# THREE-DIMENSIONAL MORPHOMETRIC ANALYSIS AND DEVELOPMENT OF NEW CLASSIFICATION SYSTEM OF IMPACTED CANINES IN ORTHODONTIC PATIENTS USING CONE BEAM COMPUTED TOMOGRAPHY

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# THREE-DIMENSIONAL MORPHOMETRIC ANALYSIS AND DEVELOPMENT OF NEW CLASSIFICATION SYSTEM OF IMPACTED CANINES IN ORTHODONTIC PATIENTS USING CONE BEAM COMPUTED TOMOGRAPHY

**by**

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| | |
|---|---|
| CBCT | Cone beam computed tomography |
| CT | Computed tomography |
| OPG | Orthopantomogram |
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| PA | Postero-anterior |
| SLOB | Same lingual opposite buccal |
| TMJ | Temporomandibular joint |
| ICW | Intercanine width |
| IPW | Inter first premolar width |
| IMW | Inter first molar width |
| AW | Arch width |
| AAW | Anterior arch width |
| PAW | Posterior arch width |
| AL | Arch length |
| PH | Palatal height |
| PHI | Palatal height index |
| V | Vertical |
| H | Horizontal |
| AP | Anteroposterior |
| N | Nasal cavity |
| LP | Labiopalatal |

| | |
|---|---|
| A | Angulated |
| M | Mental foramen |
| N | Nasion |
| Pog | Pogonion |
| FH | Frankfort horizontal |
| ANS | Anterior nasal spine |
| CEJ | Cementoenamel junction |
| HG | Cervical-pull headgear |
| RME | Rapid maxillary expander |
| USM | Universiti Sains Malaysia |
| HUSM | Hospital Universiti Sains Malaysia |
| WHO | World health organisation |
| HP | Hewlett-Packard |
| FHD | Full high definition |
| GTX | Giga Texel Shader eXtreme |
| SPSS | Statistical package for the social sciences |
| NRIC | National registration identity card |
| SD | Standard deviation |
| PS | Power and sample size |
| CI | A confidence interval of the difference |
| ICC | Intraclass correlation coefficient |
| Cohen's $\kappa$ | Cohen's kappa coefficient |

**ANALISIS MORFOMETRIK TIGA DIMENSI DAN PEMBANGUNAN SISTEM KLASIFIKASI BAHARU GIGI TARING DIKALANGAN PESAKIT ORTODONTIK MENGGUNAKAN TOMOGRAFI CONE BEAM**

## ABSTRAK

Gigi taring adalah gigi paling dominan secara estetik yang dapat memberikan senyuman sama ada menarik atau mengerikan. Mereka menentukan sudut mulut, terlibat dalam senyuman estetik, menjaga keharmonian oklusi, dan merancang bentuk lengkungan gigi. Oleh kerana kedudukan gigi taring yang terimpak berada di antara struktur anatomi penting seperti rongga hidung dan sinus di rahang atas dan saraf mental di rahang bawah, penilaian radiografi menyeluruh untuk menentukan kedudukan taring yang terimpak sangat penting sebelum merancang sebarang rawatan. Dengan menggunakan gambar CBCT, doktor dapat mengenal pasti lokasinya dengan jelas. Kajian ini bertujuan untuk menentukan kelaziman taring yang terimpak pada pesakit ortodontik dan melakukan analisis morfometrik mengenai kesan taring yang terimpak pada bentuk dan dimensi lengkung gigi dan mengembangkan sistem klasifikasi baru. Gambar CBCT pesakit berusia 15 hingga 50 tahun yang hadir di HUSM, Malaysia untuk rawatan ortodontik dianalisis, berkaitan dengan lengkungan gigi dan dikategorikan di bawah sistem klasifikasi 3D yang dicadangkan berdasarkan lokasi dan arah semasa terimpak. Hasil kajian menunjukkan bahawa kelaziman gigi taring yang terimpak pada pesakit ortodontik adalah 17.5 %, dan lebih lazim kepada wanita. Taring yang terjejas berlaku paling kerap pada subjek maloklusi Kelas I dan paling sedikit dalam maloklusi Kelas III. Hubungan yang ketara antara taring yang terimpak dan struktur anatomi berdekatan ditemui dalam kebanyakan pemboleh ubah

yang diukur. Taring yang terkena kesannya saling berkaitan dengan ukuran dimensi lengkungan. Hasil kajian menunjukkan perubahan yang ketara dalam kumpulan kajian berbanding kumpulan kawalan. Interpremolar, lebar intermolar dan panjang lengkungan secara ketara kekurangan dan lebih sempit, dengan lelangit yang lebih tinggi dilihat pada pesakit taring yang terimpak berbanding dengan kumpulan kawalan. Berdasarkan sistem klasifikasi baru, jenis taring rahang atas yang paling biasa adalah $V_1$AP, diikuti oleh $V_2$BP, $V_2$AP, dan $V_2$CP. $V_3$BL, $N_2$AP, dan $N_3$AP adalah yang paling jarang berlaku. Untuk taring pada rahang bawah yang terimpak $M_1$AP adalah yang dominan, diikuti oleh $M_2$AP, $M_1$CP, dan $M_2$AL. Manakala $M_1$AL dan $M_1$BP paling jarang berlaku. Penyiasatan 3D yang ada sekarang memberikan nilai rujukan klinikal baru untuk kelaziman taring yang terimpak berdasarkan etnik, jantina, dan pelbagai jenis maloklusi di samping hubungan dengan struktur anatomi sekitar dan dimensi lengkung gigi. Selanjutnya, kajian ini mewujudkan sistem baru untuk mengklasifikasikan taring rahang atas dan mandibula yang terimpak untuk memudahkan komunikasi antara disiplin untuk perancangan rawatan yang lebih baik.

