Dentofacial parameters associated with the unilateral palatally impacted canine

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ABSTRACT

Aims

To investigate the relationship between the unilateral palatally impacted canine (PIC) and specific dentofacial parameters.

Materials and methods

Two hundred and sixteen subjects were recruited (108 retrospective; 108 prospective). The retrospective and prospective samples consisted of 54 consecutive pre-treatment study models of subjects with unilateral PIC matched with controls for age, gender and malocclusion. These were collected from the Orthodontic Unit in Cork University Dental School and Hospital (CUDSH). The position of the PIC was identified from the relevant clinical notes or from the clinical examination and was confirmed radiographically using the parallax technique.

Dental parameters: Digital study models were produced for all subjects to assess the following dental parameters: Inter-canine and inter-molar width; palatal depth and palatal area; anterior Bolton tooth-size discrepancy (TSD); maxillary arch shape and ratio and maxillary central and lateral incisor shape and ratio.

***Facial parameters*:** Three-dimensional (3D) images were taken for test and control subjects in the prospective sample only and were used to assess the following facial parameters: Face shape; face ratio and 3D distances and angles.

Results

Dental parameters: Inter-canine width was significantly smaller in the test group compared to the control group in the retrospective (p= 0.0002) and prospective (p= 0.0018) samples. No significant difference was recorded in inter-molar width, palatal depth and palatal area between the test and control groups for both the retrospective and prospective samples. Anterior Bolton TSD was significantly higher in the prospective test group compared to controls (p= 0.0070), whereas no significant difference was found between the test and control groups in the retrospective sample (p= 0.7577). Arch ratio was significantly smaller in the test group than in the control group for the retrospective sample (p= 0.0029), whereas no significant difference

was recorded between the test and control groups in the prospective sample (p= 0.1017). Arch shape distribution was significantly different between the test and control groups in the retrospective sample (p= 0.0090), whereas no significant difference was found in the prospective sample (p= 0.149). Tooth shape distribution was significantly different between test and control groups for the maxillary right central incisor in the retrospective sample (p= 0.030), with more square/round tooth shape in the test group (17%) compared to the control group (2%). No significant difference in tooth shape distribution between test and control groups was found in the prospective sample. Tooth ratio showed no significant difference between test and control groups for both the retrospective and prospective samples.

***Facial parameters*:** No significant difference was found in face shape (p= 0.138) and face ratio (p= 0.540) between test and control groups. Basal width was significantly smaller in the test compared to the control group (p= 0.0001). No significant differences were found in all other 3D distances and angles measured between the test and control groups.

Conclusions

Inter-canine width was significantly smaller in unilateral PIC subjects compared to controls, whereas inter-molar width was not. Palatal depth and palatal area did not differ significantly between subjects with and without unilateral PIC. Anterior Bolton TSD was significantly higher in prospective unilateral PIC subjects compared to controls. Maxillary arch ratio was significantly smaller in retrospective unilateral PIC subjects with tapered arch shape being the most common. Square/tapered tooth shape was significantly more common in the retrospective unilateral PIC group. No significant difference was found in face shape and face ratio between subjects with and without unilateral PIC. Basal width was significantly smaller in subjects with unilateral PIC compared to controls.

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DECLARATION

I hereby declare that the work described in this thesis, except where otherwise mentioned, is my own and has not been submitted previously as a requirement for a degree or diploma at this or any other institution.

L. Koshak

Chapter One

Introduction

Ectopic eruption of the maxillary canine is defined as the divergence from its normal eruption pathway, which may result in buccal or palatal impaction (Chaushu et al., 2009). Palatal impaction is more common than buccal impaction with a ratio of 85:15 percent (Thilander and Jakobsson, 1968). The reported prevalence of palatal impaction of the maxillary canine (PIC) is 0.8-3 percent (Peck et al., 1994). It is more common in females than in males with a ratio of 3.1:1 (Fleury et al., 1985).

Two main theories have been reported with regard to the aetiology of PIC; the guidance theory and the genetic theory. The guidance theory relates PIC to local factors, including a small or congenitally absent maxillary lateral incisor, where the guidance for eruption of the maxillary canine is missing (Becker et al., 1981). However, the genetic theory consider PIC to be linked to other dental anomalies of tooth size and number that have a common genetic background (Peck et al., 1994). Moreover, an association between PIC and several dental parameters has been established, such as: maxillary arch width, spacing, crowding, peg-shaped maxillary lateral incisor, congenitally missing teeth, Bolton tooth-size discrepancy (Al-Khateeb et al., 2013).

The literature review will focus firstly on the epidemiology of the PIC along with the influence of age, gender and race. Then, the two theories with regard to the aetiology of the PIC will be discussed. The dentofacial parameters of width and shape of the maxillary arch, Bolton ratio and shape of the upper incisors, face shape, face ratio and 3D face parameters will be considered in turn. Finally the different methods of capturing and scanning those parameters (including digital scanning and 3D imaging), which are employed in this project, will be presented.

Chapter Two

Literature Review

Search Method

- This literature review was conducted using Pubmed, MedLine, and Science Direct as search engines.
- The MeSH terms used were ‘palatally impacted canines’, ‘dentoskeletal features’, ‘arch width’, maxillary lateral incisor’, ‘Bolton’, ‘tooth shape’ and ‘face shape’.
- Non-English literature was excluded if an English translation was not available.
- References in key papers were searched for relevant publications.
- All available literature from 1950 up to 2015 was included.

2.1 EPIDEMIOLOGY

2.1.1 Prevalence of PIC

The maxillary canine is the most likely tooth to be impacted after the third molar, with a reported prevalence of 0.8-3 percent (Bass, 1967; Brin et al., 1986; Ericson and Kurol, 1987; Peck et al., 1994; Zilberman et al., 1990) and an incidence of 1-2.2 percent (Dachi and Howell, 1961; Thilander and Myrberg, 1973).

Impaction of the maxillary canine may be either buccal or palatal. Palatal impaction is more common than buccal impaction and accounts for 70-85 percent of impactions; buccal impactions accounts for about 15 percent (Thilander and Jakobsson, 1968; Jacoby, 1983; Peck et al., 1994). The reported palatal to buccal impaction ratio varies from 2:1 to 9:1 (Jacoby, 1983; Ericson and Kurol, 1987; Stellzig et al., 1994). Unilateral palatal impaction is twice as common as bilateral impaction (Brin et al., 1986; Mossey et al., 1994; Sacerdoti and Baccetti, 2004) .

2.1.2 Association with age, gender and race

2.1.2.1 Age

The maxillary canine erupts around 10.5 to 12 years in girls and 11.5 to 13 years in boys with great individual variation (Hurme, 1948; Hägg and Taranger, 1985; Becker and Chaushu, 2000; Shapira and Kuftinec, 2001). It is important to assess the relationship between maxillary canine impaction and dental age, since it will allow further understanding of the aetiology.

Dental age has been assessed using dental eruption (Zilberman et al., 1990), dental calcification (Demirjian et al., 1973) or radiographic methods (Rozylo-Kalinowska et al., 2011).

Although dental eruption is one of the methods for assessing dental age, there is a weak correlation between chronological age and dental eruption. In addition, there is a wide individual variation in timing of tooth eruption, such that it cannot be considered as a valid measure for dental age (Björk and Helm, 1967; Hägg and Taranger, 1982; Baccetti et al., 2008). Hence, it is not acceptable to define delayed canine eruption or impaction simply on the basis of an individual's chronological age or stage of dental eruption (Baccetti et al., 2008). It has been noted, however, that the potential impaction of permanent teeth is seen more in moderate to severe retardation of dental maturation (Newcomb, 1959), and that cases with PIC were more likely to have delayed dental development than those with buccal impaction (Becker and Chaushu, 2000).

Dental calcification assesses the dental system as a whole, similar to the assessment of the skeletal system (Garn et al., 1958; Moorrees et al., 1963; Demirjian et al., 1973; Hägg and Taranger, 1982) and is, therefore, more valid than dental eruption for assessment of dental age.

Although various radiographic methods are available to assess the dental age for children and adolescents, Demirjian's method is the most widely used (Rozylo-Kalinowska et al., 2011). It is based on assessing the calcification stages of the left seven mandibular teeth, since they are visible on the panoramic radiograph, by assessing the shape and proportion of root length (rather than absolute tooth length); this reduces the effect of radiographic projection on estimation of dental age (Kataja et al., 1988; Rozylo-Kalinowska et al., 2011). It is the easiest, most reliable and accurate method to evaluate dental age (Maber et al., 2006).

Other radiographic methods are available to assess dentoskeletal development, such as hand-wrist radiographs and the Cervical Vertebral Maturation method (CVM) (Hägg and Taranger, 1982; Baccetti et al., 2005). By the end of the pubertal growth spurt all canines and premolars should be erupted as assessed by the hand-wrist method (Björk and Helm, 1967; Hägg and Taranger, 1982).

Assessment by the CVM method has shown that the permanent maxillary canine erupts mostly during the pre-pubertal stage of skeletal maturity but with large individual variability (Becker and Chaushu, 2000). The majority of the maxillary permanent canines had their physiological eruption at the CS4 stage (Baccetti et al., 2008). Moreover, it was reported that lack of eruption of the maxillary permanent canine at the post-pubertal stages (CS5 and CS6) indicates delayed eruption and canine impaction could be suspected (Baccetti et al., 2005). Suitable action should be taken to attain a definitive diagnosis (Baccetti et al., 2008).

2.1.2.2 Gender

PIC occurs more often in females than in males, (Dachi and Howell, 1961), with a ratio ranging from 1.3:1 to 3.2:1 (Racek and Sottner, 1977; Fleury et al., 1985). The female to male ratio of unilateral PIC is reported to be 1.65:1, with bilateral PIC at about 4:1 (Sacerdoti and Baccetti, 2004). In addition, anomalous lateral incisors occur more in females than in males with a ratio of approximately 2-3:1 (Becker, 1998). However, this does not prove a cause and effect relationship (Rutledge and Hartsfield Jr, 2010).

2.1.2.3 Race

Many studies have reported an ethnicity-dependant variation for PIC (Peck et al., 1994; Polder et al., 2004). PIC is approximately five times more likely to occur in Caucasians of European origin than in Asians (Peck et al., 1994; Bishara, 1992).

2.2 AETIOLOGY OF PIC

The precise aetiology of PIC is both obscure and multifactorial (McSherry, 1998; Richardson and Russell, 2000). There are primary etiological factors that may play a role in the occurrence of PIC, such as arch length discrepancy (crowding or spacing), disturbance in the eruption sequence and over-retention of the primary maxillary canine. Other possible factors are trauma to the anterior maxillary region at an early stage of development (Brin et al., 1993), rotation of the tooth bud, premature root closure and localised pathology such as cysts, odontomas, ankylosis and supernumerary teeth (Bishara, 1992; McSherry, 1998). Crowding may be an aetiological factor for buccally impacted canines but not for those that are palatally impacted (Thilander and Jakobsson, 1968). Adequately spaced arches have been found to be present in 85% of cases where the canine has migrated or been displaced (Jacoby, 1983).

Delayed exfoliation of the primary canine may cause a continuous palatal movement of the permanent canine. However, it is considered that an over-retained primary canine is a consequence rather than a cause of PIC (Thilander and Jakobsson, 1968). A higher incidence of PIC has also been reported following alveolar bone graft in patients with cleft lip and palate (Semb and Schwartz, 1997).

The path of eruption of the permanent maxillary canine has been described as tortuous and the longest among all other permanent teeth, and this may play a role in its impaction (Coulter and Richardson, 1997; Moyers, 1976). The permanent maxillary canine develops high in the maxilla and travels a long distance before eruption into the dental arch (Ericson and Kurol, 1986). This might increase the likelihood of mechanical disturbance that alters eruption, leading to impaction (Richardson and Russell, 2000).

There are two main theories that have been proposed as to the aetiology of PIC; the guidance theory and the genetic theory.

2.2.1 The guidance theory

The guidance theory regards the maxillary canine to be guided to eruption by the distal aspect of the lateral incisor root. Displacement occurs when the lateral incisor is anomalous or missing; thus guidance is absent, resulting in palatal displacement (Becker et al., 1984). Displacement may also occur if the lateral incisor is away from its normal position in a spaced arch or in a late developing dentition (Becker and Chaushu, 2000; Shapira et al., 2000). This theory is in agreement with studies that reported a PIC with peg-shaped or missing lateral incisors (Brin et al., 1986; Miller, 1963; Mossey et al., 1994; Zilberman et al., 1990)

Although these anomalies could be due to a genetic disturbance, a PIC does not have the same genetic association but occurs as a consequence of these local disturbances (Becker, 1995). The rate of congenital absence of a lateral incisor in a group of patients with PIC has been reported to be 5.5%. This was 2.4 times more than the general population, in addition to the higher incidence of small and peg shaped lateral incisors (Becker et al., 1981; Bass, 1967; Miller, 1963).

2.2.2 The genetic theory

In this theory, the disturbance in eruption of the maxillary canine is a consequence of disturbance in the dental lamina with PIC occurring as a result of polygenic, multifactorial inheritance (Peck et al., 1994).

This theory has been linked to multiple evidential observations such as familial and bilateral occurrence, gender differences and increased occurrence with other dental anomalies including: ectopic eruption of permanent first molars, infra-occluded primary molars, absence of premolars and third molars and hypodontia (Peck et al., 2002; Peck et al., 1996b).

The relatives of patients with PIC are more likely to manifest PIC, anomalous lateral incisors, delayed dental development (Zilberman et al., 1990) and ectopic first permanent molars (Bjerklin et al., 1992). In a study of 106 subjects with PIC, their first and second degree relatives had various dental anomalies. Hypodontia was observed in 19-20 percent of both the first and second degree relatives (2.5 times more than the general population), and PIC was concluded to belong to the dental anomalies spectrum related to hypodontia (Pirinen et al., 1996).

In a sample of 85 PICs, the specificity of the tooth-agenesis site was examined; PICs were found to be associated with third molar agenesis, a type of dental anomaly termed posterior-orofacial field; "a condition of increased developmental defects in the distal element of the dental series.'' Transcription factors MSX1 and PAX9 might be involved in this condition (Peck et al., 2002).

In an extensive investigation of 5000 orthodontic patients, a PIC was significantly correlated with the congenital absence of the maxillary lateral incisor (Sacerdoti and Baccetti, 2004).

Infra-occluded primary molars in 99 orthodontic patients were examined, and a significant association was also found between infra-occlusion and other dental anomalies including PIC (Shalish et al., 2010).

2.3 DENTAL PARAMETERS AND ASSOCIATION WITH PIC

Maxillary arch dimensions may play a role in the aetiology of PIC. As they are assessed as part of this study, previous research in this area will now be considered.

2.3.1 PIC and arch dimensions: Inter-canine (IC) and inter-molar (IM) width

Nine studies have assessed maxillary transverse dimensions in relation to PIC (Table 3.1). Five studies reported maxillary transverse deficiency (McConnell et al., 1995; Saiar et al., 2006; Schindel and Duffy, 2007; Kim et al., 2012; Al-Khateeb et al., 2013). Two studies reported an increase in the maxillary transverse dimension (Al-Nimri and Gharaibeh, 2005; Kuftinec and Shapira, 1994). Two studies reported no difference in anterior and posterior maxillary transverse width between PIC subjects and controls (Langberg and Peck, 2000a; Anic-Milosevic et al., 2009) and it was even suggested that the maxillary transverse dimension does not play a significant role in the aetiology of PIC (Saiar et al., 2006). All studies had a retrospective design, with a mean sample size ranging from 62 to 170 subjects and the mean age of subjects ranged from 9 to 17 years. Methods of assessment included plaster study models and boley gauge, digital models, postero-anterior cephalograms and cone-beam CT (CBCT). In one study, buccally impacted canines were not differentiated from those that were palatally impacted (McConnell et al., 1995), and another study did not match the test and control groups for the type of malocclusion (Langberg and Peck, 2000a).

There is a suggestion that transverse maxillary excess in subjects with PIC could explain the increased prevalence of PIC in subjects with Class division 2 malocclusion. This may also explains the increased prevalence in Europeans compared to Asians as the latter show a greater frequency of maxillary retrognathism.

Table 2.3.1: Summary of studies of PIC and transverse maxillary width

Author,Year Study Type Aim	Population (N) T:C M:F Age (yrs)	Canine type	Records Assessed Methods of Measurements	Conclusions
Langberg & Peck, (2000) • Retrospective • To investigate U arch deficiency associated with occurrence of PIC	Caucasian Orthodontic (62) T 31: C 31 M 10:F 21 11-17; mean age 13.6	UniL/BiL	• Pre-treatment dental casts • IPW and IMW	• NS difference in U IPW and IMW between PIC and controls
Al-Nimri & Gharaibeh, (2005) • Retrospective • To investigate occlusal features associated with aetiology PIC	Arabic Orthodontic (64) T 34 : C 34 (matched for age, sex and type of malocclusion) M 7: F 27 13-27; mean age 17.7	UniL	• Study models, sharp boley gauge • IPW and IMW of the maxillary arch	• U transverse dimensions significantly greater in PIC group than control group for IPW and IMW
Saiar et al., (2006) • Retrospective • To determine a difference in U skeletal width between PIC and control	Caucasian (158) T 79 : C 79 (matched for age, sex and malocclusion) M 21: F 58	UniL:BiL 46:33	• PA cephalogram • U and L skeletal widths and nasal cavity widths • Study models/ digital cal-	• Maxillary alveolar arch width at canine level smaller in PIC group

groups. • To determine association between PIC and nasal cavity width, U interdental arch width and U inter-alveolar arch width	9-15		lipers • U and L IMW • U inter-alveolar arch width at (canine, premolar and molar levels)	
Anic-Milosevic et al.,(2009) • Retrospective • To investigate occlusal features associated with aetiology of PIC	Caucasian (100) T 50 : C 50 (matched for age, Class I) T: M 14: F 36 C: M 25:F 25 14-16; mean age 15.6	UniL/BiL	• Study models, digital calipers • IPW and IMW of U arch	• NS difference between PIC and control group in transverse U widths
Kim et al., (2012) • Retrospective • To investigate relationship between position of and morphology of maxilla	Asian Orthodontic T: 45 (PIC), C: 45 (BIC) PIC: M 18:F 27 BIC: M 19:F 26 PIC:12.8 BIC: 12.2	28 BiL (palatal and buccal).	• Digital models: U arch shape, shape of palate, crowding • CBCT: Width of nasal cavity, width of nostrils	• U arch narrower and longer in PIC group • Palatal vault deeper in PIC group • NS difference in the nasal cavity width and nostrils between groups.
Al-Khateeb et al., (2013)	Arabic	UniL	• Digital study models, elec-	• Transverse widths

• Retrospective • To compare arch perimeter and tooth size, number and shape between affected and non-affected sides in PIC	(200) T 100 : C 100 M 40: F 60 14-25; mean age 17.93		tronic sliding calliper • Inter-canine, inter-premolar and inter-molar widths	smaller in PIC than control group
Yan et al., (2013) • Retrospective • To investigate factors associated with PIC and BIC	Chinese (340) T 170 : C 170 (age and sex matched) T: BIC 101:PIC 69 Not specified 12-30	UniL/BiL	• CBCT • Dental width: IPW, IMW • Skeletal width: U and L skeletal widths, nasal cavity width.	• IPW smaller in BIC group than PIC and control group • IMW no difference between all groups • U skeletal width significantly smaller for BIC group than other groups • L skeletal and nasal cavity width similar among all groups

Key: N= sample size; NS= not significant; T= test; C= control; yrs=years; M= males; F= females; y= years; mon= months; U= upper; L= lower; PIC= palatally impacted canine; BIC= buccally impacted canine; ICW= inter-canine width; IPW= Inter-premolar width; IMW= Inter-molar width; UniL= unilateral; BiL= bilateral; PA= posteroanterior

2.3.2 PIC and palatal depth, palatal area and maxillary complex

Several palatal and maxillary parameters have been linked to PIC, these include palatal depth, palatal area and the dimensions of the maxillary complex (Larsen et al., 2010; Al-Khateeb et al., 2013). The maxillary canine develops in the deepest part of the maxilla, follows the longest path of eruption of all the permanent teeth anterior to the permanent first molar (Dewel, 1949). In a three-dimensional study of the eruption pathway of the maxillary canine, it was found that it travelled 22 mm during its overall eruption (Coulter and Richardson, 1997). Thus, changes and differences in palatal and maxillary dimensions could play a significant role in PIC position (Larsen et al., 2010).

