The influence of radiographic parameters on the choice of surgical exposure technique for palatally impacted canines

A thesis submitted to the University of Dublin in partial fulfilment of Doctorate in Dental Surgery D.Ch.Dent. (Orthodontics)

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Declaration

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Dr Aïda Ben Cheikh
Summary: The influence of radiographic parameters on the choice of surgical exposure techniques for palatally impacted canines

Introduction

In orthodontics, palatally impacted canines (PICs) can be surgically exposed either with an open or closed technique. Due to the lack of evidence in the literature, the decision making is mostly based on operator preference.

Aims and objectives

The primary aim of this study was to assess if radiographic parameters have an influence on the decision to perform either an open or a closed surgical exposure of PICs. An additional aim was to investigate which radiographic parameters could be predictive of performing an open or closed exposure technique.

Materials and methods

The clinical records of 90 patients, who had an open or closed exposure, were assessed. Four radiographic parameters were measured on orthopantomograms: the PIC angulation to the midline, the vertical position of the PIC cusp tip, the antero-posterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor. Intra and inter-examiner reliability were carried out on 12 randomly selected orthopantomograms to evaluate the error of the study. A multivariate logistic regression was performed.
Results

The vertical position of the PIC cusp tip (P<0.01) was the only significant radiographic parameter influencing whether to perform an open or a closed surgical exposure in patients with PIC. A closed exposure technique was at higher chance to be performed if the PIC cusp tip is apical to the midpoint of the roots of the central incisors.

The angulation of the PIC to the midline, the antero-posterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor root were found to be not significant (P>0.05).

Conclusion

Radiographic parameters have an influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines.

The vertical position of the PIC cusp tip is the only significant radiographic parameter determining whether to perform an open or a closed surgical exposure in patients with PIC. The angulation of the PIC to the midline, the anteroposterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor root were found to be not significant.
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## Table of Contents

Declaration ........................................................................................................................................... 2
Summary : The influence of radiographic parameters on the choice of surgical exposure techniques for palatally impacted canines ............................................................... 3
Introduction ........................................................................................................................................ 3
Aims and objectives ......................................................................................................................... 3
Materials and methods .................................................................................................................. 3
Results .............................................................................................................................................. 4
Conclusion ....................................................................................................................................... 4
Acknowledgements ........................................................................................................................ 5

1. Introduction .................................................................................................................................... 11
   2. Literature review ....................................................................................................................... 12
      2.1. Incidence ............................................................................................................................ 12
      2.2. Aetiology ............................................................................................................................ 12
      2.3. Diagnosis ........................................................................................................................... 14
         2.3.1. Clinical diagnosis .......................................................................................................... 14
            2.3.1.1. Medical history ....................................................................................................... 14
            2.3.1.2. Age of patient ......................................................................................................... 15
            2.3.1.3. Skeletal pattern and overall malocclusion ............................................................. 15
            2.3.1.4. Relevant clinical findings ....................................................................................... 18
         2.3.2. Radiographic diagnosis ................................................................................................. 19
            2.3.2.1. Radiographic assessment .......................................................................................... 19
            2.3.2.2. 2-Dimensional radiographic assessment ................................................................... 20
            2.3.2.3. 3-dimensional radiographic assessment .................................................................. 21
      2.4. Treatment options for the PIC ............................................................................................ 23
         2.4.1. Interceptive treatment of PIC ......................................................................................... 23
         2.4.2. Orthodontic alignment of the PIC .................................................................................. 25
            2.4.2.1. Space creation ........................................................................................................... 25
            2.4.2.2. Surgical exposure ..................................................................................................... 26
            2.4.2.3. Orthodontic guiding mechanics of the PIC ............................................................ 26
         2.4.3. Surgical treatment options ............................................................................................ 27
            2.4.3.1. Open exposure procedure ........................................................................................ 27
            2.4.3.2. Closed exposure procedure ..................................................................................... 29
      2.5. Factors influencing the choice of the surgical procedure .................................................... 32
         2.5.1. Patient-related factors .................................................................................................... 32
2.5.1.1. Medical history .......................................................... 32
2.5.1.2. Age of the patient ....................................................... 32
2.5.1.3. Oral hygiene and compliance of the patient .................. 33
2.5.1.4. Post-operative discomfort ........................................ 33
2.5.1.5. Dental-related factors .............................................. 34
2.5.2. PIC-related factors .................................................... 35
2.5.2.1. Site of impaction and anatomical structure of the soft tissue... 35
2.5.2.2. Severity of impaction ............................................... 36
2.5.2.3. Risk of ankylosis ................................................... 37
2.5.3. Periodontal-related factors ......................................... 38
2.5.4. Treatment-related factors .......................................... 40
2.5.4.1. Length of treatment ............................................... 40
2.5.4.2. Failure rate ......................................................... 41
2.5.4.3. Aesthetic components ............................................ 42
2.5.4.4. Surgical complications and repeated surgery .............. 42
2.5.5. Operator preferences related factors ............................... 43
2.5.5.1. Surgical technique ................................................ 43
2.5.5.2. Factors that may influence orthodontist preference ........ 44
2.5.5.3. Factors that may influence surgeon preference ............. 45
3. Aims and Null hypotheses .................................................. 49
3.1. Aim and Null Hypothesis #1 ........................................... 49
3.2. Aim and Null Hypothesis #2 .......................................... 49
4. Material and method ....................................................... 50
4.1. Ethical approval ........................................................... 50
4.2. Recruitment procedures ............................................... 50
4.2.1. Inclusion criteria ..................................................... 50
4.2.2. Exclusion criteria .................................................... 51
4.2.3. Sample size .......................................................... 51
4.2.4. Data collection ....................................................... 51
4.3. Radiographic measurements .......................................... 52
4.3.1. Canine angulation relative to the midline ...................... 53
4.3.2. Vertical position of the canine tip ............................... 54
4.3.3. Canine root apex position antero-posteriorly ................. 54
4.3.4. Canine overlap of the adjacent incisor root ................... 55
4.4. Error of the method ..................................................... 56
4.5. Statistical analysis ....................................................... 57
4.5.1. Intra and inter-examiner reliability ........................................... 57
4.5.2. Descriptive analysis ................................................................. 57
4.5.3. Logistic regression analysis ....................................................... 58
5. Results .......................................................................................... 59
5.1. Flowchart ................................................................................... 59
5.2. Intra and inter-examiner reliability ............................................... 60
  5.2.1. Intra-examiner reliability ......................................................... 60
  5.2.2. Inter-examiner reliability ......................................................... 61
5.3. Descriptive statistics .................................................................. 62
  5.3.1. PIC distribution ....................................................................... 62
  5.3.2. The angulation to the PIC to the midline ................................. 63
  5.3.3. The vertical position of the PIC cusp tip .................................. 63
  5.3.4. The antero-posterior position of the PIC root apex .............. 64
  5.3.5. The PIC cusp tip position relative to the adjacent lateral incisor 65
5.4. Logistic Regression Analysis ......................................................... 66
6. Discussion ...................................................................................... 69
  6.1. Comments on the results ............................................................ 69
    6.1.1. PIC angulation to the midline ............................................... 69
    6.1.2. Vertical position of the PIC cusp tip ..................................... 71
    6.1.3. Antero-posterior position of the PIC root apex .................... 72
    6.1.4. PIC cusp tip position relative to the adjacent lateral incisor root 73
  6.2. Comments on the study .............................................................. 74
  6.3. Limitations ................................................................................. 78
  6.4. Further research ........................................................................ 80
7. Conclusion ...................................................................................... 82
  7.1. Conclusion #1 ........................................................................... 82
  7.2. Conclusion #2 ........................................................................... 82
## Table of Figures

**Figure 1** - Illustrations of the PIC exposed with an open surgical technique: during surgery (a) and 2 weeks post surgery (b) .......................................................... 28

**Figure 2** - Illustrations of the PIC exposed with a closed surgical technique: during surgery (a) and 2 weeks post surgery (b) .......................................................... 30

**Figure 3** - An illustration of the PIC angulation to the midline and the grading used in this radiographic parameter .......................................................... 53

**Figure 4** – An illustration of the vertical position of the PIC cusp tip and the grading system used in this radiographic parameter .......................................................... 54

**Figure 5** - An illustration of the antero-posterior position of the PIC root apex and the grading used in this radiographic parameter .......................................................... 55

**Figure 6** - An illustration of PIC cusp tip position in relation to the adjacent lateral incisor and the grading used in this radiographic parameter ........................................ 56

**Figure 7** - The flowchart of patient selection for the open and the closed surgical exposure groups .......................................................... 59
## List of Tables

**Table 1** – Local, systemic and genetic aetiological factors associated with palatally impacted canines ................................................................. 14

**Table 2** - Skeletal relationship and dental features associated with PIC ....... 18

**Table 3** - Outcomes of periodontal status following open or closed surgical technique of PICs according to the literature ........................................ 40

**Table 4** – Factors influencing the choice of the surgical exposure technique of PIC ........................................................................................................... 48

**Table 5** - Intra-examiner reliability of the study .................................................. 60

**Table 6** - Inter-examiner reliability of the study .................................................. 61

**Table 7** - Descriptive statistics of surgical exposure related to the distribution of the PIC, mean age, gender and location ........................................ 62

**Table 8** – Distribution of surgical exposure of the PIC related to the angulation of the canine to the midline ................................................................. 63

**Table 9** – Distribution of surgical exposure of PIC related to the vertical position of the PIC cusp tip ................................................................. 64

**Table 10** – Distribution of surgical exposure of the PIC relative to the AP position of the PIC root apex ................................................................. 65

**Table 11** – Distribution of surgical exposure of the PIC relative to the PIC cusp tip overlap related to lateral incisor ................................................................. 66

**Table 12** – Logistic Regression Analysis ................................................................. 67
1. Introduction

An impacted tooth is defined as a tooth prevented from erupting into its normal functional position after the expected time of eruption (Mead 1951, Burden, Mullally et al. 1999). The time of eruption for the maxillary canine is 11 to 12 years of age.

When the maxillary canine is palatally impacted, there are several treatment options which include interceptive treatment or surgical exposure with orthodontic alignment to uncover the impacted canine. The two surgical exposure techniques described in the literature are the open and the closed techniques.

Based on the existing evidence, there is no difference between the two procedures in terms of clinical outcomes (Parkin, Benson et al. 2008, Sampaziotis, Tsolakis et al. 2017). However, no study has been carried out investigating whether radiographic parameters influence the decision between performing an open or closed surgical exposure. On review of the literature, the decision seems to be mostly based on operator preference due to the lack of evidence (Parkin, Benson et al. 2008).

This project addresses this deficiency by aiming to assess if radiographic parameters have an influence on the decision to perform either an open or a closed surgical exposure for palatally impacted canine (PIC).
2. Literature review

2.1. Incidence

The permanent maxillary canine is the 2nd most frequently impacted tooth with an incidence of 0.9% to 2.8% (Thilander, Thilander et al. 1973, Ericson and Kurol 1986). Impaction are twice as common in females as in males (Bishara 1992, Mossey, Campbell et al. 1994). According to Stivaros and Mandall, 61% of maxillary canine impactions are palatal, 4.5% are buccal and 34% are impacted in the line of the arch (Stivaros and Mandall 2000). Patients with an impacted maxillary canine represent up to 5.1% of patients seeking orthodontic treatment in practice (Celikoglu, Kamak et al. 2010).

2.2. Aetiology

The aetiology of PICs is unclear and likely to be polygenic (Husain 2016). Different theories have been reported in the literature regarding the occurrence of palatally impacted canines and the two main theories described are the “guidance theory” (Becker 1984) and the “genetic theory” (Peck, Peck et al. 1994).

