IPW1, measured at central fossae	No differences of IMW in both groups	IPW1 comparison between the sample with PDC and the reference sample showed no statistically significant differences in their means, thus indicating that there was no statistically significant difference in the anterior arch width between the affected subjects and the control subjects.
McConnell et al.; 1996	57 PDC or BDC; -	103 not-PDC or non-BDC; -	Dental casts	IMW, ICW, AL, AP, arch form	No differences of IMW in both groups	Subjects with canine impactions demonstrate profound transverse maxillary deficiency located in the anterior portion of the dental arch. No significant difference in arch form is noted between the experimental and control groups.

PDC, palatally displaced or impacted canines; BDC, bucally displaced or impacted canines; PXB, posterior crossbite; F, female; M, male; SD, standard deviation

IMW, width at maxillary first molar; IPW2, second premolar; IPW1, first premolar and ICW canines

AL, Arch length; PVD, palatal vault depth; SWI, sum of the widths of the 4 maxillary incisors; AAS, available arch space; NC, nasal cavity

SUBJECTS AND METHODS

Subjects

Subjects who received a periodical orthodontic evaluation at a single private practice between 2012 and 2015 were enrolled.

Early prediction of maxillary canine impaction was made by using geometric measurements on panoramic radiographs, according to Sajani et al. (2012). The measurements included the position (sector) and angulation of the tooth, and the distance from the occlusal plane (adapted from Ericson and Kurol (1988-Nov)).

The classification of sectors depended on the location of the tip of the impacted canine relative to the surrounding teeth (Fig. 11):

- S0, between the line tangent to the distal contour of lateral incisor and the line tangent to the mesial contour of first premolar (physiological position);
- S1, between the distal contour of lateral incisor and the lateral incisor long axis;
- S2, between the lateral incisor long axis and the distal contour of central incisor;
- S3, between the distal contour of central incisor and the central incisor long axis;
- S4, between the central incisor long axis and the midline;
- S5, over the midline;
- S-1, between the lines tangent to the mesial and distal contours of first premolar;
- S-2, between the lines tangent to the mesial and distal contours of second premolar;
- S-3, over the distal contour of second premolar.

The angle α was made by the long axis of the impacted maxillary canine with the midline, defined by the following landmarks on the radiograph: intermaxillary suture, anterior nasal spine, nasal septum, and internasal suture (Fig. 12).

The distance from the occlusal plane (d1) was measured on the perpendicular line drawn from the incisal tip of the impacted canine to the occlusal plane. The occlusal plane was determined by drawing a horizontal line passing through the incisal edge of the central permanent incisor and the occlusal plane of the first permanent molar on the given side (Fig. 13).

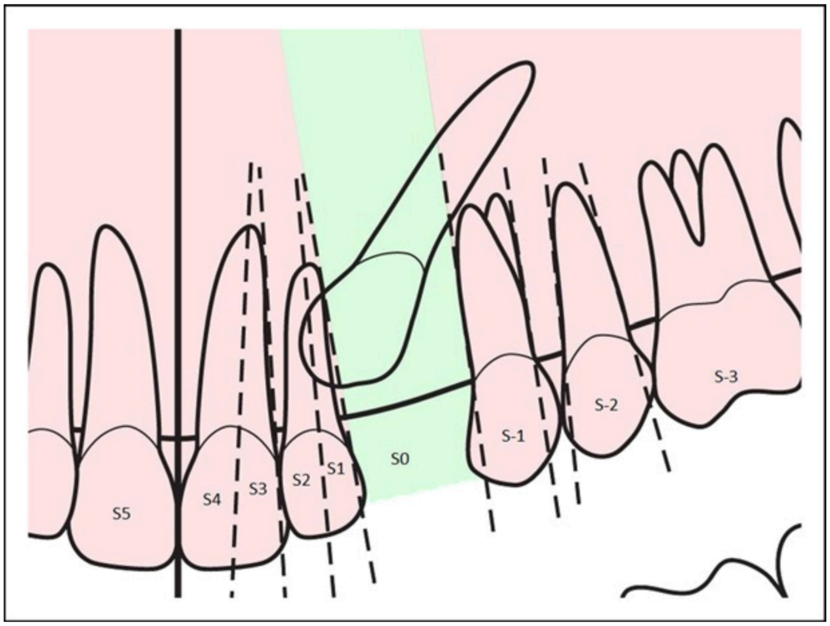


Fig. 11. Diagrammatic representation of the sectors of the impacted canine (from Ericson and Kurol, 1988 modified).

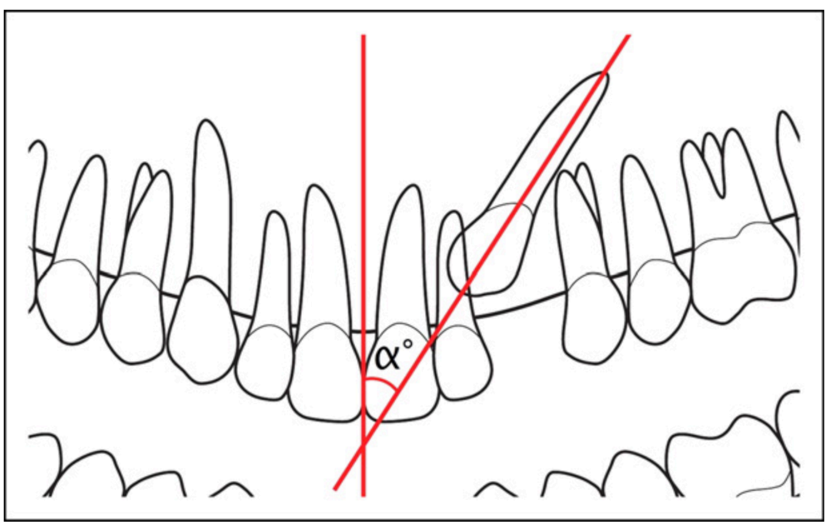


Fig. 12. Diagrammatic representation of the measurement of the angulation (from Ericson and Kurol, 1988 modified).

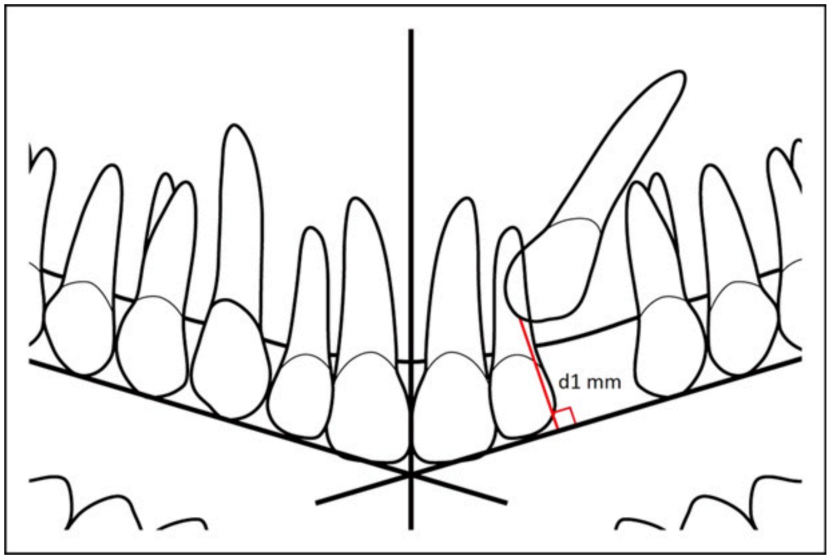


Fig. 13. Diagrammatic representation of the measurement of the distance from the occlusal plane (from Ericson and Kurol, 1988 modified).

Early diagnosis criteria of the maxillary canine impaction were as follows: (1) sector of impacted maxillary canine different from S0, (2) angulation larger than 30.0°, and (3) the distance from the occlusal plane larger than 20.0 mm (Sajani et al., 2012). Patients with bilateral impaction were included only if the position of impaction was the same on both sides. All radiographs were examined in a darkened room by using an illuminated x-ray viewing box. The panoramic radiographs were traced with 0.003-in matte acetate tracing paper and a 0.5-mm HB fine lead pencil.

In addition, the exclusion criteria were as follows: (1) patients with definitive obstructions (e.g., odontoma or supernumerary teeth), (2) patients with a systemic disease, (3) patients with craniofacial anomalies (e.g., cleft lip or palate), and (4) patients with several impacted teeth or congenitally missing teeth.

Subjects were divided into two groups: the DMC group and the control group. The DMC group consisted of 24 patients, female to male ratio 2:1, with a men age of 9.1±1.1 years, while the control group consisted of 25 subjects, female to male ratio 14:11, with a mean age of 8.7±0.9 years. The distributions of the samples are shown in Table II. Fourteen patients had bilateral maxillary canine impactions. The characteristics of the upper canines (right and left) of patients included in the DMC group are shown in Table III.

				Age, y			
	n	**Female**	**Male**	**Mean**	**SD**	**Min**	**Max**
DMC group	24	16	8	9.1	1.1	7.1	11.1
Control group	25	14	11	8.7	0.9	7.2	10.5

Table II. Demographics for the DMC and control groups.

Patient	Type of impaction	Upper right canine	Upper left canine
D-F01	Bilateral	Angolated	Angolated
D-F02	Bilateral	High	High
D-F03	Bilateral	High	High
D-F04	Unilateral	S-1	-
D-F05	Bilateral	High	High
D-F06	Bilateral	High	High
D-F07	Unilateral	S1	-
D-F08	Bilateral	High	High
D-F09	Unilateral	S1	-
D-F10	Unilateral	Angolated	-
D-F11	Bilateral	High	High
D-F12	Unilateral	-	S1
D-F13	Unilateral	-	S1
D-F14	Unilateral	S1	-
D-F15	Bilateral	High	High
D-F16	Bilateral	High	High
D-M01	Unilateral	S1	-
D-M02	Bilateral	High	High
D-M03	Unilateral	Angolated	-
D-M04	Bilateral	High	High
D-M05	Bilateral	High	High
D-M06	Bilateral	High	High
D-M07	Unilateral	S1	-
D-M08	Unilateral	-	Angolated

Table III. The characteristics of the upper canines of patients included in the DMC group.

Methods

The upper dental cast of all subjects was obtained from A-Silicone impressions (Elite HD+, Zhermack SpA, Badia Polesine, Italy; Fig. 14). The dental cast was scanned by a three-dimensional scanner (D100, Imetric 3D, Courgenay, Switzerland; Fig. 15, 16) and analysed by the VAM software (Vectra 3D, Canfield Scientific, Fairfield, NJ).

Fig. 14. Impression material.

Fig. 15. 3D laser scanner.