**THREE-DIMENSIONAL MORPHOMETRIC ANALYSIS AND DEVELOPMENT OF NEW CLASSIFICATION SYSTEM OF IMPACTED CANINES IN ORTHODONTIC PATIENTS USING CONE BEAM COMPUTED TOMOGRAPHY**

## ABSTRACT

Canine teeth are aesthetically most dominant teeth which can present a smile as either holy or evil. They define the mouth's corner, are involved in the aesthetic smile, maintain occlusal stability, and design the shape of the dental arch. As the position of the impacted canines is amidst vital anatomical structures like the nasal cavity and sinuses in the maxilla and mental nerve in the mandible, a thorough radiographic evaluation to determine the position of the impacted canines is of utmost importance prior to any treatment planning. By using a CBCT image, a clinician can clearly identify its location. The present study aimed to determine the prevalence of impacted canines in orthodontic patients and conduct morphometric analysis on the effect of impacted canines on the dental arch form and dimension and develop a new classification system. CBCT images of patients aged 15 to 50 years who attended HUSM, Malaysia, for orthodontic treatment were analysed pertaining to their arch and categorised under the proposed 3D classification system based on their location and direction during the state of impaction. The results suggested that the prevalence of impacted canines in orthodontic patients was 17.5 %, with a female preponderance. Impacted canines occurred most frequently in Class I malocclusion subjects and least in Class III malocclusion. A significant relationship between the impacted canines and adjacent anatomical structures was found in most measured variables. The impacted canines appeared to be interrelated with arch dimension measurements. The findings showed significant changes in the study group compared to the control group. Interpremolar, intermolar widths and arch length were significantly deficient and narrower, with higher palatal vault seen in impacted canine patients as compared to the control group. Based on the new classification system, the most common type of impacted maxillary canines was $V_1$AP, followed by $V_2$BP, $V_2$AP, and $V_2$CP. $V_3$BL, $N_2$AP and $N_3$AP were the least common. For impacted mandibular canines, $M_1$AP was predominant, followed by $M_2$AP, $M_1$CP, and $M_2$AL. Whilst $M_1$AL and $M_1$BP were the least prevalent. The present 3D investigation provides a new clinical reference value for the prevalence of impacted canines based on ethnicity, gender, and different types of malocclusion in addition to the relationship with surrounding anatomical structures and dental arch dimensions. Furthermore, this study established a new system for classifying impacted maxillary and mandibular canines to facilitate interdisciplinary communication for better treatment planning.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the study

Orthodontics is considered a complex problem-solving domain. The complexity of impacted canines is compounded by the scarcity of precisely controlled clinical research (Schroder et al., 2018). The cornerstone of the dental arches 'the permanent canines' are considered strategic and essential in the dental arch, both functionally and aesthetically. It stands at the corner of the dental arch creating the canine eminence to support the upper lip and the alar base, which are necessary for smile aesthetics (Ireland et al., 2017). Functionally known as 'cuspid protection', it supports the dentition, contributing significantly to its disarticulation in lateral movements and masticatory load, as well as contributing to the functional occlusion and directing the jaw into the proper orientation (Rodrigues et al., 2020).

It also helps in biting and tearing food. Its root volume and length make it one of the principal outstanding abutments for prosthetic replacement of other maxillary teeth (Piya et al., 2020). Consequently, impacted canines present many challenges for clinicians as it compromises tooth exposure as well as its movement for functional and aesthetic outcomes. For these teeth with high functional and aesthetic value, displacement and non-eruption represent significant sequelae of their ectopic eruption and impaction. Impacted canines can impose a risk of ectopic eruption, displacement or tumours of odontogenic origin (Grisar et al., 2020).

The diagnosis and treatment of impacted canines need much attention from orthodontists and dental practitioners (Seager et al., 2020). It is prudent to distinguish the position of the impacted canine, which may present either labially or palatally (Refaat and El-Desouky, 2017). Canines that are labially unerupted have a relatively favourable vertical angulation, while those that are palatally impacted are more likely to be inclined obliquely or placed horizontally (Hamada et al., 2019). Labially impacted canines may erupt in the alveolar ridge or the sulcus without surgical intervention (Seager et al., 2020). On the contrary, palatally impacted canines rarely demonstrate spontaneous eruption. Surgical exposure by eliminating the overlying mucosa and/or bone would be necessary due to resilient palatal mucosa (Arriola-Guillen et al., 2019).

An impacted tooth is an unerupted, partially erupted, or erupted tooth that does not have a normal arch relationship with other teeth in the mouth and is not entirely erupted in the occlusal line at the normal functional level (Arabion et al., 2017). Impacted canines are most common next to the impacted third molars (Sampaziotis et al., 2017; Alyami and Braimah, 2020). Maxillary canines are essential teeth in arch development, functional occlusion and form the foundation of an aesthetic smile. Whereas mandibular canines are covered by the lower lip. Canines are also known as cuspids (Al Balbeesi et al., 2020). A missing canine results in dentofacial aesthetic and functional problems. When impacted leads to a low level of self-esteem and overall poor health-related quality of life (Alyami et al., 2020).