According to the “guidance theory” (Becker 1984), local conditions are responsible for the palatal displacement of the canine. The path of eruption of the maxillary canine is the longest and deepest and represents about 22 mm (Coulter and Richardson 1997). The distal aspect of the root of the lateral incisor may act as a guide in the eruption path of the canine (Becker 1984, Becker 1995). In a study carried out on a random sample of high school students, Brin reported a prevalence of 7.1% of maxillary lateral
incisor anomalies (4% of small lateral incisors, 1.8% peg-shaped lateral incisors and 1.3% missing) and observed a prevalence of 42.6% of upper lateral incisor anomalies in teenagers with PIC (Brin, Becker et al. 1986). According to the “genetic theory” (Peck, Peck et al. 1994), PIC is assigned to have a polygenic inheritance. This theory is supported by the fact that the PIC occurs more commonly in genetic conditions, in females and in patients with a family history of PIC. As highlighted in Table 1, PICs can be associated with concomitant genetic, systemic or localised dental anomalies such as hypodontia, enamel hypoplasia, infra-occlusion of primary molars, aplasia of second premolars, and small maxillary lateral incisors (Power and Short 1993, Baccetti 1998). In a retrospective cohort study of 730 orthodontic records from children, Garib found that the relative risk assessment of developing a PIC for a patient with dental anomalies was 2.63 times higher compared to patients without a dental anomaly (Garib, Lancia et al. 2016). All these factors support the genetic component in the aetiology of palatally impacted canines (Sacerdoti and Baccetti 2004).

In summary, factors implicated in this tooth disturbance are more likely multifactorial and due to local, systemic and genetic factors as highlighted in Table 1 (Power and Short 1993).
| Local factors                | - Tooth size-arch length discrepancies.  |
|                            | - Failure of resorption of the primary canine root.  |
|                            | - Prolonged retention or early loss of primary canine.  |
|                            | - Ankylosis of the permanent canine.  |
|                            | - Cyst or neoplasm.  |
|                            | - Dilaceration of the root.  |
|                            | - The absence of the maxillary lateral incisor.  |
|                            | - Variation in root size of the lateral incisor (peg-shaped).  |
|                            | - Variation in timing of lateral incisor root formation.  |
|                            | - Iatrogenic factors.  |
|                            | - Idiopathic factors.  |
| Systemic factors            | - Endocrine deficiencies.  |
|                            | - Febrile diseases.  |
|                            | - Irradiation  |
| Genetic factors             | - Heredity.  |
|                            | - Malposed tooth germ.  |
|                            | - The presence of an alveolar cleft.  |

**Table 1** – Local, systemic and genetic aetiological factors associated with palatally impacted canines (Power and Short, 1993)

### 2.3. Diagnosis

#### 2.3.1. Clinical diagnosis

##### 2.3.1.1. Medical history

A medical investigation can be helpful for PIC diagnosis as the aetiology of PICs is multifactorial. An in-depth medical history is carried out to identify associated syndromes such as cleft lip and palate; any dental anomalies such as hypodontia, cysts, supernumeraries, peg-shaped lateral incisors or a history of trauma.
2.3.1.2. Age of patient

Bishara claims that age is one of the most important clinical signs of palatal impaction of the canine (Bishara, Kommer et al. 1976). From the age of 5 to 15 years, the position of the maxillary canine travels approximately 22 mm in three planes of space (Coulter and Richardson 1997). The canine starts to migrate buccally from its palatal position at the level of the root apex of the deciduous canine from 8 to 10 years of age. From this age, the positional changes of the canine need to be carefully observed as the canine may remain palatally impacted if it does not make this transition buccally (Power and Short 1993).

The eruption of the maxillary canines occurs before the end of the pubertal growth spurt and can be indicated by evaluation of the cervical vertebral maturation on a lateral cephalogram (Baccetti, Franchi et al. 2008).

2.3.1.3. Skeletal pattern and overall malocclusion

The current literature does not provide any significant evidence about a positive association between a PIC and an anteroposterior discrepancy of the jaws (Basdra, Kiokpasoglou et al. 2001). However, literature reports some evidence regarding skeletal pattern and dental features associated with PICs as outlined in Table 2.

The skeletal patterns associated with PICs were reported by Cernochova et al. in a retrospective study which analysed the dentoskeletal characteristics of patients with eruption disturbances of the maxillary permanent canine (Cernochova and Izakovicova-Holla 2012). They analysed the panoramic radiographs and lateral cephalograms of 636
patients (456 in Control Group vs 144 in PIC group vs 36 Buccally IC group). As outlined in Table 2, a significant difference was noted between the PIC group and the control group with respect to several features. In another retrospective cohort study, Sacerdoti and Baccetti investigated the associations between PIC, craniofacial features and other dental anomalies in a large orthodontic population (Table 2). They concluded that the prevalence of PIC is significantly associated with reduced lower facial height (60.2%) and aplasia of upper lateral incisors (Sacerdoti and Baccetti 2004).

Various malocclusion features have been associated with PICs. Palatal impaction of the maxillary canine occurs most frequently in patients with Class II division 2 malocclusion (Mossey, Campbell et al. 1994, Basdra, Kiokpasoglou et al. 2000, Al-Nimri and Gharaibeh 2005) and with increased overbite (Leifert and Jonas 2003). In a retrospective study of 199 patients based on panoramic radiographs, cephalograms and pretreatment study models, Lüdicke et al assessed the torque of maxillary incisors and the maxillary length in the sagittal direction in patients with PIC (Ludicke, Harzer et al. 2008). The results found that 45% of the patients showed features of Class II division 2 malocclusion. Lüdicke et al concluded that the labial root torque of maxillary incisors in Class II division 2 acts as a type of interference with the guidance process of maxillary canine eruption and may explain the higher prevalence of PIC in class II division 2 patients. Patients with features of Class II division 2 malocclusion should be considered as a risk group for maxillary canine impaction (Ludicke, Harzer et al. 2008).
In contrast with the previous studies, Milosevic et al. carried out a study to determine the dental and occlusal features of patients with palatally impacted canines (Anic-Milosevic, Varga et al. 2009). The study was based on 100 dental casts of patients divided into 2 groups: one group who had uni/bilateral PIC vs one control group with normally erupted maxillary canines. The mean age was 15.6 ± 1.6 years. They concluded that PIC occurred most frequently in patients with a Class I incisor relationship. In comparison with the control group, overjet was significantly smaller in the female group with PIC and overbite significantly deeper in the male group with PIC. There were no statistically significant differences noted with regards to the maxillary inter premolar and inter molar widths and palatal height for either gender (Anic-Milosevic, Varga et al. 2009).

The absence of malocclusion in PIC patients can be common which makes early diagnosis harder in such patients. 85% of PIC occur into an uncrowded arch despite adequate space being available for canine eruption (Jacoby 1983). This may explain the delay in identification of PICs and the importance of a careful examination by the orthodontist.
### SKELETAL RELATIONSHIP
- More frequent occurrence of skeletal class I; Prognathic maxilla; Hypodivergent relationship; (Cernochova et al, 2012)
- Low angle vertical relationship (60.2%) (Sacerdoti and Baccetti, 2004)

### DENTAL FEATURES
- Retroclination of maxillary central incisors; (Cernochova et al, 2012)
- Class I incisor remationship ; Congenital absence or peg-shaped lateral and /or absence of 2nd premolar (16%); Reduced overjet in female with PIC (Milosevic et al, 2009)
- Class II division 2 incisor (45%) (Ludicke et al, 2008)
- Class II division 2 incisor (44%) (Al-Nimri and Gharaibeh, 2005)
- Deep overbite (Leifert and Jonas, 2003)

Table 2 - Skeletal relationship and dental features associated with PIC

#### 2.3.1.4. Relevant clinical findings

Bishara described four clinical signs that can be assessed to diagnose the palatal impaction of a canine: age at clinical diagnosis, presence or absence of the canine bulge, retention of the deciduous canine, and distal tipping and proclination of the lateral incisor (Bishara, Kommer et al. 1976). The upper maxillary canine is normally palpable in the labial vestibule by the age of 10 to 11.5 years (Bishara, Kommer et al. 1976). According to a longitudinal study by Ericson and Kurol, 95 % of 11 years old children have erupted or palpable canines (Ericson and Kurol 1986). Therefore, the absence of palpation of the canine in the labial vestibule at this age may indicate a risk of impaction of the canine.
The retention of the primary maxillary canine was considered for a long time as responsible for the palatal impaction of the permanent maxillary canine due to its resistance to resorb. Nowadays, the over-retained primary canine is mostly considered as a consequence of PIC rather than the cause (Thilander, 1968).

The distal tipping and proclination of the lateral incisors are described as another clinical sign of impaction, due to the pressure of the developing canine on the lateral incisor root (Bishara, Kommer et al. 1976). Another relevant clinical finding was described by Baccetti who reported a significant relationship between the distal displacement of unerupted mandibular second premolars and palatal impaction of the canine. The prevalence rate for PIC in groups with distally displaced premolars was significantly higher (28%) than in the control group (4.2%). As the distally displaced premolar is often diagnosed earlier than the PIC, Baccetti suggested careful assessment of the angulation of unerupted mandibular premolar, as they represent a risk indicator for the palatal impaction of maxillary permanent canines (Baccetti, Leonardi et al. 2010).

2.3.2. Radiographic diagnosis

2.3.2.1. Radiographic assessment

Radiographic examination is carried out to assess the position of the canine in three planes of space. In the clinical guidelines from the Royal College of Surgeons (RCS), Husain states that there is little diagnostic value in radiographic assessment on a patient younger than 10-11 years of age (Husain 2016). However, radiographs are carried out on patients greater
than 11 years of age, when the canine is unerupted or not palpable (Ericson and Kurol 1987). It is also useful to exclude any complications or associated pathology that may disrupt the eruption path of the canine such as root resorption, the presence of supernumerary teeth or cystic lesions.

2.3.2.2. 2-Dimensional radiographic assessment

A single periapical film provides the clinician with a two-dimensional representation of the dentition. To evaluate the position of the canine in the bucco lingual dimension, a second periapical film is taken and compared with the first, using the parallax technique as described by Clark in 1910 and cited by Jacobs (Jacobs 1999). The parallax technique is defined as the apparent displacement of an image relative to a reference object caused by an actual change in position of the xray beam. There are two parallax techniques used in the localisation of the palatally impacted canine: the vertical and horizontal parallax techniques. Horizontal parallax compares two periapicals with a minimum of 20° tube shift difference between the two radiographs or an upper standard occlusal (USO) and a periapical centred on the canine region (Southall and Gravely 1989). Vertical parallax was described by Richards in 1952 (Richards, 1952) who uses an orthopantamogram with an angulation of 8° (OPG) and an intra oral view, either an USO or a periapical (Southall and Gravelly, 1989). The vertical angulation of the x-ray tube, when taking an USO is 60-65° but can be increased to 70-75° to enhance the accuracy of the vertical technique (Jacobs 1999).
Even though an OPG is commonly used to assess canine position, there are some limitations. According to Armstrong, the horizontal parallax technique is found to be more accurate than the vertical technique with an 83% success rate for localisation of the PIC with the horizontal technique compared to a 68% success rate with the vertical technique (Armstrong et al, 2003). Moreover, according to the literature, an OPG overestimates the angulation of the canine to the occlusal plane and underestimates its proximity to the midline (Ferguson 1990) and the incidence of root resorption of the lateral incisors (Walker 2005).

In 1999, Chaushu described a technique of magnification for determining the position of displaced maxillary canines based on OPG (Chaushu, 1999). This technique used the canine-incisor index which is the ratio of the width of the displaced canine to the width of the homolateral central incisor and the canine-canine index which is the ratio of the width of the displaced canine to the contralateral canine. OPG can be used as a useful indicator for determining the location of unerupted maxillary canine (Chaushu, 1999).