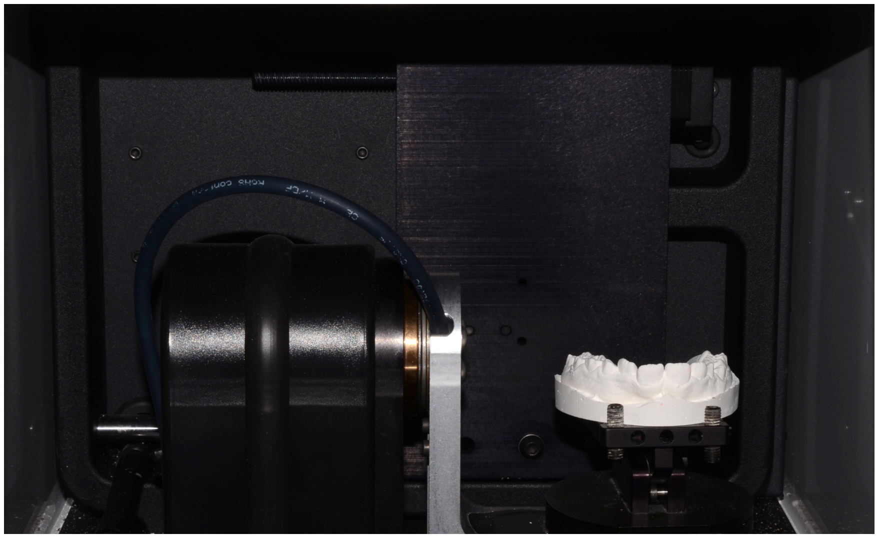


Fig. 16. Interior detail of the scanner.

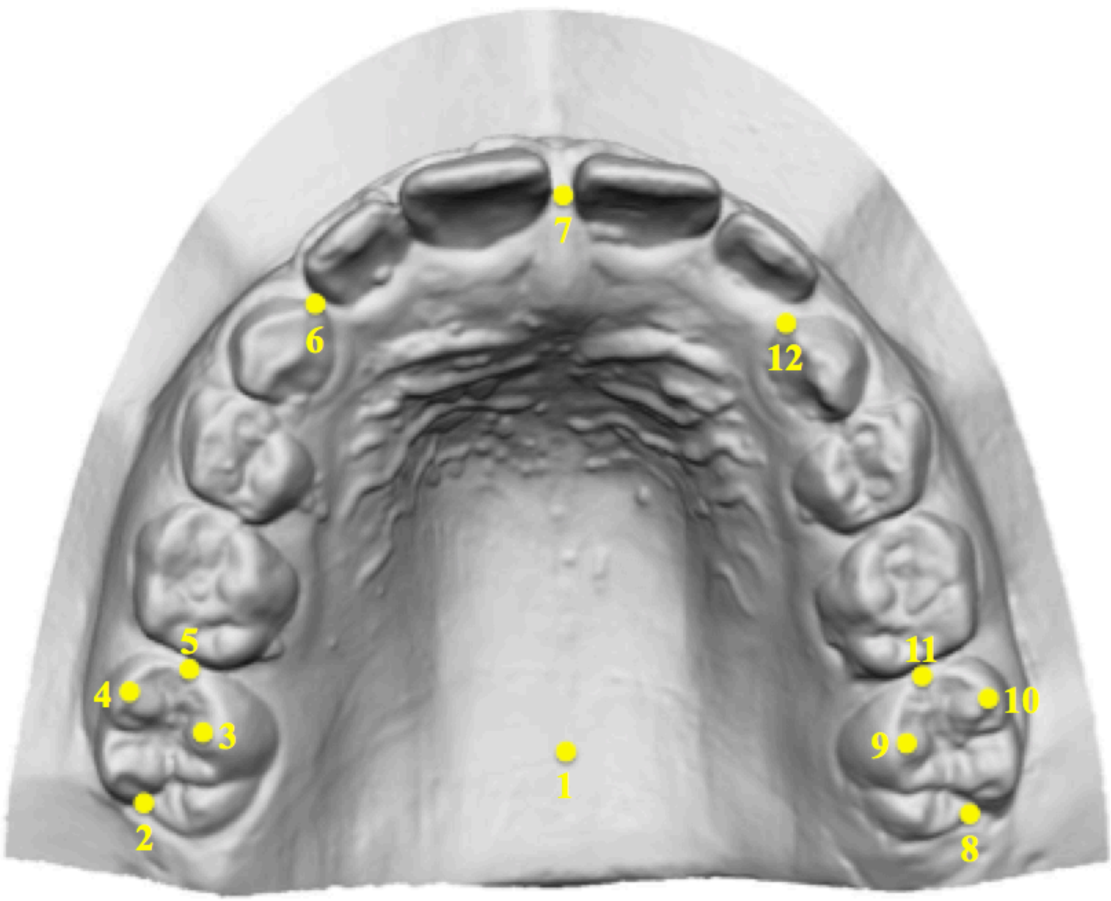


Fig. 17. Example of 12 standardized dental landmarks.

On all casts, a set of twelve standardized dental landmarks (two paired, five impaired landmarks) was identified, as follows (Fig. 17):

- The deepest point of the palatal vault (1);
- Contact point between the central incisors (7);
- Distal ends of the right and left first molars (2, 8);
- Mesio-palatal cusp tips of the first molars (3, 9);
- Mesio-buccal cusp tips of the first molars (4, 10);
- Mesial ends of the right and left first molars (5, 11);
- Mesial contact points of the right and left primary canines (6, 12).

The three-dimensional (x, y, z) coordinates of the landmarks were obtained and a customized Excel spread-sheet (Microsoft Excel, Microsoft, Redmond, WA) was used for all the subsequent calculations:

- Intermolar width (IMW) was defined as the distance between the mesio-buccal cusp tips of the first molars (Fig. 18);
- Arch length (AL) was defined as the distance from the contact point between the central incisors to the line that links the distal ends of the right and left first molars. If the antero-posterior position of the left and right maxillary central incisors differed for reasons including crowding, the values on the right and left side were measured, and the average value was used;
- Depth of the palatal vault (PVD) was defined as the vertical distance from the deepest point of the palatal vault to the contact line between the mesio-palatal cusp tips of the right and left first molars (Fig. 19);
- The upper arch was divided into four segments: two segments from the mesial ends of the right and left first molars to the mesial contact points of the right and left primary canines, two segments from the primary canines to the contact point between the central incisors. Available arch space (AAS) was estimated with the sum of these four segments, while the sum of the widths of the four maxillary incisors (SWI) was estimated with the sum of the two anterior segments (Fig. 20);
- Moreover, in the control group, the right (R) and left (L) available space was estimated respectively with the sum of the two right and left side segments. In the PDC group, all the patients with unilateral impaction were considered to be affected (Af) on the right side, while the left side was considered to be the unaffected side (Un).

The digitizer resolution was 0.013 cm/cm of range and its accuracy 0.025 cm. Digitization of landmarks was performed by a single operator.

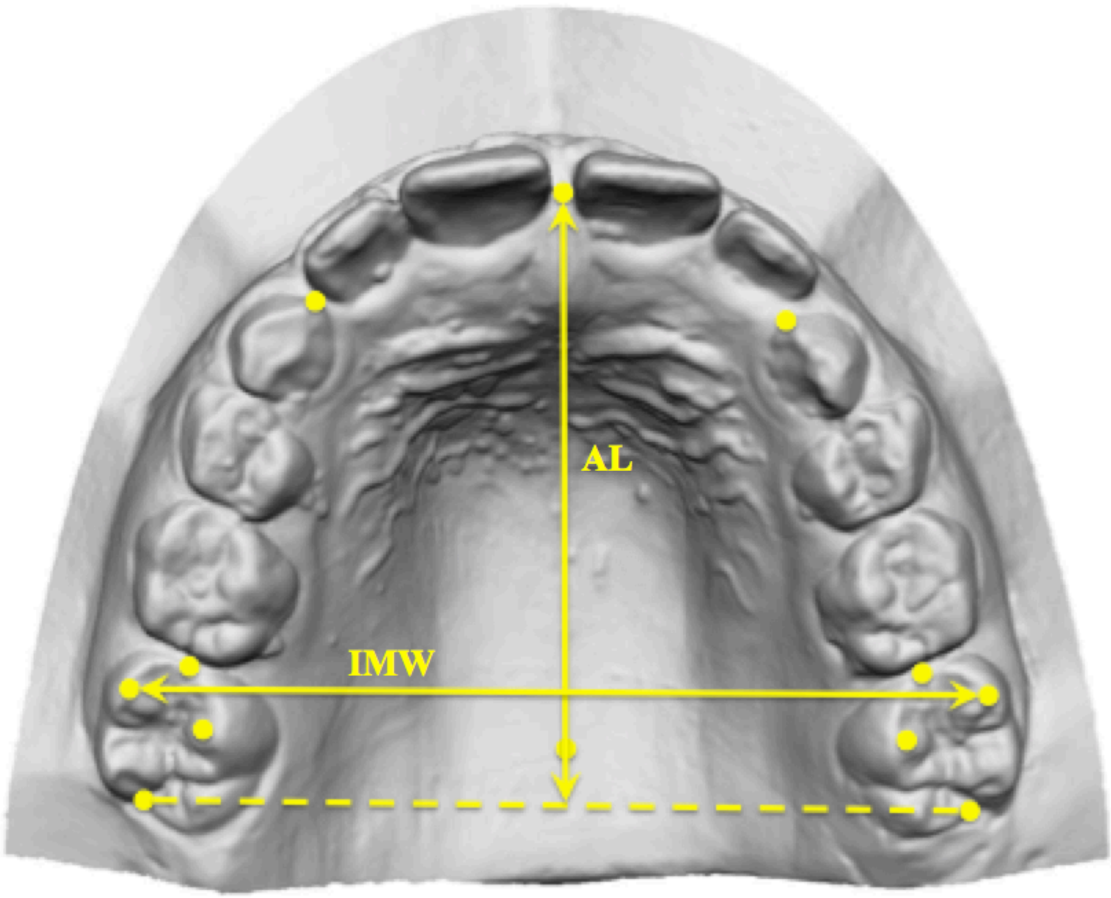


Fig. 18. Representation of the measurements of the intermolar width (IMW) and arch length (AL).

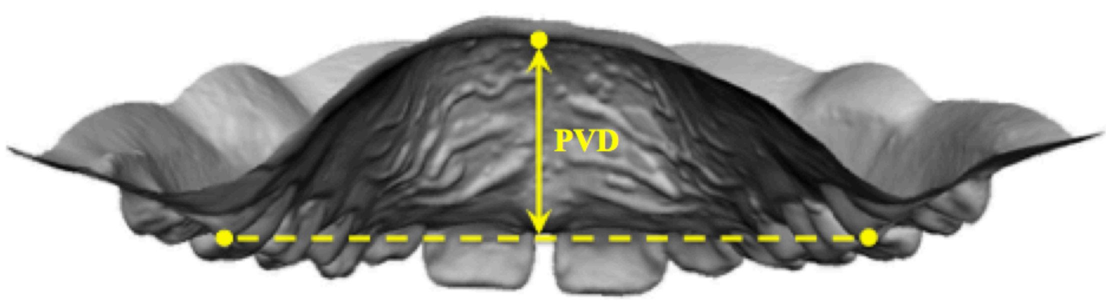


Fig. 19. Representation of the measurement of the depth of the palatal vault (PVD).