The prevalence of impacted canine values varies significantly in different ethnicities attributed to the sample selection, patient selection area, and inclusion criteria, which suggest genetic and ethnic variations (Al-Zoubi et al., 2017; Schroeder et al., 2019; Bjerklin, 2020). Permanent canine impaction occurs more frequently in females than males among different populations (Grisar et al., 2018; Seager et al., 2020). Furthermore, unilateral impactions tend to be more common than bilateral impactions (Goyal et al., 2018; Malik et al., 2019; Pasagic et al., 2020). Palatal displacement of impacted canines occurs more frequently than buccal displacement (Iancu-Potrubacz et al., 2018; Alassiry, 2019).

Two-dimensional (2D) radiographs have been traditionally used to locate impacted canines in various populations such as Italian (Laurenziello et al., 2017), Swedish (Ericson and Kurol, 2000) and Turkish (Sarikir et al., 2017). However, using 2D radiographic methods like occlusal radiography, lateral cephalometry, panoramic view, and parallax technique to locate impacted canines have several drawbacks, including distortion and superimposition of anatomical structures (Thilagavathy et al., 2020). Furthermore, in a study by Ghoneima et al. (2014), the positions of impacted maxillary canines were not studied in relation to the nasal cavity and surrounding anatomical structures due to a lack of three-dimensional (3D) visualisation. Knowing this relationship helps to determine the management of impacted canines either by orthodontic traction of impacted canine or surgical procedures in this area.

Canine impaction does not depend only on dental crowding but is influenced by other features of malocclusion (Uribe et al., 2017). Some evidence has suggested that deep overbite and Class II malocclusion have been associated with impacted canines compared to the general population (Al-Nimri and Gharaibeh, 2005; Uribe et al., 2017). Furthermore, in a study by Cacciatore et al. (2018), the relationship between canine impaction and the dental arch features was observed. In patients with canine impaction, arch length (AL) and inter first molar width (IMW) were significantly deficient.

In order to proceed with an accurate treatment plan, it is crucial to diagnose and localise the impacted canines in 3D concerning their relationship with the adjacent structures. The most reliable radiographic imaging is computed tomography (CT) scan or cone beam computed tomography (CBCT). Due to the high cost and the high levels of radiation exposure of a CT scan, most dental institutions and clinics possess a CBCT machine rather than a CT scan (Zufia et al., 2020). This signifies the importance of analysing impacted canines pertaining to their arch and introducing a 3D CBCT classification system for orthodontics and surgical management.

## 1.2 Problem statement and study rationale

The prevalence of impacted canines has shown a significant variation in different ethnicities (Schroeder et al., 2019; Arabion et al., 2017; Al-Zoubi et al., 2017). To the best of the author's knowledge, no prior studies have determined the prevalence in detail in Malaysia in different ethnic groups, genders, or types of malocclusion. No previous studies investigated the relationship between an impacted maxillary canine and the nasal cavity, as well as an impacted mandibular canine and the mental foramen. Knowing the relationship aids in determining whether the impacted canine should be managed with orthodontic traction or surgical procedures in this area.

The relationship between canine impaction and the dental arch was observed by Fattahi et al. (2012). However, this investigation did not find the relationship between the shape of the dental arch and the different types of malocclusion. Furthermore, the AL was determined using 2D analysis, which did not provide enough information on the dental arch's form and dimension in 3D, which is required to obtain more scientific data. Knowing this relationship aids in managing impacted canines and determines whether the arch dimension in impacted canine patients differs from the control group, as well as contributes to the science of anatomical structures.

Although the impacted canine has been analysed in previous studies utilising 2D radiographs (Sarikir et al., 2017; Ericson and Kurol, 2000; Laurenziello et al., 2017). However, none of these prior studies had attempted to classify the impacted canines in relation to the adjacent anatomical structures. These studies did not classify impacted canines in detail, in addition to a lack of 3D visualisation. Hsu et al. in 2019 concluded that the key to treating the impacted canines successfully is its accurate localisation. It is essential to understand detailed information on displaced canine types to enhance treatment success and facilitate orthodontics assessment and diagnosis (Ngo et al., 2018).

This inspired the analysis of the impacted canines pertaining to their arch and the development of a new classification system for impacted canines concerning adjacent teeth and anatomical structures using CBCT in dentistry, with particular significance in orthodontics, to overcome the shortcomings of the assessment of impacted canines found in the literature. The knowledge to be produced by this research would be clinically effective. It can help in constituting proper plans for managing impacted canines and significantly improving the patients' quality of life.

## 1.3 Objectives of the study

### 1.3.1 General objective

To determine the prevalence of impacted canines in orthodontic patients and conduct morphometric analysis on the effect of impacted canines on the dental arch form and develop a new classification system using CBCT.

