*European Journal of Orthodontics* 19 (1997) 171–183 

# Normal eruption of the maxillary canine quantified in three dimensions

Juanita Coulter and Andrew Richardson
Division of Orthodontics, The Queens University of Belfast, Northern Ireland, UK

SUMMARY The normal eruption path of maxillary canine teeth was quantified on annual lateral and depressed postero-anterior cephalometric radiographs of 15 females and 15 males aged 5–15 years. The lateral view was rotated so that the horizontal coincided with the Frankfort plane on the depressed view, thus orientating the two views in space.

Successive positions of canine cusps were marked on tracings of both views superimposed on the anterior outline of the zygomatic process. All positions of the canine cusps were digitized and the horizontal, vertical and lateral annual differences found by subtraction, taking the first position of the canine as the origin. The chronological data were corrected for enlargement and adjusted to increments of 12 months. Adjustments were also made to take into account varying ages of eruption.

Posterior movement occurred between 7 and 13 years (all three years before eruption, the year of eruption and the following year). Vertical movement occurred between 5 and 13 years (all of the six years before eruption, the year of eruption and the following year). Lateral movement tended to be in a palatal direction up to 2 years before eruption followed by significant buccal movement in the year before eruption, the year of eruption and the following year. Data are given for eruption in three planes.

## Introduction

The frequent impaction of maxillary canine teeth (the canines) in patients attending for orthodontic treatment has resulted in many papers describing possible aetiological factors and alternative approaches to treatment. However, for a description of the normal path of canine eruption, orthodontists rely heavily on the original work of Broadbent (1941) published more than 50 years ago. According to his classical narrative, the permanent maxillary canine begins to calcify at approximately 12 months of age between the roots of the first deciduous molar. It is then left behind as the deciduous molar erupts, allowing development of the first premolar between the deciduous molar roots. At this stage the permanent canine is located immediately above both the first premolar and the first deciduous molar. As the deciduous teeth erupt towards the occlusal plane, the permanent incisor and canine crypts migrate forward in the jaws at a greater rate than the forward movement of the deciduous teeth themselves. At the age of 7 years, the canine crown is medial to the root of its deciduous predecessor, and there is a vertical overlap of approxiamtely 3 mm (Noyes, 1930). The positional changes between 8 and 10 years of age need careful observation for detection of potential impaction (Williams, 1981). During this stage of development the canine normally migrates buccally from a position lingual to the root apex of the deciduous precursor; however, some canines do not make the transition from the palatal to the buccal side of the dental arch and remain palatally unerupted. With sufficient increase in the size of the subnasal area, the maxillary canine normally moves downward, forward and laterally away from the root end of the lateral incisor. Between 8 and 12 years of age, the 'ugly duckling' stage, there is insufficient space at the apical base to permit the axis of the lateral incisor to shift into the more erect alignment of young adulthood until the canine approaches its place in the dental arch. In the final phase of eruption, canines drive their way

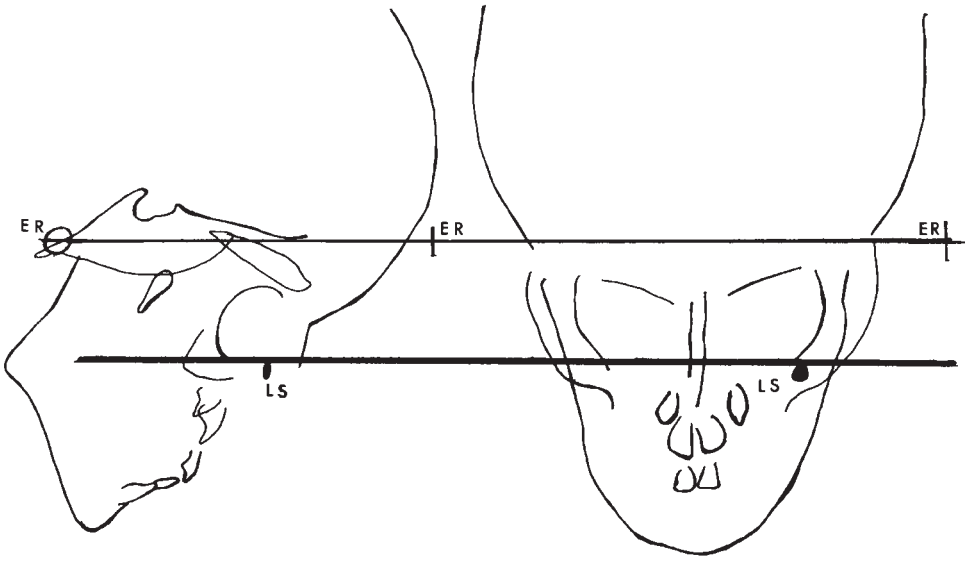


**Figure 1** Orientation of lateral and depressed postero-anterior radiographs. ER, ear rod; LS, lead spot.

between the lateral incisors and first premolars, forcing these teeth to become more upright.