2.3.2.3. 3-dimensional radiographic assessment

Radiographic dentistry was revolutionised by the introduction onto the market of cone beam technology in 1995, by Tacconi and Mozzo. Firstly introduced to the European market in 1999 as the NewTom DVT 9000 by QR company, the cone beam computed tomography or CBCT is a medical imaging technique which consists of X-ray computed tomography where the X-rays are divergent forming a cone (Angelopoulos, Scarfe et al. 2012). The CBCT offers a 3D image model that allows the rotation in 3
dimensions of space. This advantage presents a major interest in orthodontics to accurately explore the position of the PIC in relation to the adjacent teeth and in addition to assess root resorption. CBCT studies found higher rate of root resorption of the maxillary lateral incisor compared to orthopantomogram; 48% using computed tomography, 66.7% using CBCT (Ericson and Kurol 2000, Walker, Enciso et al. 2005) and 12% using orthopantamogram (Ericson and Kurol 1988). CBCT studies also found some useful radiographic factors for predictions of maxillary canine impaction (Alqerban, Jacobs et al. 2015, Naoumova, Kurol et al. 2015, Naoumova, Kurol et al. 2015). From a sample of 65 patients’ records, Alqerban et al established a prediction model of the probability of impaction using relevant predictors such as the canine rotation, the canine crown position, the canine angulation to the lateral incisor, the canine angulation to the midline and the canine cusp tip to the occlusal plane (Alqerban, Jacobs et al. 2015). They concluded that the canine crown position, the canine cusp tip to the occlusal plane and the canine angulation to the lateral incisor were the relevant predictors in this model. The prediction of canine impaction based on CBCT was considered excellent.

Two-dimensional (2D) imaging were compared to three-dimensional (3D) imaging in subject with unerupted maxillary canines. Botticelli carried out a study on 27 patients undergoing orthodontic treatment with 39 impacted maxillary canines (Botticelli et al., 2011). The aim of the study was to find if there was any difference in diagnostic information using 2D versus 3D imaging in patients with unerupted maxillary canines. The authors found that 3D imaging provide a better precision in canines localisation and a
difference in diagnosis and treatment planning of patients (Botticelli et al., 2011). However, the recent British Orthodontic Society Orthodontic Radiographs Guidelines state that the routine use of CBCT to assess a PIC cannot be justified (Isaacson 2015). It should be limited to cases that present with high risk of root resorption, unerupted supernumerary teeth or patients with cleft lip and palate. According to the European guidance and SEDENTEXCT guidelines, small Field of View (FOV) CBCT should be used and would be more appropriate if CBCT is needed (Husain 2016).

2.4. Treatment options for the PIC

The treatment of palatally impacted canines is challenging and multidisciplinary. The treatment options are influenced by the age of the patient, the location and severity of the impacted canine and the motivation of the patient undergoing orthodontic treatment.

The different therapeutic procedures in PIC management include different options such as the interceptive treatment with extraction of the deciduous canine (Ericson and Kurol 1986, Naoumova, Kurol et al. 2015) and the surgical exposure with orthodontic alignment of the unerupted canine into the dental arch (Kokich 2004).

2.4.1. Interceptive treatment of PIC

The extraction of the primary canine is often considered as the first approach when a PIC is diagnosed. The extraction of the primary canine leads to normalisation of the path of eruption of the canine in 78% of cases in 1 year in an uncrowded arch (Ericson and Kurol 1988) and 62% of cases
in a crowded arch (Power and Short 1993). However, the most up to date Cochrane review by Parkin in 2012 concluded that currently there is no evidence to support the extraction of the primary canine in 10-13 years old children with one or two palatally displaced permanent maxillary canines (Parkin, Furness et al. 2012). In contrast, Naoumova in her recent RCT concluded that extraction of the primary canine in 10-13 year old patients resulted in a shorter mean eruption time. The rate of successful eruption of PICs was 69% when the primary canine was extracted versus 39% in the control group (Naoumova, Kurol et al. 2015).

Evidence in the literature suggests that providing adequate space for the maxillary palatally impacted canine increases its likelihood of eruption. Baccetti et al and Leonardi studied the interceptive extraction of the deciduous canine associated with the use of cervical-pull headgear. This combination prevented the mesial migration of the upper posterior teeth and increased the arch length (Leonardi, Armi et al. 2004, Baccetti, Leonardi et al. 2008). Three groups were studied: extraction of the primary canines, extraction of primary canines associated with headgear and an untreated control group. Baccetti et al reported 88% significant success of PIC eruption in the headgear group, 65% for the extraction group only and 36% success for the control group (Baccetti, Leonardi et al. 2008). Leonardi reported 50% of success for the extraction group versus 80% for extraction combined with headgear use (Leonardi, Armi et al. 2004).

The success of normalisation of the eruption path of the maxillary PIC can be influenced by some predictors. Naoumava analysed radiographic factors on CBCT and concluded that the distances canine cusp tip to dental
arch plane, canine cusp tip to midline and the mesioangular angle of the PIC might be useful predictors in decision making between the interceptive extraction of the deciduous canine and orthodontic alignment with surgical exposure of the PIC (Naoumova, Kurol et al. 2015).

However, according to the RCS clinical guidelines, an alternative treatment should be considered if there is no improvement in the position of the PIC after 12 months of interceptive treatment. Interceptive treatment should be carefully selected and may be beneficial for patients between 10-13 years of age with absence of crowding and no severely displaced PIC (Husain 2016).

2.4.2. Orthodontic alignment of the PIC

The alignment of the PIC involves an orthodontic phase and a surgical procedure to expose the canine. Management is challenging and time-consuming. Two to three years of fixed orthodontic appliance treatment is required to align the canine into its correct position (Parkin, Benson et al. 2008).

2.4.2.1. Space creation

Space creation is critical for successful alignment of the PIC. Space can be obtained by using space creation methods such as extraction, expansion, distal movement of premolars or mesial movement of the labial segment (Ferguson 1990). Based on this aim, the first phase of the orthodontic phase will align and level the upper and lower arches excluding the PIC. A sequence of NiTi archwires is required to deliver constant and gentle forces due to their properties of superelasticity and shape memory.
After the first phase, an intermediate thickness round or rectangular archwire of stainless steel associated with open coil springs or space-opening loops may be used if space is required to align the canine. The majority of orthodontists prefer the PIC to be exposed within 6 to 9 months of fixed appliance treatment after the alignment phase (Kokich 2004).

2.4.2.2. Surgical exposure

The surgical exposure is usually the second phase of the combined ortho-surgical alignment of the PIC. Two surgical techniques are used for the exposure of the PIC: the open and closed techniques. The open exposure technique involves uncovering the PIC followed either by spontaneous eruption of the canine or by applying orthodontic traction to the canine, a few weeks following the surgery. The closed exposure involves bonding a gold chain to the PIC at the time of the surgical exposure. The PIC is recovered by the palatal flap and followed by orthodontic traction to the PIC.

2.4.2.3. Orthodontic guiding mechanics of the PIC

Attachments

In the case of a superficially impacted palatal canine, different attachments can be used to apply orthodontic traction (Fleming, Sharma et al. 2010). These include a conventional bracket, button or hook. When the impaction is deep, an alternative attachment should be used which may include a gold chain or lasso ligature.
Traction mechanics

Before commencing orthodontic traction to the PIC, the entire arch is consolidated with a heavy round or a rectangular stainless steel arch wire to reinforce anchorage. The forces used to pull the canine from the palate to the line of the arch are light and recommended to be in the range of 20 to 60g (Bishara 1992).

Depending on the initial position of the PIC relative to the adjacent teeth, the canine can be mechanically drawn directly or indirectly to the labial arch wire. According to Kornhauser, when the direct line between the PIC and the arch wire is obstructed by the presence of the lateral incisor root, it is preferable to initially pull the PIC vertically downward or distally before moving the PIC into the line of the arch (Kornhauser, Abed et al. 1996).

2.4.3. Surgical treatment options

During the exposure surgery, any potential obstruction that has impeded the normal eruption of the maxillary canine is removed (Becker and Chaushu 2015). Within the different approaches, two main surgical methods are described in the literature: the open exposure (OE) and the closed exposure (CE) procedures.

2.4.3.1. Open exposure procedure

The standard procedure for an open exposure consists of elevation of a full muco-periosteal palatal flap, made apical to the gingival sulcus of the premolars and ipsilateral incisors.
The bone overlying the canine's crown is removed from its cusp tip down to the level of the cementoenamel junction. This is achieved by using a curette if the bone is soft or a surgical handpiece with a diamond bur if the canine is embedded deeply in the bone. The follicular envelope surrounding the crown is a common finding and it is removed at the periphery of the crown down to the cementoenamel junction.

The palatal mucosa overlying the tooth is excised to expose the crown and the flap is then repositioned in place. A periodontal dressing is placed for 7 to 10 days to allow healing (Clark 1971). Post exposure, the PIC can be allowed to erupt spontaneously for 6-9 months. Alternatively, an attachment is bonded and the canine pulled after a few weeks (Kokich and Mathews 1993).

**Figure 1** - Illustrations of the PIC exposed with an open surgical technique: during surgery (a) and 2 weeks post surgery (b). During surgery (a), a full thickness palatal mucoperiosteal flap was raised, the bone and the palatal mucosa overlying the UR3 were removed. The flap was sutured back. Post surgery (b), an attachment was bonded on the UR3 for the orthodontic traction.

The advantages of the open exposure technique reported by the literature are listed below:

- Physiological and spontaneous eruption (Clark 1971, Mathews and Kokich 2013);
• Shorter duration of treatment (Mathews and Kokich 2013, Smailiene, Kavaliauskiene et al. 2013);
• Reduced surgical procedure time (Pearson, Robinson et al. 1997, Gharaibeh and Al-Nimri 2008);
• Attachment bonding on dry tooth by orthodontist;
• Easier Inspection (Wisth, Norderval et al. 1976);
• Quicker rebonding (Wisth, Norderval et al. 1976);
• Favourable periodontal health after treatment (Schmidt and Kokich 2007).

According to the evidence, the disadvantages of the open exposure technique are:
• Longer recovery time (Chaushu, Becker et al. 2004, Chaushu, Becker et al. 2005, Gharaibeh and Al-Nimri 2008);
• Difficult for deep and horizontal PIC (Mathews and Kokich 2013);
• Cleaning difficult (Wisth, Norderval et al. 1976);
• Failure rate 15%: regrowth of palatal tissue covering the crown of PDC (Pearson, Robinson et al. 1997).

2.4.3.2. Closed exposure procedure
In the closed exposure technique, a mucoperiostal flap is elevated and sufficient bone is removed to expose the impacted canine crown and permit tooth movement. A gold chain is bonded to the uncovered crown during the surgery. The tooth is covered back by repositioning the flap and the gold
chain is left exiting through the palatal gingiva. Once the area has healed, the tooth can be guided orthodontically into the oral cavity (Lewis, 1971).

**Figure 2** - Illustrations of the PIC exposed with a closed surgical technique: during surgery (a) and post surgery (b). During surgery (a), a full thickness palatal mucoperiosteal flap was raised and the bone overlying the UR3 was removed. A gold chain was bonded on the UL3 during the surgery for immediate orthodontic traction. The palatal flap was sutured back intact. Post surgery (b), the gold chain was reactivated for orthodontic traction of the UL3.

The advantages of the closed exposure technique reported by the literature are listed below:

- Preservation of periodontal tissue and less inflammation (Becker and Chaushu 2013);
- Patient comfort (Chaushu, Becker et al. 2004, Chaushu, Becker et al. 2005);
- Bonding during surgery allow gentle forces and immediate loading (Becker and Chaushu 2013).

According to the evidence, the disadvantages of the closed exposure technique are:

- Absence of visibility during the eruption process: risk of root resorption of the lateral incisor, bone loss (Crescini, Nieri et al. 2007, Mathews and Kokich 2013);
• Greater palatal pocket depth (Wisth, Norderval et al. 1976);
• No direct inspection (Wisth, Norderval et al. 1976);
• Increase risk of ankylosis 14.5% vs 3.5% for OE (Koutzoglou and Kostaki 2013);
• Failure rate 31%: debonding of the orthodontic attachment of PIC (Pearson 1997).

Currently there is no clear evidence to support one surgical technique over the other in terms of periodontal health, aesthetics, economics and patient factors (Parkin, Benson et al. 2008).

Recently, an updated version of the Cochrane review on open versus closed surgical exposure of PICs concluded that currently, the evidence suggests that neither the open or closed surgical technique for PIC exposure is superior to the other (Parkin, Benson et al. 2017).