### 1.3.2 Specific objectives

a. To determine the prevalence of impacted canines in orthodontic patients attending HUSM based on ethnicity.

b. To determine the prevalence of impacted canines in orthodontic patients attending HUSM based on gender.

c. To determine the prevalence of impacted canines based on different types of malocclusion.

d. To analyse the position of the impacted maxillary canines in relation to the nasal cavity.

e. To analyse the position of the impacted mandibular canines in relation to the mental foramen.

f. To analyse the impacted maxillary and mandibular canine position in relation to the dental arch form and dimension and compare the dental arch form and dimension of both study and control groups.

g. To develop a new classification system for impacted canines (maxillary and mandibular) utilising CBCT.

## 1.4 Research questions

a. What is the prevalence of impacted canines in orthodontic patients attending HUSM based on ethnicity?

b. What is the prevalence of impacted canines in orthodontic patients attending HUSM based on gender?

c. What is the prevalence of impacted canines based on different types of malocclusion?

d. Is there a relationship between the impacted maxillary canines and the nasal cavity?

e. Is there a relationship between the impacted mandibular canines and the mental foramen?

f. Is there a relationship between the impacted maxillary and mandibular canine and the dental arch form and dimension?

## 1.5 Research hypothesis

a. There is no significant difference in the prevalence of impacted canines among HUSM orthodontic patients based on ethnicity.

b. There is no significant difference in the prevalence of impacted canines among HUSM orthodontic patients based on genders.

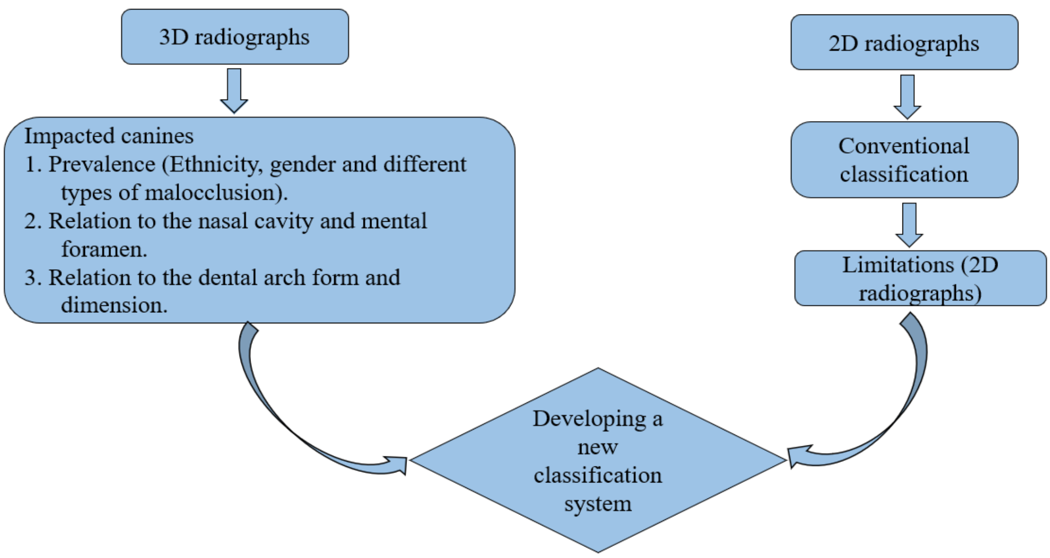
c. There is a significant difference in the prevalence of impacted canines based on different types of malocclusion.

d. There is no significant relationship between the impacted maxillary canines and the nasal cavity.

e. There is no significant relationship between the impacted mandibular canines and the mental foramen.

f. There is no significant difference in the relationship between the impacted canines and the dental arch form and dimension.

## 1.6 Conceptual framework of the study



# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

### 2.1.1 Background

With the advancement of orthodontic knowledge and the increase in the number of patients, it is crucial to understand the changes that occur in adult craniofacial structures (Laurenziello et al., 2017). The speciality of orthodontics is filled with various challenges that necessarily require careful diagnosis and planning; one of these challenges involves impacted canines.

Canines are the most widely recognised teeth having the possibility of displacement from their normal position during the eruption in dentistry, with particular significance in the orthodontic field (Schroder et al., 2018), where many patients are affected by it every year. Despite this, there is still insufficient information regarding the location of impacted canines with a lack of 3D visualisation to eradicate the problem. This inspired a study of impacted canines in relation to their arch, arch form and dimension, as well as the development of a new classification system based on their location and direction during the state of impaction concerning adjacent teeth and anatomical structures in order to overcome the limitations of the assessment of impacted canines found in the literature and provide more information to facilitate diagnosis and treatment planning.

Treatment of impacted canines is an interesting and absorbing challenge for every clinician, both from a diagnostic point of view and creating a therapeutic plan, and may involve different specialities, such as orthodontics and maxillofacial surgery. It is a treatment that often is multidisciplinary (i.e., a combination of surgical and orthodontic intervention) (Hamada et al., 2019). To enact the correct orthodontic treatment plan and surgery after diagnosis, it is necessary to determine the impacted tooth's precise location in 3D. For orthodontic treatment of impacted canines, a proper understanding of canine position in relation to adjacent anatomical structures is essential.