All authors agree that the maxillary canine follows a longer, and more tortuous path of eruption than any other tooth, but the length of this eruption path and the magnitude and timing of the changes in direction do not seem to have been quantified.

The object of this study was to measure the normal eruption pathway of the maxillary canine in three dimensions from 5 to 15 years of age.

## Material and methods

Annual lateral and depressed postero-anterior (PA) cephalometric radiographs of 15 females and 15 males aged 5–15 years were drawn from the Belfast Growth Study records (Adams, 1972). The following were the criteria for selection: (i) all 22 radiographic records available; (ii) both maxillary canines erupted into good position as confirmed by examination of study casts taken at 6 monthly intervals; (iii) no orthodontic treatment or surgery carried out during the period under investigation; (iv) the lateral incisors present.

To assist the radiographer in taking the films, a lead spot was stuck to the skin over the lowest point on the rim of the right orbit. For the lateral view, the head was orientated so that the spot coincided with a horizontal line passing through the ear rod marked on a large protractor. For the PA view the head was tilted downwards so that the spot coincided with a second line on the protractor at 30 degrees to the horizontal. The ear rods and spot showed clearly on both films. In order to ensure that the lateral and PA films were precisely orientated to each other, the following technique was used (Fig. 1). The lateral and depressed PA radiographs at 5 years were placed side by side on the tracing desk so that a horizontal line passed through the mid-points of the images of the ear rods. A second horizontal line was drawn through the upper margin of the lead spot on the PA view. The lateral view was then rotated round the image of the ear rod until the upper margin of the lead spot on the lateral view coincided with the second line. Thus, the views were orientated to each other in the three planes of space. Using acetate tracing material, the horizontal lines and the outline of the anterior surface of the zygomatic process were traced from both radiographs using a 9H pencil. The anterior surface of the zygomatic process

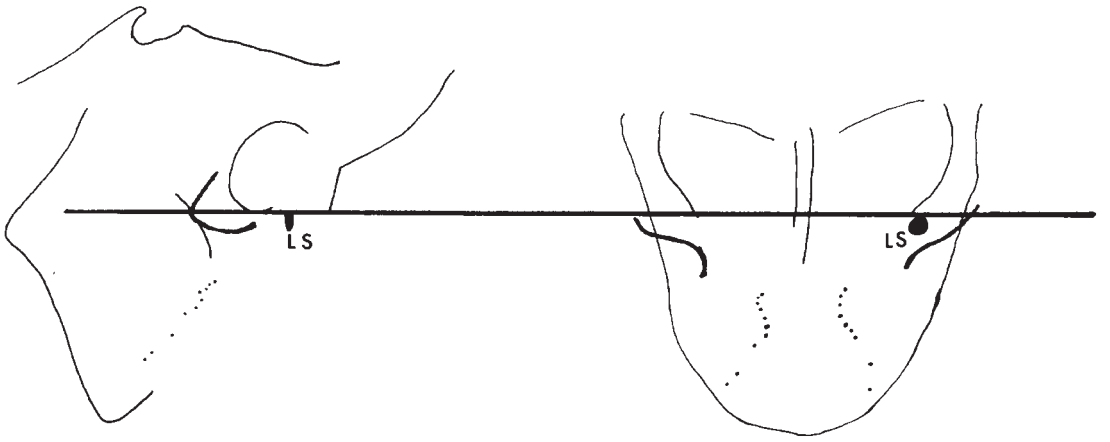


**Figure 2** Composite tracing showing annual movement of the canine cusp tip. LS, lead spot.

was chosen for superimposition as it has been shown to be stable in relation to metallic implants throughout the period in question (Björk and Skieller, 1977; Doppel *et al.*, 1994). The canine tips were marked on both tracings with dots. Where the vertical positions of the canines did not correspond on the lateral view, it was possible to differentiate between the right and left sides by noting which was lower on the PA view. Two tracings were made of each lateral view to show the position of the right and left canines separately. In addition, the palatal outline was traced from the lateral view and the nasal septum from the PA view. The lateral tracings were placed individually over the lateral view at 6 years with the anterior surface of the zygomatic process and palatal outlines in register and the second position of the canine tips added to the tracing. Similarly, the second positions of the canine tips were added to the PA tracing with the anterior surface of the zygomatic process and midline in register.