2.3.2.1 Palatal depth

Palatal depth is described as the measurement at a perpendicular distance from the palatal vault opposite to the first molars to a line connecting palatal points located on the first molar at the gingival level (Laine and Alvesalo, 1986). Palatal depth has been reported to be smaller in a group of subjects with unilateral PIC when compared to controls (Al-Khateeb et al., 2013). On the contrary, no significant difference in palatal depth between PIC and controls was found in a Caucasian population (Anic-Milosevic et al., 2009). A reduced palatal depth might be a consequence of PIC rather than a cause, and this effect would manifest as an alveolar ridge height underdevelopment (Al-Khateeb et al., 2013).

2.3.2.2 Palatal area

Palatal area has been described as the measurement of the x and y coordinates of twelve points representing the centre of the clinical crown of incisors, canines, buccal cusps of premolars and mesiobuccal cusps of the first molars. These were plotted to obtain the polynomial function that best described the curve corresponding to the dental arch form (Al-Khateeb et al., 2013). In subjects with unilateral PIC, the palatal area was significantly larger than on the non-displacement side. This could be attributed to the displacement of the midline toward the non-displacement side by the PIC. However, this difference should be attributed with caution, since measuring a flat projection of a curved area such as the palatal vault might be questionable, taking into consideration the differences in height and inclination of the alveolar bone between the displacement and the non-displacement side (Al-Khateeb et al., 2013).

2.3.2.3 Maxillary complex

A study of the maxillary complex dimensions and its association with maxillary canine ectopia reported that the size of the maxillary complex in patients with PIC is significantly enlarged transversely, but it is smaller sagittally and vertically (Larsen et al., 2010).

2.3.3 TOOTH-SIZE DISCREPANCY AND PIC

The relevance of tooth-size discrepancy (TSD) to PIC is assessed as part of this project in both a group with a unilateral PIC and in a control group. The prevalence and incidence of TSD in the general orthodontic population is, therefore, of relevance to the latter and will be reviewed.

2.3.3.1 Tooth-size discrepancy

Tooth-size discrepancy (TSD) is a disproportion in the size of individual teeth (Proffit et al., 2006). TSD was first formally investigated by Black by measuring a large number of human teeth and setting mean measurements (Black, 1902). TSD was then investigated in several studies (Ballard, 1944; Neff, 1949; Steadman, 1952; Lundström, 1955). However, Bolton's study is regarded as the best study of TSD in relation to malocclusion (Bolton, 1958). He developed two ratios for assessing TSD, an anterior ratio and an overall ratio, by summing the mesiodistal widths of mandibular to maxillary anterior teeth for the anterior ratio, and the total mesiodistal widths of all mandibular to maxillary teeth from first molar to first molar for the overall ratio (Bolton, 1958; Othman and Harradine, 2007). Bolton's original sample had excellent occlusion and all the cases had Bolton normal ratios, which did not prevent good occlusion. Thus, the use of Bolton's ratio in an orthodontic population may overestimate the presence of a clinically significant TSD. Hence, TSD can be used as an indicator for good occlusion, but the standard deviations of the ratio might be a poor guide for a clinically significant TSD (Othman and Harradine, 2007).

It was suggested by Proffit and Fields (2006), that by comparing the sizes of the upper and lower lateral incisors, a quick estimate of the anterior TSD can be done. Unless the maxillary lateral incisor is larger, a discrepancy will exist, whereas a quick check for posterior teeth can be done by comparing the sizes of the upper and lower second premolars, which should be about the same size (Proffit et al., 2006)

The prevalence of TSD in the general population has been reported to be 5% (Proffit et al., 2006). However, the basis of this ratio has not been fully investigated, and appears to be the proportion of subjects who will fall outside two standard deviations from Bolton's ratio.

Several studies have reported on TSD in orthodontic and non-orthodontic populations, (Table 3.2.1)

Table 2.3.2.1: Summary of the studies that reported on the prevalence of TSD

Author, year	Population	Sample size	Anterior TSD %	Total TSD %
Crosby and Alexander, (1989)	Orthodontic	109	22.9	-
Freeman., (1996)	Orthodontic	157	30.6	13.5
Santoro., (2000)	Orthodontic Dominican Americans	54	28.0	11.0
Araujo and Souki, (2003)	Orthodontic	300	22.7	
Bernabé et al., (2004)	School	200	20.5	5.4
Uysal and Sari, (2005)	Orthodontic Turkish	150	78.26	89.88
Othman and Harradine, (2007)	Orthodontic	150	17.4	5.4
Endo et al., (2008)	Orthodontic Japanese	Class I:60 Class II:60 Class III:60	77.63 77.92 77.54	91.14 91.43 91.46
O'Mahony et al., (2011)	Orthodontic Irish	240	37.9	

2.3.2.2 PIC and TSD

Reduction in the overall tooth size associated with PIC has been reported (Langberg and Peck, 2000b).

Seven studies have reported on the association between TSD and PIC. (Table 3.2.2.) Two studies reported a smaller mesio-distal crown diameter and a smaller lateral incisor on the PIC side (Becker et al., 1981; Langberg and Peck, 2000b). Four studies have reported no difference between PIC and controls (Al-Nimri and Gharaibeh, 2005; Anic-Milosevic et al., 2009; Al-Khateeb et al., 2013; Yan et al., 2013). One study found no difference between PIC and control in females, but in males tooth size were statistically smaller in the PIC group than in controls (Becker et al., 2002). The findings that confirm the association between PIC and reduced tooth sizes explain the likelihood of the presence of spaced dentition in PIC subjects (Jacoby, 1983; Becker, 1984; Zilberman et al., 1990; Peck et al., 1996a).

Table 2.3.2.2: Summary of the studies of TSD and PIC

Author, Year/ Study Type Aim	Population/ (N)/ T:C/ M:F/ Age (yrs)	Canine type	Records Assessed Methods Measurements	Conclusions
Becker et al., (1981) • Retrospective • To investigate small 2 adjacent to PIC.	Caucasian (88) T 26:C 62, M 61.5%:F 51.6% Dental age ≥ 13	UniL	• Study models • Maximum MD diameter of U and L 2 • 2 classified as: absent, peg-shaped, small; normal.	• 2 slightly smaller on affected side for M and F
Langberg & Peck, (2000b) • Retrospective • To investigate MD crown size of U and L of PIC subjects	Caucasian Orthodontic (62) T 31 : C 31 (matched for age and sex) M 10:F 21 11-17; mean age 13.6	NS	• Study models, orthodontic callipers • MD crown size of U left central and lateral incisor • MD crown diameter of L left centre and lateral inci-sor	• MD crown diameter for U and L incisors smaller in PIC group than in control
Becker et al., (2002) • Retrospective • To measure size of U	Caucasian Orthodontic (98) T 58 (consecutive): C 40 (not		• Study model and a dial calliper • MD and BL widths of all	• Uni PIC: no differ-ence between affect-ed and non-affected

teeth in PIC subjects to determine: • Differences in size between PIC and control group (canine erupted normally) • Differences in size between affected and non-affected sides in UniL PIC • Differences in size between UniL and BiL PIC. • Differences between M and F subjects.	matched) T: M 21:F 37, C: M 20: F20 11-15		permanent erupted teeth mesial to first molars.	side for M and F • PIC group: no difference between M and F • Control group: MD width larger in M • In M only, MD and BL widths narrower in PIC than in control • MD width of F BiL PIC smaller than UniL
Al-Nimri & Gharaibeh, (2005) • Retrospective • To investigate occlusal features associated with aetiology of PIC	Arabic Orthodontic (68) T 34 : C 34 (matched for age, sex and type of malocclusion) M 7: F27 13-27; mean age 17.7	UniL PIC	• Study model and sharp Boley gauge • MD width of U teeth	• NS difference in MD width of U teeth between PIC and control
Anic-Milosevic et al., (2009) • Retrospective	Caucasian T 50: C 50 (matched for age,	UniL/BiL	• Study model measurements and digital callipers	• UniL PIC group: no difference between

• To investigate dental and occlusal features that could contribute to aetiology of PIC	Class I) T: M 4: F36, C: M 25: F 25 14-16; mean age 15.6		• MD and BL dimensions of all teeth	affected and non-affected side for both genders. • Control M/F: MD width larger in M than F • Test M/F: no difference • M test/control: no difference • F test/control: BL dimension smaller for 2 in Bi PDC group
Al-Khateeb et al., (2013) • Retrospective • To compare arch perimeter and tooth size, number and shape between affected and non-affected sides in PIC	Arabic (200) T 100 : C 100 M 40: F 60 14-25 mean age 17.93	UniL	• Digital study models and an electronic sliding calliper	• No difference detected between the affected and non-affected side in PIC • Small significant difference between PIC and control group, second premolars, canines and 2 smaller in PIC than in

				controls • NS difference between PIC and control with regards to Bolton ratios
Yan et al., (2013) • Retrospective • To investigate factors associated with PIC and BIC	Chinese (340) T 170 : C170 (matched for age and sex) BIC:PIC 101:69 M:F (not specified) 12-30	UniL/BiL	• CBCT measurements • MD and BL width of U central and lateral incisors and canines	• No difference between MD and BL widths of 1s and 2s between affected and non-affected sides in unilateral PIC group • MD width of canine on impacted side was significantly greater than non-impacted • MD width of 2 in PIC group significantly smaller than BIC and controls

Key: N= sample size; NS= not significant; T= test; C= control; yrs= years; M= male; F= female; 1= Maxillary central incisor; 2= Maxillary lateral incisor; Uni= unilateral; BiL= bilateral; U= upper; L= lower; MD= mesiodistal; BL= Buccolingual; BIC: buccally impacted canine

2.3.4. PIC and maxillary lateral incisors

Studies which have investigated the relationship between PIC and maxillary lateral incisor dimensions, orientation and angulation are all summarised in Table 3.3.

Several studies have reported that maxillary lateral incisors adjacent to PIC are smaller, ‘‘peg-shaped’’, than those adjacent to normal canines (Becker et al., 1981; Peck et al., 1996a; Baccetti, 1998; Becker et al., 1999; Sacerdoti and Baccetti, 2004; Al-Nimri and Gharaibeh, 2005; Liuk et al., 2013a; Liuk et al., 2013b), while other studies have found an increased prevalence of missing maxillary lateral incisors adjacent to PIC (Garib et al., 2010; Al-Nimri and Bsoul, 2011). However, in a Caucasian population, Peck et al.,1996a, reported that PIC was reported to be more associated with missing third molars, second premolars and peg-shaped maxillary lateral incisors than with missing maxillary lateral incisors (Peck et al., 1996a; Peck et al., 2002).

Table 2.3.3: Summary of the studies of PIC and 2

Author/Year Study Type Aim	Population (N) T:C M:F Age (yrs)	Methods of Measurement	Results	Conclusion
Becker et al., (1981) • Retrospective • To investigate small 2 adjacent to PIC	Caucasian (88) T 26: C 62, UniL M 61.5%: F 51.6% Dental age ≥ 13	• Study model measurements • Maximum MD diameter of U and L lat I. • 2 classified as: absent, peg-shaped, small; normal. • Measurements for both PIC and normal sides, for both sexes	• Agenesis of 2 was among female, none among males. • Half the cases showed normal 2 • 17% peg-shaped 2 • In UniL PIC, 2 were slightly smaller on affected side for both M and F	• Possibility of PIC should be investigated where anomalous 2 is noted
Peck et al., (1996) • Retrospective	Caucasians, Orthodontic (58)	• Radiographic identification of	• Statistically significant increased absence of third	• Findings are consistent with a hypoth-

• To examine a sample with PIC to determine frequencies and patterns of associated tooth agensis. • To record occurrence of "peg-shape'' 2	T:C (not specified) M 21: F 37 Mean age 14.2 y	missing teeth • Clinical observation of conical crown-size reduction	molars and second premolars associated with PIC • NS difference in 2 agenesis compared with reference values. • Statistically significant increase (ten folds) in 2 "peg-shape'' anomaly in PIC subjects	esis that anomalies of tooth agenesis, tooth-size reduction, and PIC are biologic co-variables in complex of genetically related dental disturbances
Baccetti,(1998) • Retrospective • To reveal patterns of association among seven types of dental anomalies (aplasia of second premolars, small 2, infraocclusion of primary molars, enamel hypoplasia, ectopic eruption of first molars, supernumerary teeth, and	Caucasians, Orthodontic (4980) T 3,980 : C 1000 M 482: F 518 7-14 y	• Study models, Int.oral photographs, and radiographic assessment	• Significant associations were found among five dental anomalies, of which(small size 2, and PIC), suggesting a common genetic origin for these conditions	• The existence of associations between different tooth anomalies is clinically relevant, as the early diagnosis of one anomaly may indicate an increased risk for others

PIC).				
Becker et al., (1999) • Retrospective • To test the hypothesis that PIC is completely under genetic influence	Caucasians, Orthodontic. (19) with missing 2 on one side, and “peg-shape’’ 2 on the other side, with PIC	• Study models and radiographic assessment	• PIC occurred more frequently on the “peg-shape’’ 2 side.	• There is an environmental factor involved in PIC
Becker et al., (2002) • Retrospective • To measure the size of U teeth in PIC dentitions to determine: • Differences in size between PIC and a matched sample • Differences in size between the affected and non-affected sides in UniL PIC • Differences in size between UniL and BiL PIC	Caucasians, Orthodontic (98) T 58 (consecutive) : C40 T: M:F 21:37, C: M:F 20:20 11-15 y	• Retrospective • Study model and a dial calliper • MD and BL widths of all permanent erupted teeth mesial to the first molars	• NS difference in BL and MD width of 2 in UniL PIC between affected and non-affected sides for both M and F • Statistically significant difference in MD width of 2 between BiL PIC and UniL PIC (BiL PIC smaller MD width) for F	• In UniL PIC, NS difference between the size of 2 between affected and non-affected sides

• Differences between M and F subjects				
Sacerdoti & Baccetti, (2004) • Retrospective • To investigate association between PIC, craniofacial features and other dental anomalies such as aplasia or small sized 2	Caucasians, Orthodontic (4620) T 3620 : C1000 M 468:F 532 7-17 y	• Study models, int.oral photographs, and radiographic assessment	• UniL PIC significantly associated with aplasia of 2, whereas BiL PIC was associated with aplasia of third molars. • PIC showed significant association with BiL small sized 2	• Both UniL and BiL PIC are significantly associated with small 2 • UniL PIC was significantly associated with aplasia of 2
Al-Nimri & Gharaibeh, (2005) • Retrospective • To investigate the occlusal features associated with the aetiology of PIC	Arabic Orthodontic (68) T 34:C34 (matched for age, sex and type of malocclusion) M 7:F 27 13-27 y, mean age 17.7 y	• Study model and sharp Boley gauge • MD width of U teeth	• There is a significant association between PIC and anomalous 2	• The presence of an anomalous 2 may contribute to the aetiology of palatal canine impaction
Al-Nimri & Bsoul, (2011) • Retrospective • To investigate the	Arabic (246) with missing 2. M 78:F 168	• Pre-treatment orthodontic casts were di-	• 12.6% had PIC • NS in the PIC and non-PIC groups in sex distri-	• There is a strong association between missing 2 and PIC

prevalence of PIC in subjects with missing 2 • To investigate the dental occlusal of features that could contribute to this displacement	15-35 y	vided into two groups: PIC, and non-PIC. The non-displacement group served as a control group and was matched according to age, sex, malocclusion and UniL/BiL absences of 2	bution, type of congenital absence of 2, dental and occlusal features.	• In subjects missing 2, no other dental or occlusal features were found to play a role in PIC
Garib et al., 2010 • Retrospective • To evaluate the prevalence of dental anomalies in patients with agenesis of 2 • To compare the findings with the general population	White: 80%, Black: 20% T 126 : C general population M 42:F 84 7-35	• Panoramic and periapical radiographs and dental cases of subject with at least one missing 2 were analysed for: • Agenesis of other permanent	• Subjects with U lat I. agenesis had increased prevalence of other permanent tooth agenesis (18.2%), excluding third molars • U 2nd premolar agenesis 10.3%, L 2nd premolar agenesis 7.9%, microdontia of 2 38.8% and disto-	• Permanent tooth agenesis, 2 microdontia, PIC and distoangulation of L 2nd premolar are frequently associated with 2 agenesis

		teeth • Ectopic eruption, including PIC, distoangulation/ mesioangulation L 2nd premolar • 2 microdontia • Supernumeraries.	angulation of L 2nd premolar 3.9% (significantly increased compared to the general population) • Prevalence of PDC was high, 5,2%	
Liuk et al., 2013 • Retrospective • To evaluate the relationship between the location and orientation of PIC and dimension and orientation of 2	Caucasian (70) T: 40 patients with 46 PIC, C: 30 patients with 60 canines (age and sex matched). T: M 20: F 26 C: M 26: F 34 T: 10.5-15.9 y C: 10.4-15.7 y	• CBVT. • Angular and linear measurements of U canines and 2. were taken using software measurement tools	• 2 in PIC group tended to be more upright in the sagittal and coronal planes. • The most significant independent variables for the canine variables were the coronal and sagittal angulation of the 2 length and BL root width of the 2 and age.	• The orientation of location of PIC were associated with changes in the angulation of 2 and small 2
Liuk et al., 2013 • Retrospective • To compare dimen-	Caucasian (70) T: 40 patients with 46 PIC,	• CBVT DICOM files imported into Dolphin	• In PIC group: The mean length of the 2 was 2.1mm shorter	• 2 adjacent to PIC were smaller in comparison to those adja-

	sions of 2 in subjects with and without PIC	C: 30 subjects with 60 canines (age & sex matched) T: M 20: F 26 C: M 26: F 34 T: 10.5-15.9 y C: 10.4-15.7 y	imaging software • Linear measurements of the 2 were taken using digital measurement tool	• Mean root width was smaller especially in the BL dimension by 0.7mm	cent to normally erupting U canines

Key: N= Sample size; T= test; C= control; M= male; F= female; y= years; 2=Maxillary Lateral Incisor, Uni=Unilateral, BiL=Bilateral, BL= Buccolingual, MD=mesiodistal, NS= non-significant, Int.oral= intra-oral

2.3.5 PIC and arch shape

Arch form is affected by dimensional changes during growth or after orthodontic treatment (Taner et al., 2004). Many studies have assessed and investigated these changes (Moorrees et al., 1969; Knott, 1972; Shapiro, 1974; Gardner and Chaconas, 1976; Glenn et al., 1987; Sadowsky et al., 1994; Elms et al., 1996). There is a general increase in the inter-molar width during the transition from the primary to the permanent dentition (Moorrees et al., 1969). This increase is accompanied by a reduction in arch depth (Lee, 1999; Henrikson et al., 2001).