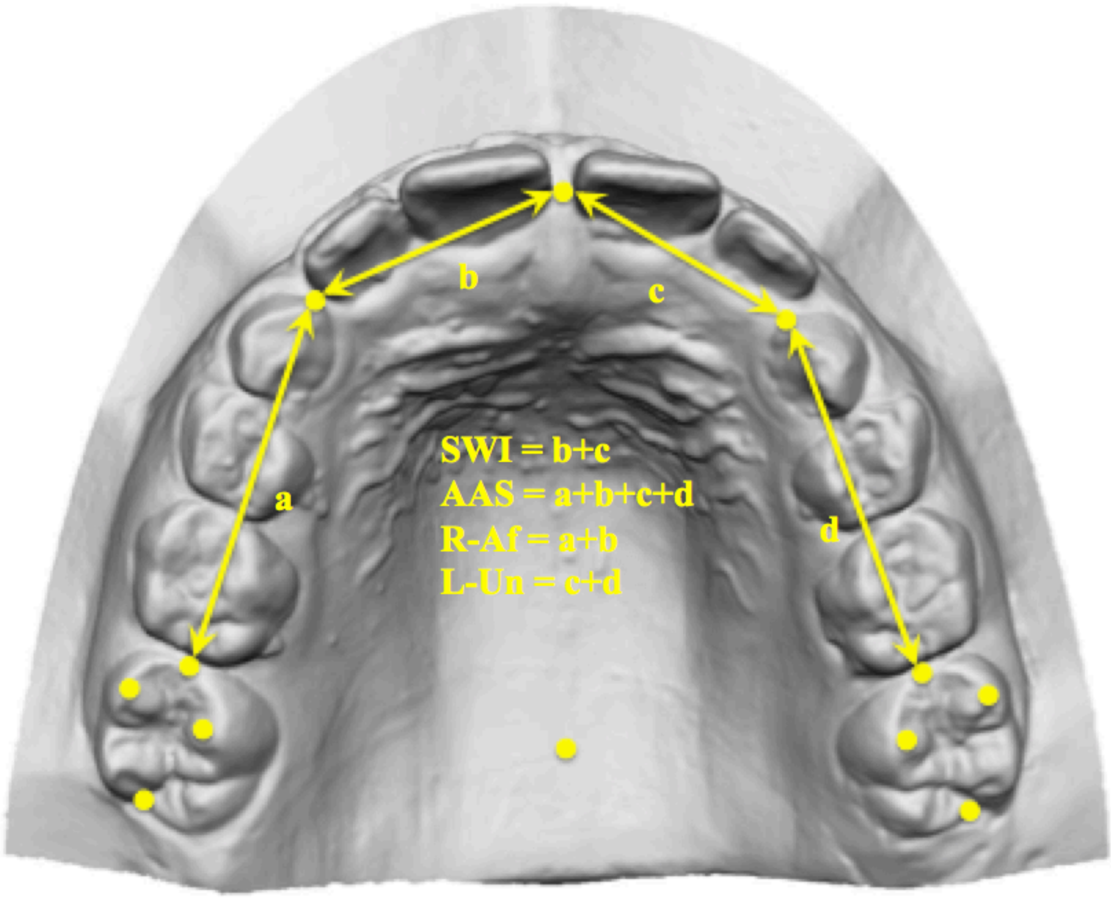


Fig. 20. Representation of the measurements of sum of the widths of the four maxillary incisors (SWI), available arch space (AAS), right/affected (R-Af) and left/unaffected (L-Un) available spaces.

Error of the method and power of the study

The level of significance was fixed at 0.01 for all statistical tests. Seven dental casts were randomly selected by both groups and redigitized by the same operator. The variables were recalculated and Student's t-tests were executed in order to determine the repeatability of the method. No statistically significant differences ($P<0.01$) were found between the two digitizations, for all examined variables (Table IV).

The power of the study for the unpaired t-test was assessed on the basis of the sample size of the DMC and control samples, an alpha level of 0.01, with a mean difference for the clinically relevant variable (IMW) of 2.54 mm and with a standard deviation of 2.48 mm. The calculated power was 0.86 (SigmaStat version 3.5, Systat Software, Point Richmond, Calif).

Statistical Analysis

The chi-square test and two-way factorial ANOVA for independent samples were calculated to compare respectively the female:male ratio and the ages of the samples. No statistically significant differences were found both for the female:male ratio (chi-square=0.22; P=0.639) and the ages (F=1.21; P=0.277) of the two groups. The normal distribution and homoscedascity of the samples were checked before starting inferential analysis, by using the Shapiro-Wilk test (P<0.01) and Levene's test (P<0.01), respectively.

Preliminary t-tests between patients with bilateral and unilateral displacement were executed. As no statistically significant differences were recorded between the two groups in all variables, patients with bilateral and unilateral displacement were considered parts of the same group (DMC group). Therefore, differences between the DMC group and the control group were calculated directly by means of Student's t-test for independent samples. On the contrary, the differences between the right/affected and left/unaffected sides were evaluated by paired samples t-tests (Microsoft Excel, Microsoft, Redmond, WA).

	First digitization		Second digitization			
Measurements (mm)	**Mean**	**SD**	**Mean**	**SD**	**p-value**	**Significance**
IMW	48.59	1.19	48.69	1.16	0.87708	**NS**
AL	37.14	1.99	36.84	2.05	0.78717	**NS**
PVD	14.95	1.13	14.99	1.06	0.95451	**NS**
SWI	30.06	1.57	29.89	1.12	0.82386	**NS**
AAS	75.19	2.56	74.62	2.24	0.66528	**NS**
R-Af	37.40	1.12	37.18	1.07	0.70497	**NS**
L-Un	37.79	1.52	37.44	1.20	0.64757	**NS**

Table IV. Comparisons between the two digitizations. P-values obtained by Student's t-tests.

RESULTS

The measurements obtained in all patients of the DMC and control groups are presented in Tables V and VI, respectively. The means, standard deviations and results of the Student's t-test for independent samples between the two groups are shown in Table VII, while the values of the comparisons between the right/affected and the left/unaffected sides of both groups are given in Table VIII.

Regarding the comparison between the DMC and control groups, both IMW (Fig. 21) and AL (Fig. 22) in the DMC group resulted statistically significant decreased relative to the control group ($P<0.01$), indicating that patients with displaced canines presented a narrower and shorter palate than subjects without eruption problems. The greater difference between both groups was registered in the IMW (2.5 mm), while the difference in the AL was 1.7 mm.

No statistically significant differences between the two groups were found in the PVD (Fig. 23).

Moreover, the values of the SWI and AAS used to determine eruption space were significantly decreased ($P<0.01$) in the DMC group relative to the controls (Fig. 24, 25). These findings are consistent with those found for AL and IMW. The right/affected and left/unaffected sides were shorter in the DMC group as well ($P<0.01$), although there were no statistically significant differences between the two sides (right/affected, left/unaffected) in both groups (Fig. 26, 27).

Patient	IMW	AL	PVD	SWI	AAS	R-Af	L-Un
D-F01	47.43	37.13	13.83	28.08	72.96	36.62	36.34
D-F02	42.20	38.24	14.85	28.50	74.22	36.61	37.60
D-F03	46.79	36.51	15.41	28.47	73.67	36.52	37.16
D-F04	46.31	38.11	14.09	30.50	76.07	38.37	37.70
D-F05	41.61	36.24	12.71	27.65	72.89	36.58	36.30
D-F06	45.55	35.14	13.78	29.66	72.20	35.04	37.16
D-F07	46.88	33.79	15.12	27.94	70.74	35.85	34.89
D-F08	47.17	37.11	13.35	30.15	73.85	36.28	37.57
D-F09	50.70	35.62	13.71	30.77	75.88	37.95	37.93
D-F10	51.81	35.55	14.37	30.47	72.08	35.87	36.21
D-F11	48.90	33.19	14.45	28.58	73.37	36.95	36.42
D-F12	47.37	37.14	13.74	30.04	71.99	35.17	36.82
D-F13	45.74	32.21	16.16	24.13	67.08	31.86	35.22
D-F14	47.22	39.29	16.35	30.21	75.56	37.41	38.15
D-F15	44.82	35.27	15.36	25.44	70.43	35.05	35.37
D-F16	46.58	36.52	14.78	28.56	75.04	37.15	37.89
D-M01	49.55	36.27	16.40	30.55	75.56	39.21	36.35
D-M02	50.03	39.27	13.99	28.37	78.11	39.72	38.38
D-M03	47.52	36.82	16.97	30.62	73.82	36.75	37.07
D-M04	47.41	39.36	15.57	33.46	79.22	39.07	40.15
D-M05	46.03	36.93	14.69	30.60	72.90	37.03	35.86
D-M06	48.35	34.08	13.16	25.45	71.12	34.14	36.98
D-M07	51.49	38.99	15.65	30.12	78.35	39.16	39.20
D-M08	45.67	36.14	15.08	31.25	74.55	37.60	36.95

Table V. Palatal and dental measurements obtained in the DMC group. All values are in mm.

Patient	IMW	AL	PVD	SWI	AAS	R-Af	L-Un
C-F01	49.29	35.67	15.57	29.75	74.23	37.44	36.79
C-F02	50.11	36.10	14.34	29.38	75.37	37.54	37.82
C-F03	50.40	37.39	15.58	31.69	77.88	38.82	39.06
C-F04	48.51	37.12	15.57	28.67	74.44	36.86	37.58
C-F05	46.20	36.09	13.79	32.22	76.44	37.22	39.22
C-F06	48.52	37.61	15.54	28.94	75.19	37.04	38.16
C-F07	49.47	37.13	13.60	30.69	75.65	37.41	38.24
C-F08	48.48	39.70	13.61	31.52	78.00	38.91	39.09
C-F09	46.92	41.55	15.05	36.41	83.83	43.10	40.73
C-F10	47.74	39.66	14.16	34.71	82.42	40.89	41.53
C-F11	48.01	34.70	14.51	28.73	72.18	35.88	36.29
C-F12	49.65	41.04	15.32	31.25	78.58	39.14	39.44
C-F13	49.62	36.55	14.18	32.12	75.50	37.32	38.18
C-F14	54.39	41.49	15.28	36.12	85.14	42.08	43.06
C-M01	54.44	36.10	11.80	33.31	79.16	39.72	39.43
C-M02	51.65	36.29	17.23	31.70	75.97	37.77	38.20
C-M03	51.27	39.39	15.10	30.95	79.14	40.07	39.07
C-M04	51.93	38.31	15.93	33.21	77.62	38.88	38.74
C-M05	48.30	37.51	14.78	32.30	78.48	38.32	40.17
C-M06	51.35	34.70	11.60	29.71	74.68	37.66	37.01
C-M07	46.23	39.48	15.86	31.44	75.87	38.09	37.78
C-M08	51.66	39.27	12.61	31.72	79.86	40.39	39.47
C-M09	50.03	40.94	12.37	36.87	82.47	41.23	41.24
C-M10	51.66	40.97	17.13	34.32	81.08	40.46	40.62
C-M11	47.92	39.28	16.33	31.41	77.78	38.15	39.63

Table VI. Palatal and dental measurements obtained in the control group. All values are in mm.