This process was repeated with each pair of radiographs in turn so that the successive locations of each canine cusp was represented by a series of dots (Fig. 2). No more than one set of tracings was made in any period of 90 minutes in order to reduce tracer fatigue. All tracings were made by the same observer and were repeated after at least 2 weeks for reproducibility testing.

Digitization of the tracings were performed using an SS1/Microcad Lightmaster backlit digitizing system 1624LM-PC and a GTCO T5 16 button Clearvu cursor. A horizontal line generated by the digitizer was marked on the screen. Tracings were placed on the screen with the tracing horizontally superimposed on the horizontal line and successive positions of the canine tip digitized. The '*x*' (horizontal) and '*y*' (vertical) coordinates were digitized on the lateral tracings and the '*z*' (lateral) coordinate on the PA tracing. All digitizations were repeated after an interval of time. Thus, there were double digitization of double tracings of lateral and PA views of both canines of 30 subjects on 11 occasions, giving 5280 digitizations in all. These data were imported into a spreadsheet for application of correction factors and subsequent statistical analysis using SPSS for Windows.

The position of the canine tip at age 5 years was used as the origin.

The four recordings of annual movements of the canine tooth were averaged to give the best estimate of the annual changes.

### *Correction factors*

*Magnification factor.* The cephalostat layout is illustrated in Figure 3. Midline structures were 1524 mm from the tube and 1654 mm from the tube to the film. The distance from each canine to the midline was measured on the depressed PA view and found to vary between 15 and 30 mm. For the right maxillary canine the magnification varied from 1654/1494 = 1.11:1 if 30 mm from

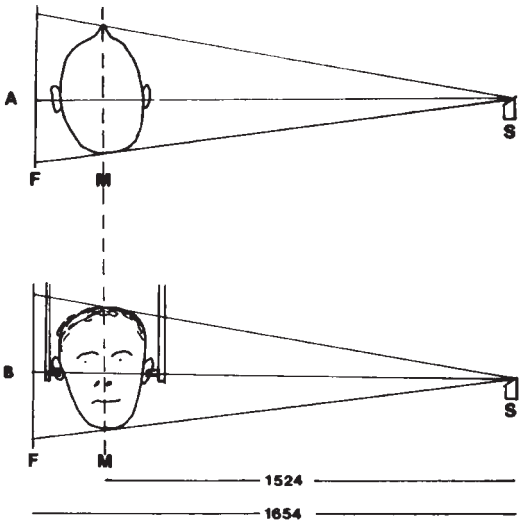


**Figure 3** Layout for cephalometric radiographs.

the midline, to 1654/1509 = 1.10:1 if 15 mm from the midline. When applied to the data, it was found that the greatest possible effect of magnification was 0.01 mm. This insignificant variation led to the use of a common correction factor of 0.905 for the right canine, and 0.935 for the left canine, as depicted on the lateral view. In the depressed PA view the range of variation between the canine and the ear rod plane was between 20 and 50 mm. A common correction factor of 0.94 was used for the PA measurements.

*Age.* Six per cent of the radiographs were not taken within 3 months of the anniversary of the first. The data were standardized to a 12 month observation period.

Data following these corrections were called the chronological data. The mean annual eruption increments were tested for statistical significance against a theoretical expectation of zero on the null hypothesis using paired *t*-tests.

The reproducibility of measurements between times of tracing and times of digitization was tested using paired *t*-tests, correlation coefficients and the standard error according to Dahlberg's (1940) method.

Using the theorem of Pythagoras, the combined distance moved in the *x*-, *y*- and *z*-planes was calculated for both canines. The data were then reorganized to take account of individual variations in age of eruption into the oral cavity derived from the study casts taken at 6 monthly intervals. Canine tooth movement could then be analysed in relation to the date of eruption (the dental stage data). The mean age of eruption was 11.7 years for females and 12.1 years for males.

## Results

The values for the reproducibility tests are given in Table 1.