There have been several unsuccessful attempts to define the ideal arch shape (Henrikson et al., 2001; Felton et al., 1987; Raberin et al., 1993) due to the existence of considerable individual variation (Taner et al., 2004). A pentamorphic arch system was developed which included five types of arch form: normal, ovoid, tapered, narrow ovoid, and narrow tapered (Ricketts, 1989). Different methods are used to define these forms mathematically, such as geometric curves, which include: ellipses (Brader, 1972; Currier, 1969; Sampson, 1981), parabolas (Ferrario et al., 1994), catenary curves (Musich and Ackerman, 1973; Pepe, 1975). Another mean of definition is by a mathematical equation such as: polynomial functions (Raberin et al., 1993; Ferrario et al., 1994; Noroozi et al., 2001), cubic splines (Begole, 1980; BeGole and Lyew, 1998), conic sections (Sampson et al., 1995), B-functions (Noroozi et al., 2001; Braun et al., 1998), and the Bezier cubic equation (Taner et al., 2004).

Taking into account the inter-canine distance, arch form can be classified as square, ovoid and tapered as follows:

Square arch form

The anterior teeth are set straight up, incisal edges are even and approach is a straight line.

Ovoid arch form

Inter-canine distance is wider, the central incisors slant slightly inwards, the lateral incisors overlap the central and are depressed at the neck.

Tapered arch form

the arch is narrow between the maxillary canines, teeth slant out and the incisal edges are forward from the cervical (Rai, 2010).

In order to quantify arch form mathematically, an equation was developed by

Rai, (2010): $\frac{C1-C2}{VF} = R$

Where V is the midpoint between the central incisors.

C1 and C2 are the tip of the maxillary canines, and the two points were joined together to form a straight line. A perpendicular is dropped from point V to meet C1-C2 distance at point F.

VF is the perpendicular distance from point V to C1-C2 distance.

R is a constant.

According to the R value, arch form can be determined as the follows:

- R < 3.5, arch form is tapered.
- R 3.5 - 4, arch form is square.
- R > 4, arch form is ovoid (Rai, 2010).

No studies have reported previously on the association between PIC and different arch forms.

2.4 TOOTH SHAPE ASSESSMENT

Although tooth size of the upper lateral incisor has been shown to be related to PIC, its shape has also been mentioned as an associated factor (Becker et al., 1999).

Classification of tooth shape for all of the upper incisors, however, does not appear to have been assessed in relation to a PIC group with age, gender and malocclusion matched controls.

2.4.1 Tooth shape classification

Several guidelines and classifications of upper incisor shape have been reported in the literature. A correlation between the inverted face shape and maxillary central incisor shape has been proposed (the law of harmony) (Williams, 1917). Multiple classifications for the shape of the maxillary anterior teeth have been reported; these are tapered, ovoid and square-shaped (Williams, 1917; Bell, 1978), or triangular, square and square/tapered (Gobbato et al., 2012).

Face shape and central incisor shape, however, have been found not to be correlated (Wolfart et al., 2004; Mavroskoufis and Ritchie, 1980; Sellen et al., 1998). Neither has maxillary central incisor shape and the shape of the mandibular dental arch been shown to be correlated (Paranhos et al., 2012).

The correlation between the widths of the maxillary anterior teeth and the inter-pupillary distance, inner canthal distance and interalar width has been assessed. A strong link between the width of the central incisors and the inter-pupillary distance was found, whereas the widths of the lateral incisors and canines were correlated to the combination of inter-pupillary width and inter-alar width (Isa et al., 2010).

With regards to the prevalence of the different shapes of the maxillary incisors, one study reported 25% of the sample to be tapered, 39% ovoid, and 36% square-shaped (Wolfart et al., 2004). In a North American sample, 15 subjects had triangular, 46 subjects had square/tapered and 39 subjects had a square shape of the upper incisor teeth (Gobbato et al., 2012). Tooth shape classification, however, was carried out subjectively in several studies (Bell, 1978; Mavroskoufis and Ritchie, 1980; Gobbato et al., 2012).

2.4.2 Tooth ratio

In order to reduce the subjectivity in determining tooth shape, tooth height to width ratio was proposed as a valid measurement to aid classifying tooth shape (Gobbato et al., 2012).

Crown height is measured as the distance between the most apical portion of the labial surface and the incisal edge of the crown parallel to the long axis of the tooth. Crown width is measured as the mesiodistal distance at the junction between the cervical and the middle section, perpendicular to the long axis of the tooth.

Tooth ratio is calculated by dividing tooth height over tooth width. A mean height to width ratio equal to 39.93 percent indicates a triangular tooth shape, a ratio equal to 48.06 percent indicates a square/ tapered tooth shape and a ratio equal to 55.90 percent indicates a square tooth shape (Gobbato et al., 2012).

2.5 FACE SHAPE ASSESSMENT

As part of the facial features assessed in this study, face shape is assessed in subjects with PIC and controls, to identify any possible correlation between both. This has not been explored previously.

2.5.1 Face shape

Face shape has been previously linked to the form of the central incisor (Section 4.1) and used to predict its shape in cases where the central incisor is missing, for complex dental rehabilitation and full denture prosthesis (Williams, 1917; Mavroskoufis and Ritchie, 1980). In this regard, both face and tooth shape are classified into three categories: square, tapered and ovoid (Williams, 1917).

Previous studies that attempted to assess this relationship classified face shape subjectively with no standardised method used for classification (Mavroskoufis and Ritchie, 1980; Wolfart et al., 2004).

In a Chinese study, several face shape classifications have been reported:

- Face shape classification in art and sketch:

  Elliptic, round, rectangular, square, inverted large, triangle, narrow and long and diamond.

- Face shape classification according to human observation:

  Ellipse, ovoid, inverse ovoid, round, square, rectangular, diamond, tapered, inverted tapered and pentagram.

- Face shape classification according to pattern recognition: Round, elliptical, square and two angle.

The submaxilla is included and is classified as: pointed chin, round chin and level chin.

- Face shape classification according to anthropometry:

Hyperleptoprosopic, leptoprosopic, mesoprosopy, chameprosopic and hyperchame-prosopic.

The study specifically looked at classification of the female face shape and concluded a classification of the female face shape as the following: round, diamond, heart-shape, melon seed, pear-shape, square and ellipse (Xu et al., 2010).

2.5.2 Face ratio

In addition to face shape classification, face height to width ratio is assessed in this study, to assess any possible correlation with PIC. Face ratio has been studied previously as a predictor for human behaviour, for example aggression, achievement drive and competitiveness (Carré and McCormick, 2008; Deaner et al., 2012; Lewis et al., 2012; Lefevre et al., 2012).

Face height to width ratio measurement as reported by Carré and McCormick, (2008) is as follows:

- Face width is measured as the bizygomatic width as the maximum horizontal distance between the right and left facial boundary.
- Face height is measured as the vertical distance between the highest point of the upper lip and the highest point of the eyelids.
- The face ratio is calculated by dividing the height over the width.

2.6 METHODS OF ASSESSMENT

This study uses digital study models to assess arch and tooth dimensions and shape, and three- dimensional (3D) imaging to record 3D landmarks and facial form. These will now be considered.

2.6.1 Digital scanners

In this project, digital models have been used for dental measurements. Plaster study models have been an integral part of orthodontic practice and patient records. They provide an accurate representation of the patient's dentition and the surrounding structures (Peluso et al., 2004), used for diagnosis and treatment planning and to provide a progressive record of the treatment (Abizadeh et al., 2012).

There are, however, some limitations for their use such as frequent breakages and chipping, the need for storage space and the related expenses (Peluso et al., 2004; Kau et al., 2011; Abizadeh et al., 2012).

These limitations have encouraged researchers to look for alternatives to plaster study models such as photocopying, holography, stereophotogrammetry, photography, digitised study models and cone beam CT scanning.

Digital study models were first introduced in the 1990s (Joffe, 2004; Mah, 2007), and the continuous development in hardware and software has reduced their cost over time (Mah, 2007). They are produced by laser scanning or a combination of laser scanning and stereophotogrammetry to make a 3D digital scan of the study model that can be rotated in any plane through 360 degrees (Abizadeh et al., 2012).

Digital models have several advantages reported in the literature; they are not subjected to physical damage or degradation; the digital file can be transferred with ease to other clinicians and retrieved at multiple locations and they are also digitally stored with no need for physical storage (Bell et al., 2003; Kau et al., 2011).

Currently there are three methods to produce digital 3D models:

- Laser scanning of plaster models or alginate impressions.
- CBCT scans and CBCT scanning of alginate impressions or plaster models.
- Direct intra-oral scanning of the dentition (Macchi et al., 2006; Rangel et al., 2008; Fleming et al., 2011)

Applications of digital models in orthodontics include linear measurements, treatment planning (Rheude et al., 2005; Whetten et al., 2006), Bolton analysis and space analysis (Mullen et al., 2007), PAR scoring (Mayers et al., 2005; Stevens et al., 2006), inter-arch measurements, overjet, overbite, arch-length measurements (Santoro et al., 2003; Quimby et al., 2004; Leifert et al., 2009) and the assessment of the American Board of Orthodontics Objective Grading Score (Costalos et al., 2005; Okunami et al., 2007).

Digital models have been found to be as valid as plaster models, with adequate reliability to be used in a clinical setting (Zilberman et al., 2003; Santoro et al., 2003; Quimby et al., 2004; Dalstra and Melsen, 2009), with reasonable reproducibility and accuracy (Abizadeh et al., 2012).

2.6.2 Three-Dimensional facial imaging

3D imaging allows accurate representations of facial soft tissue morphology (Kau et al., 2007; McCance et al., 1992; Moss et al., 2003). It can be used to evaluate growth changes (Kau and Richmond, 2008; Nute and Moss, 2014), predict and compare treatment outcomes (Palomo et al., 2005; Hajeer et al., 2004c) and assess pre-treatment dentoskeletal relationships (Hajeer et al., 2004a).

3D imaging concept

In two-dimensional (2D) imaging, there are two axes (the horizontal and the vertical axes). However, in a 3D imaging system, the Cartesian coordinates system consist of the x-axis (representing the transverse dimension), y-axis (the vertical dimension), and the z-axis (the antero-posterior dimension or the depth axis). The x-, y- and z-coordinates define a space in which multi-dimensional data are presented and this is called the 3D space (Udupa and Herman, 1999; Hajeer et al., 2004a).

There are three steps to generate 3D models, the first being ‘modelling’ which uses mathematics to describe the physical properties of an object; as part of modelling, ‘image’ or ‘texture mapping’, adds a surface to the object by placing a layer of pix-els. The second step is the addition of some shading and lighting to bring some real-ism to the object. The final step, or ‘rendering’, is where the anatomical data collect-ed from the patient are converted into a life-like 3D object viewed on the computer screen (Seeram, 1996).

Techniques for 3D imaging of the face are the following: 3D cephalometry; 3D CT scanning and 3D laser scanning.

3D imaging in this project is carried out using stereophotogrammetry, which is one of the vision-based scanning techniques. These are:

- Moiré' topography
- Structured light technique
- Stereophotogrammetry
- 3D facial morphometry

They are non-invasive, non-contact.

For the purpose of this study, stereophotogrammetry will be discussed further as it is the technique employed to record images of subjects with unilateral PIC and controls.

Stereophotogrammetry:

In stereophotogrammetry, two cameras configured as a stereopair use triangulation to recover 3D distances of features on the surface of the face (Hajeer et al., 2001). The use of a portable stereometric camera optically linked to a simple plotting instrument has allowed the use of this technique clinically, and the incorporation of recent advancements in computer technology has allowed complex algorithms to be processed to convert simple photographs to 3D measurements of facial changes (Burke and Beard, 1967).

Many available systems use stereophotogrammetry. A stereophotogrammetric system developed by Ras et al., (1996), gives the three-dimensional coordinates of any chosen facial landmark, allowing changes in facial morphology to be detected by calculating linear and angular measurements. The system includes two synchronised semi-metric cameras, positioned on a frame with 50cm distance between them and mounted convergently with an angle of 15 degrees.

In addition, the C3D imaging system is another stereophotogrammetry system that is based on a stereo digital cameras and special textured illumination, with a capturing time of 50 milliseconds, and being advantageously cost-effective to be used in daily clinical practice. The system offers a life-like 3D model of the patient's head that can be enlarged, rotated and measured in 3 dimensions (Ayoub et al., 1995; Ayoub et al., 1998; Hajeer et al., 2001). The estimated accuracy is reported to be around 0.5mm, with good validity (Ayoub et al., 2003).

DI3D, another stereophotogrammetry system used in this project, produces fully textured 3D surface contour maps of the head and face, with ear to ear view (180 degrees); for the creation of accurate, ultra-high resolution, full colour image two stereo pairs of 3D images are formed using four standard digital still cameras. The system includes software that is used to create a three-dimensional surface using triangulation (www.DI4D.com) (Winder et al., 2008)).

Assessment of the surgical and/or orthodontic outcome and facial deformity can be carried out by two methods, subjective and objective. The subjective assessment using 3D models allow them to be manipulated in any direction. Evaluation of outcome can also be carried out by simple visual comparison between pre- and post-treatment models placed side by side (Hajeer et al., 2004b).

For objective assessment, different methods and analyses have been reported (Kobayashi et al., 1990; McCance et al., 1992; Moss et al., 1994; Hajeer et al., 2001), such as landmark displacement (Berkowitz and Cuzzi, 1977), inter-landmark distances and angles (Ras et al., 1996), colour-millimetric maps (Moss et al., 1994) and volumetric changes (Kobayashi et al., 1990; Motegi et al., 1999).

Chapter Three

Aims and Null Hypotheses

3.1 Overall aim

To investigate the relationship between the unilateral PIC and specific dentofacial parameters.

This study has seven aims and null hypothesises. These are listed below.

3.2 Aims

Aim 1: To investigate if differences exist in inter-canine and inter-molar widths between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in inter-canine and inter-molar widths between subjects with and without unilateral PIC.

Aim 2: To investigate if differences exist in palatal depth and palatal area between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in palatal depth and palatal area between subjects with and without unilateral PIC.

Aim 3: To investigate if differences exist in anterior Bolton TSD ratio between subjects with and without PIC.

Null hypothesis:

There is no difference in anterior Bolton TSD ratio between subjects with and without unilateral PIC.

Aim 4: To investigate if differences exist in maxillary arch shape and ratio between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in maxillary arch shape and ratio between subjects with and without unilateral PIC.

Aim 5: To investigate if differences exist in maxillary central incisor and lateral incisor shape and ratio between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in maxillary central incisor and lateral incisor shape and ratio between subjects with and without unilateral PIC.

Aim 6: To investigate if differences exist in face shape and face ratio between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in face shape and face ratio between subjects with or without unilateral PIC.

Aim 7: To investigate if differences exist in 3D facial distances and angles between subjects with and without unilateral PIC.

Null hypothesis:

There is no difference in 3D facial distances and angles between subjects with and without unilateral PIC.

Chapter Four

Materials and Methods

4.1 Study sample

The current study included two samples, a retrospective and a prospective sample. Both consisted of subjects with a unilateral PIC (test) matched with age, gender and Class of malocclusion to controls.

4.1.1 Retrospective sample

Test sample

This consisted of 54 pre-treatment study models of consecutive subjects diagnosed with unilateral PIC. These were identified retrospectively from January 2009 onward by a letter for surgical exposure or removal of PIC in the case notes kept at the Orthodontic Unit at Cork University Dental School and Hospital (CUDSH). The position of the PIC was confirmed by two examiners independently using the parallax technique applied to radiographs available in the case notes.

Control sample

This consisted of 54 consecutive pre-treatment study models of subjects without maxillary canine impaction matched for age, gender and Class of malocclusion to the test sample. These were selected retrospectively from the Orthodontic Unit in CUDSH from January 2009 onward.

4.1.2 Prospective sample

Ethical approval and informed consent

This project received ethical approval from Clinical Research Ethics Committee; University College Cork (Appendix 1).

All subjects (test and control) recruited for the prospective study gave informed consent for impression and wax bite to be taken for study models and for 3D images to be recorded (Appendix 2).

Test sample

This consisted of 54 subjects diagnosed with unilateral PIC clinically and confirmed radiographically by one examiner using the parallax technique. All subjects were recruited prospectively from the Orthodontic Unit in CUDSH from January 2013 until January 2014, or refereed to the Oral Surgery unit in CUDSH for unilateral PIC surgical exposure or removal from April 2013 until September 2014

Control sample

This consisted of 54 non-orthodontic subjects, without maxillary canine impaction who were recruited consecutively and matched for age, gender and Class of malocclusion to the test sample. These subjects volunteered to participate in the study and were given a financial reward (€ 10) for their participation.

4.2 Inclusion/exclusion criteria for retrospective and prospective samples

The inclusion criteria were as follows:

- Subjects of Caucasian origin diagnosed with unilateral PIC clinically and radiographically using the parallax technique (Prospective sample)
- Subjects referred for unilateral PIC surgical exposure or removal, confirmed clinically and radiographically (Prospective sample)
- Good quality pre-treatment study models for subjects with unilateral PIC confirmed from the relevant clinical notes and radiographically by the parallax technique (Retrospective sample)
- Maxillary right and left first permanent molars present and fully erupted
- No restorative treatment affecting the mesial and distal surfaces of the six maxillary anterior teeth
- Female subjects > 10 years; male subjects > 11 years

The following exclusion criteria were applied:

- Subjects of non-Caucasian origin
- Buccally impacted maxillary canines or canines impacted in the line of the arch
- Bilateral PIC
- Missing maxillary first permanent molars

- Restored or carious mesial and distal surfaces of the six maxillary anterior teeth
- Fractured of chipped study models
- Cleft lip and palate or other craniofacial anomaly

Variable assessment:

Each subject's ethnicity, gender and age was determined from the orthodontic case notes. Malocclusion type was assessed either clinically or using the pre-treatment study models for the prospective sample and using the pre-treatment study models for the retrospective sample; reference was made to the clinical notes also where there was any uncertainty about the malocclusion. Malocclusion type was classified based on the incisor classification as defined by the British Standard Institute (BSI) (Institute., 1983) Classification.