Two systematic reviews and meta-analyses were also recently published on open versus closed surgical exposures of PICs. Sampaziotis et al. concluded that there is no difference between the two techniques in terms of periodontal outcomes, postoperative pain during the first day and aesthetic appearance. A shorter surgical procedure was found for the open exposure group. However, these conclusions were based on only two single trials with high level of evidence, the remaining the studies were at high risk of bias (Sampaziotis, Tsolakis et al. 2017). In contrast, Cassina et al concluded that regarding the treatment duration and the risk of ankylosis, the open surgical technique seems to be superior over the closed
technique. However, Cassina also concluded that further research was needed to establish clinical recommendations (Cassina 2017).

2.5. Factors influencing the choice of the surgical procedure

Based on the literature, the choice of the surgical technique to expose palatally impacted canines is somewhat controversial and based on several influencing and conflicting factors.

2.5.1. Patient-related factors

2.5.1.1. Medical history

Certain medical conditions may prevent patients from having surgical procedures. Any risk related to the medical history of the patient will be a contra-indication to both methods of surgical exposure which may compromise the orthodontic treatment of PIC.

2.5.1.2. Age of the patient

According to Mathews and Kokich, the open exposure surgical technique with natural eruption is favourable for patients in the mixed dentition. This allows for spontaneous eruption of the PIC without the need for orthodontic traction; thus reducing the treatment duration (Mathews and Kokich 2013). However, it has been reported that the limitation of this approach is that impaction of maxillary canines is usually not diagnosed when the patient is in the mixed dentition. In contrast, according to Galloway and Stirrups, the
optimal time for surgical exposure and orthodontic alignment is in the permanent dentition (Galloway and Stirrups 1989).

Ericson and Kurol suggested that treatment for impacted maxillary canines should commence by the age of 12 years at the latest to reduce the risk of resorption to the adjacent incisor roots (Ericson and Kurol 1988).

2.5.1.3. Oral hygiene and compliance of the patient

Cooperation and motivation of the patient are crucial to successful treatment. The risks of orthodontic treatment such as demineralisation and root resorption are correlated to the duration of treatment. According to Wisth, the open exposure technique is described as more difficult to clean, compared to the closed exposure. Immediately after open exposure has taken place, the palatal tissue surrounding the surgical area is inflamed and uncomfortable for the patient thereby compromising oral hygiene (Wisth, Norderval et al. 1976).

2.5.1.4. Post-operative discomfort

The most recent Cochrane Database on open versus closed exposure of maxillary PICs, reviewed by Parkin in 2008, found only one prospective study that investigated patients perception of recovery after open and closed surgical exposures of PIC (Parkin, Benson et al. 2008). Chaushu et al. investigated post-operative discomfort by means of a questionnaire with 4 main criteria: pain, oral function, ability to have routine daily activities and other symptoms such as bleeding, swelling or bad taste (Chaushu, Becker et al. 2005). They concluded that patients who had a
closed surgical exposure showed a shorter recovery time apart from the ability to perform everyday life activities. In addition, patients who received a closed exposure have the attachment bonded during surgery under anaesthesia which contributes to patient’s comfort. Even though patients were not randomly allocated in this study, the closed exposure technique is considered as the most comfortable procedure according to Chaushu et al. (Chaushu, Becker et al. 2004, Chaushu, Becker et al. 2004, Chaushu, Becker et al. 2005).

In 2008, Gharaibeh and Al-Nimri carried out a prospective randomised clinical study on 32 patients comparing the duration of the surgical exposure and the perception of pain for patients after a closed and an open exposure of unilateral PICs. The duration of surgery was recorded and the degree of pain was assessed during the week following the surgery. Postoperative pain in the 2 groups after surgery was comparable and was not significantly different. However, pain regression was faster in the closed exposure group (Gharaibeh and Al-Nimri 2008).

2.5.1.5. Dental-related factors

The overall malocclusion of the patient should also be considered when deciding whether to proceed with either an open or closed exposure technique. According to Mathews and Kokich, an open exposure should be carried out in patients with well-aligned arches as it has the advantage of allowing spontaneous eruption of the PIC without orthodontic traction. The surgical procedure is undertaken first and followed by the orthodontic phase of upper and lower fixed appliances. This timing avoids extended
orthodontic treatment duration and so reduces the risks related to fixed appliances (Mathews and Kokich 2013).

2.5.2. PIC-related factors

The choice of the surgical exposure technique also depends on PIC factors such as the site of impaction, the anatomical structure of the gingival tissue and the severity of impaction of the PIC.

2.5.2.1. Site of impaction and anatomical structure of the soft tissue

Surgical exposure is necessary to stimulate the natural eruption of the tooth through the attached gingival tissue. The type of gingival tissue covering the impacted tooth is a determinant factor in deciding which surgical technique to embark on.

The decision regarding which surgical technique to adopt with buccally impacted canines is easier. The decision is made with respect to the position of the impacted maxillary canine relative to the mucogingival junction. An open exposure such as an apically positioned flap (ARF) is preferred if the impaction is below the mucogingival junction (Kokich 2004). In contrast, palatally impacted canines have no recommendation due to the fact that, regardless of the severity and site of impaction, they are impacted in keratinized tissue. Therefore, both open and closed surgical techniques can be carried out (Smailiene, Kavaliauskiene et al. 2013).

According to Chapokas et al, whatever the clinical or radiographic parameters, the site of impaction is the factor to be considered when deciding whether to proceed with either an open or closed exposure. He
stated that the PIC should always be exposed with an open exposure (Chapokas, Almas et al. 2012).

2.5.2.2. Severity of impaction

The severity of impaction and the 3D location of the PIC are important factors to consider when planning the type of surgical approach to adopt for the exposure of the PIC. The location and severity of the canine impaction can be assessed by the presence or absence of a canine bulge (Bishara, Kommer et al. 1976). If the bulge is palpable, the PIC is superficial and an open exposure technique is more likely to be carried out. In the case of a strongly retained primary canine, distal tipping and proclination of the lateral incisor or loss of vitality of incisors, the PIC is likely to be more deeply impacted and a closed exposure may be preferred. However, the severity is confirmed by the use of radiographic images.

Radiographic parameters on an OPG are used to assess the position of the PIC and the severity of its impaction. These factors help in determining whether to align or extract the PIC. These parameters include the PIC angulation to the midline, the vertical position of the PIC cusp tip, the anteroposterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor (Stivaros and Mandall 2000, Al-Moghrabi 2015). Research carried out by Al-Moghrabi, using the same parameters, demonstrated the vertical position of PIC cusp tip and the anteroposterior position of the PIC root apex were the most significant factors in deciding whether to align or extract the PIC.
Mathews and Kokich classified the PIC into two categories according to the severity of impaction of the PIC: simple and complex. The simple PIC is defined as a canine not deeply embedded within the alveolus whereas, the complex PIC is a deeply impacted canine positioned near the apices of the incisors roots. With respect to Mathews and Kokich's classification, an open exposure should be carried out for all simple PIC whereas closed exposure should be the technique of choice for all complex PIC (Mathews and Kokich 2013).

2.5.2.3. Risk of ankylosis

Ankylosis may occur when attempting to align PIC, however, the risk is low (Kokich 2004). According to the prospective clinical study led by Koutzoglou on 118 patients, there was evidence of association between the risk of ankylosis and the choice of the surgical procedure. Indeed, they found 14.5% of PIC to be ankylosed when the closed exposure technique was adopted versus 3.5% with the open exposure technique (Koutzoglou and Kostaki 2013). They concluded that the risk of ankylosis might be four times more likely with the closed exposure technique versus the open exposure. However, closed exposure is often associated with an increased severity of impaction of PIC and this procedure is usually undertaken when the canine is in an unfavourable position. Therefore, the risk of ankylosis may be more influenced by the severity of the impaction rather than the procedure itself.
2.5.3. Periodontal-related factors

The long-term periodontal health of a PIC is an important factor to consider when deciding whether to proceed with an open or closed exposure technique. However, a Cochrane review of the current literature and a randomised clinical trial found no difference in periodontal outcomes when comparing open and closed exposure techniques (Parkin, Benson et al. 2008, Parkin, Milner et al. 2013, Sampaziotis, Tsolakis et al. 2017).

In a controlled prospective study, Smailiene et al concluded that there were no significant differences with respect to periodontal pocket depth or bone support between the surgical open technique with free eruption and the closed exposure technique. The choice of surgical method is not associated with any significant difference in the post-treatment periodontal status of PICs and adjacent teeth. However, both techniques showed, significant bone loss on the mesial aspect of the canine and the distal aspect of the lateral incisors in cases of PICs surgically exposed and treated orthodontically, compared to the control group with naturally erupted canines (Smailiene, Kavaliauskiene et al. 2013).

Crescini reported similar results and found that the periodontal pocket depth (PPD) of the impacted canines was 0.18mm deeper than normally erupted canines (Crescini, Nieri et al. 2007). Woloshyn also reported a significant difference in probing depths and crestal bone height between PIC and normally erupted canines. However, they concluded that the periodontal impact to the PIC with an open exposure appeared to be better than with a closed exposure (Woloshyn, Artun et al. 1994).
According to Mathews and Kokich, the risk of alveolar defects is higher in cases of immediate traction with the closed exposure technique. They explained that for the closed exposure technique, the PIC is still buried beneath the palatal bone. Immediate traction of the PIC with a gold chain pulls the crown of the canine against the palatal bone and creates a direct contact between the enamel and the bone. Due to the fact that the enamel is acellular, this interface results in bone resorption, most likely due to pressure necrosis (Mathews and Kokich 2013).

In contrast, some other authors reported excellent long-term periodontal health (Becker, Kohavi et al. 1983, Kohavi, Becker et al. 1984, Quirynen, Op Heij et al. 2000, Crescini, Nieri et al. 2007) with less periodontal destruction and reduced clinical attachment loss after canine exposure using closed surgical technique (Wisth, Norderval et al. 1976). However, in her Cochrane review, Parkin concluded that these studies were retrospective and consequently at a higher risk of bias (Parkin, Benson et al. 2008).

Smailiene concluded in her prospective study that the level of bone support and periodontal changes are not related to the age of the patient at the start of treatment, the duration of treatment, nor the initial horizontal and vertical position of the impacted canine (Smailiene, Kavaliauskiene et al. 2013).

The table below outlines and compares the outcomes found in the literature regarding the periodontal status of PICs following an open or a closed surgical exposure technique (Table 4):
<table>
<thead>
<tr>
<th>Article</th>
<th>Number of patients</th>
<th>Surgical exposure</th>
<th>Type of study</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisth et al 1976*</td>
<td>34 vs 22*</td>
<td>OE vs CE*</td>
<td>Retrospective*</td>
<td>CE better than OE*</td>
</tr>
<tr>
<td>Becker et al 1983</td>
<td>23</td>
<td>Closed</td>
<td>Retrospective</td>
<td></td>
</tr>
<tr>
<td>Kohavi et al 1984</td>
<td>23</td>
<td>Closed</td>
<td>Retrospective</td>
<td></td>
</tr>
<tr>
<td>Parkin et al, 2013</td>
<td>27 vs 25</td>
<td>OE vs CE</td>
<td>Prospective</td>
<td>No difference</td>
</tr>
<tr>
<td>Parkin et al, 2015</td>
<td>34 vs 33</td>
<td>OE vs CE</td>
<td>Prospective</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Outcomes of periodontal status following open (OE) or closed (CE) surgical technique of PICs according to the literature

2.5.4. Treatment-related factors

2.5.4.1. Length of treatment

The duration of treatment in orthodontics is an important parameter to consider in the decision-making process both for patient and clinician. An increased duration of treatment can lead to risk of demineralization, compliance loss and failure rate to complete the orthodontic treatment.