There were no significant differences between digitizations or between tracings, the correlation coefficients varied from 0.949 to 0.999 and the standard errors given by Dahlberg's equation varied from 0.04 to 0.32 mm.

Student's *t*-tests showed no significant

**Table 1** Reproducibility data for *x*-, *y*- and z-coordinates of left and right maxillary canines between digitizations and between tracings

| | Between digitizations | | | | Between tracings | | | |
|---|---|---|---|---|---|---|---|---|
| Coordinates | Mean (mm) | SD (mm) | *r* | SE (Dahlberg) (mm) | Mean (mm) | SD (mm) | *r* | SE (Dahlberg) (mm) |
| LX | –0.0003 | 0.058 | 0.999 | 0.040 | –0.0060 | 0.400 | 0.976 | 0.277 |
| LY | 0.0017 | 0.074 | 0.999 | 0.054 | 0.156 | 0.370 | 0.984 | 0.242 |
| LZ | –0.0020 | 0.063 | 0.999 | 0.043 | –0.0025 | 0.368 | 0.971 | 0.237 |
| RX | 0.003 | 0.096 | 0.999 | 0.045 | –0.0023 | 0.387 | 0.979 | 0.249 |
| RY | –0.0028 | 0.455 | 0.978 | 0.046 | 0.0044 | 0.438 | 0.980 | 0.277 |
| RZ | –0.0017 | 0.067 | 0.999 | 0.049 | –0.354 | 0.481 | 0.949 | 0.323 |

L, left; R, right; SD, standard deviation; SE, standard error; *r*, correlation coefficient.

differences between eruption in males and females at the 1 per cent level and the data were pooled for subsequent calculations.

*Horizontal movement—chronological data*

The total horizontal movement of all canines between 5 and 15 years averaged 11.48 mm in a posterior direction. The annual changes are shown in Table 2. Initially, the direction was posterior in some cases and anterior in others. This was followed by a period of posterior movement which was statistically significant for each year between 7 and 13 years. These movements are illustrated in Figure 4, which shows the movement of six typical canines. The crosses indicate stages of clinical eruption.

*Vertical movement—chronological data*

The total vertical movement of all canines between 5 and 15 years averaged 18.56 mm. The annual changes are shown in Table 3. Movement in the vertical plane was always downward. The annual movement in each year from 5 to 13 years was highly significant at the 0.1 per cent level with the exception that the significance level for the left canine between the ages of 12 and 13 was 1 per cent. The right canine also showed significant changes between the age of 13 and 14 at the 5 per cent level.

These movements are illustrated in Figure 5, which shows six typical canines. The crosses indicate stages of clinical eruption. The graphs for the *y*-coordinate are consistent with all movement being in the same direction. The rate and timing of eruption shows individual variation, with most of the movement occurring between the ages of 5 and 13 years.

*Lateral movement—chronological data*

The mean overall movement of the canine tip in the lateral plane was 2.67 mm in a buccal direction. Movement in the lateral plane varied from year to year as shown in Table 4. For the left canine, negative movement was towards the midline and positive movement was away from the midline. For the right canine, negative movement was away from the midline and positive movement was towards the midline. Between the ages of 5 and 9 years both positive and negative movement occurred. The movement was mainly palatal but not statistically significant. Movement occurring between the ages of 10 and 12 years was invariably in a buccal direction. The left canine showed significant movement between 11 and 12 years at the 0.1 per cent level and between 12 and 13 years at the 5 per cent level. Movement of the right canine between 10 and 11 years was significant at the 0.1 per cent level, between 11 and 12 years at the 1 per cent level, and between 12 and 13 years at the 5 per cent level.

These movements are illustrated in Figure 6, which shows six typical canines. The crosses indicate stages of clinical eruption. The graphs for the *z*-coordinate are quite consistent. Initially there was either buccal or palatal movement. Between the ages of 5 and 8 movement was predominantly palatal. Thereafter movement was mainly buccal. Between the ages of 10 and 12 years there was marked buccal movement.

*Three-dimensional data*

The mean total distance travelled by canines was 21.99 mm.

The three-dimensional data calculated using Pythagoras' theorem showed that the combined annual movement occurring in each year from the age of 5 to 13 years was highly significant at the 0.1 per cent level (Table 5). The greatest movement occurred between 9 and 12 years of age.