4.3 Sample size calculation

Sample size calculation was carried out using data from two studies investigating width of the nostrils and inter-canine width respectively in relation to PIC (Kim et al., 2012; Al-Khateeb et al., 2013).

Previous data regarding inter-canine width reported a mean difference between the PIC group and the control group of 1.49mm with a mean inter-canine width for the test group of 28.65 (SD 2.63) mm. Previous data regarding the width of the nostril reported a mean width of 24.11 (SD 2.24) mm for the PIC group (Kim et al., 2012; Al-Khateeb et al., 2013).

Therefore, it was estimated that a sample size of 54 subjects was needed to demonstrate a significant difference of 1.49 mm in inter-canine width and a sample size of 54 subjects was needed to demonstrate a significant difference of 1.9 mm in nostril widths, with 80% probability power at the 5% level of significance. Thus, the total sample size was 108 for the both the retrospective and prospective samples.

No allocation was made in the sample size calculation for sample size attrition as all subjects were required to attend only once for the relevant impressions and 3D images.

4.4 Study model measurements

All subjects in the prospective sample had upper and lower alginate impressions taken and a wax occlusal registration recorded for study models by one operator.

4.4.1 Study model scanning

Two hundred and sixteen study models were scanned by one examiner using a digital scanner R700 (ESM Digital Solutions Ltd, Swords, Co. Dublin, Ireland). The OrthoAnalyzer (3Shape AS, Copenhagen, Denmark) software program was used to view and analyse these models. A single horizontal line was marked on each digital model using the calliper measuring tool; a screenshot was then taken and the image saved. All images were then landmarked in Paint (Microsoft, Redmond, California) by a separate operator. The horizontal line was used to help measure accurate distances as it was of known length in millimetres and pixels. Each distance measured was recorded in pixels and could be converted accurately to millimetres.

The following measurements were carried out:

- Maxillary inter-canine (IC) and inter-molar (IM) width
- Palatal depth
- Palatal area
- Anterior Bolton TSD
- Arch shape and arch ratio
- Maxillary central incisor and lateral incisor shape classification and ratio

4.4.2 Landmark identification

- Maxillary IC and IM width landmarks (Figure 4.1)

  The maxillary right and left canine tip and molar mesiobuccal cusp tip were identified and marked from the occlusal aspect using Paint software (Microsoft, Redmond, California). For each point, the x and y coordinates were identified and recorded. The difference between the x coordinates and the y coordinates was calculated, then the square root formula was used to calculate the IC and the IM widths.

  In the test sample, on the side of the impaction, the distance from the maxillary lateral incisor to the maxillary first premolar was identified and then marked halfway to represent the PIC landmark or in cases where the primary canine was present, the primary canine cusp tip was marked (Al-Khateeb et al., 2013).

- Palatal depth

  Using the OrthoAnalyzer software, palatal depth was calculated using the method described by Al-Khateeb et al. (2013). This measured the perpendicular distance from the palatal vault opposite the first molars to a line connecting palatal points located on the first molar at the gingival level.

- Palatal area (Figure 4.2)

The digital models were exported to DI3D software (Dimensional Imaging, Glasgow, Scotland, UK). The palatal area of each was selected and measured using the area tool.

- Anterior Bolton TSD landmarks

  The mesial and the distal points of the six maxillary and mandibular anterior teeth were identified from the occlusal aspect zooming in on each individual tooth.

  In addition, the OrthoAnalyzer program allowed for the models to be rotated, thus ensuring the landmarks for each tooth were directly made over each specific tooth.

  This method was found to be the best combination of accuracy, repeatability, and speed of measurements (Horton et al., 2010).

  Following landmark identification, the tooth axes tool on the OrthoAnalyzer program was utilised. This ensured that the mesio-distal measurements were made through the long axis of the crown of each individual tooth. The landmarked images were then saved.

- Arch shape (Figure 4.3)

  Maxillary arch shape was classified visually into square, tapered or ovoid by one examiner according to the arch shape classification presented by (McLaughlin et al., 2001).

- Arch ratio

  Maxillary arch ratio was calculated using the equation <u>UL3-UR3</u> = Ratio

MR

where M is the midpoint between the central incisors.

In Paint (Microsoft, Redmond, California), the tips of UL3 and UR3 were landmarked, and the two points were joined together to form a straight line. A perpendicular was dropped from point M to meet UL3-UR3 distance at point R.

MR is the perpendicular distance from point M to UL3-UR3 distance.

The x and y co-ordinates of M and R were identified and recorded and the square root formula was used to calculate the distance.

Ratio is a constant. According to the ratio value, arch form was then classified as follows:

- < 3.5, arch form is tapered.
- 3.5- 4, arch form is square.
- > 4, arch form is ovoid (Rai, 2010).

- Maxillary central and lateral incisor shape

  This was classified visually to be square, tapered, round, square/tapered or square/round by one examiner.

- Maxillary central and lateral incisor height to width ratio (Figure 4.4 , Figure 4.5)

Tooth ratio was calculated as the crown height in relation to the crown width. Crown height was measured as the distance between the most apical portion of the labial surface and the incisal edge of the crown parallel to the long axis of the tooth. Crown width was measured as the mesiodistal distance at the junction between the cervical and the middle section of the crown, perpendicular to the long axis of the tooth (Gobbato et al., 2012). Using the OrthoAnalyser software the teeth were “extracted” individually and rotated until the long axis of each was perpendicular to the true horizontal. A screenshot was then taken and the image saved. Four landmarks were placed on each tooth using Paint software (Microsoft, Redmond, California) and the x and y coordinates identified and recorded. The differences between the x coordinates and the y coordinates were calculated, and then the square root formula was used to calculate the tooth height and width. Tooth ratio was calculated by dividing crown height by crown width.

4.5 3D Measurements

4.5.1 3D imaging technique

A stereophotogrammetric camera system (www.di4d.com; (Ayoub et al., 1998), re-calibrated for each session, was connected to a Dell Dimension 980 PC with images captured using DI3DCapture software (Dimensional Imaging, Glasgow, Scotland, UK). The reported accuracy for this system is 0.1 mm (Johnston et al., 2001). The cameras simultaneously recorded a pair of images corresponding to the left and right side of the face. One operator, experienced in 3D image capture, recorded one facial expressions after giving each subject identical verbal and visual instructions.

The rest position was recorded for all subjects (test and control groups) for the pro-spective sample using the following prompt recommended by Zachrisson, (1998)

Say 'Mississippi' then swallow and say 'N'.

Subjects practiced the expression twice before each image was taken. The 3D coor-dinates for the landmarks used were recorded for each image by an experienced ob-server (Farkas et al., 1980).

The process of constructing a 3D image is shown in Figure 4.6

4.5.2 3D landmarks, distances and angles

- 3D landmarks

  Twelve landmarks were recorded on each image (Figure 4.7). These are listed in Table 4.1 along with their definitions.

- 3D distances and angles

- The 3D distances and angles given in Table 4.2 were then recorded for each image for the test and control subjects in the prospective sample.

These parameters describe the main antero-posterior, vertical and transverse relationships in the facial shape analysis (Al Ali et al., 2012).

4.5.3 Face shape assessment

A screenshot of each 3D facial image was taken and opened in Paint (Microsoft, Redmond, California, USA). Each image was then outlined, and the relative shape of the face was assessed visually by one examiner subjectively using the face shape classification described by Williams, (1917).

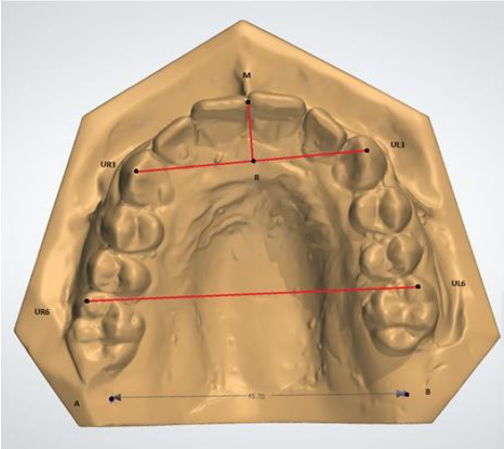
Face shape was classified into: square, tapered and ovoid.

4.5.4 Face ratio assessment (Figure 4.8)

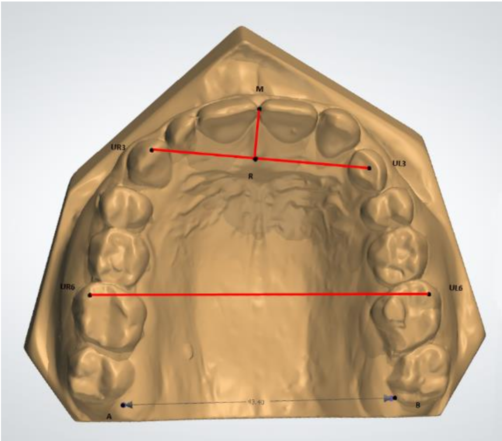
A screenshot of all 3D facial images was taken and opened in Paint (Microsoft, Redmond, California, USA). Four landmarks were on each face using Paint and the x and y coordinates identified and recorded. The differences between the x coordinates and the y coordinates were calculated, and then the square root formula was used to calculate the face height and width. Face height was measured from hair line to soft tissue chin, and face width was measured from the left to the right zygion (bizygomatic width) (Carré and McCormick, 2008). Face ratio was calculated by dividing face height by face width.

Figure 4.1 Maxillary arch landmarks for a) test and b) control subjects

a)



b)



Key: UR6= upper right first molar mesiobuccal cusp tip; UL6= upper left first molar mesiobuccal cusp tip; UR3= upper right canine cusp tip; UL3= upper left canine cusp tip; UR6-UL6= inter-molar width; UR3-UL3= inter-canine width; M= mid point between central incisors; R=intersection of inter-canine width and a perpindicular from M; MR= distance from M to R; A and B, points on horizontal line used to convert measurements from pixels to millimeters

Figure 4.2 Palatal area outlined on digital model

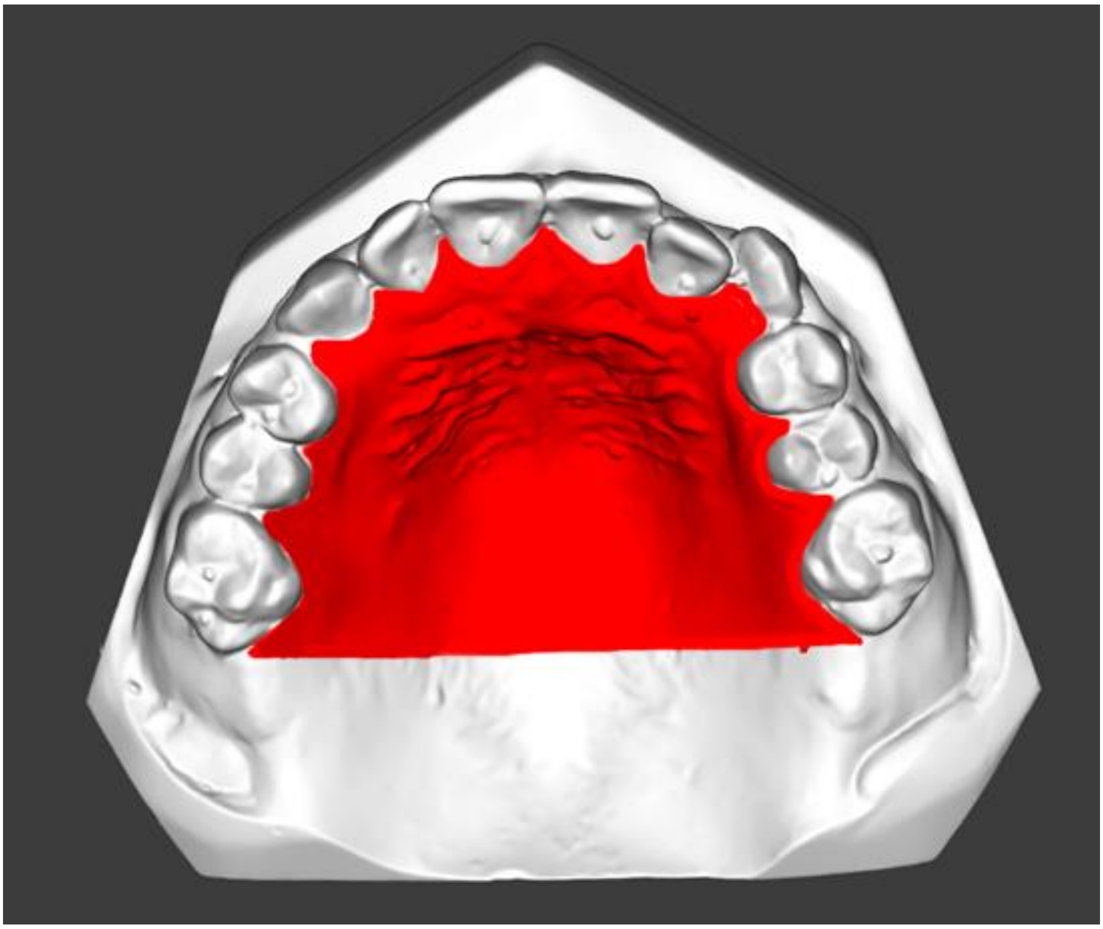


Figure 4.3 Classification of arch shapes

a) Tapered **b) Square** **c) Ovoid**

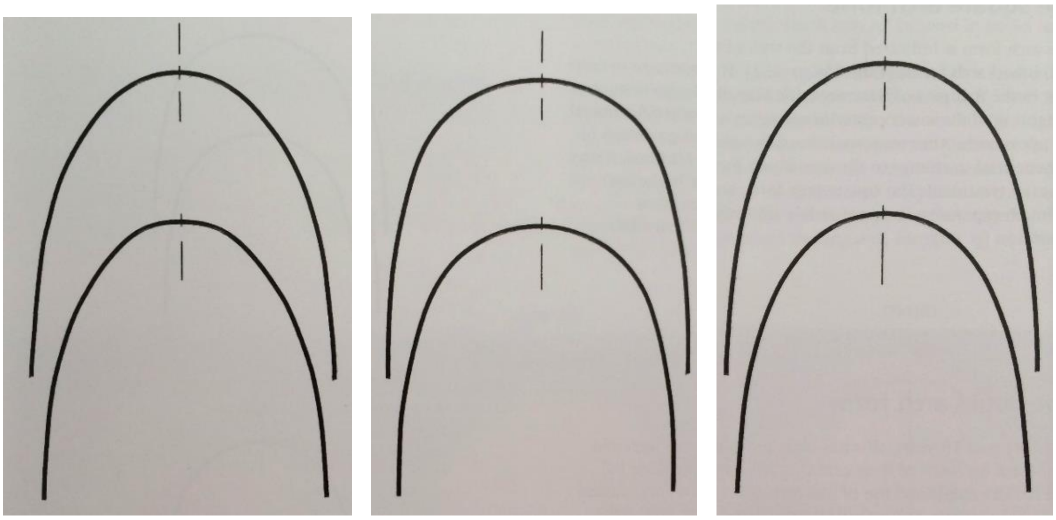
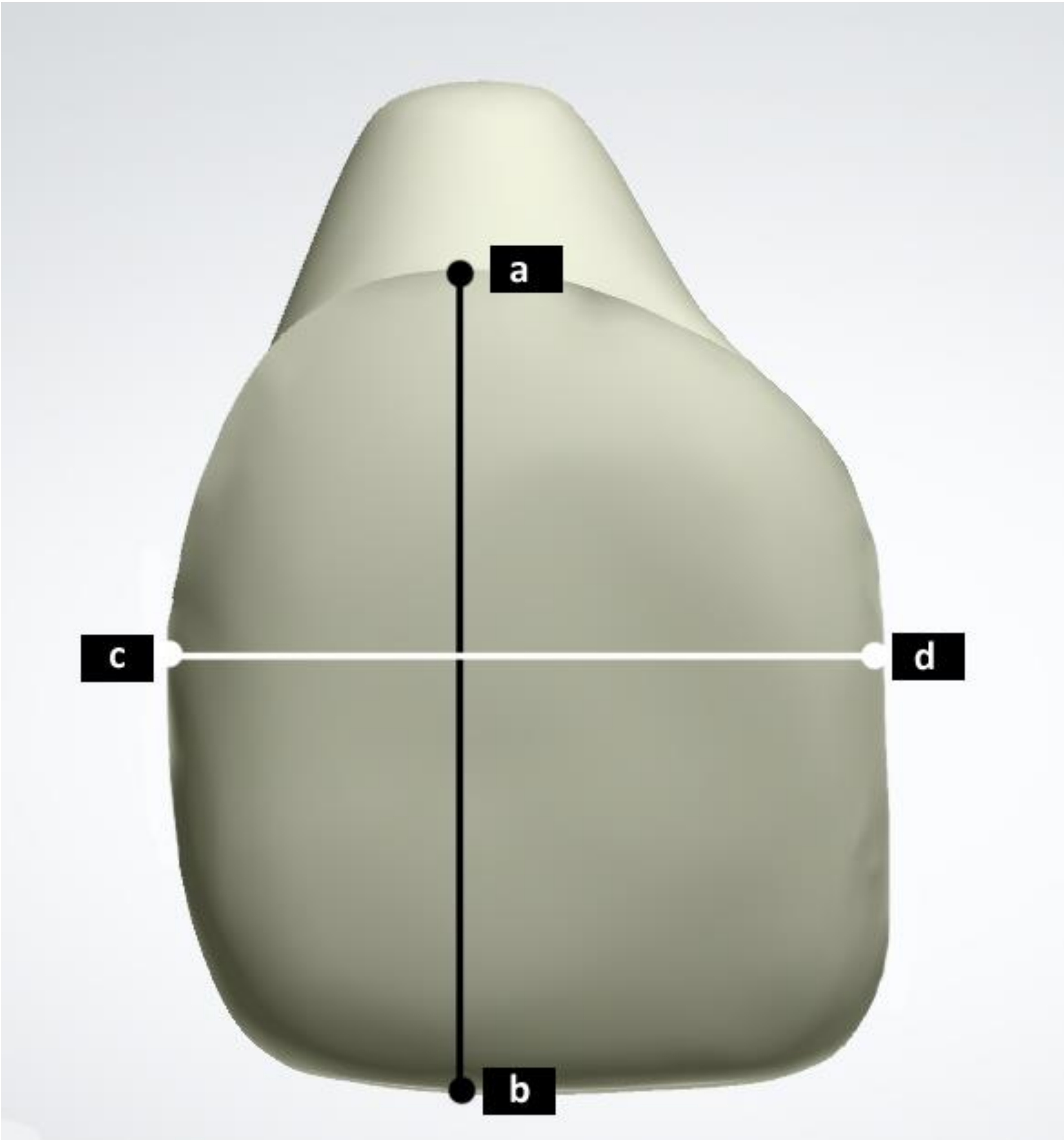