The current literature reports an average treatment duration of palatally impacted canines to be 18–30 months (Parkin, Benson et al. 2008) with an average of 22 months after the closed surgical exposure versus 18 months after the open surgical exposure (Wisth, Norderval et al. 1976). Wisth argued that the increased duration of treatment for the closed technique was most likely due to the absence of direct vision during orthodontic
traction. In contrast, some authors claim that the overall duration of orthodontic treatment is increased with an open exposure (Becker and Chaushu 2003, Litsas and Acar 2011, Manne, Gandikota et al. 2012). The difference between these average treatment durations can be explained by the fact that it didn’t include the period of spontaneous eruption of the PIC that may occur with an open exposure. Indeed, the spontaneous eruption can take an average 6 to 8 months before commencing the orthodontic treatment (Pearson, Robinson et al. 1997, Zuccati, Ghobadlu et al. 2006, Fleming, Scott et al. 2009, Smailiene, Kavaliauskiene et al. 2013).

An increased treatment duration could be expected with some parameters such as the distance of the impacted canine from the occlusal plane (Stewart, Heo et al. 2001, Zuccati, Ghobadlu et al. 2006) and patient’s age (Becker and Chaushu 2003). In contrast, Smailiene found in her prospective study that the duration of treatment is neither related to patient’s age at the start of treatment, nor to the initial vertical and horizontal localisation of the impacted tooth (Smailiene, Kavaliauskiene et al. 2013).

2.5.4.2. Failure rate

The failure rates of surgically exposed PIC are 15% for the open exposure; 31% for the closed exposure (Pearson, Robinson et al. 1997). For the open exposure technique, failure is mainly due to the regrowth of the palatal tissue covering the crown of PIC (Pearson, Robinson et al. 1997). However, in the case of a closed exposure, the higher failure rate is due to debonding of the orthodontic attachment to the PIC. This then necessitates
an additional surgical procedure to re-attach the gold chain (Pearson, Robinson et al. 1997, Becker and Chaushu 2003, Becker, Chaushu et al. 2010).

2.5.4.3. Aesthetic components

Parkin et al in 2015 carried out a multicenter randomised controlled study investigating patients’ aesthetic judgments of PIC post orthodontic treatment following an open or closed exposure technique. 67 patients were randomly allocated to two groups: open versus closed surgical exposure of the PIC. The appearance of the PICs was assessed on intra-oral photographs three months after orthodontic treatment. The aesthetic judgments of orthodontists and laypeople were compared. They concluded that there is no difference in the aesthetic judgments of orthodontists and laypersons, whether the canine was exposed with a closed or an open surgical technique (Parkin, Freeman et al. 2015).

2.5.4.4. Surgical complications and repeated surgery

Surgical complications can occur with both exposure techniques. General complications and common risks associated with surgery include swelling, bleeding or allergy. Gharaibeh and Al-Nimri reported that arterial bleeding is more common during open exposure surgery (Gharaibeh and Al-Nimri 2008). Local risks include the risk of damaging the canine and adjacent teeth and the excess removal of bone tissue which may create a bony defect.
2.5.5. Operator preferences related factors

2.5.5.1. Surgical technique

According to the conclusion of the Cochrane review on open versus closed surgical exposure of PIC, there is a lack of evidence to support one technique over the other. The literature is conflicting and the decision-making should be left to the preference of the operator (Parkin, Benson et al. 2008). In a survey carried out in the United Kingdom to investigate the orthodontists’ preference of surgical technique for PIC, it was found that the proportions were equally divided between open and closed techniques (Clark 1994).

There is no consensus regarding which surgical procedure to undertake (Burden, Mullally et al. 1999). Those who support the closed exposure technique with immediate traction claim the benefits of this technique to be easier bonding during the surgical procedure (Becker and Chaushu 2003) allowing immediate traction using a gold chain through the palate (Becker and Chaushu 2013), ability to influence the direction of extrusion of the PIC, patient comfort during the healing process (Chaushu, Becker et al. 2005) (Gharaibeh and Al-Nimri 2008) and acceptable periodontal health after treatment (Quirynen, Op Heij et al. 2000, Crescini, Nieri et al. 2007, Zasciurinsiene, Bjerklin et al. 2008, Parkin, Milner et al. 2013).

Other authors support the open exposure technique with spontaneous eruption of the PIC or with early traction. The advantages of this technique are the visibility of movement during orthodontic traction; the bonding of the attachment by the orthodontist a few weeks after the surgery; time saving during the surgical procedure (Pearson, Robinson et al. 1997, Gharaibeh
and Al-Nimri 2008); time saving during the orthodontic treatment in spontaneous eruption (Mathews and Kokich 2013) and acceptable periodontal health after treatment (Schmidt and Kokich 2007, Parkin, Milner et al. 2013).

### 2.5.5.2. Factors that may influence orthodontist preference

According to Becker and Chaushu, one of the most important factors for an orthodontist to assess is the orientation of the long axis of the PIC relative to the midline and the exact position of the root apex (Becker and Chaushu 2015). Incorrect localisation of the PIC is considered as a major reason for treatment failure (Becker, Chaushu et al. 2010).

According to Mathews and Kokich, the vertical severity of the impaction of PIC is an important factor to consider in deciding which surgical exposure technique to adopt (Mathews and Kokich 2013).

#### Application of immediate traction

The ability to apply immediate traction to a gold chain is one of the most important advantages of the closed surgical technique according to Becker and Chaushu. It allows quicker and better control of eruption by immediate traction of the PIC away from the adjacent teeth when the risk of root resorption is high (Becker and Chaushu 2015).

#### Bonding attachment

Bonding an attachment during surgery on a tooth surrounded by haemorrhagic tissue is challenging. The open surgery is more likely to have
surgical complications such as bleeding (Gharaibeh and Al-Nimri 2008). Also, the bonding is a highly sensitive technique and rarely used by the surgeon. The bonding of the attachment by the surgeon during closed exposure can lead to failure and this will involve a repeated surgery (Becker and Chaushu 2015).

**Bonding site selection and direction of traction**

Bonding an attachment on an inappropriate surface of the PIC can create a rotational component during traction of the PIC. Consequently, this unwanted tooth movement may extend the treatment duration. Drawing a gold chain in a wrong direction will lead to the traction of the canine in a wrong direction or the need to repeat the surgery to reorient it (Becker and Chaushu 2015).

**2.5.5.3. Factors that may influence surgeon preference**

According to Becker and Chaushu, the location of the crown of the PIC in the 3 planes of space and its relation to the roots of the adjacent teeth are the most important factors for a surgeon (Becker and Chaushu 2015).

The surgeon plays an essential role by:

- Providing a way for autonomous natural eruption by exposing the tooth;
- Simplifying orthodontic treatment (Schmidt and Kokich 2007, Mathews and Kokich 2013);
- Providing optimal condition for the orthodontist to apply traction to the canine;
- Reducing the impaction by removing any obstruction or supernumerary tooth.

Operating time and extent of surgical procedure

Pearson compared the mean surgical duration for an open and closed surgical exposure. He reported an average operating time of 36 minutes for closed exposure compared to 12 minutes for open exposure. The time taken for a closed exposure is found to be 3 times greater than that for open exposure. This is due to bonding of a gold chain and the suturing of the palatal flap (Pearson, Robinson et al. 1997).

In a similar study, Gharibeh and Al-Nimri reported a statistically significant difference between the two surgical techniques (P = .006). The open exposure operating time was 30.9 +/- 10.1 min compared to 37.7 +/- 8.4 min for the closed exposure technique (Gharibeh and Al-Nimri 2008).

Repeated surgery

In cases of failure, the need for repeated surgery is inevitable (Fournier, Turcotte et al. 1982, Pearson, Robinson et al. 1997, Becker and Chaushu 2003). Repeated surgeries are more common with the closed exposure technique which has a failure rate of 31% versus 15% for the open exposure technique (Burden, Mullally et al. 1999). The repeated surgery involves the removal of the palatal tissue to re-uncover the PIC.
Cost

Cost is a factor to consider both for patients and for clinicians. The cost of the surgical procedure is higher for the closed exposure technique because of the use of a gold chain. The high risk of failure for both techniques involves repeated surgery and repeated cost (Pearson, Robinson et al. 1997). Also, an increase in treatment duration leads to a higher cost of orthodontic treatment.

The surgeon’s preference is an important factor in determining success rates for the exposure. However, the choice of the surgical procedure needs to be jointly decided by both orthodontist and surgeon. Before the surgical exposure of the PIC, the orthodontist localises the PIC and assesses the risk of resorption to the adjacent teeth. She/he visualises the direction of traction and plans the orthodontic appliance system.
The table below highlights the factors that may influence the choice of the surgical technique (Table 4).

| Patient-related factors | - Medical history  
|                         | - Age  
|                         | - Oral hygiene and compliance  
|                         | - Post-operative discomfort  
|                         | - Malocclusion  
| PIC-related factors     | - Site of impaction and anatomical structure of the soft tissue  
|                         | - Severity of impaction  
| Periodontal-related factors | - Periodontal Pocket Depth  
|                         | - Bone Support  
| Treatment-related factors | - Duration of treatment  
|                         | - Failure rate  
|                         | - Surgical complications and repeated surgery  
| Operator-related factors | - Surgical technique  
|                         | - Orthodontist's preference  
|                         | - Surgeon's preference  

**Table 4** – Factors influencing the choice of the surgical exposure technique of PIC

In summary, on one hand, some authors will support the open exposure (Kokich and Mathews 1993, Chapokas, Almas et al. 2012) whilst in contrast, others will claim the benefits of the closed exposure (Chaushu, Becker et al. 2005, Becker and Chaushu 2013). Nevertheless, due to the lack of evidence in the current literature, the choice of the surgical exposure technique will often be left to the personal decision of the surgeon and orthodontist (Parkin, Benson et al. 2008). The decision is based on the subjective importance that the operators attach to the advantages and disadvantages of open and closed techniques of exposure.
3. Aims and Null hypotheses

3.1. Aim and Null Hypothesis #1

To investigate if radiographic parameters are predictive in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines.

The null hypothesis is radiographic parameters have no influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines.

3.2. Aim and Null Hypothesis #2

To determine which radiographic parameters are predictors of whether to perform an open or closed exposure technique in patients with palatally impacted canines.

The null hypothesis is there is no difference between radiographic parameters in predicting whether to perform an open or closed exposure technique in patients with palatally impacted canines.
4. Material and method

4.1. Ethical approval

This retrospective study was carried out after ethical approval was obtained from the School of Dental Science Research Ethical Committee of Dublin in August 2015.

The data collection was permitted by the Regional Orthodontic Unit Manager of St. James’s Hospital.

4.2. Recruitment procedures

Data of patients treated in the Regional Orthodontic Unit in St. James’s Hospital were screened according to the following criteria:

4.2.1. Inclusion criteria

1. Patients graded as 5i using the Index of Orthodontic Treatment Needs (IOTN) from the Health Service Executive (HSE) guidelines in Ireland. 5i grade is defined as a tooth that is impeded from eruption due to crowding, displacement, presence of supernumerary teeth, retained deciduous teeth, and any pathological cause;

2. Palatally impacted canine;

3. Bilateral or unilateral PIC;

4. Surgical exposure of PIC performed between 2011 and 2016;

5. Pre-treatment orthopantomogram available.
4.2.2. Exclusion criteria

1. Maxillary impacted canine in the line of the arch and buccally exposed;
2. Presence of cleft lip/palate or other craniofacial syndromes;
3. Pathology or cyst associated with PIC;
4. Pre-treatment orthopantomogram not adequate for accurate diagnosis.

4.2.3. Sample size

Sample size calculation could not be used in this research project, as there was no previous study in the literature. However, according to the guidelines made by Peduzzi, a number of 10 events per variable are required for the use of the logistic regression analysis (Peduzzi, Concato et al. 1996) to ensure parameter estimates are unbiased. This study included 4 radiographic parameters with a total of 10 different grades. A total of 10 events for 10 grades provide a sample size of 100.

A minimum sample size of 100 PICs was proposed to demonstrate a significant change in the influence of the radiographic parameters on the decision to perform an open or closed surgical technique with power (1-Beta) of 0.95 and a significance level of 0.05.