### 2.1.2 Aetiology of canine impaction

At four to five months of age, canine development commences lateral to the piriform fossa, high in the maxilla, and has the longest eruption path at 22 mm (Wedl et al., 2004). The calcification of the crown begins at one year and completes at six to seven years, including the roots of the deciduous first molar. After that, it migrates downwards and forward to lie mesial and buccal to the apex of the deciduous canine, then moves along the distal part of the upper lateral incisor's root downwards (Haralur et al., 2017). Before the crown of the tooth is calcified, the canine remains high in the maxilla, often above the lateral incisor's root, according to Piya et al. (2020). It then erupts over the distal surface of the lateral incisor, causing the closure of the physiological diastema if present while the canine erupts into location. If not self-corrected, it leads to midline spacing. This is called the ugly duckling stage (Piya et al., 2020). Maxillary canines generally erupt at 11 to 12 years (Seager et al., 2020).

At the age of four months, the mandibular canines begin to calcify, and by the age of seven years, the enamel of the crown is fully developed. Around the age of 9 to 10 years, the permanent mandibular canines erupt, with the eruption in females earlier than in males. The permanent canine teeth typically erupt between the ages of 9.3 to 13.1 years (Chaitanya et al., 2018).

Displacement of canine is categorised as buccal, palatal, or in the arch line (Figures 2.1 and 2.2). Occasionally, canines lie horizontally above the maxillary incisors' apices or are displaced near the nasal cavity (Laurenziello et al., 2017). The impacted canines are more commonly attributed to inadequate dental arch width, length and crowding based on the aetiology and related occlusal features (Kafle and Xia, 2010; Alhammadi et al., 2018). Jacoby observed that crowding was determined as the critical etiological aspect of canine impactions (Jacoby, 1983). Similar evidence stated that a lack of arch width was considered a local mechanical reason for impacted canines (Cacciatore et al., 2018).

This high rate of impaction of canines has been attributed to the fact that they take the longest time for development, the last tooth to develop and the most tortuous path. They travel from the stage of development, lateral toward the piriform fossa until they arrive at the final destination in properly functioning occlusion. They are frequently prone to displacements and mechanical obstructions from adjacent teeth through this long journey (Becker and Chaushu, 2015).

There are numerous hypotheses as to why canines get impacted, but they can be categorised into genetics and guidance. According to the prevailing theory, the neighbouring lateral incisor's root serves as a guide for the canine to erupt normally into the arch (Becker, 2012). However, there is no guidance for the canine to travel along if the adjacent lateral incisor is congenitally missing, peg-shaped with minimal mesiodistal width, or malformed. Consequently, the canine will fail to erupt. This is known as the guidance theory (Schroeder et al., 2019).

The potential guidance factors are an irregular eruption rate, abnormal eruption of teeth, and late deciduous teeth resorption, as Caprioglio et al. (2019) cited. Approximately half of the cases of palatally impacted canines examined were associated with abnormal lateral incisors (Caprioglio et al., 2019). Sharma et al. (2018) also noted that incisor inclination, such as that seen in Angle's Class II malocclusion, could be a contributing factor for canine impaction and sometimes associated with peg-shaped lateral incisor in 7.50 % and palatal impaction in 33.5 % of cases.

The genetic theory considered the dental anomaly of canine impaction a consequence of genetic and environmental multifactorial inheritance (Peck et al., 1994; Stellzig-Eisenhauer et al., 2010; Sunnak et al., 2015). They based their approach that palatally displaced canines are concomitant with other dental abnormalities, such as peg laterals and lateral premolar hypodontia, that they occur bilaterally, and there is a familial, gender, and population variation in occurrence (Seager et al., 2020). Evidence for genetic aetiology has numerous forms. Uribe et al. (2017) noted a relationship between canine impactions and other dental anomalies. He found that impacted canines are related to genetic factors such as race, gender, small or congenitally absent lateral incisors, agenesis of adjacent teeth, aplasia, and supernumerary teeth, suggesting a genetic aetiology. Gender might be a significant factor because impacted canines occur twice as often in females as males (Uribe et al., 2017). Sharma et al. (2018) concluded that genetic and guidance or environmental factors could lead to canine impaction but act at different periods.

The dominance of palatal canine impactions over buccal impactions could be an additional complication in part of the impaction. Although the canine develops higher along the sinus and the orbit and buccal to the root of the neighbouring tooth, 85 % of impacted canines can be found palatally (Arriola-Guillen et al., 2019). The most common complications associated with impacted canines include shortening of dental arches, gingival recession, bone loss, and the adjacent root resorption of central and lateral incisors (Iancu-Potrubacz et al., 2018; Rodrigues et al., 2020).

One or a combination of the following aetiologies may cause permanent canine impaction: (1) space deficiency in the dental arch, (2) disturbances in tooth eruption sequence, (3) trauma, (4) over-retained primary canine (Grisar et al., 2018), (5) premature root closure, (6) supernumerary teeth, (7) rotation of tooth buds ankylosis, (8) missing adjacent lateral incisor (Pakravan et al., 2018), (9) overlying cysts or tumours, (10) cleft lip or palate reconstructive surgery, (11) soft or bone tissue thickening (Cruz, 2019; Alamri et al., 2020).

Figure 2.1: Palatally impacted canine (Anand et al., 2016).

Figure 2.2: Buccally impacted canine (Anand et al., 2016).

**2.2 Prevalence of impacted canines among different populations based on ethnicity and gender**

The impacted canine is relatively common and has been reported in various literature with variable results (Laurenziello et al., 2017; Schroeder et al., 2019; Bjerklin, 2020). The evidence outlined in the literature review has shown a significant variation in the prevalence of impacted canine values in different ethnicities (Arabion et al., 2017; Alkadhi et al., 2017; Herrera-Atoche et al., 2017) (Table 2.1).