	DMC		Controls			
Measurements (mm)	**Mean**	**SD**	**Mean**	**SD**	**p-value**	**Significance**
IMW	47.21	2.48	49.75	2.19	0.00042	**
AL	36.46	1.92	38.16	2.13	0.00510	**
PVD	14.73	1.11	14.67	1.49	0.87840	**NS**
SWI	29.15	2.08	31.97	2.32	0.00005	**
AAS	73.82	2.73	77.88	3.23	0.00002	**
R-Af	36.75	1.78	38.82	1.78	0.00018	**
L-Un	37.07	1.23	39.06	1.57	0.00001	**

Table VII. Results of statistical comparisons between the groups with an independent 2-sample t test.

	R-Af (mm)		L-Un (mm)			
Groups	**Mean**	**SD**	**Mean**	**SD**	**p-value**	**Significance**
DMC	36.75	1.78	37.07	1.23	0.26364	**NS**
Controls	38.82	1.78	39.06	1.57	0.20924	**NS**

Table VIII. Results of statistical comparisons between the right/affected and left/unaffected sides with a paired 2-sample t test.

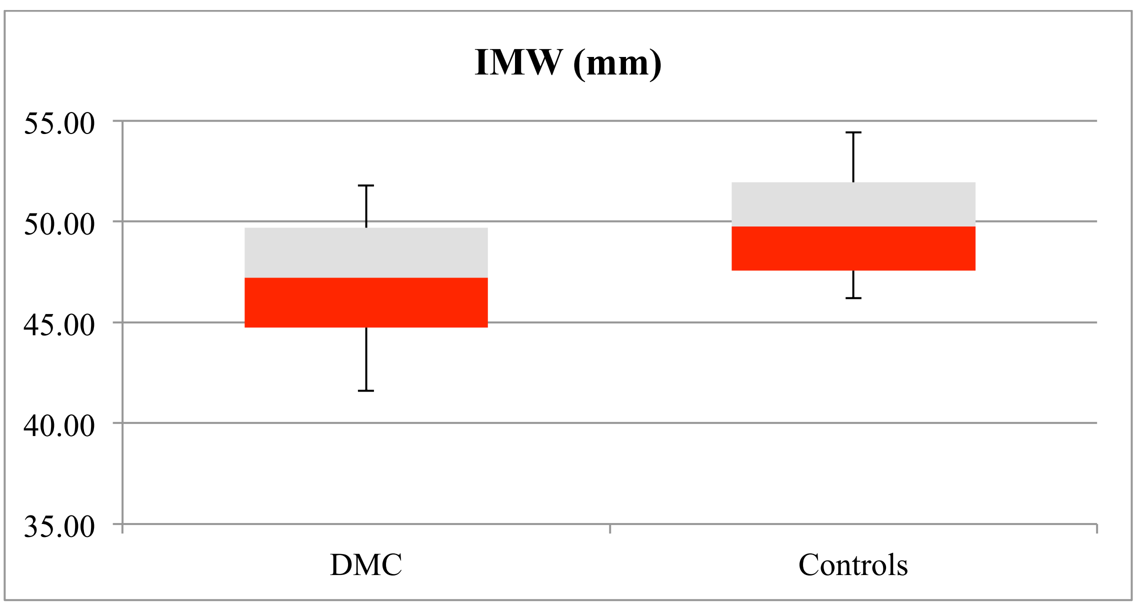


Fig. 21. Comparison between the intermolar widths of the two groups.
Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

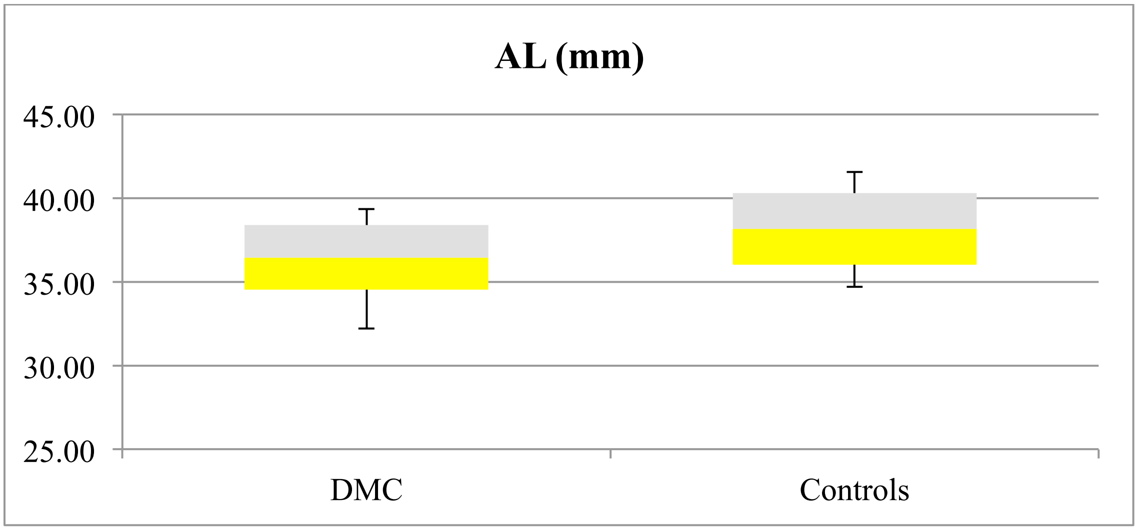


Fig. 22. Comparison between the arch lengths of the two groups.

Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

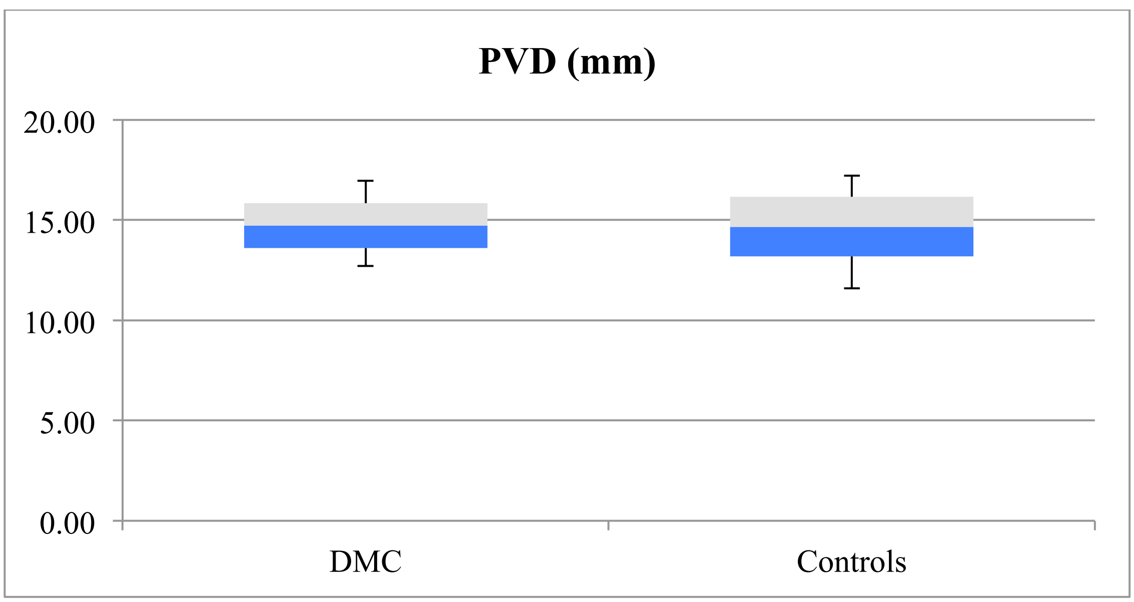


Fig. 23. Comparison between the depths of the palatal vault of the two groups.

Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

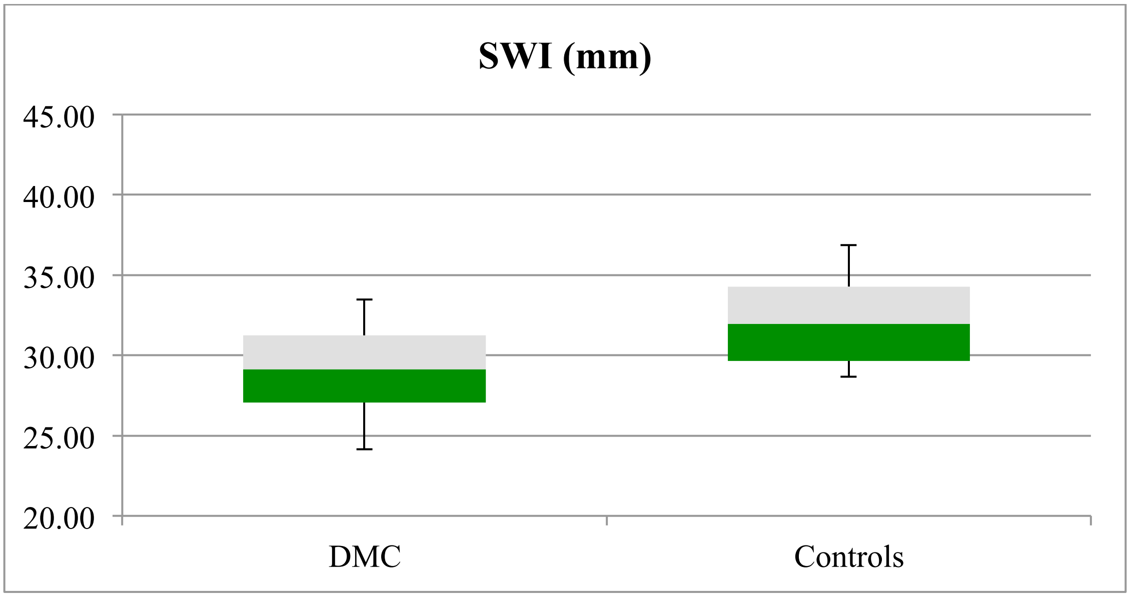


Fig. 24. Comparison between the sum of the widths of the four maxillary incisors of the two groups. Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