4.2.4. Data collection

The gatekeeper retrieved the hospital number of patients treated from 2011 to 2016 in the Orthodontic Regional Unit of St. James’s Hospital and registered as 5i according to the IOTN guidelines modified from the HSE.
Patient data was accessed retrospectively from their corresponding chart and clinical notes on the Orthotrac Clinical software program (© Carestream Health, Inc., 2010 Orthotrac, Version 11.4.1.4).

The following patient data were collected:

1. Location of the impaction;
2. Surgical exposure technique employed;
3. Pre-treatment orthopantomogram.

Data were then screened and analysed by the main investigator according to the inclusion and exclusion criteria. 342 patients were found to be classified as 5i between 2011 and 2016 but only 90 met the inclusion criteria. An allocated number was given to each patient and information was collected on a Microsoft® Excel spreadsheet (Microsoft® Excel® 2010, ©2010 Microsoft Corporation).

4.3. Radiographic measurements

Four specific radiographic parameters were measured and recorded by the investigator on the orthopantomogram for each patient allocated by a number. The investigator was blinded from the surgical procedure during the radiographic measurements.

Tracing was made using a LED lightbox and an orthodontic tracing kit including a black pencil 0.3mm diameter, an orthodontic clear ruler and acetate tracing paper (G&H Wire Company .003 Matte Finish 8 inches x 10 inches). 5 tracings per day were made in a dark room in St. James’s
Hospital to avoid examiner fatigue. Radiographic parameters traced and measured were the canine position relative to the midline (Figure 3), the vertical position of the canine cusp tip (Figure 4), the antero-posterior position of the PIC root apex (Figure 5) and the overlap of PIC cusp tip relative to the adjacent incisor root (Figure 6).

4.3.1. Canine angulation relative to the midline

The first line constructed was the midline which is, as shown in the figure, the red line that passes between the most prominent convexity of the mesial surfaces of the maxillary central incisors. The second line (blue line) was drawn through the root apex and the cusp tip of the PIC. The angle between those two lines represents the canine angulation in relation to the midline.

![Figure 3 - An illustration of the PIC angulation to the midline and the grading used in this radiographic parameter. The angle was measured between the long axis of the PIC (blue line) and the midline (red line) (Al-Moghrabi, 2015).](image)

The grading used in this study for the angulation of the canine related to midline (Figure 3) was a modified grading from the studies by Power and Short and Stivaros and Mandall (Power and Short 1993, Stivaros and Mandall 2000).

<table>
<thead>
<tr>
<th>Grade 1</th>
<th>0° - 30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 2</td>
<td>31° - 45°</td>
</tr>
<tr>
<td>Grade 3</td>
<td>&gt; 45°</td>
</tr>
</tbody>
</table>
4.3.2. Vertical position of the canine tip

The first line constructed was the midline as described previously. The second line (line 1) is the occlusal line which is defined as the horizontal line passing through the incisal edges of the maxillary central incisors. The third line draw (line 2) is the horizontal line passing midway through the maxillary central roots. If there was a difference in root lengths, two horizontal lines were drawn, one for each root and line 2 was recorded in the middle of these two lines. Line 3 is the horizontal line passing through the apices of the maxillary central incisors roots.

![Diagram of vertical position of the canine tip](image)

**Figure 4** – An illustration of the vertical position of the PIC cusp tip and the grading system used in this radiographic parameter. The PIC cusp tip was graded according to its position relative to the horizontal lines (Al-Moghrabi, 2015).

The grading used in this study for the vertical position of the canine (Figure 4) was a grading modified from the studies by Power and Short and Stivaros and Mandall (Power and Short 1993, Stivaros and Mandall 2000).

4.3.3. Canine root apex position antero-posteriorly

The first line constructed was the occlusal line passing through the incisal edges of the maxillary central incisors as described previously. The second
line (blue line) is a vertical line drawn perpendicularly to the horizontal line and passing through the most prominent point on the mesial surface of the first premolar. The third line (orange line) is a vertical line drawn perpendicularly to the horizontal line and passing through the most prominent point on the distal surface of the first premolar.

**Figure 5** - An illustration of the antero-posterior position of the PIC root apex and the grading used in this radiographic parameter. The antero-posterior position of the PIC root apex was graded according to its position relative the blue and orange lines (Al-Moghrabi, 2015).

The grading system used in this study for the canine root apex position of the canine (Figure 5) was a modified grading from studies by Power and Short and Stivaros and Mandall (Power and Short 1993, Stivaros and Mandall 2000).

**4.3.4. Canine overlap of the adjacent incisor root**

The line constructed (green line) was the line passing through the long axis of the adjacent lateral incisor root which is drawn from the middle of the edge and the apex of the adjacent lateral incisor root.

<table>
<thead>
<tr>
<th>Grade 1</th>
<th>The root apex of the PIC is positioned mesial to the blue vertical line above the upper canine position.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 2</td>
<td>The root apex of the PIC is positioned between the blue and the orange line above the upper first premolar.</td>
</tr>
<tr>
<td>Grade 3</td>
<td>The root apex of the PIC is positioned distal to the orange vertical line above the upper second premolar region.</td>
</tr>
</tbody>
</table>
Figure 6 - An illustration of PIC cusp tip position in relation to the adjacent lateral incisor and the grading used in this radiographic parameter. The PIC cusp tip position in relation to the adjacent lateral incisor was graded relative to the long axis of the adjacent lateral incisor (green line) (Al-Moghrabi, 2015).

The grading used in this study for the canine root apex position (Figure 6) is the grading modified from Power and Short and Stivaros and Mandall studies (Power and Short 1993, Stivaros and Mandall 2000).

All data were recorded by the investigator on a Microsoft® Excel spreadsheet.

4.4. Error of the method

Intra-examiner reliability and inter-examiner reliability were carried out on 12 randomly selected orthopantomograms to evaluate the error of the method. It included the tracing and measurement of the four radiographic parameters into grades (as above): PIC angulation to the midline, the vertical position of PIC cusp tip, the anteroposterior position of the PIC root apex and the PIC cusp tip position in relation to the adjacent lateral incisor.
The intra-examiner error was assessed by re-measuring the radiographic parameters on the 12 randomly selected OPGs after a 2-week interval by the same operator.

Inter-examiner reliability was ensured by repeating the measurements with a consultant orthodontist in the same department.

4.5. Statistical analysis

4.5.1. Intra and inter-examiner reliability

Intra and inter-examiner reliability were carried out using the Percentage of Agreement, the weighted Cohen Kappa Statistical Test. In addition, Gwet test was carried out to limit the Cohen’s Kappa paradox and reinforce the inter and intra-examiner statistics (Gwet 2014).

The reliability can be interpreted as outlined below (Gwet 2014):

- Poor agreement = Less than 0.20
- Fair agreement = 0.21 to 0.40
- Moderate agreement = 0.41 to 0.60
- Good agreement = 0.61 to 0.80
- Very good agreement = 0.81 to 0.99
- Perfect agreement = 1

4.5.2. Descriptive analysis

Descriptive statistics analysed the sample related to gender, age, PIC location and distribution. The distribution of the open and closed surgical procedures according to the different grades was also recorded.
4.5.3. Logistic regression analysis

Multivariate logistic regression analysis was carried out to predict the outcomes of the categorical variables used in this study. The variables are the radiographic parameters and were recorded according to the grades (Grade 1; Grade 2; Grade 3):

- The angulation to the PIC related to the midline
- The vertical position of the PIC cusp tip
- The anteroposterior position of the PIC root apex
- The PIC cusp tip overlap related to the lateral incisor

A multivariate logistic regression analysis was carried out using R Commander Software version 2.11.1.

Statistical values were reported as:

- Odds ratio: level of significance for the independent values of each parameter
- Adjusted odds ratio: level of significance for the independent values taking into consideration the four radiographic parameters.

The value was described as significant if the p-value was less than 0.05.
5. Results

5.1. Flowchart

As highlighted in the flowchart below, 342 patients were referred as 5i in St. James’s hospital. Of those, 224 patients had maxillary impacted canines of which 132 were palatally impacted.

According to inclusion and exclusion criteria: 42 patients were excluded from the study. The reasons for exclusion were missing data on the patient chart, poor quality of the orthopantomogram or extraction of the PIC due to the orthodontic treatment planning.

The final sample comprised 60 patients who had an open exposure of the PIC and 30 patients who had a closed exposure of the PIC.

![Flowchart of patient selection for the open and the closed surgical exposure groups](image)

**Figure 7** - The flowchart of patient selection for the open and the closed surgical exposure groups
5.2. Intra and inter-examiner reliability

5.2.1. Intra-examiner reliability

According to the following table, the percentage of agreement between the main operator at T1 and at T2 were categorised as good (0.61 to 0.80) to very good agreement (0.81 to 0.99) for the following radiographic parameters (P<0.01):

- Angulation of the PIC related to midline;
- Anteroposterior position of the PIC apex;
- PIC cusp tip overlap to the lateral incisor.

There was a perfect agreement (1) on the grading of the vertical position of the PIC cusp tip.

<table>
<thead>
<tr>
<th>Radiographic parameters</th>
<th>Percentage agreement</th>
<th>KAPPA</th>
<th>GWET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K</td>
<td>95% CI</td>
</tr>
<tr>
<td>Angulation</td>
<td>0.91</td>
<td>0.86</td>
<td>0.57-1</td>
</tr>
<tr>
<td>Vertical</td>
<td>1</td>
<td>1</td>
<td>1-1</td>
</tr>
<tr>
<td>AP Position</td>
<td>0.75</td>
<td>0.53</td>
<td>0.02-1</td>
</tr>
<tr>
<td>Overlap</td>
<td>0.91</td>
<td>0.88</td>
<td>0.61-1</td>
</tr>
</tbody>
</table>

Table 5 - Intra-examiner reliability of the study

K = Kappa coefficient
AC = Gwet agreement coefficient
5.2.2. Inter-examiner reliability

According to the table below, the percentage of agreement between the main operator and the second operator was categorised as good (0.61 to 0.80) to very good agreement (0.81 to 0.99) for the following radiographic parameters (P<0.01):

- Vertical position of the PIC cusp tip;
- Anteroposterior position of the PIC apex.

There were perfect agreement (1) on the grading of:

- Angulation of the PIC related to midline;
- PIC cusp tip overlap to the lateral incisor.

<table>
<thead>
<tr>
<th>Radiographic parameters</th>
<th>Percentage agreement</th>
<th>KAPPA</th>
<th>GWET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K</td>
<td>95% CI</td>
</tr>
<tr>
<td>Angulation</td>
<td>1</td>
<td>1</td>
<td>1-1</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.92</td>
<td>0.625</td>
<td>0.10-1</td>
</tr>
<tr>
<td>AP Position</td>
<td>0.83</td>
<td>0.67</td>
<td>0.19-1</td>
</tr>
<tr>
<td>Overlap</td>
<td>1</td>
<td>1</td>
<td>1-1</td>
</tr>
</tbody>
</table>

*Table 6 - Inter-examiner reliability of the study*

*K = Kappa coefficient
AC = Gwet agreement coefficient*
5.3.  Descriptive statistics

5.3.1. PIC distribution

The distribution of the sample is described in the following table (Table 7). Mean ages in the open and the closed exposure groups were 15.07. There was a greater proportion of female patients in both groups.

<table>
<thead>
<tr>
<th>Exposure technique</th>
<th>Number of PICs</th>
<th>DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>By mean age</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPEN</td>
<td>60</td>
<td>15.07</td>
</tr>
<tr>
<td>CLOSED</td>
<td>30</td>
<td>15.07</td>
</tr>
</tbody>
</table>

*One of the bilateral PIC was excluded from the sample as PIC was extracted

Table 7 - Descriptive statistics of surgical exposure related to the distribution of the PIC, mean age, gender and location
5.3.2. The angulation to the PIC to the midline

The following table (Table 8) highlights the distribution across the different grades for the angulation to the midline radiographic parameter for both groups (open and closed exposure techniques).