*Dental stage data*

Movement in the horizontal plane was significant at the 0.1 per cent level in each of the 3 years prior to the appearance of the canine in the oral cavity, in the year of eruption and in the following year (Table 6). Movement in the vertical plane was significant at the 0.1 per cent level in the 6 years prior to appearance in the oral cavity, and in the year after appearance in the oral cavity. Movement in the second year after eruption was much diminished, although significant at the 5 per cent level (Table 7). Movement in the lateral plane was significant at the 1 per cent level in the year prior to appearance of the canine in the oral cavity, at the 0.1 per cent level in the year of appearance in the oral cavity, and in the following year at the 5 per cent level (Table 8).

**Table 2** Annual movement of canine teeth in the horizontal ($x$) plane—chronological data

| Age (years) | | Mean (mm) | SD (mm) | $t$-value |
|---|---|---|---|---|
| Left canine | | | | |
| 5–6 | LXC1 | –0.16 | 0.98 | –0.88 |
| 6–7 | LXC2 | –0.33 | 1.20 | –1.49 |
| 7–8 | LXC3 | –1.01*** | 1.30 | –4.26 |
| 8–9 | LXC4 | –2.04*** | 1.60 | –6.97 |
| 9–10 | LXC5 | –2.44*** | 1.51 | –8.90 |
| 10–11 | LXC6 | –2.10*** | 1.54 | –7.46 |
| 11–12 | LXC7 | –2.03*** | 1.97 | –5.64 |
| 12–13 | LXC8 | –0.94** | 1.70 | –3.04 |
| 13–14 | LXC9 | –0.08 | 0.92 | –0.44 |
| 14–15 | LXC10 | –0.21 | 1.01 | –1.14 |
| Right canine | | | | |
| 5–6 | RXC1 | 0.04 | 0.81 | 0.24 |
| 6–7 | RXC2 | –0.05 | 1.00 | –0.27 |
| 7–8 | RXC3 | –1.61*** | 1.46 | –6.02 |
| 8–9 | RXC4 | –1.98*** | 1.85 | –5.87 |
| 9–10 | RXC5 | –1.83*** | 2.23 | –4.51 |
| 10–11 | RXC6 | –2.06*** | 1.63 | –6.92 |
| 11–12 | RXC7 | –2.17*** | 1.62 | –7.33 |
| 12–13 | RXC8 | –1.02*** | 1.49 | –3.76 |
| 13–14 | RXC9 | –0.65 | 1.41 | –2.52 |
| 14–15 | RXC10 | –0.16 | 0.52 | –1.68 |

***$P < 0.001$; **$P < 0.01$.

+, anterior; –, posterior; L, left; R, right; X, $x$-coordinate; C, standardized for magnification and age.

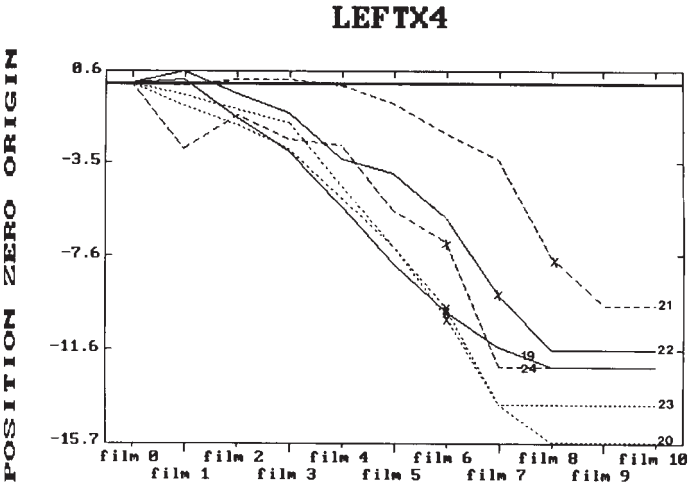


**Figure 4** Antero-posterior movement of six typical canines (mm). Negative values indicate posterior movement. Film 0 at 5 years, film 10 at 15 years. Crosses indicate the stages of clinical eruption.