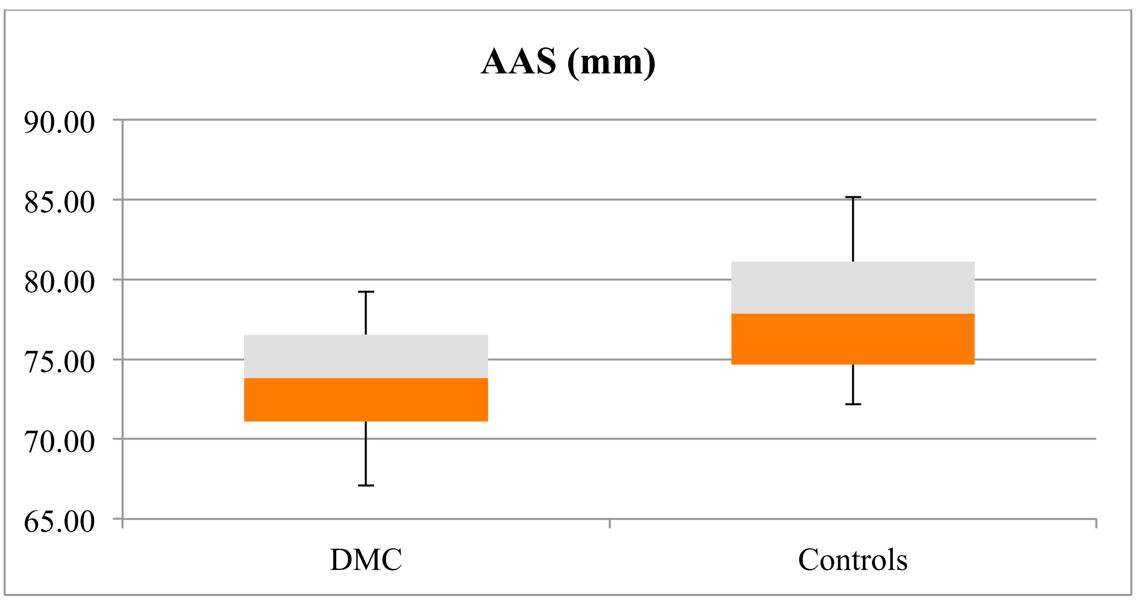


Fig. 25. Comparison between the available arch space of the two groups. Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

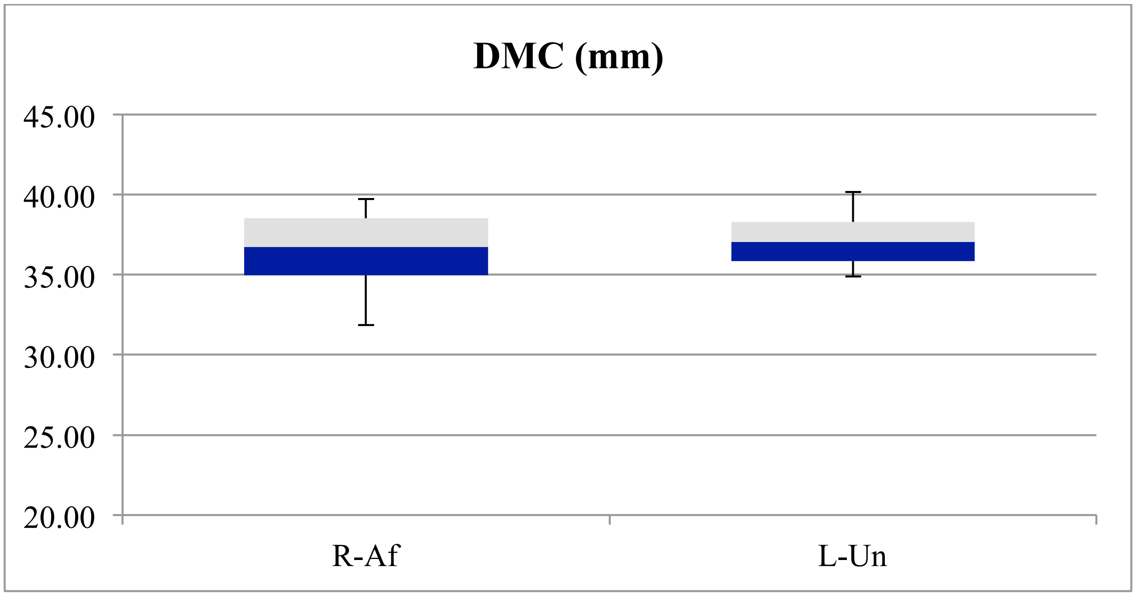


Fig. 26. Comparison between the affected and unaffected sides in the DMC group.
Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

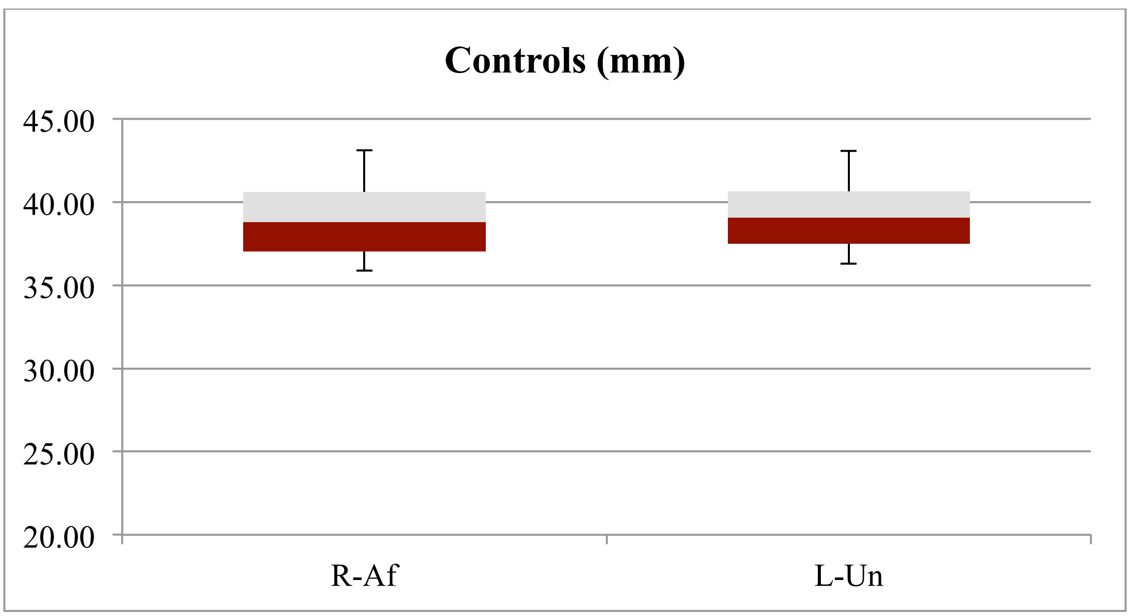


Fig. 27. Comparison between the right and left sides in the control group.
Boxes represent means±standard deviations, whiskers represent the minimum and maximum.

DISCUSSION

Aim of the study

Increasing interest is being aroused to displaced maxillary canines, either on the palatal or buccal side of the alveolar process. While the aetiology of buccally displaced canines (BDC) is related to space deficiency for the canine and/or a narrow maxillary arch (Yan et al., 2013; Jacoby, 1983), the exact cause(s) of palatally displaced canines (PDC) is unknown. The two current theories on the aetiology of PDC are known as the guidance theory and the genetic theory. The guidance theory suggests that the canine erupts along the root of the lateral incisor, which serves as a guide. If the root of the lateral incisor is absent or abnormal, the canine will not erupt and will become impacted (Brin et al., 1986; Becker et al., 1981). The genetic theory, however, attributes a hereditary component to PDC. It suggests that the PDC often presents with other genetic dental anomalies, such as permanent tooth agenesis and abnormally sized or shaped maxillary lateral incisors (Peck et al., 2002; Pirinen et al., 1996; Peck et al., 1994).

In addition to these two theories, many investigators have been trying to uncover a relationship between the width of the maxilla, skeletally and dentally, and the occurrence of PDC. Some studies have shown that a transverse maxillary deficiency or a posterior cross-bite was related to canine impaction, but these studies did not differentiate whether the impactions were buccal or palatal (Schindel and Duffy, 2007; McConnell et al., 1996). Kim et al. (2012) compared dental casts of a PDC group with those of a BDC group and stated that the shape of the palate was narrower, longer and deeper in the PDC group compared with the BDP group. The choice to compare a PDC group with a BDC group seems to be inappropriate, as the aetiology of PDC (the “guidance” theory, the “genetic” theory) (Leonardi et al., 2003; Becker et al., 2002) is different from that of BDC (crowding) (Langberg and Peck, 2000-Aug). Langberg and Peck (2000-Aug) examined pre-treatment dental casts of patients with PDC and found no significant difference in the arch width between the PDC and control groups. On the other hand, Al-Nimri and Gharaibeh (2005) investigated the pre-treatment dental casts of patients with PDC and reported that patients with PDC showed greater maxillary transverse dimensions than the control group. Saiar et al. (2006) examined the posteroanterior cephalograms of patients with PDC and reported no association between the skeletal maxillary width (measured from points J to J) with PDC. More recently, Yan et al. (2013) studied the pre-treatment CBCT of patients with PDC and found there was no correlation between the maxillary skeletal width (measured from points J to J) and PDC. Hong et al. (2015) evaluated the pre-treatment CBCT of a PDC group and concluded that the maxillary transverse width, both skeletally and dentally, was not related to the occurrence of PDC. However, previous studies neither examined patients in mixed dentition only nor used digital dental casts for measurements. The aim of the present study was to examine whether there is a relationship between impacted maxillary canines, early diagnosed by using panoramic radiographs, and the morphology of the maxilla on 3D model casts.

Significant features

Finding an association between PDC and the morphology of the maxilla at an early stage is extremely important, as orthodontists could change the shape of the palate with their treatments. The earlier orthodontic treatments, such as rapid maxillary expander (RME) and cervical-pull headgear (HG) or a combination of these modalities (RME+HG), are undertaken, the more efficient they will be (Agostino et al., 2014; Thiruvenkatachari et al., 2013; Armi et al., 2011). Moreover, complications described for early treatment (Thiruvenkatachari et al., 2013; Petrén et al., 2003) were fewer than those described for the surgical exposure of the crown of the canine followed by orthodontic traction of the impacted tooth. While most surgical procedures proceed without untoward events, some produce secondary effects and complications depending on the degree of tissue damage. Rarely occurring complications after surgical intervention include post-operative bleeding from the surgical site, hematoma, post-operative pain, purulent discharge, transient paresthesia, unsatisfactory healing, iatrogenic damage to adjacent soft tissue, maxillary sinus perforation, sub-conjunctival haemorrhage and discoloration of adjacent teeth. Further, the presence of an impacted canine may cause root resorption of the adjacent teeth (Sajnani and King, 2014).