In the open exposure technique group, the distribution between each of the 3 grades ranges from 28.3% to 38.3% with a majority of the PIC found to be in grade 3 (angulation higher than 45° related to the midline).

In the closed exposure technique group, the distribution between each of the 3 grades ranges from 26.7% to 43.3%, with a majority of the PIC found to be in grade 2 (angulation related to midline between 30 to 45°).

<table>
<thead>
<tr>
<th>Exposure technique</th>
<th>Grade 1 (0° - 30°)</th>
<th>Grade 2 (31° - 45°)</th>
<th>Grade 3 (&gt; 45°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEN (n=60)</td>
<td>17 (28.3%)</td>
<td>20 (33.3%)</td>
<td>23 (38.3%)</td>
</tr>
<tr>
<td>CLOSED (n=30)</td>
<td>8 (26.7%)</td>
<td>13 (43.3%)</td>
<td>9 (30.0%)</td>
</tr>
</tbody>
</table>

*Table 8 – Distribution of surgical exposure of the PIC related to the angulation of the canine to the midline*

5.3.3. The vertical position of the PIC cusp tip

The following table (Table 9) highlights the distribution of the PIC across the different grades for the vertical position of the PIC cusp tip radiographic parameter for both groups (open and closed exposure techniques).

In the open exposure technique group, the distribution between each of the 3 grades ranges from 0% to 95% with 95% of the PIC found to be in grade
1 (PIC cusp tip located occlusal to midway of the roots of the central incisors) (95%) and 5% in grade 2 (PIC cusp tip apical to midway of the roots of the central incisors).

In the closed exposure technique group, the distribution between each of the 3 grades ranges from 0% to 73.3% with 73.3% of the PIC found to be in grade 1 and 26.6 % in grade 2.

However, none of the exposed PIC were in grade 3. Therefore, grade 3 was combined with grade 2 for the logistic regression analysis.

<table>
<thead>
<tr>
<th>Exposure technique</th>
<th>Vertical position of the PIC cusp tip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
</tr>
<tr>
<td></td>
<td>Occlusal to mid central incisor root</td>
</tr>
<tr>
<td>OPEN (n=60)</td>
<td>57 (95%)</td>
</tr>
<tr>
<td>CLOSED (n=30)</td>
<td>22 (73.3%)</td>
</tr>
</tbody>
</table>

**Table 9** – Distribution of surgical exposure of PIC related to the vertical position of the PIC cusp tip

5.3.4. The antero-posterior position of the PIC root apex

The following table (Table 10) highlights the distribution of the PIC across the different grades for the antero-posterior position of the PIC root apex radiographic parameter for both groups (open and closed exposure techniques).

In the open exposure technique group, the distribution between each of the 3 grades ranges from 5% to 75% with a majority of the PIC found to be in
grade 2 (PIC had the root apex positioned between the mesial and the distal aspect of the first premolar root).

In the closed exposure technique group, the distribution between each of the 3 grades ranges from 10% to 66.7% in each of the 3 grades with a majority of the PIC found to be in grade 2. However, less than 10 % of the exposed PIC was in grade 1. Therefore, grade 1 and grade 2 were combined for the logistic regression analysis.

<table>
<thead>
<tr>
<th>Exposure technique</th>
<th>AP position of PIC root apex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1 Mesial to 1st premolar root</td>
</tr>
<tr>
<td>OPEN (n=60)</td>
<td>3 (5%)</td>
</tr>
<tr>
<td>CLOSED (n=30)</td>
<td>3 (10%)</td>
</tr>
</tbody>
</table>

Table 10 – Distribution of surgical exposure of the PIC relative to the AP position of the PIC root apex

5.3.5. The PIC cusp tip position relative to the adjacent lateral incisor

The following table (Table 11) highlights the distribution of the PIC across the different grades for the PIC cusp tip position relative to the adjacent lateral incisor radiographic parameter for both groups (open and closed exposure techniques).
In the open exposure technique group, the distribution between each of the 3 grades ranges from 13.3% to 61.7% with a majority of the PIC found to be in grade 3 (PIC cusp tip overlaps the mesial aspect of lateral incisor root).

In the closed exposure technique group, the distribution between each of the 3 grades ranges from 20.7% to 55.2% with a majority of the PIC found to be in grade 3.

<table>
<thead>
<tr>
<th>Exposure technique</th>
<th>PIC cusp tip overlap related to lateral incisor</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
<td>Grade 2</td>
</tr>
<tr>
<td></td>
<td>Overlap &lt; ½ root</td>
<td>Overlap &gt; ½ root</td>
</tr>
<tr>
<td>OPEN (n=60)</td>
<td>15 (25%)</td>
<td>8 (13.3%)</td>
</tr>
<tr>
<td>CLOSED (n=30)</td>
<td>7 (24%)</td>
<td>6 (20.7%)</td>
</tr>
</tbody>
</table>

Table 11 – Distribution of surgical exposure of the PIC relative to the PIC cusp tip overlap related to lateral incisor

5.4. Logistic Regression Analysis

The crude odds ratio considers the effect of each independent predictor variable on the decision of having an open or a closed surgical exposure according to one radiographic parameter.

On the other hand, the adjusted odds ratio includes and confounds the 4 predictor variables and account for each parameter, the odds of having an
open or closed surgical exposure technique, considering the 3 other parameters.

<table>
<thead>
<tr>
<th>Radiographic parameters</th>
<th>GRADES</th>
<th>CRUDE ODDS RATIO</th>
<th>ADJUSTED ODDS RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OR 95% CI P-value</td>
<td>Adjusted OR 95% CI P-value</td>
</tr>
<tr>
<td><strong>Angulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>0.72</td>
<td>0.24-2.14 0.56</td>
<td>0.79 0.21-2.93 0.72</td>
</tr>
<tr>
<td>Grade 3</td>
<td>1.20</td>
<td>0.38-3.80 0.75</td>
<td>1.4 0.27-7.44 0.69</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>0.145</td>
<td>0.02-0.55 0.0074*</td>
<td>0.124 0.024-0.498 0.00547*</td>
</tr>
<tr>
<td><strong>AP position</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>0.82</td>
<td>0.29-2.46 0.72</td>
<td>0.62 0.17-2.38 0.48</td>
</tr>
<tr>
<td><strong>MD position</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>0.62</td>
<td>0.15-2.53 0.5</td>
<td>0.39 0.08-1.89 0.24</td>
</tr>
<tr>
<td>Grade 3</td>
<td>1.08</td>
<td>0.35-3.10 0.89</td>
<td>0.76 0.18-3.1 0.7</td>
</tr>
</tbody>
</table>

*Table 12 – Logistic Regression Analysis*

Radiographic parameters have an influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines.
According to the multivariate logistic regression, only the vertical position of the PIC cusp tip radiographic parameter was statistically significant (P<0.01). P-value was 0.00547 with a confidence interval 0.024-0.498.

The angulation of the PIC to the midline, the anteroposterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor root were found to be not significant (P>0.05).

The null hypotheses were that radiographic parameters have no influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines and there is no difference between radiographic parameters in predicting whether to perform an open or closed exposure technique in patients with palatally impacted canines. Both null hypotheses were rejected.
6. Discussion

The aims of this study were to investigate whether radiographic parameters are predictive factors and which factor can be predictive in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines. Four radiographic parameters were measured: the angulation of the PIC to the midline, the vertical position of the PIC, the anteroposterior position of the PIC root apex and the PIC cusp tip position in relation to the adjacent lateral incisor. Both null hypotheses were rejected. Radiographic parameters can have an influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines and there is a difference between radiographic parameters in predicting whether to perform an open or closed exposure technique in patients with palatally impacted canines.

The vertical position of the PIC was the only parameter statistically significant in the matter of deciding whether to proceed with an open or a closed surgical exposure of the PIC.

6.1. Comments on the results

6.1.1. PIC angulation to the midline

The angulation of the PIC to the midline was not found to be a statistically significant radiographic parameter affecting the decision to perform an open or a closed exposure of the impacted canine.
In the literature, no study looked at this radiographic parameter in deciding whether to perform an open or a closed surgical technique. However, previous retrospective studies found that the angulation of the PIC relative to the midline was an important factor in determining whether to align or to extract PICs and was also a predictor of treatment success (Stivaros and Mandall 2000, Motamedi, Tabatabaie et al. 2009). These findings were in contradiction with the results of the thesis project carried out by Al-Moghrabi, who found that the angulation to the midline was not a statistically significant factor in the decision to align or extract the PIC (Al-Moghrabi 2015).

The reason why this parameter was not significant in the choice of surgical exposure technique may be, that, regardless of the surgical technique chosen, the main objective of the procedure is to partially uncover the crown to allow application of orthodontic traction to PIC. Therefore, regardless of the angulation, the location of the crown of the PIC is the parameter the surgeon is most concerned about when considering which exposure technique to adopt.

OPGs underestimate the incidence of root resorption to lateral incisors (Walker, Enciso et al. 2005) and overestimate the angulation of the PIC to the midline (Ferguson 1990). As the risk of root resorption is higher when the angulation of the PIC is increased (Ericson and Kurol 1988), some authors may support the open exposure technique as it provides better visibility and control of the vector of force application during orthodontic traction of the PIC (Wisth, Norderval et al. 1976, Crescini, Nieri et al. 2007, Mathews and Kokich 2013).
6.1.2. Vertical position of the PIC cusp tip

The vertical position of the PIC cusp tip was the only radiographic parameter which was statistically correlated with the surgical technique performed: open or a closed surgical exposure of the PIC (P<0.01). A closed exposure technique was statistically performed more frequently when the PIC cusp tip was located apical to the middle of the root of the upper central incisors. This radiographic parameter may be used to indicate which surgical technique to proceed with to expose PIC.

There was no previous study that looked at the impact of vertical positioning of the PIC cusp tip in deciding whether to proceed with an open or closed exposure of PICs. However, this finding was in accordance with Mathews and Kokich’s recommendation to classify the PICs into two categories relative to the severity of impaction (Mathews and Kokich 2013). The simple PICs, not deeply embedded within the alveolus, were recommended to be exposed with an open technique, whereas, the complex PICs, deeply impacted positioned near the apices of the incisors roots were recommended to be exposed with a closed technique (Mathews and Kokich 2013).

Moreover, according to the literature, the closed exposure technique should be considered when the PIC is deep and horizontally impacted (Mathews and Kokich 2013). This may be due to the difference between the two surgical procedures and the risks associated with either technique as an open exposure would involve more gingival tissue and bone removal. A closed exposure would provide more patient comfort (Chaushu, Becker et al. 2005) and more ability for cleaning (Wisth, Norderval et al. 1976). It
would also reduce the risk of failure due to the regrowth of gingival tissue if the PIC is deeply impacted.

Furthermore, the higher the vertical position of the PIC cusp tip, the more challenging the PIC will be to align (Pitt, Hamdan et al. 2006) and the longer the treatment duration is (Zucatti, Ghobadlu et al. 2006, Crescini, Nieri et al. 2007, Schubert and Baumert 2009). This finding was also supported by Al-Moghrabi who found that the vertical position of the PIC cusp tip was a statistically significant predictor in the treatment decision of whether to extract or align the PIC (Al-Moghrabi 2015).

### 6.1.3. Antero-posterior position of the PIC root apex

The antero-posterior position of the PIC root apex was not found to be a statistically significant radiographic parameter in determining whether to perform an open or a closed exposure of the PIC. There is no previous study in the literature that investigated the impact of this factor in the decision to proceed with an open or closed exposure technique for PICs. However, this parameter was not found to be significant in influencing the treatment duration (Fleming, Scott et al. 2009), or the success of orthodontic alignment of impacted canines (Stivaros and Mandall 2000, Motamedi, Tabatabaie et al. 2009). These findings were in contradiction with Al-Moghrabi who found that the antero-posterior position of the PIC root apex factor was a statistically significant factor in deciding whether to align or extract the PIC (Al-Moghrabi 2015).