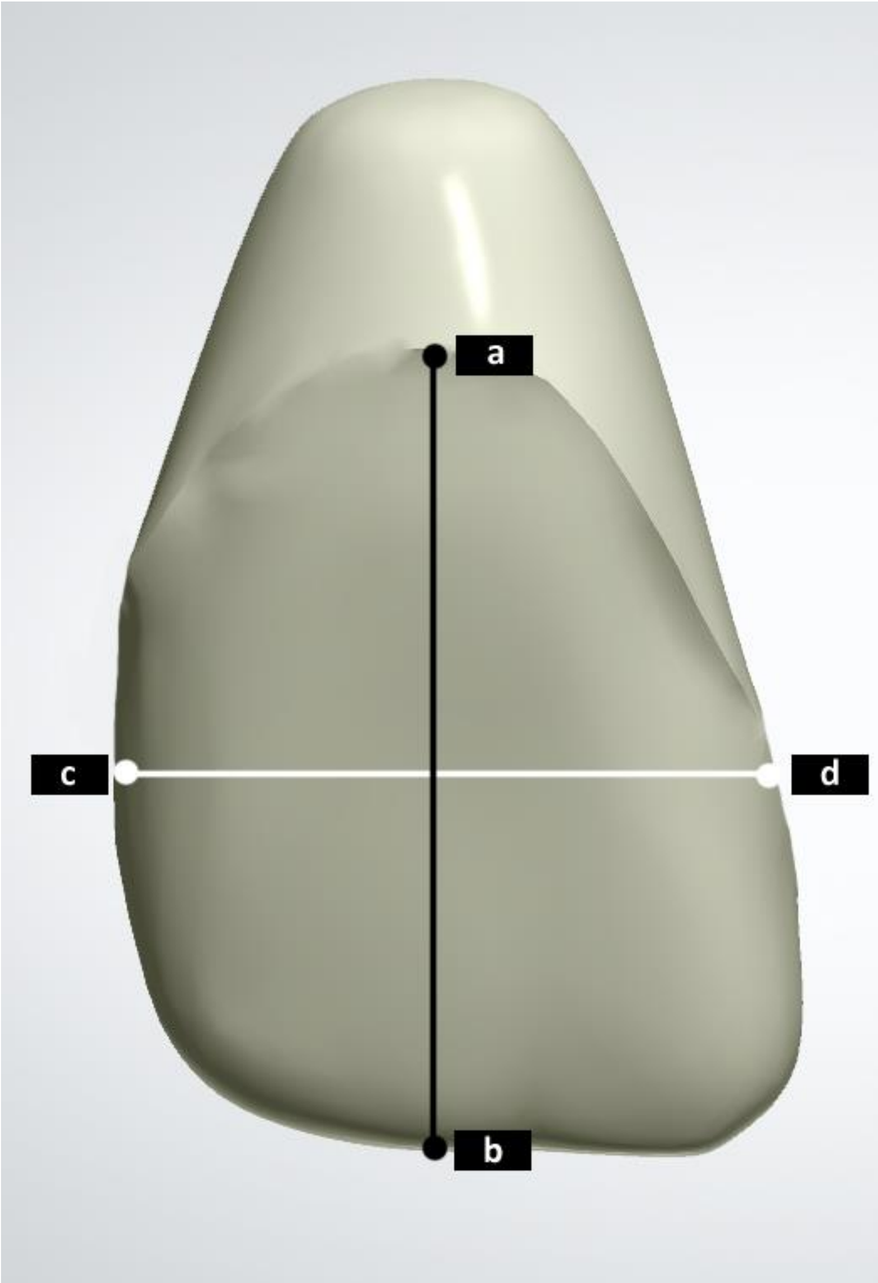
Figure modified from Mosby Elsevier - MCLAUGHLIN, R. P., BENNETT, J. C. & TREVISI, H. J. 2001. Systemized orthodontic treatment mechanics, Elsevier Health Sciences pg 77

Figure 4.4 Landmarks used to calculate maxillary central incisor ratio



Key: ab= crown height; cd= crown width

Figure 4.5 Landmarks used to calculate maxillary lateral incisor ratio



Key: ab= crown height; cd= crown width

Figure 4.6 3D model construction process: (a) four facial images are recorded by DI3DCapture; (b) these are then converted to a 3D object where the 2D images are transferred onto the 3D object to give the (c) completed model

a)

b)

c)

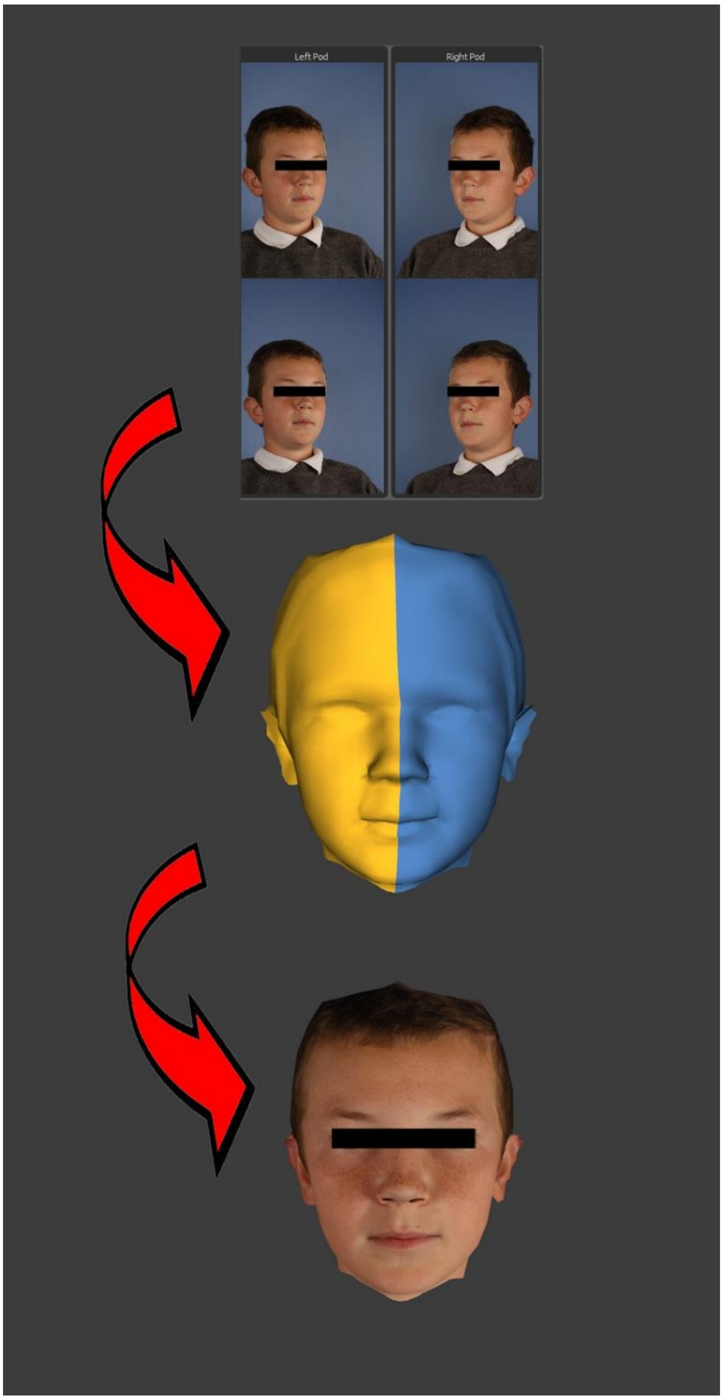


Figure 4.7 Facial landmarks.

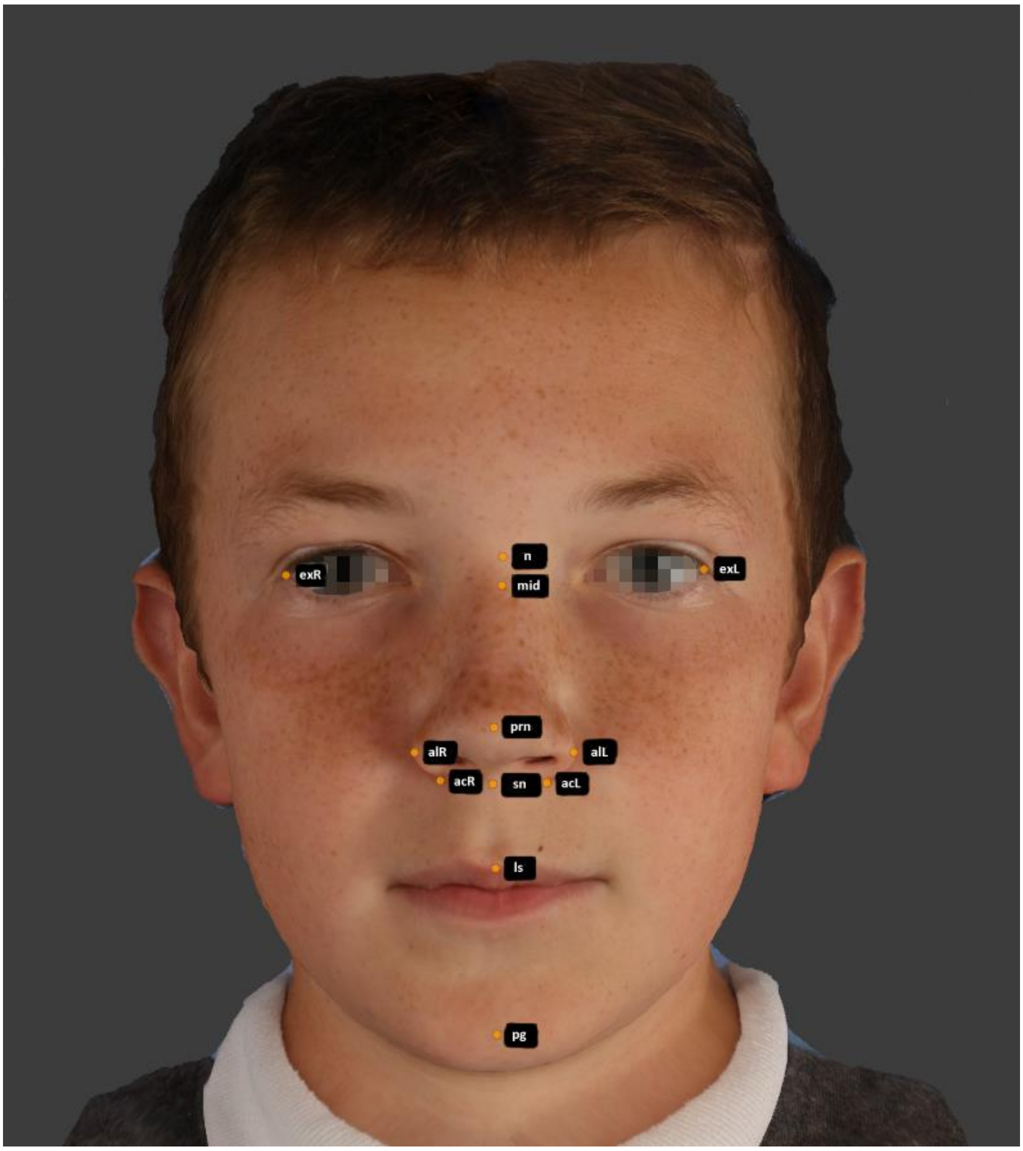


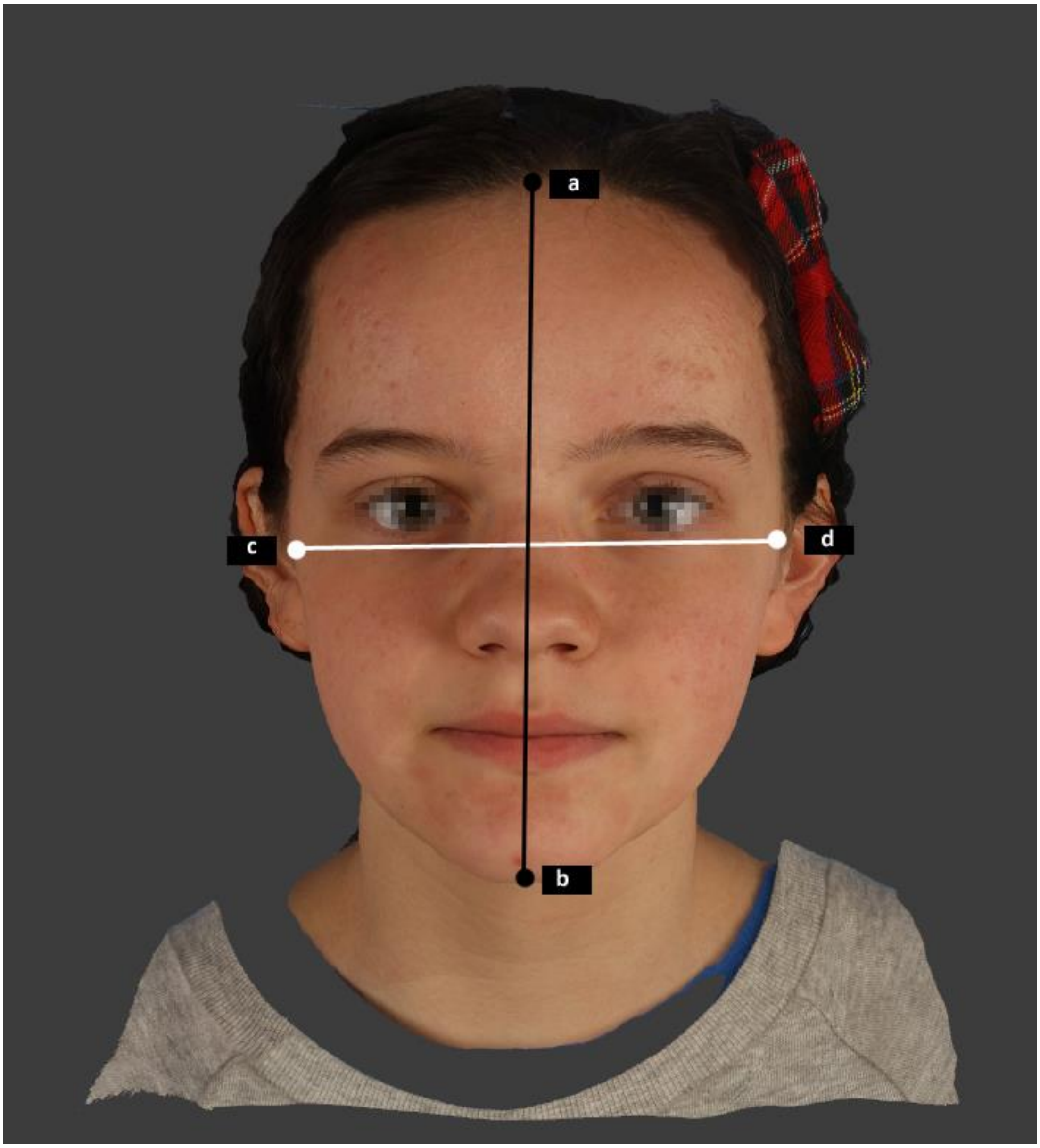
Table 4.1 3D landmarks and definitions

Landmark name	Definition
Midpoint between the eyes (mid)	The halfway distance between exocanthion left and right
Soft tissue nasion (n)	Point in the midline of both the nasal root and nasofrontal suture
Exocanthion right (exR)	Outer most point on commissure of right eye fissure
Exocanthion left (exL)	Outer most point on commissure of left eye fissure
Pronasale (prn)	Most protruded point of apex nasi
Subnasale (sn)	Midpoint of angle where lower nasal septum and lips meet
Alare right (alR)	Most lateral point of the right alar contour
Alare left (alL)	Most lateral point of the left alar contour
Alar curvature Right (acR)	Most lateral point in the curved base line of right alar base
Alar curvature Left (acL)	Most lateral point in the curved base line of left alar base
Labiale superioris (ls)	Midpoint on upper vermilion border
Pogonion (pg)	Most anterior midpoint on chin

Table 4.2 3D distances and angles

3D distances	Definition
Eye distance	Distance between exR-exL
Nose width	Distance between alR-alL
Basal width	Distance between acR-acL
Total face height	Distance between n-pg
Lower face height	Distance between ls-pg
Mid- face height	Distance between ls- mid
3D angles	**Definition**
Mid-face angle	Angle between exR-pg-exL
Face convexity	Angle between s-sn-pg
Nose prominence	Angle between n-pr-sn
Philtrum depth	Angle between prn-sn-ls

Figure 4.8 Landmarks and distances used to calculate face ratio



Key: ab= face height; cd= face width

4.6 Error study

The position of the PIC was assessed on two separate occasions two weeks apart. A reliability assessment was carried out. There was 100% agreement between the first and second time assessments of the radiographs to diagnose the position of the impacted maxillary canine.

Landmarks and measurements for digital (palatal depth, palatal area, Bolton ratio) and 3D models were recorded by one operator. The second operator landmarked all images for widths and ratios on Paint.

Intra-examiner error of landmark identification, measurements and shape assessment was investigated by re-assessing 40 randomly selected digital models, teeth and 3D images (20% of cases) after two weeks. The error for palatal depth, palatal area and Bolton ratio was 0.09mm, 0.42mm^2 and 0.14% respectively. The landmark error for 3D images was 0.58mm. The landmark error for images on Paint was 0.05mm with 100% accuracy in reporting of arch shape, tooth shape and face shape.

4.7 Statistical analyses

Numeric parameters were compared between groups using general linear models. Age, gender and malocclusion type were included in these models.

Categorical parameters were compared between groups using Fisher's exact test.

Separate analyses were performed for the retrospective and prospective studies. The level of significance was 5%. Analyses were performed in SAS® (Version 9.4).

Chapter Five

Results

5.1 Details of the retrospective and prospective study samples

The retrospective sample comprised of 36 males and 72 females, whereas the prospective sample comprised of 34 males and 74 females; there were 54 test (with PIC) subjects and 54 control subjects in both the retrospective and prospective samples. For the sample characteristics of the retrospective and prospective samples with regard to the test and control groups for each are given in (Table 5.1).

For the retrospective study, the average age was 13.92 (SD 2.05) years, with a mean age of 13.91 (SD 1.99) years for the test group and 13.93 (SD 2.14) years for the control group.

For the prospective study, the average age was 14.38 (SD 1.94) years, with a mean age of 14.50 (SD 1.71) years for the test group, and 14.25 (SD 2.15) years for the control group.

No statistically significant difference for age was found between test and control groups for both retrospective (p=0.96) and prospective (p=0.51) samples.