Using digital models for the investigation brings important advantages besides (Peluso et al., 2004). Although traditional plaster study models have been used for many years, they have many limitations. For one, plaster study models break. Continued use for measurements and display can wear away plaster, decreasing accuracy and increasing the likelihood of fracture. Storage is another concept presenting both space and time problems. Models are usually kept in boxes for easy retrieval while keeping them from physical and chemical damage. Time is an exacerbating factor as well. The shortest amount of time that records should be kept is based on the applicable statute of limitations period during which a malpractice suit may be filed. This period of time varies from state to state and ranges from 5 to 15 years. This statute may start at the last day of treatment or may be delayed until the patient reaches the age of maturity. Another problem is portability. Traveling with even a few sets of fragile study models is a difficult task. Communication is difficult when only one set of models exist. The treating orthodontist might have to duplicate a patient's models, a process that is both costly and time consuming, to communicate with other dentists and specialists.

Digital models alleviate many of the obstacles encountered with using plaster models. They are not subject to physical damage and do not create any dust or other mess. They also require negligible storage space. The digital information for each case can be stored on an office computer's hard drive, on portable storage devices such as CDs, or on a central server. Retrieval is fast and efficient because the models are stored by patient name and number. Another advantage is that it is possible to view digital models at multiple locations from any office computer linked to the practice's central server (Redmond et al., 2000), allowing patients to be treated at multiple sites with easy access to their records. The electronic files in JPEG format contain all of the model information of numerous views of the models and can be transferred electronically to colleagues, specialists, and insurance companies. This decreases the time and expense of model duplication and shipment.

Digital models are also an excellent tool for patient education. The younger generation of patients currently in treatment are familiar with computers and are comfortable with computer-generated images. They can relate to digital models and probably expect to see this technology when they visit their orthodontists. Digital models can be shown to the patient and their guardians during treatment conferences, during treatment, and at the conclusion of treatment to illustrate the improvement in their dentition. There are also services that will set up secure Web sites that contain patient records and treatment information so that the patient can view these images from their home. Ultimately, digital models improve communication between the clinician and the patient, enhancing informed consent (Peluso et al., 2004).

Methodology of the research

Concerning the methodology of the study, the level of significance was fixed at 0.01, since all measurements are interrelated. Although the number of patients included in the sample was lower than that included in the majority of the comparable studies (Hong et al., 2015; Kim et al., 2012; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug), the power of the study for the unpaired t-test exceeded 0.80.

As written above, palatal displacement is more prevalent in female patients. In our sample, the female:male ratio (2:1) is comprised within the range of prevalence rates found in literature (1.3:1 to 3.2:1) (Bishara, 1998; Peck et al., 1994). No previous studies compared a group of female patients with one of male patients with DMC (Hong et al., 2015; Yan et al., 2013; Kim et al., 2012; Schindel and Duffy, 2007; Saiar et al., 2006; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug; McConnell et al., 1996). We decided to include female and male patients in the same sample, as well, but this does not preclude the design of future studies taking sex into consideration in the statistical analyses.

The majority of the Authors (Hong et al., 2015; Yan et al., 2013; Kim et al., 2012; Saiar et al., 2006; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug; McConnell et al., 1996) evaluated patients with displacement of one or both maxillary canines; Hong et al. (2015) and Yan et al. (2013) compared also the crown dimensions of maxillary anterior teeth between the impaction and normal sides of unilateral impaction subjects; Al-Nimri and Gharaibeh (2005) determined the types of malocclusion frequently associated with only unilateral palatal canine impactions; Schindel and Duffy (2007) investigated whether maxillary arch width discrepancy was associated with the occurrence of potentially impacted canines, based on type of impaction (unilateral or bilateral). As no statistically significant differences were recorded between the patients with bilateral and unilateral displacement, no distinction between patients with one or both affected sides was made in this research.

Findings

The most important finding of this study was that both intermolar width (IMW) and arch length (AL) resulted statistically significant decreased ($P<0.01$) in the DMC group relative to the controls, indicating that patients with maxillary canines which could have some problems during the eruption process presented a narrower and shorter palate compared with subjects without any eruption problems.

The reduction of the IMW was consistent with the results found by Kim et al. (2012) and Schindel and Duffy (2007), but in contrast with those by other Authors that didn't find any statistically significant differences between patients with PDC and the controls (Hong et al., 2015; Yan et al., 2013; Saiar et al., 2006; Langberg and Peck, 2000-Aug; McConnell et al., 1996); Al-Nimri and Gharaibeh (2005) even stated that the transverse arch dimension was significantly wider in the impaction group than in the comparison group. The reduction of the AL was in contrast with the two articles that investigated this measurement (Kim et al., 2012; McConnell et al., 1996), but it was in agreement with the findings by Baccetti et al. (2011) and the recent study by Mucedero et al. (2015). Baccetti et al. (2011) showed that a significant mesial movement of the upper first molars (about 2.5 mm) occurred in subjects with untreated PDC, while Mucedero et al. (2015) asserted the mesial intraosseous displacement of the maxillary first premolar is significantly associated with the displacement of the permanent canine in the intermediate mixed dentition.

The present study compared the depth of the palatal vault (PVD) between patients with DMC and a control group of patients without eruption problems first. No statistically significant differences were found in the PVD between the two groups. Kim et al. (2012) also evaluated the PVD, but they compared a PDC group with a BDC group. A deeper palatal vault was observed in patients with PDC relative to those with BDC. No other Authors among those studying dental arches in patients with impacted canines investigated this measurement (Hong et al., 2015; Yan et al., 2013; Schindel and Duffy, 2007; Saiar et al., 2006; Al-Nimri and Gharaibeh, 2005; Langberg and Peck, 2000-Aug; McConnell et al., 1996).

Consistently with the reduction of IMW and AL, the sum of the widths of the four maxillary incisors (SWI) and the available arch space (AAS) were also significantly decreased in the DMC group compared with the control group ($P<0.01$). If the upper dental arch was considered round, the IMW could be estimated as the diameter of the circumference and the AAS as half of the arch perimeter. The SWI is part of this perimeter. The interrelation among IMW, AL, SWI and AAS can explain the uniformity of these findings. On the contrary, Kim et al. (2012) didn't find any statistically significant differences in the eruption space between the palatally and buccally impacted canine groups.

Likewise, the right/affected and left/unaffected sides were shorter in patients with DMC relative to the controls ($P<0.01$), although there were no statistically significant differences between the two sides (right/affected, left/unaffected) in both groups. A possible explanation is that the number of patients with bilateral displaced canines was greater than those with unilateral impaction. This result disagrees with the recent work by Talinada et al. (2015). They evaluated the alveolar arch perimeter discrepancy in unilateral palatally impacted canines, finding that there was a significant decrease in the arch perimeter on the impacted side.

A summary of the differences between the DMC and control groups is shown in figures 28 and 29, where an example of the comparison between a patient with DMC and a subject without eruption problems is illustrated. Palatal rugae (Ashmore et al., 2002; Van der Linden, 1978) and the contact point between the central incisors were used for the superimposition of the upper digital casts. It is evident how the width and length of the DMC patients were reduced, whereas no differences could be observed in the symmetry of the dental models. If the deepest point of the palatal vault is considered to be identified at level of the first upper molars, a negligible difference is present in the PVD of both subjects.

The findings of the current study have a direct clinic application, because they corroborate the interceptive procedures aimed to increase maxillary arch width and length, so the arch perimeter. Currently, protocols as RME and HG are the only that reach a high level of scientific evidence, among all orthodontic preventive protocols proposed for PDC. Although Baccetti et al. (2008) stated that extraction of the primary canine (EC) only is an effective procedure to increase the rate of normal eruption of maxillary PDC, the systematic review of Parkin et al. (2012) evaluated that the study has deficiencies in design, conduct, analysis and reporting and is at high risk of bias, concluding that there is currently no reliable evidence of the effect of EC to facilitate the eruption of the palatally ectopic maxillary permanent canine.

Since Baccetti et al. (2011) investigated the effect of transpalatal arch (TPA) therapy in combination with EC on the eruption of PDC, it would be improper to consider the use of a TPA an efficient procedure to avoid palatal impaction of maxillary canines. So RME (Baccetti et al., 2009), HG (Armi et al., 2011; Silvola et al., 2009) or a combination of these modalities (RME+HG) (Armi et al., 2011) remain the only orthodontic procedures effective in the prevention of PDC. Baccetti et al. (2009) found that the use of RME in the early mixed dentition appears to be an effective procedure to increase the rate of eruption of PDC (65.7%) when compared with an untreated control group (13.6%). Armi et al. (2011) showed that the improvement of the perimeter of the upper arch is effective in preventing canine impaction of PDC, as well. The rate of success in the HG and RME+HG groups (82.3% and 85.7% respectively) is slightly more favourable than previous results by Olive et al. (2002), who found that 75% of the canines emerged after orthodontic treatment with fixed appliances to create space in the upper arch after extraction of the primary canine. Headgear wear resulted in a significant reduction in the amount of mesial displacement of the upper molar (0.2 mm), thus maintaining the space available for canine eruption. Moreover, Silvola et al. (2009) demonstrated that the early treatment with HG can affect the inclination of the maxillary canine during eruption. The inclination of the erupting canine in relation to the maxillary midline and midline of the lateral incisor was significantly more vertical after HG use. The investigations by Baccetti et al. (2009) and Silvola et al. (2009) were also included in the recent systematic review by Sunnak et al. (2015). As the systematic reviews reach the highest level of scientific evidence, the strength of the consistency between the findings of the reduction of IMW and AL and the effectiveness of protocols that increase maxillary arch width and length is raised.

Limitations of this investigation and future researches

As anticipated, some limitations occurred in the current study. First of all, no distinction between female and male patients was made, so it cannot be deduced if differences in the morphology of the maxilla relied on gender exists. Additionally, the DMC and control samples were composed by only European patients, who, according to literature, exhibit more prevalence than African or Asian subjects (Peck et al., 1994). So, the extension of the present results to other populations should be verified.

Additionally, the most significant limitation of the work concerned the group of DMC, that included unilateral as well as bilateral maxillary canine impactions. The influence of the type of impaction on the shape of the palate remains unclear.

Further researches are needed to overcome these limitations. A comprehensive study which considers the different prevalence of the maxillary canine impaction in patients of different genders or ethic origins, and evaluate the aetiology of unilateral and bilateral impactions, should be encouraged. Similarly, the association between the upper canine displacement and other dental anomalies (peg-shaped lateral incisors, missing teeth, etc.) or the volumetric investigation of the maxilla could help clinicians to understand and face this phenomenon better. Surely, the possibility to collect digital casts makes the realization of a multicentre study possible and the extension of the sample easier.