## Discussion

The horizontal defined on the lateral view is unconventional. Depressed PA views were used for the growth study to diminish superimposition of the jaws and teeth on more posterior cranial structures. In order to make orthogonal comparisons, the lateral views were similarly depressed as described for the purposes

**Table 3** Annual movement of canine teeth in the vertical (*y*) plane—chronological data

| Age (years) | | Mean (mm) | SD (mm) | *t*-value |
|---|---|---|---|---|
| Left canine | | | | |
| 5–6 | LYC1 | –1.15*** | 0.52 | –12.12 |
| 6–7 | LYC2 | –1.41*** | 0.68 | –11.31 |
| 7–8 | LYC3 | –1.87*** | 1.12 | –9.10 |
| 8–9 | LYC4 | –2.66*** | 1.79 | –8.13 |
| 9–10 | LYC5 | –3.38*** | 1.86 | –10.01 |
| 10–11 | LYC6 | –3.16*** | 2.07 | –8.36 |
| 11–12 | LYC7 | –2.86*** | 2.26 | –6.92 |
| 12–13 | LYC8 | –1.43** | 2.24 | –3.51 |
| 13–14 | LYC9 | –0.68 | 1.87 | –2.00 |
| 14–15 | LYC10 | –0.14 | 0.46 | –1.71 |
| Right canine | | | | |
| 5–6 | RYC1 | –0.10*** | 0.77 | –7.11 |
| 6–7 | RYC2 | –1.35*** | 0.68 | –10.77 |
| 7–8 | RYC3 | –1.83*** | 1.42 | 7.03 |
| 8–9 | RYC4 | –2.48*** | 1.62 | 8.42 |
| 9–10 | RYC5 | –2.74*** | 1.27 | 11.82 |
| 10–11 | RYC6 | –3.13*** | 1.93 | 8.86 |
| 11–12 | RYC7 | –3.10*** | 2.80 | 6.06 |
| 12–13 | RYC8 | –1.66*** | 2.28 | 4.00 |
| 13–14 | RYC9 | –0.89* | 2.00 | 2.44 |
| 14–15 | RYC10 | –0.07 | 0.28 | 1.45 |

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.
–, downward; L, left; R, right; Y, *y*-coordinate; C, standardized for magnification and age.

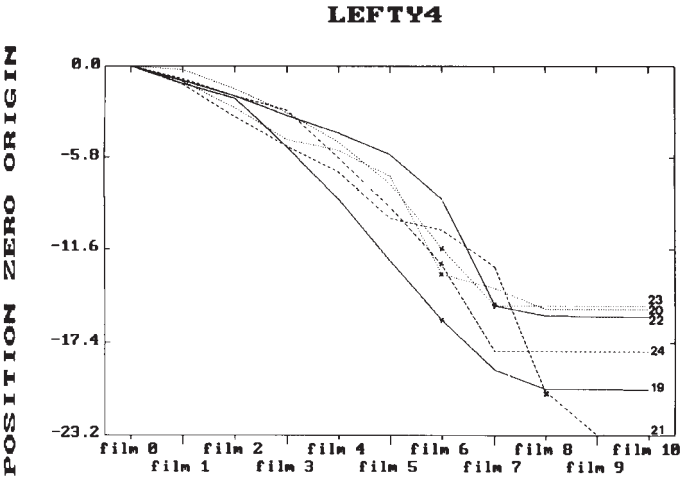


**Figure 5** Vertical movement of six typical canines (mm). Negative values indicate downward movement. Film 0 at 5 years, film 10 at 15 years. Crosses indicate the stages of clinical eruption.

of this study. Thus, horizontal and vertical movements were measured with the horizontal 30 degrees depressed in relation to the Frankfort horizontal.

The anterior surface of the zygomatic process of the maxilla was the outline of choice for superimposition of the annual radiographs since it is a natural reference structure in the maxilla

**Table 4** Annual movement of canine teeth in the lateral (*z*) plane—chronological data

| Age (years) | | Mean (mm) | SD (mm) | *t*-value |
|---|---|---|---|---|
| Left canine | | | | |
| 5–6 | LZC1 | –0.28 | 0.88 | –1.72 |
| 6–7 | LZC2 | –0.16 | 1.06 | –0.82 |
| 7–8 | LZC3 | 0.03 | 0.94 | 0.15 |
| 8–9 | LZC4 | –0.06 | 1.82 | –0.19 |
| 9–10 | LZC5 | 0.36 | 2.00 | 0.99 |
| 10–11 | LZC6 | 0.41 | 1.66 | 1.34 |
| 11–12 | LZC7 | 1.30*** | 0.26 | 5.67 |
| 12–13 | LZC8 | 0.66* | 1.73 | 2.09 |
| 13–14 | LZC9 | 0.09 | 0.74 | 0.65 |
| 14–15 | LZC10 | 0.07 | 0.89 | 0.44 |
| Right canine | | | | |
| 5–6 | RZC1 | 0.35** | 0.67 | 2.91 |
| 6–7 | RZC2 | –0.21 | 1.09 | –1.06 |
| 7–8 | RZC3 | 0.56 | 1.73 | 1.75 |
| 8–9 | RZC4 | –0.36 | 1.34 | –1.48 |
| 9–10 | RZC5 | –0.10 | 1.28 | –0.42 |
| 10–11 | RZC6 | –1.27*** | 1.60 | –4.34 |
| 11–12 | RZC7 | –0.87** | 1.57 | –3.04 |
| 12–13 | RZC8 | –0.62* | 1.53 | –2.22 |
| 13–14 | RZC9 | –0.35 | 1.16 | –1.65 |
| 14–15 | RZC10 | –0.03 | 0.50 | –0.28 |