Laurenziello et al. (2017) reported that the prevalence of maxillary impacted permanent canines in the Italian population was 24.7 %. In India, Sharmila (2016) pointed out that the prevalence of maxillary canine impaction was 4.18 %. The prevalence in European societies (8.79 % in Greece as announced by Fardi et al. (2011), 4.70 % in Croatian as noticed by Prskalo et al. (2008)). Based on the literature, the prevalence of permanent canine impaction was more frequent in females than in males among different populations (Al-Zoubi et al., 2017; Schroeder et al., 2019; Bjerklin, 2020; Piya et al., 2020) (Table 2.1).

A possible explanation for these discrepancies can be attributed to the considerable heterogeneity of race, inclusion criteria, gender, sample selection, area of patient selection, age, and environmental and genetic factors. To the best of the author's knowledge, no prior studies have determined the prevalence in detail in Malaysia in different genders and ethnicities.

**Table 2.1: Summary of the prevalence of impacted canines in different populations using 2D radiographs**

| Authors, year | Maxillary canine | Mandibular canine | Age | No. of patients with impacted canine/total no. of patients (prevalence %) | Race | Gender |
|---|---|---|---|---|---|---|
| Laurenziello et al., 2017 | 54.00 | Not studied | 09.00-10.00 | 54.00/218 (24.77 %) | Italy | Not reported |
| Sharmila, 2016 | 14.00 | 03.00 | 22.00 | 17.00/406 (4.187 %) | India | Female (58.80 %); Male (41.20 %) |
| Fardi et al., 2011 | 109 | | 17.00-48.00 | 109/1239 (8.797 %) | Greece | Female (52.10 %); Male (47.90 %) |
| Altaee, 2014 | 45.00 | Not studied | 15.00-36.00 | 45.00/975 (4.615 %) | Iraq | Female (64.40 %); Male (35.50 %) |
| Watted and Abu-Hussein, 2014 | 82.00 | 13.00 | 10.50-39.50 | 95.00/2200 (4.318 %) | Palestine | Female (61.60 %); Male (38.40 %) |
| Prskalo et al., 2008 | 8.000 | Not reported | 13.00 | 8.000/170 (4.705 %) | Croatia | No gender specific differences |
| Herrera-Atoche et al., 2017 | 52.00 | Not studied | | 52.00/860 (6.046 %) | Mexico | The female to male ratio was 02.06 : 1 |

## 2.3 Prevalence of impacted canines based on different types of malocclusion

The interdigitation of the mandibular and maxillary teeth is known as occlusion. The interactions between the teeth, neuromuscular system, and temporomandibular joint are recognised by the functional principle of occlusion (Roth, 1981; Pokorny et al., 2008). Malocclusion can be described as a deviation from normal occlusion. It is one of the most prevalent oral health problems that may lead to aesthetics, masticatory, psychological, and social problems (Bhardwaj et al., 2011; Mtaya et al., 2009).

The planning of orthodontic treatment within the community's health organisation requires information about the prevalence and distribution of malocclusion. Knowing each patient's occlusion can provide more comprehensive treatment and guidance. Malocclusion identification facilitates patient referral to a clinician, offers several valuable reference points for patient guidance, and specifies appropriate procedure adaptations (Abu-Hussein et al., 2015a).

The majority of studies have assumed that the concept of malocclusion is essentially synonymous with Angle's classification, which is the 'gold standard' in orthodontic practice and is the most communicative system. It is a system of classifying the permanent first molars based on the anteroposterior position of the maxillary and mandibular first permanent molars (Proffit et al., 2013). It is a simple method of describing dental malocclusions which attracts the treating clinician. The mesiobuccal cusp of the maxillary first permanent molar articulates in the buccal groove of the mandibular first permanent molar in normal occlusion (Angle, 1899).

Al-Nimri and Gharaibeh (2005) conducted a study to assess the types of malocclusion commonly related to unilateral palatal impacted maxillary canines and identify the occlusal features associated with this pattern. They performed a study on a sample of thirty-four patients (twenty-seven females and seven males) with palatally maxillary canine impaction (impaction group) at the Dental Hospital, Jordan's Science and Technology University, Jordan, relating to the following criteria: the location of non-syndromic patients with unilaterally impacted maxillary permanent canine was determined using the parallax technique, completely developed root apex of impacted canines with no eruption indication in the oral cavity, and the deciduous canine had to be enclosed in the dental arch when impressions were obtained.

The dentoalveolar arch relationship, absent or abnormality teeth, the maxillary dental arch perimeter, the mesiodistal width of every maxillary tooth, and the maxillary inter first premolar width (IPW) and IMW were assessed. This study indicated that palatally impacted canines were most common in Class II malocclusion subjects. There was no difference in the mesiodistal widths of the maxillary teeth between the impaction and the control groups. This study suggested that palatal arch width and lateral incisor anomalous may contribute to the aetiology of impacted canines.

However, the parallax technique determined the position of impacted canines, and the arch width was measured using a dental cast which did not provide sufficient information regarding the localisation of impacted canines in relation to the adjacent anatomical structures. Moreover, the relationship between the impacted canine and the dental arch form, AL, and palatal height (PH) was not considered in this study by Al-Nimri and Gharaibeh (2005). Knowing the relationship is required for a proper diagnosis and treatment approach for impacted canines. It also aids in understanding the relationship between impacted canine location and dental arch characteristics and determines if the arch dimension in impacted canine patients differs significantly from that of a control group.