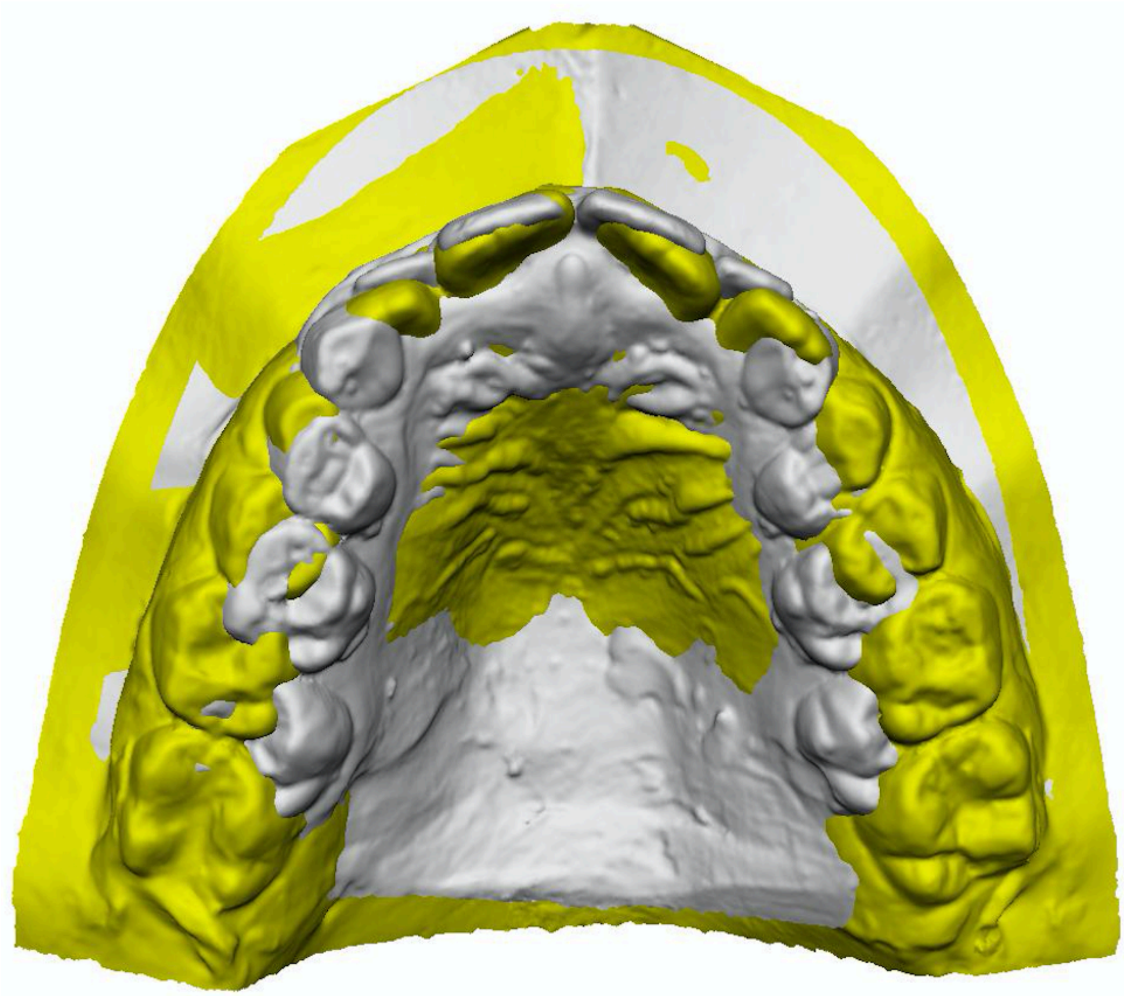


Fig. 28. Comparison between a patient with DMC (grey) and a control subject (yellow): occlusal view.

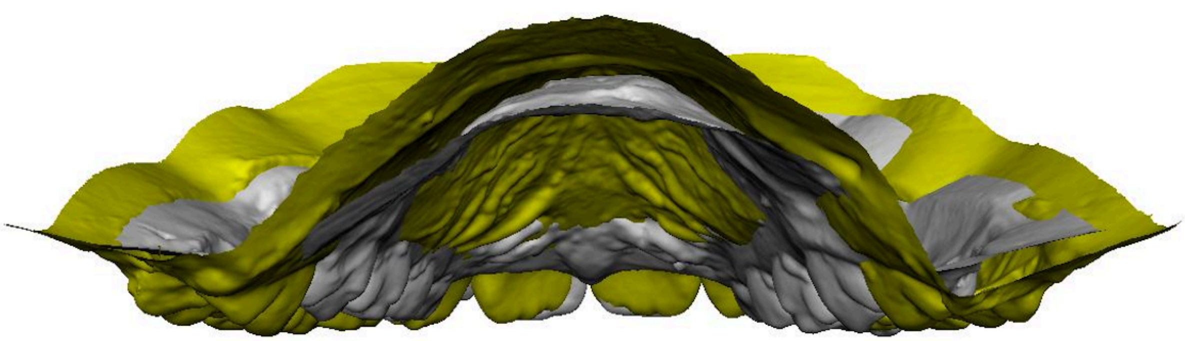


Fig. 29. Comparison between a patient with DMC (grey) and a control subject (yellow): posterior view.

CONCLUSIONS

The aim of this study was to examine whether there is a relationship between impacted maxillary canines, early diagnosed by using panoramic radiographs, and the morphology of the maxilla on 3D model casts.

- Both IMW and AL in the DMC group resulted statistically significant decreased relative to the control group ($P<0.01$), indicating that patients with displaced canines presented a narrower and shorter palate than subjects without eruption problems.

- No statistically significant differences between the two groups were found in the PVD.

- Moreover, the values of the SWI and AAS used to determine eruption space were significantly decreased ($P<0.01$) in the DMC group relative to the controls. These findings are consistent with those found for AL and IMW.

- The right/affected and left/unaffected sides were shorter in the DMC group as well ($P<0.01$), although there were no statistically significant differences between the two sides (right/affected, left/unaffected) in both groups.

- The findings of the current study have a direct clinic application, because they corroborate the interceptive procedures aimed to increase maxillary arch width (RME) and length (HG), so the arch perimeter.

- Further researches are needed to investigate the differences between unilateral and bilateral impactions.

REFERENCES

- Agostino P, Ugolini A, Signori A, Silvestrini-Biavati A, Harrison JE, Riley P. Orthodontic treatment for posterior crossbites. Cochrane Database Syst Rev. 2014 Aug 8;8:CD000979.
- Al-Nimri K, Gharaibeh T. Space conditions and dental and occlusal features in patients with palatally impacted maxillary canines: an aetiological study. Eur J Orthod. 2005 Oct;27(5):461-5.
- Armi P, Cozza P, Baccetti T. Effect of RME and headgear treatment on the eruption of palatally displaced canines: a randomized clinical study. Angle Orthod. 2011 May;81(3):370-4.
- Ashmore JL, Kurland BF, King GJ, Wheeler TT, Ghafari J, Ramsay DS. A 3-dimensional analysis of molar movement during headgear treatment. Am J Orthod Dentofacial Orthop. 2002 Jan;121(1):18-29.
- Baccetti T, Sigler LM, McNamara JA Jr. An RCT on treatment of palatally displaced canines with RME and/or a transpalatal arch. Eur J Orthod. 2011 Dec;33(6):601-7.
- Baccetti T, Mucedero M, Leonardi M, Cozza P. Interceptive treatment of palatal impaction of maxillary canines with rapid maxillary expansion: a randomized clinical trial. Am J Orthod Dentofacial Orthop. 2009 Nov;136(5):657-61.
- Baccetti T, Leonardi M, Armi P. A randomized clinical study of two interceptive approaches to palatally displaced canines. Eur J Orthod. 2008 Aug;30(4):381-5.
- Baccetti T. A clinical and statistical study of etiologic aspects related to associated tooth anomalies in number, size, and position. Minerva Stomatol. 1998 Dec;47(12):655-63.
- Baccetti T. A controlled study of associated dental anomalies. Angle Orthod. 1998 Jun;68(3):267-74.

- Baccetti T, Franchi L, Cecchi JM, Pacciani E. Associated dental anomalies in an Etruscan adolescent. Angle Orthod. 1995;65(1):75-9.
- Becker A, Chaushu S. Etiology of maxillary canine impaction: a review. Am J Orthod Dentofacial Orthop. 2015 Oct;148(4):557-67.
- Becker A, Sharabi S, Chaushu S. Maxillary tooth size variation in dentitions with palatal canine displacement. Eur J Orthod. 2002 Jun;24(3):313-8.
- Becker A. In defense of the guidance theory of palatal canine displacement. Angle Orthod. 1995;65(2):95-8.
- Becker A. Ectopic eruption of maxillary canines. Eur J Orthod. 1993 Oct;15(5):425.
- Becker A. Etiology of maxillary canine impactions. Am J Orthod. 1984 Nov;86(5):437-8.
- Becker A, Smith P, Behar R. The incidence of anomalous maxillary lateral incisors in relation to palatally-displaced cuspids. Angle Orthod. 1981 Jan;51(1):24-9.
- Berglund L, Kurol J, Kvint S. Orthodontic pre-treatment prior to autotransplantation of palatally impacted maxillary canines: case reports on a new approach. Eur J Orthod. 1996 Oct;18(5):449-56.
- Bishara SE. Clinical management of impacted maxillary canines. Semin Orthod. 1998 Jun;4(2):87-98.
- Bishara SE. Impacted maxillary canines: a review. Am J Orthod Dentofacial Orthop. 1992 Feb;101(2):159-71.
- Brenchley Z, Oliver RG. Morphology of anterior teeth associated with displaced canines. Br J Orthod. 1997 Feb;24(1):41-5.
- Brin I, Becker A, Shalhav M. Position of the maxillary permanent canine in relation to anomalous or missing lateral incisors: a population study. Eur J Orthod. 1986 Feb;8(1):12-6.
- Burden DJ, Mullally BH, Robinson SN. Palatally ectopic canines: closed eruption versus open eruption. Am J Orthod Dentofacial Orthop. 1999 Jun;115(6):640-4.
- Chu FC, Li TK, Lui VK, Newsome PR, Chow RL, Cheung LK. Prevalence of impacted teeth and associated pathologies--a radiographic study of the Hong Kong Chinese population. Hong Kong Med J. 2003 Jun;9(3):158-63.
- Drake RL, Vogl AW, Mitchell AWM, Tibbitts RM, Richardson PE. Gray's Atlas of Anatomy, 2nd ed. Philadelphia: Elsevier/Churchill Livingstone. 2015.