Table 5.1 Sample characteristics of the retrospective and prospective samples with unilateral PIC

Sample	Number of subjects per retrospective/ prospective studies T:C M:F	Age (years) Mean (SD) for T/ C M/F	Number of subjects per class of malocclusion (BSI) (T:C)
Retrospective	108 54:54 36:72	13.92 (2.05) T: 13.91 (1.99) C: 13.93 (2.14) M:13.39 F:14.48	I:44 (22:22) II/1:20 (10:10) II/2:20 (10:10) III:24 (12:12)
Prospective	108 54:54 34:74	14.38 (1.94) T:14.50 (1.71) C:14.25 (2.15) M:14.45 (1.85) F:14.35 (1.99)	I:48 (24:24) II/1:16 (8:8) II/2:34 (17:17) III:10 (5:5)

Key: T=Test; C=Control; F=Female; M=Male; BSI= British Standard Institute (Institute., 1983); I= Class I; II/1= Class II division 1; II/2= Class II division 2; III= Class III

5.2. STUDY MODEL MEASUREMENTS

5.2.1 Arch dimensions (Table 5.2, Table 5.3)

5.2.1.1 Maxillary inter-canine (IC) and inter-molar (IM) widths

Inter-canine width

- Retrospective sample

A statistically significant difference was recorded between the test (mean 31.74mm, SD 2.96) and control (mean 32.46mm, SD 2.85) group; (p=0.0002) with a mean difference value between the two groups of (2.33mm, SD (0.11)). No statistically significant differences were found with regard to genders (p=0.2415), age (p=0.2500) or Class of malocclusion (p=0.7083).

- Prospective sample

A statistically significant difference was recorded between the test (mean 30.46mm, SD 3.32) and control (mean 31.89mm, SD 3.35) groups (p=0.0186), and between Class of malocclusion (p=0.0073) with Class I subjects having the largest IC width (mean 32.30mm, SD 3.67; p=0.0018). No statistically significant differences were found with regard to gender (p=0.7146) and age (p=0.3625).

Inter-molar width

- Retrospective sample

A statistically significant difference was recorded between genders ($p=0.0024$), with females (mean 31.08mm, SD 3.02) having lower mean IM width values than males (mean 31.74mm, SD 3.32). No statistically significant differences were found in mean IM width between test (mean 48.22mm, SD 3.01) and control (mean 49.21mm, SD 3.51) groups; ($p=0.1128$), or for age or Class of malocclusion ($p=0.3816$) for either group.

- Prospective sample

No statistically significant differences were recorded between the test (mean 48.27mm, SD 3.41) and control (mean 49.04mm, SD 3.83) groups ($p=0.2876$), age ($p=0.7403$), gender ($p=0.5560$) or Class of malocclusion ($p=0.4630$).

Table 5.2 Summary of means, SD (mm), and P values for inter-canine (IC) and inter-molar (IM) widths for the retrospective sample with uni-lateral PIC

	Mean (mm)	SD (mm)	P value
IC width			
Gender			
Male	31.74	3.32	
Female	31.08	3.02	0.2415
Group			
Test	30.13	2.96	
Control	32.46	2.85	0.0002
Malocclusion			
I	31.02	3.00	
II/1	30.99	2.85	
II/2	31.57	3.58	
III	31.83	3.28	0.7083
IM width			
Gender			
Male	50.10	3.26	
Female	48.03	3.11	0.0024
Group			
Test	48.22	3.01	
Control	49.21	3.51	0.1128
Malocclusion			
I	48.72	3.06	
II/1	48.52	3.52	
II/2	47.79	3.51	
III	49.64	1.92	0.3816

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.3 Summary of the means, SD and P values for IC and IM widths for the prospective sample with unilateral PIC

	Mean (mm)	SD (mm)	P value
IC width			
Gender			
Male	31.05	3.11	
Female	31.23	3.54	0.7146
Group			
Test	30.46	3.32	
Control	31.89	3.35	0.0186
Malocclusion			
I	32.30	3.67	
II/1	30.36	2.03	
II/2	30.69	2.69	
III	28.78	4.29	0.0073
IM width			
Gender			
Male	48.93	3.61	
Female	48.53	3.66	0.5560
Group			
Test	48.27	3.41	
Control	49.04	3.83	0.2876
Malocclusion			
I	49.26	3.51	
II/1	48.25	3.91	
II/2	48.24	3.58	
III	47.81	3.99	0.4630

Key: I= Class I; II/1= Class II division 1; II/2= Class II division 2; III= Class III

5.2.1.2 Arch ratio (Table 5.4)

- Retrospective sample

The test group had a lower arch ratio (mean 3.99, SD 1.15) than the control group (mean 5.03, SD 2.75); (p=0.0029), with Class III malocclusion having the largest (mean 4.69, SD 1.92) and Class II division 2 malocclusion having the smallest (mean 2.15, SD 0.67) arch ratio value (p=0.0037).

- Prospective sample

No statistically significant differences were recorded with regard to test and control groups (p=0.1017), genders (p=0.9207), age (p=0.4754) or Class of malocclusion (p=0.1825).

Table 5.4 Summary of the means, SD and P values for arch ratio for the retrospective and prospective samples with unilateral PIC

Retrospective	Mean	SD	P value
Gender			
Male	4.32	1.21	
Female	4.60	2.51	0.9715
Group			
Test	3.99	1.15	
Control	5.03	2.75	0.0029
Malocclusion			
I	4.34	1.50	
II/1	3.53	0.78	
II/2	2.15	0.67	
III	4.69	1.92	0.0037
Prospective			
Gender			
Male	4.30	2.41	
Female	3.93	1.04	0.9207
Group			
Test	4.35	2.08	
Control	3.75	0.81	0.1017
Malocclusion			
I	3.93	1.20	
II/1	4.18	1.47	
II/2	4.36	2.18	
III	3.33	0.85	0.1825

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

5.2.1.3 Palatal depth and palatal area (Table 5.5, 5.6)

Palatal depth

- Retrospective sample

As age increased, palatal depth increased (p=0.0012). No statistically significant differences were found between test and control groups (p=0.4888), genders (p=0.5966) or Class of malocclusion (p=0.9848).

- Prospective sample

Mean palatal depth was significantly larger in males (mean 14.70mm, SD 2.47) than females (mean 13.66mm, SD 2.14); (p=0.0138) and increased significantly with age (p=0.0001). No statistically significant difference was recorded between the test and control groups (p=0.4705) or Class of malocclusion (p=0.0503).

Palatal area:

- Retrospective sample

Palatal area increased significantly with age (p=0.0001), and was greater in Class III malocclusion (p=0.0297).

- Prospective sample

The mean palatal area was significantly smaller in females (mean 16.04mm^2, SD 2.50) than in males (mean 17.49mm^2, SD 2.40); (p=0.0018), and increased significantly with age (p=0.0001). No statistically significant difference was found with regard to test and control groups (p=0.4566) and class of malocclusion (p=0.5158).

Table 5.5 Summary of the means, SD and P values for the palatal depth (mm) and palatal area (mm^2) for the retrospective sample with unilateral PIC

	Mean (mm)	SD	P value
Palatal Depth			
Gender			
Male	13.49	2.12	
Female	13.93	1.81	0.5966
Group			
Test	13.67	1.75	
Control	13.90	2.09	0.4888
Malocclusion			
I	13.91	1.78	
II/1	13.67	2.37	
II/2	14.00	1.53	
III	13.47	2.14	0.9848
Palatal Area	(mm^2)		
Gender			
Male	16.15	2.21	
Female	16.25	2.40	0.4429
Group			
Test	15.99	2.27	
Control	16.45	2.40	0.2043
Malocclusion			
I	16.28	2.52	
II/1	17.10	2.04	
II/2	16.44	2.13	
III	15.19	7.80	0.0297

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.6 Summary of the means, SD and P value for the palatal depth and palatal area for the prospective sample with unilateral PIC

	Mean (mm)	SD	P value
Palatal Depth			
Gender			
Male	14.70	2.47	
Female	13.66	2.14	0.0138
Group			
Test	14.18	2.24	
Control	13.79	2.33	0.4705
Malocclusion			
I	13.66	2.18	
II/1	14.19	1.73	
II/2	13.93	2.44	
III	15.44	2.77	0.0503
Palatal Area	(mm^2)		
Gender			
Male	17.49	2.40	
Female	16.04	2.50	0.0018
Group			
Test	16.42	2.53	
Control	16.56	2.58	0.4566
Malocclusion			
I	16.49	2.62	
II/1	16.35	2.63	
II/2	16.37	2.56	
III	17.17	3.53	0.5158

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

5.2.1.4 Bolton ratio (Table 5.7)

- Retrospective sample:

The Bolton ratio was significantly smaller in females (mean 75.59, SD 5.13) than in males (mean 78.92, SD 9.53); (p=0.0914).

No statistically significant differences were found with regard to test and control groups (p=0.7577), age (p=0.8191) or Class of malocclusion (p=0.5952).

- Prospective sample:

The test group showed a statistically higher Bolton ratio (mean 79.46, SD 6.07) than the control group (mean 76.59, SD 4.60); (p=0.0070). No statistically significant differences were found with regard to age (p=0.5355), gender (p=0.3962) or Class of malocclusion (p=0.4303).

Table 5.7 Summary of the means, SD and P values for Bolton ratio for the retrospective and prospective samples with unilateral PIC

Retrospective	Mean	SD	P value
Bolton Ratio			
Gender			
Male	78.92	9.53	
Female	75.59	5.13	0.0914
Group			
Test	77.02	7.47	
Control	76.37	6.66	0.7577
Malocclusion			
I	75.77	8.29	
II/1	76.45	5.19	
II/2	76.25	3.91	
III	78.96	7.80	0.5952
Prospective			
Bolton Ratio			
Gender			
Male	77.44	5.33	
Female	78.30	5.66	0.3926
Group			
Test	79.46	6.07	
Control	76.59	4.60	0.0070
Malocclusion			
I	77.75	5.47	
II/1	76.56	4.88	
II/2	78.79	6.03	
III	79.10	5.36	0.4303

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

5.2.1.5 Arch shape (Table 5.8, Table 5.9)

- Retrospective sample

The tapered arch shape was the most prevalent among the test group (48%), followed by ovoid (39%) and square (13%), whereas the ovoid arch shape was the most prevalent among the control group (43%), followed by square (33%) and tapered (24%).

The distribution of arch shape between test and control groups was statistically significant (p=0.009).

- Prospective sample

The ovoid arch shape was the most prevalent among the test (52%) and control (71%) groups, followed by tapered (test: 35%; control: 20%) and square (test: 13%; control: 9%). Tapered and square arch shapes were more prevalent in the test than in the control group. No statistically significant difference was recorded in the distribution of arch shape between the test and control groups (p=0.149).

Table 5.8 Summary of the arch shape distribution for the retrospective and prospective samples with unilateral PIC with regard to gender group and malocclusion

Retrospective	Shape Tapered n (%)	 Square n (%)	 Ovoid n (%)
Gender			
Male	11 (30)	10 (28)	15 (42)
Female	28 (39)	15 (21)	29 (40)
Group			
Test	26 (48)	7 (13)	21 (39)
Control	13 (24)	18 (33)	23 (43)
Malocclusion			
I	17 (38)	6 (14)	21 (48)
II/1	12 (60)	2 (10)	6 (30)
II/2	3 (15)	11 (55)	6 (30)
III	7 (29)	6 (25)	11 (46)
Prospective			
Gender			
Male	8 (24)	7 (21)	19 (55)
Female	22 (30)	5 (7)	47 (63)
Group			
Test	19 (35)	7 (13)	28 (52)
Control	11 (20)	5 (9)	38 (71)
Malocclusion			
I	8 (17)	9 (19)	31 (64)
II/1	3 (19)	1 (6)	12 (75)
II/2	13 (38)	2 (6)	19 (56)
III	6 (60)	-	4 (40)

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.9 Summary of frequency distribution of arch shape for retro-spective and prospective samples with unilateral PIC

Sample	Table Probability (P)	Two-sided Pr<=P
Retrospective	0.0003	0.0099
Prospective	0.0059	0.1492

5.2.2 Tooth shape and tooth ratio

Tooth shape

- Retrospective sample (Table 5.10, Table 5.11)

The most common tooth shape for the central incisor was square for both the test (74%) and control (78%) groups, whereas for the lateral incisor, square/round was the most common for both test (57%) and control (72%) groups.

The distribution of tooth shape between test and control groups was statistically significant for the right central incisor (p=0.030).

- Prospective sample (Table 5.12, Table 5.13)

The most common tooth shape for the central incisor was square for both the test (93%) and control (88%) groups, whereas for the lateral incisor square/round was the most common for the test (46%) and control (50%) groups.

No statistically significant difference was found in the distribution of tooth shape between the test and control groups.

Table 5.10 Summary of the distribution of UL1, UL2 and UR1, UR2 tooth shape for gender, group and malocclusion for the retrospective sample with unilateral PIC

	Shape							
	Square/ Tapered n (%)	Square n (%)	Square/Round n (%)	Ovoid n (%)	Square/ Tapered n (%)	Square n (%)	Square/Round n (%)	Ovoid n (%)
UL1					UL2			
Gender								
Male	4 (11)	29 (810)	3 (8)	-	5 (14)	1 (3)	23 (66)	6 (17)
Female	14 (19)	53 (74)	5 (7)	-	20 (28)	2 (3)	45 (63)	4 (6)
Group								
Test	7 (13)	40 (74)	7 (13)	-	13 (24)	3 (6)	30 (57)	7 (13)
Control	11 (20)	42 (78)	3 (7)	-	12 (23)	-	38 (72)	3 (5)
Maloccl								
I	12 (27)	29 (66)	3 (7)	-	16 (37)	2 (5)	20 (47)	5 (11)
II/1	1 (5)	18 (90)	1 (5)	-	1 (5)	-	16 (80)	3 (15)
II/2	3 (15)	17 (85)	-	-	4 (20)	-	16 (80)	-
III	2 (8)	18 (75)	4 (17)	-	4 (17)	1 (4)	16 (70)	2 (9)
UR1					UR2			
Gender								
Male	4 (11)	29 (81)	3 (8)	-	3 (9)	1 (3)	25 (76)	4 (12)
Female	7 (10)	58 (80)	7 (10)	-	13 (18)	2 (3)	53 (73)	4 (6)
Group								
Test	5 (9)	40 (74)	9 (17)	-	5 (10)	2 (4)	38 (73)	7 (13)

Control	6 (11)	47 (87)	1 (2)	-	11 (21)	1 (2)	40 (75)	1 (2)
Maloccl								
I	5 (11)	36 (82)	3 (7)	-	12 (29)	1 (2)	27 (64)	2 (5)
II/1	2 (10)	16 (80)	2 (10)	-	1 (5)	-	27 (64)	2 (5)
II/2	2 (10)	18 (90)	-	-	1 (5)	-	18 (90)	1 (5)
III	2 (8)	17 (71)	5 (21)	-	2 (9)	2 (9)	19 (82)	-

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III; UL1= upper left central incisor; UL2= upper left lateral incisor; UR1= upper right central incisor; UR2= upper right lateral incisor; Maloccl=Malocclusion

Table 5.11 Summary of frequency distribution of tooth shape for UL1, UL2, UR1 and UR2 for the retrospective sample with unilateral PIC.

	Table Probability (P)	Two-sided Pr<=P		Table Probability (P)	Two-sided Pr<=P
UL1			UL2		
	0.0044	0.0698		0.0022	0.1848
UR1			UR2		
	0.0022	0.0308		0.0009	0.0566

Key: UL1= upper left central incisor; UL2= upper left lateral incisor; UR1= upper right central incisor; UR2= upper right lateral incisor.

Table 5.12 Summary of the distribution of UL1, UL2 and UR1, UR2 tooth shape for gender, group and malocclusion for the prospective sample with unilateral PIC

	Shape							
	Square/ Tapered n (%)	Square n (%)	Square/Round n (%)	Ovoid n (%)	Square/ Tapered n (%)	Square n (%)	Square/Round n (%)	Ovoid n (%)
UL1					UL2			
Gender								
Male	1 (2)	33 (98)	-	-	6 (18)	6 (18)	14 (41)	8 (23)
Female	7 (9)	67 (91)	-	-	19 (26)	8 (11)	38 (51)	9 (12)
Group								
Test	4 (7)	50 (93)	-	-	14 (26)	6 (11)	25 (46)	9 (17)
Control	6 (12)	42 (88)	-	-	11 (20)	8 (15)	27 (50)	8 (15)
Maloccl								
I	-	16 (100)	-	-	10 (21)	5 (10)	24 (50)	9 (19)
II/1	1 (3)	33 (97)	-	-	6 (38)	1 (6)	5 (31)	4 (25)
II/2	1 (10)	9 (90)	-	-	7 (21)	7 (21)	18 (53)	2 (5)
III	2 (3)	58 (97)	-	-	2 (20)	1 (10)	5 (50)	2 (20)
UR1					UR2			
Gender								
Male	-	34 (100)	-	-	7 (21)	3 (9)	20 (58)	4 (12)
Female	6 (8)	67 (90)	1 (1)	-	11 (15)	11 (15)	45 (61)	7 (9)
Group								
Test	3 (6)	51 (94)	-	-	11 (15)	7 (13)	32 (59)	7 (13)

Control	3 (6)	50 (92)	1 (2)	-	10 (19)	7 (13)	33 (61)	4 (7)
Maloccl								
I	5 (10)	42 (88)	1 (2)	-	8 (17)	5 (10)	32 (67)	3 (6)
II/1	-	16 (100)	-	-	5 (31)	2 (13)	8 (50)	1 (6)
II/2	1 (3)	33 (99)	-	-	5 (15)	5 (15)	20 (59)	4 (11)
III	-	10 (100)	-	-	-	2 (20)	5 (50)	3 (30)

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III; UL1= upper left central incisor; UL2= upper left lateral incisor; UR1= upper right central incisor; UR2= upper right lateral incisor Maloccl=Malocclusion

Table 5.13 Summary of frequency distribution of tooth shape for UL1, UL2, UR1 and UR2 for the prospective sample with unilateral PIC

	Table Probability (P)	Two-sided Pr<=P		Table Probability (P)	Two-sided Pr<=P
UL1			UL2		
	0.2841	1.000		0.0063	0.8553
UR1			UR2		
	0.1608	1.000		0.0072	0.8189

Key: UL1= upper left central incisor; UR1= upper right central incisor; UL2= upper left lateral incisor; UR2= upper right lateral incisor

Tooth ratio

- Retrospective sample (Table 5.14, Table 5.15, Table 5.16, Table 5.17)

No statistically significant difference in tooth ratio was found between test and control groups (p=0.7630), genders or Class of malocclusion for the upper left central incisor (UL1).

- Prospective sample (Table 5.18, Table 5.19, Table 5.20, Table 5.21)

No statistically significant difference in tooth ratio was found between test and control groups, genders or Class of malocclusion.