Abu-Hussein et al. (2015b) found that patients with Angle's Class II malocclusion were the most prevalent (61, 36 %), followed by Angle's Class I malocclusion (21, 09 %). In contrast, the least prevalent was Angle's Class III malocclusion (17, 55 %) (Angle, 1899) among the Palestinian subpopulation aged 10.2 to 39.5 years. However, the relationship between the impacted canine and the dental arch form and dimension was not found in this study by Abu-Hussein et al. (2015b). Additionally, the impacted canine was measured using conventional 2D analysis, which is inaccurate and insufficient to provide reliable volumetric data. To obtain more scientific data, the determination of canine position using 3D analysis is required.

### 2.4 Classification of impacted canine utilising 2D radiographs

Different radiographic exposures, including conventional 2D radiographs such as occlusal film, periapical view, panoramic view or orthopantomogram (OPG), lateral cephalogram, and posteroanterior view, can aid in assessing the canine's position. However, all these strategies assist in visualising the tooth in two dimensions (Goyal et al., 2018).

Furthermore, 2D radiographs have been found to be unreliable for canine localisation, root anomalies, root resorption visualisation, ankylotic processes, and root surface changes (Rohlin and Rundquist, 1984; Sameshima and Asgarifar, 2001; Counihan et al., 2013) because they did not provide sufficient information regarding the precise direction, position, and angulation of impacted canine and have overlapped anatomical structures (Ericson et al., 2002; Chaushu et al., 2004; Konda et al., 2011; Alqerban et al., 2016). Additionally, the conventional images generated with the 2D film are prone to magnification, distortion, and superimposition (Pittayapat et al., 2014; Thilagavathy et al., 2020). Consequently, three-dimensional radiographic techniques were introduced, such as CT and CBCT. Due to the high radiation exposure and the high cost of a CT scan, a CBCT scan gained acceptance in all dental specialities (Pasagic et al., 2020).

The following are the aids to localise the impacted canines using 2D radiographs:

### 2.4.1 Panoramic radiograph

Archer (1975) assessed the maxillary impacted canines based on OPGs as follows (Figure 2.3): Class I: Palatally impacted canine (Canine impaction located in the palate); a) Horizontal, b) Vertical, c) Semivertical (Angulated), Class II: Buccally or labially impacted canine (Canine impaction situated in labial or buccal surface of maxilla); a) Horizontal, b) Vertical, c) Semivertical (Angulated), Class III: Impacted cuspids located in both the palatal and labial surfaces (for example, a crown is on the palate and root of the neighbouring teeth and ends in the buccal or labial surface), Class IV: Canine impaction situated in the alveolar process, typically vertically between first bicuspids and incisor, and impacted canines in an edentulous maxilla are classified as Class V. However, this classification was generated using 2D radiograph often has superimposition, distortion, and magnification as its drawback for assessing impacted maxillary canines, which is inaccurate and overlaps anatomical structures.

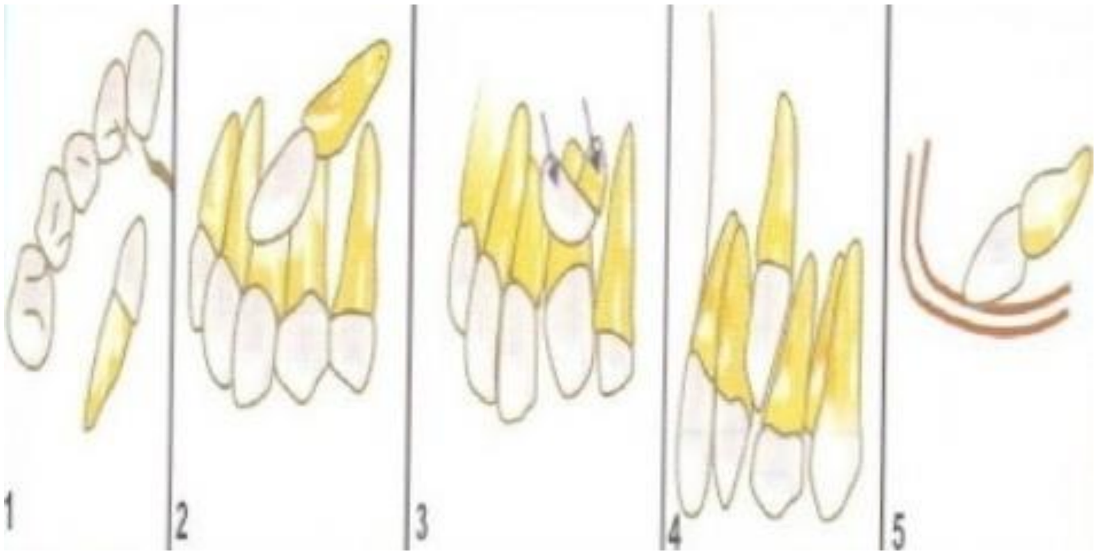



Figure 2.3: Impacted maxillary canine position; (1) Palatally placed, (2) Labially placed, (3) Partly on the labial side and partly on the palatal side, (4) Canine locked between the roots of adjacent teeth, (5) Canine in the edentulous maxilla (Becker, 2012).