In this study, the reason for this finding may be similar to that discussed above with regard to the angulation of midline; in that regardless of the
surgical technique chosen, the main objective of the exposure procedure is to partially uncover the crown. Therefore, wherever the PIC root apex is relative to the premolar, the location of the crown of the PIC is the parameter the surgeon is most likely concerned about with regards to the surgical procedure.

6.1.4. PIC cusp tip position relative to the adjacent lateral incisor root

The PIC cusp tip position relative to the adjacent lateral incisor root was not found to be a statistically significant radiographic parameter affecting the decision of whether to perform an open or a closed exposure of the PIC. There is no previous study that looked at the significance of this factor in deciding whether to proceed with an open or closed exposure. According to the literature, the risk of root resorption of the adjacent lateral incisor is higher and more severe in cases where the canine overlapped the adjacent lateral incisor beyond the long axis of the tooth (Ericson and Kurol 1988, Jung, Liang et al. 2012, Kim, Hyun et al. 2012). However, according to the most recent Cochrane review, with respects to surgical exposure of PIC, the consequences to the lateral incisor were similar when the two surgical techniques were compared (Parkin, Benson et al. 2008). Two studies investigated root lengths of PIC and lateral incisor following an open (Schmidt and Kokich 2007) and a closed exposure technique (Woloshyn, Artun et al. 1994). Both studies found no difference between the two surgical techniques with respect to the root lengths of the PIC and
the lateral incisor which were found to be slightly shorter than the contralateral canine and lateral incisor with both techniques.

6.2. Comments on the study

Surgical exposure techniques have advantages and disadvantages and both techniques are supported by authors who prefer one technique over the other. However, no study has investigated the influence of radiographic parameters on the decision of whether to perform an open or a closed exposure for PIC.

In the current literature, studies only compared the differences in outcomes between the two surgical exposure techniques based on clinical factors. The value of this study is that; to our knowledge, it is the first research to assess the influence of radiographic parameters on the choice of exposure technique for PICs based on an orthopantomogram. The advantage of an orthopantomogram is that it is commonly taken for treatment planning in patients with PIC, and its sole use would not expose the patient to further unnecessary radiation (Isaacson 2015).

This study may help guide the orthodontist in their choice of surgical exposure technique for PICs. Indeed, by examining the location of the PIC, the orthodontist could analyse the four different radiographic parameters and change the prescription letter for the surgeon from an open exposure to a closed exposure technique if the PIC is deeply impacted vertically. In contrast, the orthodontist could also change the prescription letter from a closed exposure to an open exposure if the root of the PIC is located near to the premolars roots. These parameters would not change the operator
preferences but it may help with operator consistency and influence the choice of surgical technique when the orthodontist requests the exposure of a severely impacted PIC by an oral surgeon.

This study sample comprised patients with palatally impacted canines which were surgically exposed with either the open or closed technique. The position of the impacted teeth was first of all evaluated using the vertical parallax technique which was found to be accurate in 68% of impaction cases (Armstrong, Johnston et al. 2003). Then, the location was confirmed or rejected by the use of the surgical report provided by the surgeon after the PIC exposure was made which confirmed the location and the type of surgical technique performed. This technique of diagnosis was an advantage in this study, as it was the most sensitive technique and presented 100% accuracy in diagnosis and data collection of PICs. Canines that were in the line of the arch and buccally impacted canines were excluded of this study due to the difference with respect to aetiologies and surgical techniques of exposure compared to PICs (Clark 1971, Lewis 1971, Jacoby 1983, Brin, Becker et al. 1986, Peck, Peck et al. 1994, Bishara 1998, Al-Nimri and Gharaibeh 2005).

The method of measurement using the grading system was another advantage of this research. The radiographic factors used in this study have been previously described in a thesis project which assessed the influence of radiographic parameters in the decision making of whether to extract or align PICs (Al-Moghrabi 2015). These factors were modified from
Power and Short (1993) and Stivaros and Mandall (2000). The main reason for these changes was that patients’ data in this study was collected from the Regional HSE Orthodontic Unit in St. James's Hospital, which included only the most severely impacted palatal canines as most of the simple PICs were treated at younger age with interceptive treatment. As a result, very few patients were classified in grade 1 according to Power and Short (1993) and Stivaros and Mandall (2000) grades. In addition, as the angulation of PIC to the midline recorded on an OPG is overestimated (Ferguson 1990), it would not have reflected the effect on radiographic parameters for PICs less than 15°. Therefore, Grades 1 and 2 were combined and a third grade was introduced (Figure 3) to take into consideration more severe canine angulations. Regarding the vertical grading system, firstly, it was decided to change the vertical grading system from metric to linear grades as measurement in millimetres recorded on an orthopantomogram is less reliable due to distortion and magnification (Tronje, Eliasson et al. 1981, Coupland 1984). Secondly, the vertical position of the PIC cusp tip was measured relative to horizontal lines which bypass the central incisors roots (Figure 4), instead of the lateral incisors as used by Stivaros and Mandall (2000) to reduce the risk of bias as the prevalence of lateral incisor anomalies is higher in patients with PIC (Brin, Becker et al. 1986). Thirdly, this study included three grades rather than the four described by Stivaros and Mandall (2000). However, due to the absence of PICs in the grade 3, grade 2 and 3 were combined and only two grades were used for the vertical grading system.
In the same manner, for the anteroposterior grading system, grades 1 and 2 were merged and only two grades were used for the statistical analysis. For the overlap of the PIC relative to the lateral incisor grading system was assessed by the mean of three grades.

This study used a multivariate regression analysis to investigate the effect of radiographic parameters in deciding whether to perform an open or a closed exposure technique for PICs. The main advantage of the multivariate regression analysis is that it takes into consideration all the four radiographic parameters together as an entity. The position of the PIC is considered relative to the four parameters which may give a more accurate result. This statistical analysis was also used in the thesis project carried on by Al-Moghrabi (2015) and was in contrast with the previous study by Stivaros and Mandal who used a stepwise logistic regression analysis (Stivaros and Mandal 2000) which is a controversial test as the test is described as biased (Wilkinson and Dallal, 1981).

Moreover, inter and intra-examiner reliability were carried out to evaluate the error of the study. As shown in tables 5 and 6, both the intra-examiner (Table 5) and inter-examiner (Table 6) reliability for all radiographic parameters measurements were strong and statistically significant (P<0.01). Three different agreement analyses were performed. Percentage of agreement and the weighted Cohen Kappa test were used to assess the reliability of the measurements. In addition, Gwets analysis was performed to counteract the limitations of Cohen Kappa analysis (Gwets 2002).
6.3. Limitations

This study was a retrospective study which is associated with the inherent limitations and risks of bias.

First of all, these limitations include the risk of operator bias with regards to the exposure technique chosen, as the decision is mostly based on operator preference (Parkin, Benson et al. 2008). Indeed, in our sample, the PICs exposures were performed by one oral surgeon who received for each PIC, a referral letter from the treating orthodontist. On the referral letter, some orthodontists requested a particular type of surgical exposure according to their own preference. In some of the cases, the surgeon may have performed the exposure according to the prescription letter, whereas in other cases, the surgeon may have decided on the exposure technique according to their own criteria. These factors are a limitation of the study as it would not always reflect the true effect of the radiographic parameters on the decision to perform an open or a closed exposure technique.

Secondly, the sample size was another limitation on this study and a simulation of a sample size can be used as long as previous informative data exists. There was no previous study that investigate the influence of radiographic parameters on the decision to perform an open or closed surgical exposure of PIC. Therefore, the sample size was estimated using Peduzzi guidelines (Peduzzi, Concato et al. 1996). On a simulation study of the number of events per variable needed using logistic regression analysis, Peduzzi recommended at least 10 events per variable (Peduzzi, Concato et al. 1996). These guidelines are required to ensure parameter
estimates are unbiased. This study included 4 radiographic parameters with a total of 10 different grades. A total of 100 PICs would have been recommended based on Peduzzi’s guidelines. The sample size of this study was another limitation as it included 90 PICs. However, this study included the data from all patients referred to the Orthodontic Department Unit in St James’s Hospital. It would have needed more patients with PICs and additional time to complete the sample size based on the simulation. It is also important to consider that most of the severely displaced PICs were extracted and this was also a limitation as it reduced the number of PICs in our sample. This also helps to explain the difference in numbers between the open (60 PICs) and closed (30 PICs) exposure groups as closed exposures are more likely considered for severely impacted palatal canines.

The use of orthopantomograms may have been another limitation in this study as the measurements were carried out on two-dimensional radiographs which are susceptible to distortion (Tronje, Eliasson et al. 1981, Coupland 1984). Even if intra and inter reliability test were performed, this technique of measurement may have introduced another bias on the findings. However, tri-dimensional images such as CBCTs cannot be justified as a routine assessment for patients with PIC (Isaacson 2015, Husain 2016). To reduce this bias, the measurement were considered as non acceptable (NA) on the statistical analysis when the radiographic structures were found to be unclear. For one of the PICs, the root apex of was considered at risk of tracing error. Therefore, the anteroposterior
position of the root apex relative to the premolar was not recorded for one of the values in the sample.

Finally, this study was carried out in the Health Service Executive of Dublin, in Ireland, where most severe cases are referred for orthodontic treatment from several local service in a large population. Even though the sample of the study included patient from 2011, as the study was carried out in only one unit, the generalisability is questionable.

6.4. Further research

This research opens the door for more complex research to be completed. Indeed, future research could be multicentre and include more operators and patients to answer the question of generalisability. The sample size would increase if patient’s data could be collected from different Orthodontic Department Units. This might especially increase the number of PICs in the closed exposure group.

The risk of bias due to operator preference could be reduced by collecting patient’s data of PICs’ exposures performed by different operators such as oral surgeons and periodontists. Operator consistency, in relation to their choice of exposure technique, could also be assessed by investigating the percentage agreement between the orthodontist request in the referral letter and the surgical technique performed by the surgeon.

The influence of different clinical parameters, such as the age of the patient, the risk of root resorption and the amount of crowding could also be investigated on the decision of whether to perform an open or closed surgical technique in patients with PICs. It would also be interesting to
update the incidence of PIC's exposure failures relative to the exposure technique performed and the need for a second exposure surgery.

Finally, the influence of cost of treatment on the choice of surgical exposure also could be investigated by collecting data in different private practices. The results could be compared to the ones found in The Regional HSE Orthodontic Unit in St. James's Hospital, where patients treated in funded by the state.
7. Conclusion

7.1. Conclusion #1

Radiographic parameters have an influence in deciding whether to perform an open or a closed surgical exposure technique in patients with palatally impacted canines.

7.2. Conclusion #2

The vertical position of the PIC cusp tip is the only significant radiographic parameter determining whether to perform an open or a closed surgical exposure in patients with PIC.

The angulation of the PIC to the midline, the anteroposterior position of the PIC root apex and the PIC cusp tip position relative to the adjacent lateral incisor root were found to be not significant.
Al-Moghrabi (2015). The influence of radiographic parameters on decision making in adolescents with palatally impacted canines. Dublin Dental University Hospital, Trinity College Dublin. Clinical Doctorate in Dental Surgery (Orthodontics).


Dear Aida Ben Cheikh,

RE: Can Radiographic Parameters Predict The Need For Open Versus Closed Surgical Exposure Of Palatally Impacted Canines

I am pleased to inform you that based on the opinions of two independent reviewers, I am granting ethical approval for this study to commence. If you require any further assistance, please do not hesitate to contact me.

Gary Moran
Chair, Dental School REC
6 March 2015

/KT

Dr. Aida Ben Cheikh
Postgraduate Orthodontic Student
Dublin Dental University Hospital
Lincoln Place
Dublin 2

Re: Research Permission
Title: The influence of radiographic parameters on the choice of surgical exposure technique for palatally impacted canines.

Dear Aida,

Further to your request for permission to access patient charts and radiographs for the above research project, I wish to advise that you the necessary permission to access same in our department.

As we have discussed, any information pertaining to patient names should be anonymised in line with Data Protection requirements.

May I take this opportunity to wish you the very best of luck in your studies during your time with us.

Yours sincerely,

Keith Treacy
Unit Manager