Table 5.14 Summary of UL1 and UR1 tooth ratio for gender, group and malocclusion for the retrospective group with unilateral PIC

	Mean	SD
UL1		
Gender		
Male	1.14	0.07
Female	1.11	0.09
Group		
Test	1.12	0.08
Control	1.11	0.08
Malocclusion		
I	1.11	0.07
II/1	1.16	0.07
II/2	1.12	0.10
III	1.11	0.09
UR1		
Gender		
Male	1.11	0.12
Female	1.09	0.10
Group		
Test	1.09	0.09
Control	1.10	0.11
Malocclusion		
I	1.10	0.10
II/1	1.11	0.09
II/2	1.09	0.12
III	1.08	0.11

Key: UL1= upper left central incisor; UR1= upper right central incisor; I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.15 Summary of UL2 and UR2 tooth ratio for gender, group and malocclusion for the retrospective group with unilateral PIC

		Mean	SD
UL2			
Gender			
	Male	1.18	0.17
	Female	1.16	0.13
Group			
	Test	1.17	0.13
	Control	1.17	0.16
Malocclusion			
	I	1.16	0.13
	II/1	1.20	0.15
	II/2	1.18	0.16
	III	1.15	0.17
UR2			
Gender			
	Male	1.14	0.15
	Female	1.15	0.16
Group			
	Test	1.15	0.15
	Control	1.15	0.16
Malocclusion			
	I	1.15	0.15
	II/1	1.14	0.13
	II/2	1.16	0.17
	III	1.14	0.17

Key: UL2= upper left lateral incisor; UR2= upper right lateral incisor I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.16 Summary of fixed effects for tooth ratio for UL1 and UR1 for the retrospective group with unilateral PIC

Ratio	Effect	Num DF	Den DF	F Value	Pr > F
RatioUL1	UL1	2	102	0.30	0.7442
	Group	1	102	0.09	0.7630
	UL1*Group	2	102	0.05	0.9479
RatioUR1	UR1	2	102	0.44	0.6437
	Group	1	102	0.03	0.8552
	UR1*Group	2	102	0.89	0.4122

Key: UL1= upper left central incisor; UR1= upper right central incisor.

Table 5.17 Summary of fixed effects for tooth ratio for UL2 and UR2 for the retrospective group with unilateral PIC

Ratio	Effect	Num DF	Den DF	F Value	Pr > F
RatioUL2	UL2	3	99	0.42	0.7361
	Group	1	99	0.00	0.9503
	UL2*Group	2	99	0.59	0.5573
RatioUR2	UR2	3	97	0.98	0.4075
	Group	1	97	1.27	0.2624
	UR2*Group	3	97	0.71	0.5484

Key: UL2= upper left lateral incisor; UR2= upper right lateral incisor.

Table 5.18 Summary of UL1 and UR1 tooth ratio for gender, group and malocclusion for the prospective group with unilateral PIC

	Mean	SD
UL1		
Gender		
Male	1.30	0.38
Female	1.32	0.36
Group		
Test	1.34	0.41
Control	1.28	0.31
Malocclusion		
I	1.87	0.33
II/1	1.36	0.36
II/2	1.35	0.4
III	1.19	0.38
UR1		
Gender		
Male	1.17	0.25
Female	1.08	0.14
Group		
Test	1.13	0.23
Control	1.09	0.11
Malocclusion		
I	1.91	0.34
II/1	1.08	0.09
II/2	1.09	0.12
III	1.07	0.09

Key: UL1= upper left central incisor; UR1= upper right central incisor; I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.19 Summary of UL2 and UR2 tooth ratio for gender, group and malocclusion for the prospective group with unilateral PIC

	Mean	SD
UL2		
Gender		
Male	1.24	0.42
Female	1.27	0.31
Group		
Test	1.35	0.45
Control	1.17	0.17
Malocclusion		
I	1.24	0.37
II/1	1.19	0.28
II/2	1.34	0.35
III	1.11	0.31
UR2		
Gender		
Male	1.14	0.17
Female	1.14	0.16
Group		
Test	1.15	0.16
Control	1.14	0.16
Malocclusion		
I	1.15	0.61
II/1	1.12	0.15
II/2	1.14	0.16
III	1.16	0.17

Key: UL2= upper left lateral incisor; UR2= upper right lateral incisor I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.20 Summary of fixed effects for tooth ratio for UL1 and UR1 for the prospective group with unilateral PIC

Ratio	Effect	Num DF	Den DF	F Value	Pr > F
RatioUL1	UL1	1	104	0.39	0.5346
	Group	1	104	1.23	0.2709
	UL1*Group	1	104	0.54	0.4650
RatioUR1	UR1	2	103	0.32	0.7276
	Group	1	103	0.83	0.3633
	UR1*Group	1	103	2.59	0.1109

Key: UL1= upper left central incisor; UR1= upper right central incisor.

Table 5.21 Summary of fixed effects for tooth ratio for UL2 and UR2 for the prospective group with unilateral PIC

Ratio	Effect	Num DF	Den DF	F Value	Pr > F
RatioUL2	UL2	3	100	0.18	0.9121
	Group	1	100	2.96	0.0886
	UL2*Group	3	100	0.73	0.5375
RatioUR2	UR2	3	100	2.85	0.0411
	Group	1	100	0.06	0.8124
	UR2*Group	3	100	0.81	0.4894

Key: UL1= UL2= upper left lateral incisor; UR2= upper right lateral incisor.

5.3. 3D IMAGING MEASUREMENTS

5.3.1 Face shape and face ratio

Face shape (Table 5.22)

Ovoid (41%) and square (41%) were the most common face shapes in the test sample, whereas ovoid (54%) was the most common face shape among the control sample. No significant difference was found in face shape distribution between the test and control groups in the prospective sample (p=0.1383).

Table 5.22 Summary of face shape distribution for gender, group and malocclusion for the prospective sample with unilateral PIC

	Face shape		
	Tapered n (%)	Square n (%)	Ovoid n (%)
Gender			
Male	5 (15)	14 (41)	15 (44)
Female	18 (24)	20 (27)	36 (49)
Group			
Test	10 (18)	22 (41)	22 (41)
Control	13 (24)	12 (22)	29 (54)
Malocclusion			
I	16 (33)	9 (19)	23 (48)
II/1	2 (12)	8 (50)	6 (38)
II/2	3 (9)	16 (47)	15 (44)
III	2 (20)	1 (10)	7 (70)

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Face ratio (Table 5.23)

Subjects with Class I malocclusion demonstrated the highest mean face ratio (Mean 1.49 SD 0.19) ($p=0.0116$). No statistically significant differences existed with regard to the test and control samples ($p=0.5409$), age ($p=0.2214$) or gender ($p=0.5074$).

Table 5.23 Summary of mean face ratio for gender, group and malocclusion for the prospective sample with unilateral PIC

	Mean face ratio	SD
Gender		
Male	1.43	0.09
Female	1.46	0.16
Group		
Test	1.15	0.18
Control	1.46	0.08
Malocclusion		
I	1.49	0.19
II/1	1.41	0.07
II/2	1.14	0.07
III	1.47	0.06

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

5.3.2 3D landmarks (Table 5.24, Table 5.25)

Test subjects manifested significantly smaller basal width (mean 18.91mm, SD 1.47) than controls (mean 20.57mm, SD 2.57); (p=0.0001).

All 3D distances and angles were statistically higher values for males compared to females, with the exception of nose prominence and philtrum depth (Table 5.24, Table 5.25).

As age increased, eye distance, total face height, lower face height, mid-face height, and nose prominence increased. (Table 5.24, Table 5.25).

Subjects with Class III malocclusion had statistically larger values for all the 3D distances and angles except for nose width, mid-face angle, nose prominence and philtrum depth. (Table 5.24, Table 5.25).

Table 5.24 Summary of the 3D distances differences for gender, group, and malocclusion for the prospective sample with unilateral PIC

	Mean (mm)	SD	P value
Eyes Distance			
Gender			
Male	88.85	3.78	
Female	86.44	3.51	0.0020
Group			
Test	87.12	3.23	
Control	87.12	3.23	0.6645
Malocclusion			
I	87.21	3.84	
II/1	86.58	3.97	
II/2	87.41	3.37	
III	87.46	4.64	0.9919
Nose Width			
Gender			
Male	32.41	2.28	
Female	31.45	2.33	0.0485
Group			
Test	31.61	2.18	
Control	31.89	2.51	0.5314
Malocclusion			
I	32.19	2.51	
II/1	31.00	1.94	
II/2	31.59	2.20	
III	31.37	2.54	0.3160
Basal Width			
Gender			
Male	20.25	1.87	
Female	19.51	2.37	0.0182
Group			
Test	18.91	1.47	
Control	20.57	2.57	0.0001*
Malocclusion			

I	20.22	2.53	
II/1	19.50	2.13	
II/2	18.93	1.41	
III	20.56	2.62	0.0153
Total Face Height			
Gender			
Male	106.92	5.64	
Female	101.44	5.94	0.0001
Group			
Test	103.12	6.42	
Control	103.21	6.35	0.7701
Malocclusion			
I	103.51	6.05	
II/1	101.27	6.16	
II/2	101.98	5.89	
III	108.60	7.34	0.0040
Lower Face Height			
Gender			
Male	42.47	4.37	
Female	38.84	3.80	0.0001
Group			
Test	39.55	3.98	
Control	40.42	4.61	0.1724
Malocclusion			
I	40.64	4.35	
II/1	39.06	4.00	
II/2	38.72	3.67	
III	42.63	5.32	0.0068
Midface Height			
Gender			
Male	58.27	3.40	
Female	55.21	3.51	0.0001
Group			
Test	56.66	3.53	
Control	55.70	3.92	0.1776
Malocclusion			

I	56.15	3.15	
II/1	55.32	3.52	
II/2	55.98	4.37	
III	58.33	4.15	0.1564

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Table 5.25 Summary of the 3D angles differences for gender, group, and malocclusion for the prospective sample with unilateral PIC

	Mean (°)	SD	P value
Midface Angle			
Gender			
Male	47.96	2.46	
Female	49.43	2.54	0.0013
Group			
Test	49.04	2.63	
Control	48.91	2.59	0.6987
Malocclusion			
I	48.59	2.34	
II/1	50.09	2.71	
II/2	49.59	2.36	
III	46.95	3.13	0.0053
Face Convexity			
Gender			
Male	160.97	5.18	
Female	163.72	4.84	0.0131
Group			
Test	163.01	4.86	
Control	162.70	5.35	0.7509
Malocclusion			
I	163.63	4.51	
II/1	160.89	4.34	
II/2	161.85	4.96	
III	165.69	7.56	0.0826
Nose Prominence			
Gender			
Male	102.60	5.62	
Female	102.44	5.69	0.7561
Group			
Test	101.91	5.65	
Control	103.08	5.62	0.3758

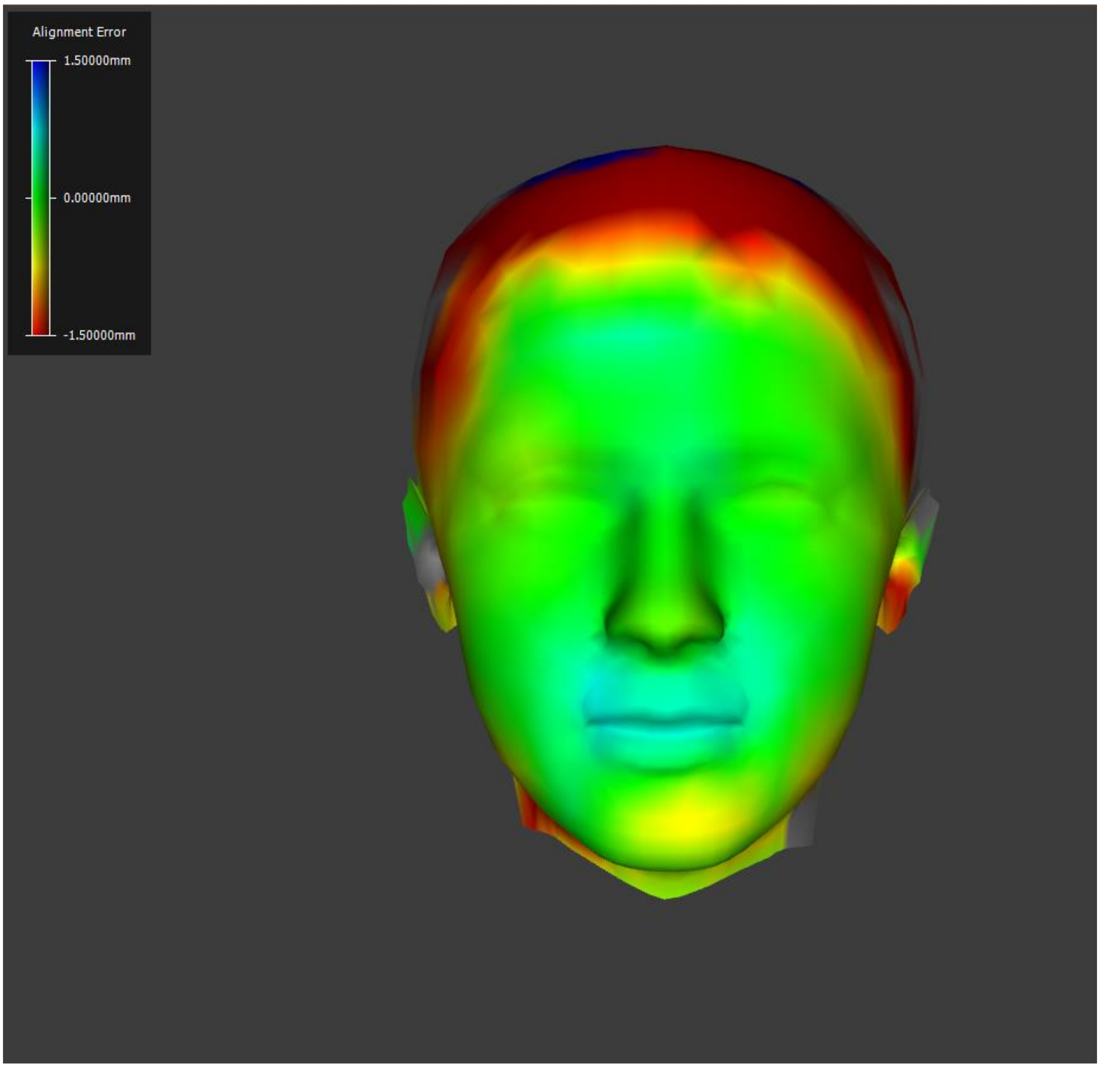
Malocclusion			
I	102.36	5.44	
II/1	103.19	4.34	
II/2	102.20	5.85	
III	103.04	6.48	0.8788
Philtrum Depth			
Gender			
Male	130.06	9.88	
Female	132.16	8.09	0.2024
Group			
Test	131.96	9.15	
Control	131.05	8.30	0.5240
Malocclusion			
I	131.30	8.34	
II/1	129.51	11.09	
II/2	132.70	8.44	
III	131.60	7.63	0.5109

Key: I= Class I; II/1= Class II division1; II/2= Class II division 2; III= Class III

Figure 5.1 3D average face for the test group in the prospective sample

Figure 5.2 3D average face for the control group in the prospective study

Figure 5.3 3D colour map showing superimposition of the average test and control face



Key- Blue: changes > 1.5 cm^3; green: no changes; red: changes in opposite direction to blue changes

Chapter Six

Discussion

6.1 Study design and sample characteristics

Study design

This is a case control cohort study with retrospective and prospective samples of subjects with unilateral PIC. Both samples have been looked at separately with regard to maxillary arch dimensions, Bolton TSD, maxillary arch shape and ratio, maxillary central incisor and lateral incisor shape and ratio, face shape and ratio and 3D facial distances and angles.

These dental parameters have been assessed previously by several studies with retrospective samples only. These may, therefore, be subjected to selection bias (Al-Nimri and Gharaibeh, 2005; Saiar et al., 2006; Anic-Milosevic et al., 2009; Al-Khateeb et al., 2013).

Unilateral PIC

Only cases with unilateral PIC were considered in this study. Thus, confounding factors such as cases with bilateral PICs (Sacerdoti and Baccetti, 2004; Anic-Milosevic et al., 2009) or buccally impacted canines (Kim et al., 2012; Mercuri et al., 2013a; Mercuri et al., 2013b) were eliminated in this study. Samples with unilateral PIC only were also assessed in two previous studies (Al-Nimri and Gharaibeh, 2005; Al-Khateeb et al., 2013).

PIC diagnosis

Identification of the PIC for the retrospective sample was done using the referral letter for surgical exposure or removal from the relevant clinical notes, whereas for the prospective sample, the diagnosis of PIC was carried out clinically. In both samples, the position of the PIC was confirmed using the radiographic parallax technique. Similar methods of PIC diagnosis were reported previously by Anic-Milosevic et al., (2009) and Al-Khateeb et al., (2013).

Reliability of canine position

The position of the unilateral PIC was verified on two occasions by one operator, two weeks apart, and 100 percent agreement was recorded for intra-observer reliability. Similarly, Murcuri et al., (2013) in a study of both buccally and PIC, reported on the reproducibility of maxillary canine position.

Sample size

The total sample size was 216, with 108 subjects for retrospective and prospective samples respectively, with 54 test and 54 control subjects in each sample. The sample size calculation was carried out using data from two studies investigating dental and facial parameters associated with PIC (Kim et al., 2012; Al-Khateeb et al., 2013). This is the largest sample size to report on dental and facial parameters associated with unilateral PIC.

Matching of subjects

All subjects in the test group in the retrospective and prospective samples were compared to control subjects, matched for age, gender and Class of malocclusion for an accurate comparison between the two groups. Matched test groups to controls for age, gender and Class of malocclusion has also been undertaken by some previous studies (Al-Nimri and Gharaibeh, 2005; Al-Khateeb et al., 2013). However, one study had matching controls for age and Class of malocclusion but not for genders (Anic-Milosevic et al., 2009).

Ethnicity

All subjects in the present study were of Caucasian ethnicity. Saiar et al., (2006) and Anic-Milosevic et al., (2009) also assessed Caucasian subjects only. Whereas Al-Nimri and Gharaibeh, (2005) and Al-Khateeb et al., (2013) reported on a sample of Arabic origin.

Female to male ratio

There were a greater number of females than males in the present study in the retrospective and prospective samples, with both having female to male ratio of 2:1. This is in agreement to what was reported in the literature of increased prevalence of females with PIC than males (Dachi and Howell, 1961; Peck et al., 1994). Several previous studies reported similar female to male ratio (Anic-Milosevic et al., 2009; Al-Khateeb et al., 2013).

Age

The mean age for the subjects was 13.9 years and 14.3 years for retrospective and prospective samples respectively. This was younger than the mean age reported previously by Al-Khateeb et al., (2013) where mean age was 17.93 years and by Anic-Milosevic et al., (2009) where mean age was 15.6 years.

Malocclusion

malocclusion was assessed in the present study based on incisor classification by the British Standard Institute (BSI) (Institute., 1983). The majority of subjects demonstrated class I malocclusion in the retrospective (40%) and the prospective (44%) samples, followed by Class III for the retrospective (22%) and class II division 2 for the prospective (31%) samples. Anic-Milosevic et al., (2009) reported similar findings, where the majority of PIC sample demonstrated Class I malocclusion (44%). However, in a study of an Arabic population, the most prevalent malocclusion reported was Class II division 2 for the PIC group (Al-Nimri and Gharaibeh, 2005).

The increased prevalence of Class I malocclusion in PIC subjects in the present study is in agreement to what was previously reported in the literature, that PIC is the only orthodontic problem these patients have, and the absence of malocclusion in these patients explains the frequent delay in diagnosis of PIC (Becker, 1998; Mercuri et al., 2013b)

Laterality of the PIC

PIC were found to occur more frequently on the left side than on the right side for both the retrospective (53 %) and the prospective (55 %) samples. This is similar to what was reported by Al-Khateeb et al., (2013), where unilateral PIC occurred more on the left side (54 %) than on the right side (46 %).