- Ericson S, Bjerklin K, Falahat B. Does the canine dental follicle cause resorption of permanent incisor roots? A computed tomographic study of erupting maxillary canines. Angle Orthod. 2002 Apr;72(2):95-104.
- Ericson S, Kurol PJ. Resorption of incisors after ectopic eruption of maxillary canines: a CT study. Angle Orthod. 2000 Dec;70(6):415-23.
- Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. A clinical and radiographic analysis of predisposing factors. Am J Orthod Dentofacial Orthop. 1988 Dec;94(6):503-13.
- Ericson S, Kurol J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. Eur J Orthod. 1988 Nov;10(4):283-95.
- Ericson S, Kurol J. Radiographic examination of ectopically erupting maxillary canines. Am J Orthod Dentofacial Orthop. 1987 Jun;91(6):483-92.
- Fernández E, Bravo LA, Canteras M. Eruption of the permanent upper canine: a radiologic study. Am J Orthod Dentofacial Orthop. 1998 Apr;113(4):414-20.
- Graber TM, Vanarsdall RL, Vig KWL. Orthodontics: current principles and techniques, 5th ed. St. Louis: Elsevier Mosby. 2012.
- Hadler-Olsen S, Pirttiniemi P, Kerosuo H, Bolstad Limchaichana N, Pesonen P, Kallio-Pulkkinen S, Lähdesmäki R. Root resorptions related to ectopic and normal eruption of maxillary canine teeth - A 3D study. Acta Odontol Scand. 2015;73(8):609-15.
- Hitchin AD. The impacted maxillary canine. Br Dent J. 1956; 100:1–14.
- Hong WH, Radfar R, Chung CH. Relationship between the maxillary transverse dimension and palatally displaced canines: A cone-beam computed tomographic study. Angle Orthod. 2015 May;85(3):440-5.
- Hurme VO. Ranges of normalcy in the eruption of permanent teeth. J Dent Child. 1949;16(2):11-5.
- Kim Y, Hyun HK, Jang KT. Interrelationship between the position of impacted maxillary canines and the morphology of the maxilla. Am J Orthod Dentofacial Orthop. 2012 May;141(5):556-62.
- Kokich VG. Surgical and orthodontic management of impacted maxillary canines. Am J Orthod Dentofacial Orthop. 2004 Sep;126(3):278-83.

- Jacobs SG. Reducing the incidence of unerupted palatally displaced canines by extraction of deciduous canines. The history and application of this procedure with some case reports. Aust Dent J. 1998 Feb;43(1):20-7.
- Jacoby H. The etiology of maxillary canine impactions. Am J Orthod. 1983 Aug;84(2):125-32.
- Langberg BJ, Peck S. Adequacy of maxillary dental arch width in patients with palatally displaced canines. Am J Orthod Dentofacial Orthop. 2000 Aug;118(2):220-3.
- Langberg BJ, Peck S. Tooth-size reduction associated with occurrence of palatal displacement of canines. Angle Orthod. 2000 Apr;70(2):126-8.
- Leifert S, Jonas IE. Dental anomalies as a microsymptom of palatal canine displacement. J Orofac Orthop. 2003 Mar;64(2):108-20.
- Leonardi R, Peck S, Caltabiano M, Barbato E. Palatally displaced canine anomaly in monozygotic twins. Angle Orthod. 2003 Aug;73(4):466-70.
- Lindauer SJ, Rubenstein LK, Hang WM, Andersen WC, Isaacson RJ. Canine impaction identified early with panoramic radiographs. J Am Dent Assoc. 1992 Mar;123(3):91-2, 95-7.
- Mazor Z, Peleg M, Redlich M. Immediate placement of implants in extraction sites of maxillary impacted canines. J Am Dent Assoc. 1999 Dec;130(12):1767-70.
- McConnell TL, Hoffman DL, Forbes DP, Janzen EK, Weintraub NH. Maxillary canine impaction in patients with transverse maxillary deficiency. ASDC J Dent Child. 1996 May-Jun;63(3):190-5.
- McSherry P, Richardson A. Ectopic eruption of the maxillary canine quantified in three dimensions on cephalometric radiographs between the ages of 5 and 15 years. Eur J Orthod. 1999 Feb;21(1):41-8.
- McSherry PF. The ectopic maxillary canine: a review. Br J Orthod. 1998 Aug;25(3):209-16.
- Moss JP. Autogenous transplantation of maxillary canines. J Oral Surg. 1968 Dec;26(12):775-83.
- Mossey PA, Campbell HM, Luffingham JK. The palatal canine and the adjacent lateral incisor: a study of a west of Scotland population. Br J Orthod. 1994 May;21(2):169-74.

- Mucedero M, Franchi L, Ricchiuti MR, Cozza P. Association between mesially displaced maxillary first premolars and early displaced maxillary canines. Eur J Paediatr Dent. 2015 Mar;16(1):45-50.
- Nelson SJ. Wheeler's Dental Anatomy, Physiology, and Occlusion, 10th ed. St Louis: Elsevier/Saunders. 2015.
- Neville BW, Damm DD, Allen CM, Bouquot JE. Oral and Maxillofacial Pathology, 3rd ed. St Louis: Elsevier/Saunders. 2009.
- Olive RJ. Orthodontic treatment of palatally impacted maxillary canines. Aust Orthod J. 2002 Nov;18(2):64-70.
- Oliver RG, Mannion JE, Robinson JM. Morphology of the maxillary lateral incisor in cases of unilateral impaction of the maxillary canine. Br J Orthod. 1989 Feb;16(1):9-16.
- Orton HS, Garvey MT, Pearson MH. Extrusion of the ectopic maxillary canine using a lower removable appliance. Am J Orthod Dentofacial Orthop. 1995 Apr;107(4):349-59.
- Parkin N, Benson PE, Shah A, et al. Extraction of primary (baby) teeth for unerupted palatally displaced permanent canine teeth in children. Cochrane Database Syst Rev. 2009 Dec 12;CD004621.
- Paulsen F, Waschke J. Sobotta Atlas of Human Anatomy, 15th ed. Munich: Elsevier/Urban & Fischer. 2013.
- Peck S, Peck L, Kataja M. Concomitant occurrence of canine malposition and tooth agenesis: evidence of orofacial genetic fields. Am J Orthod Dentofacial Orthop. 2002 Dec;122(6):657-60.
- Peck S, Peck L, Kataja M. Site-specificity of tooth agenesis in subjects with maxillary canine malpositions. Angle Orthod. 1996;66(6):473-6.
- Peck S, Peck L, Kataja M. Sense and nonsense regarding palatal canines. Angle Orthod. 1995;65(2):99-102.
- Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. Angle Orthod. 1994;64(4):249-56.
- Peluso MJ, Josell SD, Levine SW, Lorei BJ. Digital models: an introduction. Seminars in Orthodontics. 2004 Sep;10(3):226-238.

- Petrén S, Bondemark L, Söderfeldt B. A systematic review concerning early orthodontic treatment of unilateral posterior crossbite. Angle Orthod. 2003 Oct;73(5):588-96.
- Pirinen S, Arte S, Apajalahti S. Palatal displacement of canine is genetic and related to congenital absence of teeth. J Dent Res. 1996 Oct;75(10):1742-6.
- Rayne J. The unerupted maxillary canine. Dent Pract Dent Rec. 1969 Feb;19(6):194-204.
- Redmond WR, Redmond WJ, Redmond MJ. Clinical implications of digital orthodontics. Am J Orthod Dentofacial Orthop. 2000 Feb;117(2):240-1.
- Ricketts RM. Orthodontic Treatment in the Growing Patient. Vol. I. Scottsdale, Ariz: American Institute for Bioprogressive Education; 1998:16–21.
- Ricketts RM, Bench RW, Hilgers JJ, Schulhof R. An overview of computerized cephalometrics. Am J Orthod. 1972 Jan;61(1):1-28.
- Rimes RJ, Mitchell CN, Willmot DR. Maxillary incisor root resorption in relation to the ectopic canine: a review of 26 patients. Eur J Orthod. 1997 Feb;19(1):79-84.
- Romanes GJ. Cunningham's textbook of anatomy, 12th ed. New York: Oxford University Press. 1981.
- Sagne S, Lennartsson B, Thilander B. Transalveolar transplantation of maxillary canines. An alternative to orthodontic treatment in adult patients. Am J Orthod Dentofacial Orthop. 1986 Aug;90(2):149-57.
- Saiar M, Rebellato J, Sheats RD. Palatal displacement of canines and maxillary skeletal width. Am J Orthod Dentofacial Orthop. 2006 Apr;129(4):511-9.
- Sajnani AK, King NM. Complications associated with the occurrence and treatment of impacted maxillary canines. Singapore Dent J. 2014 Dec;35:53-7.
- Sajnani AK, King NM. Early prediction of maxillary canine impaction from panoramic radiographs. Am J Orthod Dentofacial Orthop. 2012 Jul;142(1):45-51.
- Schindel RH, Duffy SL. Maxillary transverse discrepancies and potentially impacted maxillary canines in mixed-dentition patients. Angle Orthod. 2007 May;77(3):430-5.
- Stahl F, Grabowski R.Maxillary canine displacement and genetically determined predisposition to disturbed development of the dentition. J Orofac Orthop. 2003 May;64(3):167-77.

- Sambataro S, Baccetti T, Franchi L, Antonini F. Early predictive variables for upper canine impaction as derived from posteroanterior cephalograms. Angle Orthod. 2005 Jan;75(1):28-34.
- Svinhufvud E, Myllärniemi S, Norio R. Dominant inheritance of tooth malpositions and their association to hypodontia. Clin Genet. 1988 Dec;34(6):373-81.
- Tadinada A, Mahdian M, Vishwanath M, Allareddy V, Upadhyay M, Yadav S. Evaluation of alveolar bone dimensions in unilateral palatally impacted canine: a cone-beam computed tomographic analyses. Eur J Orthod. 2015 Dec;37(6):596-602.
- Thilander B, Jakobsson SO. Local factors in impaction of maxillary canines. Acta Odontol Scand. 1968 May;26(2):145-68.
- Thiruvenkatachari B, Harrison JE, Worthington HV, O'Brien KD. Orthodontic treatment for prominent upper front teeth (Class II malocclusion) in children. Cochrane Database Syst Rev. 2013 Nov 13;11:CD003452.
- Usiskin LA. Br J Orthod. Management of the palatal ectopic and unerupted maxillary canine. 1991 Nov;18(4):339-46.
- Van der Linden FP. Changes in the position of posterior teeth in relation to ruga points. Am J Orthod. 1978 Aug;74(2):142-61.
- Vastardis H. The genetics of human tooth agenesis: new discoveries for understanding dental anomalies. Am J Orthod Dentofacial Orthop. 2000 Jun;117(6):650-6.
- Warford JH Jr, Grandhi RK, Tira DE. Prediction of maxillary canine impaction using sectors and angular measurement. Am J Orthod Dentofacial Orthop. 2003 Dec;124(6):651-5.
- Williams BH. Diagnosis and prevention of maxillary cuspid impaction. Angle Orthod. 1981 Jan;51(1):30-40.
- Yan B, Sun Z, Fields H, Wang L, Luo L. Etiologic factors for buccal and palatal maxillary canine impaction: a perspective based on cone-beam computed tomography analyses. Am J Orthod Dentofacial Orthop. 2013 Apr;143(4):527-34.
- Zilberman Y, Cohen B, Becker A. Familial trends in palatal canines, anomalous lateral incisors, and related phenomena. Eur J Orthod. 1990 May;12(2):135-9.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Professor Sforza, for her continuous support during my PhD studies in her department. She treated me as her equal and always combined her professionalism with an intense humanity. I will never forget her teachings and conversations and am looking forward to continue collaborating with her during future research studies.