The number of sectors was specified by Ericson and Kurol (1988) to identify types of impaction. Based on the radiographic presentation on OPG, they assessed prognostic factors for orthodontic and surgical treatment of maxillary canine impaction (Figure 2.4).


Figure 2.4: Sector description by Ericson and Kurol (1988).

Sector 1: If the canine cusp tip is between the inter-median incisor's line and the long axis of the central incisor; sector 2: If the canine cusp tip is between the central and lateral principal axes; sector 3: If the canine's cuspid height is between the lateral and the first premolar central axis. Angle α was utilised to describe the angle created by the canine's long axis and the inter-incisor midline, and "d" was used to represent the perpendicular distance between the impacted canine's cusp tip and the occlusal plane. Location through division strategies seems to be more prognostic than diagnostic value. If the cusp of the canine is related to sector 1 or 2 and the α angle is more than 25˚, the possibility of resorption of the lateral incisor's root enhances by 50 %. If the canine is in sector 1, the treatment duration is longer, but the treatment duration is shorter if the canine is in sector 3. If this angle increases, the necessity for orthodontic and surgical treatment difficulty becomes more challenging.

Based on the researchers, as the cusp tip of the canine approaches, the midline and the inclination of its long axis enhances, an expanded period of orthodontic and surgical treatment time is predicted. Furthermore, the adjacent lateral incisor root resorption risk is also raised. However, since panoramic radiographs are 2D and subject to distortions, this study used them to localise impacted maxillary canines. Consequently, this study did not provide sufficient knowledge on the precise relationship between anatomical structures, including the nasal cavity, nasal floor boundary, and sinuses in the maxilla.

Lindauer et al. studied the impacted canine using a different strategy from Ericson and Kurol's. He located the cusp tip of the unerupted canine following the root of the lateral incisor in another of four categories (Ericson and Kurol, 1988). He assessed the panoramic radiographs taken during the late mixed dentition phase and categorised them into four divisions;

The location distal to a line tangent to the distal heights of the lateral incisor crown and root contour was described as a sector I. The area mesial to division I, but distal to a line bisecting the mesiodistal measurement of the long axis of lateral incisor tooth, was described as sector II. The area was mesial to segment II but distal to a line tangent to the mesial heights of the contour of the lateral incisor crown, and the root was described as a sector III. All areas mesial to sector III were the sector IV. He discovered that 78 % of the canines destined to get impacted had cusp tips in sectors II, III, and IV (Figure 2.5) (Lindauer et al., 1992). However, this study has insufficient information regarding the precise position, direction, and angulation of impacted canine, including angulation to the midline, vertical canine height, the position of canine root apex, and canine overlap with the neighbouring teeth due to the superimposition, which is a major disadvantage for evaluating impacted canines, which affects the localisation and treatment planning of the impacted canines.

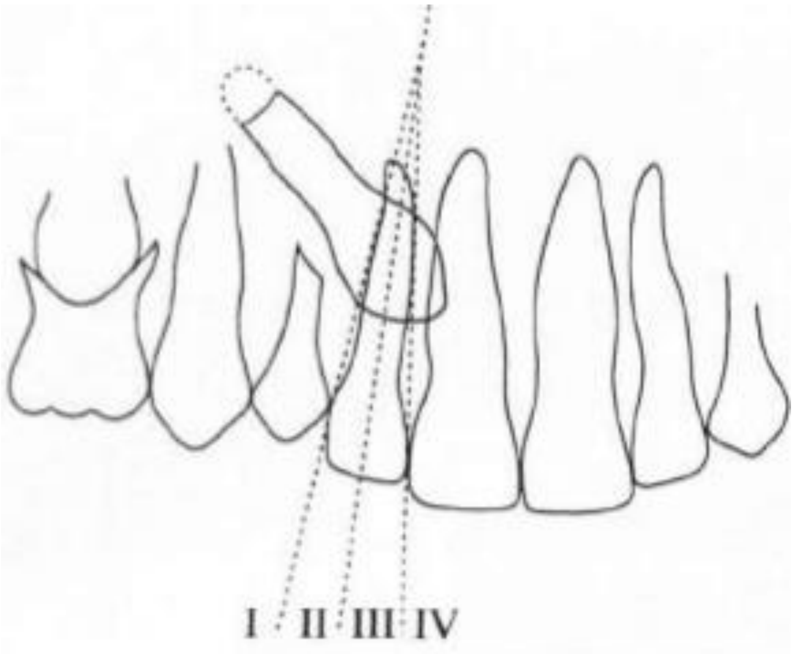



Figure 2.5: Lindauer’s et al. description (1992).

Kuftinec and Shapira (1995) investigated the position of the maxillary canine based on OPG in a 2D view. If the cusp tip of the maxillary canine is medial to the long axis of the adjacent lateral incisor, the palatal position is most probable. The labial impaction is assumed when the canine cusp tip radiographically overlaps the root of the neighbouring lateral incisor and is palpated labially. Labially impacted canines often involves severe tipping of the adjacent maxillary lateral incisor with medial radiographic orientation (Figures 2.6 a and b). However, this study did not consider different types of impacted canines. The maxillary canine location was examined based on the radiographic presentation on the 2D view, which often has distortion,