6.2 Parameters assessed and methods of measurements

Parameters assessed

The parameters assessed in this study were chosen based on several factors.

Maxillary inter-canine and inter-molar widths were assessed to further clarify the conflicting evidence reported in previous studies in subjects with PIC, with regard to maxillary width. Some studies reported a decrease in maxillary width compared to controls (McConnell et al., 1995), whereas others reported an increase (Al-Nimri and Gharaibeh, 2005) or no difference (Langberg and Peck, 2000a).

Palatal depth and palatal area were assessed previously with regard to unilateral PIC previously in two studies (Anic-Milosevic et al., 2009; Al-Khateeb et al., 2013).

This study aimed to assess these parameters in an Irish population as this has not been explored to date.

Bolton ratio was also assessed in this study to ascertain if the findings of previous studies reporting smaller tooth size in subjects with PIC compared to control subjects (Becker et al., 1981; Oliver et al., 1989; Al-Khateeb et al., 2013) were also pertinent in a Caucasians sample of Irish origin.

Other parameters assessed in this study have not been assessed before with regard to unilateral PIC, such as tooth shape classification and tooth ratio, arch shape classification and arch ratio.

This study assessed for the first time unilateral PIC in relation to face shape classification, face ratio and 3D distances and angles measured on 3D images taken for the prospective test and control groups.

Methods of assessment

Digital models were used to assess dental parameters, whereas 3D images were used to assess facial parameters. Previous studies used digital models for assessment of dental and arch parameters (Al-Khateeb et al., 2013), whereas other studies used digital callipers (Anic-Milosevic et al., 2009; Kim et al., 2012) or a Boley gauge (Al-Nimri and Gharaibeh, 2005). It has been reported previously that digital study models are of adequate accuracy and reproducibly (Abizadeh et al., 2012).

Assessment error

An error study was carried out in the present study for all measurements by randomly selecting twenty percent of cases and repeating all measurements after two weeks.

6.2.1. Maxillary inter-canine (IC) and inter-molar (IM) width

Inter-canine width

In the retrospective sample, the mean IC width was 2.36 mm smaller in the PIC group than in the control group, whereas this difference was 1.43 mm in the prospective sample. Both differences were statistically significant.

These findings are in agreement with those reported by several previous studies (McConnell et al., 1995; Saiar et al., 2006; Schindel and Duffy, 2007; Al-Khateeb et al., 2013). However, Al-Nimri and Gharaibeh, (2005) reported an increase in the transverse maxillary width in the PIC group compared to controls. Compared to the present study, Al-Khateeb et al., (2013) reported smaller IC width values for the test (mean 28.65, SD 2.63) and the control (mean 30.14, SD 2.11) groups. These differences may be due to differences in sample ethnicity between the two studies.

Inter-molar width

Unlike what was previously reported by several studies, where IM width was significantly smaller in the PIC group than in the control group (Saiar et al., 2006; Al-Khateeb et al., 2013), the results of this study showed no statistically significant difference between test and control groups. In the retrospective sample, this could be due to the limitations of the retrospective sample characteristics such as selection bias. However, other studies also found no difference in IM width between PIC and controls (Langberg and Peck, 2000a; Anic-Milosevic et al., 2009). McConnell et al., (1995) in their study did not differentiate between palatal and buccal canines, so their conclusions must be interpreted with caution.

The conflicting evidence reported in this study and in the literature with regard to IC and IM widths in subjects with PIC could be attributed to the differences in the sample characteristics, such as age and ethnicity.

6.2.2 Arch ratio and arch shape

Arch ratio

A mean difference of 1.04 was recorded between the test and the control groups in the retrospective sample, indicating an increased trend toward a tapered arch from in the test group than in the control group (Rai, 2010). This could be explained by the alveolar ridge on the side of the canine displacement being underdeveloped due to the PIC (Anic-Milosevic et al., 2009), resulting in a narrower arch shape and a smaller arch ratio.

However, no statistically significant differences were found between the test and control groups for the prospective sample.

Arch shape

A statistically significant difference was found in the distribution of arch shape between the test and control groups in the retrospective sample, with tapered arch shape being the most prevalent among the test group (48%) and ovoid arch shape being the most prevalent among the control group (43%).

These findings are in agreement with the arch ratio findings for the retrospective group, where a smaller arch ratio indicated a trend toward a more tapered arch shape in the test group (Rai, 2010)

Most previous studies that have reported on maxillary arch parameters used absolute distances. However, when comparing the shape, a relative ratio is more suitable than an absolute value (Kim et al., 2012).

In agreement with the present study, Kim et al., (2012) reported that the shape of the maxillary arch was narrower and longer in PIC subjects.

However for the prospective sample, no statistically significant difference was found in arch shape distribution between the test and control subjects, with ovoid arch shape being the most prevalent among the test and control groups.

The differences in findings with regard to arch shape and arch ratio between the retrospective and prospective samples may be a consequence of selection bias for the retrospective sample.

6.2.3 Palatal depth and palatal area

Palatal depth

Palatal depth increased significantly with age in both retrospective and prospective samples.

No statistically significant difference was recorded between the test and control groups for both samples. Anic-Milosevic et al., (2009) also found no significant difference in palatal depth between test and control groups. However, two studies reported a decrease in palatal depth (Kim et al., 2012; Al-Khateeb et al., 2013) in the test group compared to the control group. A reduction in palatal depth might be a consequence of PIC instead of a cause, which is demonstrated as an underdevelopment of the alveolar ridge on the impaction side (Al-Khateeb et al., 2013).

Differences in the findings between the present study and previous studies could be due to the differences in ethnicity of the groups studied, where Al-Khateeb et al., (2013) assessed an Arabic sample, and Kim et al., (2012) assessed an Asian sample. Moreover, differences in the method of assessment of palatal depth could play a role in differences of the findings. Al-Khateeb et al., (2013) assessed the palatal depth as the perpendicular distance from a line connecting palatal points located on the first molar at the gingival level to the palatal vault opposite to the first molars using an electronic sliding digital depth calliper. Whereas Kim et al., (2012) defined palatal depth as the vertical distance from the contact line between the mesiopalatal cusp tips of the right and left first molars to the palatal vault, and it was assessed using a Bernklau plate and a digital calliper.

Palatal area

Palatal area increased significantly with age for both retrospective and prospective samples. No statistically significant difference was recorded between the test and control groups in both samples.

Palatal area was assessed in subjects with unilateral PIC, and compared between the displaced and the non-displaced sides (Al-Khateeb et al., 2013), and was significantly larger on the displaced side. The difference between previous findings and the findings of the present study may be due to the shift of the midline toward the non-displacement side by the impacted canine. In addition, the method of assessment of the palatal area may also be a factor, where Al-Khateeb et al., (2013), assessed palatal area as the x and y coordinates of 12 points on the dental cast image. These were plotted to obtain a polynomial function that best described the curve related to the dental arch form.

6.2.4 Bolton TSD

No statistically significant difference was found in anterior Bolton ratio between the test and control groups for the retrospective sample. One of the limitations of the retrospective study design is selection bias that may have influenced the results of this sample. Nonetheless, the findings of the present study are in agreement with a previous study which reported no significant difference in Bolton ratio between a unilateral PIC group and a control group (Al-Khateeb et al., 2013). However for the prospective sample, a statistically higher Bolton ratio was recorded for the test group compared with the control group.

6.2.5 Tooth shape and tooth ratio

Tooth shape

Square and square/round were the most common tooth shape for the maxillary central incisor and lateral incisor respectively for the retrospective and prospective samples, with no significant difference between test and control subjects except for the maxillary right central incisor, where a significant difference in the distribution of tooth shape was found between test and control subjects.

Tooth ratio

Both retrospective and prospective samples showed no significance difference in maxillary central incisor and lateral incisor ratio between the test and control groups.

No previous studies have investigated the relation between PIC, tooth shape classification and tooth ratio. The results of this study suggest that there is no statistically significant difference in tooth shape and tooth ratio between test and control groups except for the maxillary right central incisor shape in the retrospective sample, where square/round shape showed significantly higher frequency in the test group compared to the control group.

These results are in agreement with a previous study reported on the size but not the shape of the maxillary lateral incisor where no difference was found in the size of maxillary lateral incisor between displacement and the non-displacement side in a unilateral PIC group (Becker et al., 2002)

6.2.6 Face shape and face ratio

Face shape

The most common face shape among the test group was ovoid (41%) and square (41%), whereas ovoid (54%) was the most common face shape among the control group for the prospective sample.

Face ratio

No significant difference was found between test and controls with regard to face ratio.

No previous study has investigated the relationship between face shape, face ratio and unilateral PIC.

Mercuri et al., (2013), assessed facial type and facial profile using clinical and photographic assessments in a group of buccally and PIC, and reported no significance association between facial type and PIC. Whereas normal facial profile was significantly associated with PIC.

The results of the present study may suggest that face shape and ratio does not play a role in the occurrence or aetiology of PIC.

6.2.7 3D distances and angles

Basal width was significantly smaller by almost 2 mm in test subjects compared to control subjects.

In a CBCT study, width of the nostrils and the nasal cavity width was assessed with regard to PIC subjects, and no difference was found between test and control groups (Kim et al., 2012)

The differences in reported results between the two parameters could be due to the differences in the method of assessment, where CBCT was used by Kim et al., (2012) and 3D imaging was used in the present study.

6.3 Strengths, limitations and clinical implications

Strengths

The strengths of this study lie in that it is the first study to assess unilateral PIC in a consecutive prospective sample. All previous studies that investigated PIC had a retrospective sample, and thus selection bias cannot be avoided. In addition to the prospective sample, this study included a retrospective sample of equivalent size, making a total sample size of 216 subjects, with 108 test subjects and 108 controls. All PIC subjects in this study were compared to a control matched for age, gender and malocclusion. Subjects with bilateral PIC were excluded, thus reducing confounding factors that may contribute to inconsistencies in the results.

There appears to be no previous studies that have reported on tooth shape classification and tooth ratio in relation to unilateral PIC. Similarly, maxillary arch shape and ratio have not been assessed previously in relation to unilateral PIC.

This would also appear to be the first study to carry out 3D imaging for subjects with unilateral PIC and their controls, to assess and compare several 3D distances and angles between the two groups. An additional strength is the use of 3D digital models to calculate arch parameters using OrthoAnalyser software.

Limitations

One of the limitations of this study is not being able to carry out a radiographic assessment for different dental anomalies associated with PIC in the control group, since it would be unethical to expose those subjects to unnecessary radiation.

Moreover, radiographic assessments of the severity of impaction parameters such as the mesiodistal and vertical position of PIC, inclination to the occlusal plane and terminal root position were not assessed in this study. Thus, some PIC cases might be mildly impacted and amenable for orthodontic alignment, while others might be severely impacted and indicated for surgical removal. The treatment outcomes for PIC in the retrospective and prospective samples were not recorded as well.

The PIC laterality was identified on the study models for the retrospective sample and clinically for the prospective sample, but was not confirmed radiographically for both samples.

A further limitation is that unilateral PIC prevalence could not be investigated, since it requires a larger sample size. And this could be a recommendation for future research.

Clinical implications

Clinical implications of this study include the confirmatory finding that subjects with unilateral PIC have smaller inter-canine width in comparison with controls. In addition, it highlights that subjects with unilateral PIC tend to have more anterior Bolton TSD ratio than controls.

Chapter Seven

Conclusions

Conclusions

The aims and null hypotheses of the present study were outlined in Chapter three. The conclusions and null hypotheses relating to each are given below.

Aim 1: To investigate if differences exist in inter-canine and inter-molar widths between subjects with and without unilateral PIC.

Conclusion

- Retrospective and prospective samples

Inter-canine width was significantly smaller in unilateral PIC subjects compared to controls, whereas inter-molar width was not.

Null hypothesis 1

There is no difference in inter-canine and inter-molar width between subjects with and without unilateral PIC.

For inter-canine width: the null hypothesis was rejected.

For inter-molar width: the null hypothesis was accepted.

Aim 2: To investigate if differences exist in palatal depth and palatal area between subjects with and without unilateral PIC.

Conclusion

- Retrospective and prospective samples

Palatal depth and palatal area did not differ significantly between subjects with and without unilateral PIC.

Null hypothesis 2

There is no difference in palatal depth and palatal area between subjects with and without unilateral PIC.

The null hypothesis was accepted.

Aim 3: To investigate if differences exist in anterior Bolton TSD ratio between subjects with and without unilateral PIC.

Conclusion

- Retrospective sample

No statistically significant difference was recorded between test and control groups.

- Prospective sample

Anterior Bolton TSD was significantly higher in prospective unilateral PIC subjects compared to controls.

Null hypothesis 3

There is no difference in anterior Bolton TSD ratio between subjects with and without unilateral PIC.

The null hypothesis was accepted for the retrospective sample.

The null hypothesis was rejected for the prospective sample.

Aim 4: To investigate if differences exist in maxillary arch shape and ratio between subjects with and without unilateral PIC.

Conclusion

- Retrospective sample

Maxillary arch ratio was significantly smaller in retrospective unilateral PIC subjects with tapered arch shape being the most common.

- Prospective sample

Arch shape distribution and arch ratio did not differ significantly between test and control groups.

Null hypothesis 4

There is no difference in maxillary arch shape and ratio between subjects with and without unilateral PIC.

The null hypothesis was rejected for the retrospective sample.

The null hypothesis was accepted for the prospective sample.

Aim 5: To investigate if differences exist in maxillary central incisor and lateral incisor shape and ratio between subjects with and without unilateral PIC.

Conclusion

- Retrospective sample

Square/tapered tooth shape was significantly more common in the retrospective unilateral PIC group. No statistically significant difference was found in tooth ratio between test and control groups for any of the maxillary incisors teeth.

- Prospective sample

Tooth shape distribution and tooth ratio did not differ significantly between test and control groups.

Null hypothesis 5

There is no difference in maxillary central incisor and lateral incisor shape and ratio between subjects with and without unilateral PIC.

The null hypothesis was rejected for the retrospective sample.

The null hypothesis was accepted for the prospective sample.

Aim 6: To investigate if differences exist in face shape and face ratio between subjects with and without unilateral PIC.

Conclusion

- Prospective sample

No significant difference was found in face shape and face ratio between subjects with and without unilateral PIC.

Null hypothesis 6

There is no difference in face shape and face ratio between subjects with or without unilateral PIC.

The null hypothesis was accepted.

Aim 7: To investigate if differences exist in 3D facial distances and angles between subjects with and without unilateral PIC.

Conclusion

- Prospective sample

Basal width was significantly smaller in subjects with unilateral PIC compared to controls. No statistically significant difference was recorded for all other 3D distances and angles between the test and control groups.

Null hypothesis 7

There is no difference in 3D facial distances and angles between subjects with and without unilateral PIC.

The null hypothesis was rejected.

Chapter Eight

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Chapter Nine

Appendices

Appendix 1 Ethical approval

COISTE EITICE UM THAIGHDE CLINICIÚIL
Clinical Research Ethics Committee

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Lancaster Hall,
6 Little Hanover Street,
Cork,
Ireland.

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Our ref: ECM 4 (n) 05/11/13

4th November 2013

Professor Declan Millett
Professor of Orthodontics
Cork University Dental School & Hospital
Wilton
Cork

Re: Associated dentofacial parameters of palatal canine ectopia.

Dear Professor Millett

Expedited approval is granted to carry out the above study at:

- Cork University Dental School and Hospital.

The following documents have been approved:

- Application Form
- Protocol Ectopic Canines Version 1 dated October 2013
- Consent Form Version 1 October 2013.

We note that the co-investigators involved in this study will be:

- Niamh Kelly and Postgraduate Students.

Yours sincerely

Michael Molloy

Professor Michael G Molloy
Chairman
Clinical Research Ethics Committee
of the Cork Teaching Hospitals

Appendix 2 Prospective subject informed consent from

CONSENT BY SUBJECT FOR PARTICIPATION IN RESEARCH PROTOCOL

Section A

Protocol Number:________________ Patient Name:______
______

Title of Protocol: Associated dentofacial parameters of palatal canine ectopia

Doctor(s) Directing Research: Prof. D. Millett Phone: 021 4901139

You are being asked to participate in a research study. The doctors at University College Cork study the nature of disease and attempt to develop improved methods of diagnosis and treatment. In order to decide whether or not you want to be a part of this research study, you should understand enough about its risks and benefits to make an informed judgment. This process is known as informed consent. This consent form gives detailed information about the research study, which will be discussed with you. Once you understand the study, you will be asked to sign this form if you wish to participate.

Section B

I. NATURE AND DURATION OF PROCEDURE(S):

In this study we wish to find out if the position of your adult 'eye' teeth is connected to the shape of your other teeth, to the shape of your top set of teeth and to the shape of your face

To do this we will take a mould of your top set of teeth and pour a plaster cast of your teeth. We will then take a special picture of this cast (3D scan) to allow us to make measurements.

We may also take special pictures called three-dimensional (3D) images of your face. 3D pictures allow us to see and examine your face on a computer screen from all directions. These pictures allow us to measure your face very accurately. A camera will be used to take pictures of your face at rest. We will tell you what we want you to do before we take the picture. It will take about 15 minutes for you to get the 3D picture taken.

Only those directly involved in the study will have access to your details. All your information will be confidential. At the end of the study we hope to publish our findings in a scientific journal. Your name will never be shown in any report or publication.

II. POTENTIAL RISKS AND BENEFITS:

There are no risks associated with having your 3D pictures taken. The information we collect during the study will help us understand relationships between teeth and face shape. This will allow us to better plan orthodontic treatment in the future.

III. POSSIBLE ALTERNATIVES:

Treatment may still proceed if you decide not to take part. It is your choice to take part in this study or not. You can withdraw at any time without giving a reason.

Section C AGREEMENT TO CONSENT

The research project and the treatment procedures associated with it have been fully explained to me. All experimental procedures have been identified and no guarantee has been given about the possible results. I have had the opportunity to ask questions concerning any and all aspects of the project and any procedures involved. I am aware that participation is voluntary and that I may withdraw my consent at any time. I am aware that my decision not to participate or to withdraw will not restrict my access to health care services normally available to me. Confidentiality of records concerning my involvement in this project will be maintained in an appropriate manner. When required by law, the records of this research may be reviewed by government agencies and sponsors of the research.

I understand that the sponsors and investigators have such insurance as is required by law in the event of injury resulting from this research.

I, the undersigned, hereby consent to participate as a subject in the above described project conducted at the Cork Teaching Hospitals. I have received a copy of this consent form for my records. I understand that if I have any questions concerning this research, I can contact the doctor(s) listed above. If I have further queries concerning my rights in connection with the research, I can contact the Clinical Research Ethics Committee of the Cork Teaching Hospitals, Lancaster Hall, 6 Little Hanover Street, Cork.

After reading the entire consent form, if you have no further questions about giving consent, please sign where indicated.

Doctor: ______________________ ____________________________________
Signature of Subject

Witness:______________________ ____________________________________

Signature of Parent or Guardian

Date: ____________ Time:__________AM

(Circle) PM