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.
Left canine: +, buccal; –, palatal.
Right canine: –, buccal; +, palatal.
L, left; R, right; Z, *z*-coordinate; C, standardized for magnification and age.

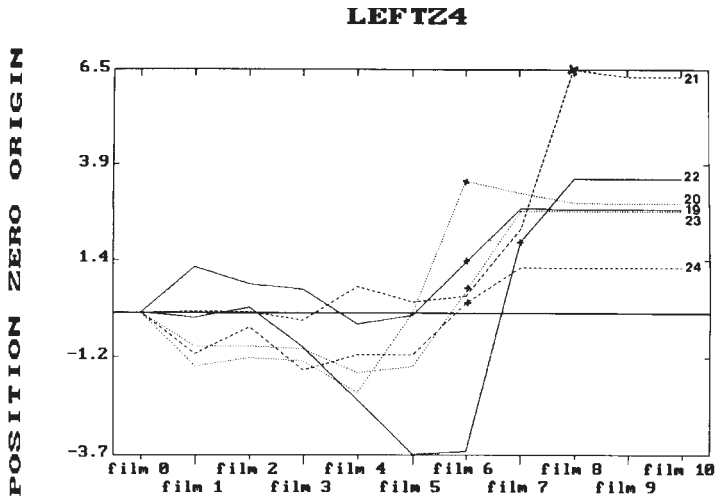


**Figure 6** Lateral movement of six typical canines (mm). Positive values indicate buccal movement, negative values palatal movement. Film 0 at 5 years, film 10 at 15 years. Crosses indicate the stages of clinical eruption.

which is stable throughout the period under review (Björk and Skieller, 1977; Doppel *et al.*, 1994). In this study identification of the anterior surface of the zygomatic process was confirmed by radiographing a dried skull with the area marked with lead foil.

**Table 5** Annual combined movement of canine teeth in the three planes of space—chronological data

| Age (years) | | Mean (mm) | SD (mm) | *t*-value |
|---|---|---|---|---|
| Left canine | | | | |
| 5–6 | LC1 | 1.70*** | 0.71 | 13.04 |
| 6–7 | LC2 | 2.14*** | 0.72 | 16.27 |
| 7–8 | LC3 | 2.59*** | 1.26 | 11.22 |
| 8–9 | LC4 | 3.92*** | 2.20 | 9.76 |
| 9–10 | LC5 | 4.70*** | 2.26 | 11.41 |
| 10–11 | LC6 | 4.37*** | 2.19 | 10.93 |
| 11–12 | LC7 | 4.05*** | 2.85 | 7.79 |
| 12–13 | LC8 | 2.18*** | 3.08 | 3.89 |
| 13–14 | LC9 | 0.81 | 2.17 | 2.04 |
| 14–15 | LC10 | 0.52* | 1.35 | 2.13 |
| Right canine | | | | |
| 5–6 | RC1 | 1.46*** | 0.80 | 10.02 |
| 6–7 | RC2 | 1.98*** | 0.72 | 15.17 |
| 7–8 | RC3 | 3.14*** | 1.86 | 9.28 |
| 8–9 | RC4 | 3.76*** | 1.94 | 10.60 |
| 9–10 | RC5 | 3.89*** | 1.94 | 10.96 |
| 10–11 | RC6 | 4.35*** | 2.38 | 10.01 |
| 11–12 | RC7 | 4.33*** | 3.01 | 7.88 |
| 12–13 | RC8 | 2.23*** | 2.99 | 4.08 |
| 13–14 | RC9 | 1.25* | 2.67 | 2.56 |
| 14–15 | RC10 | 0.29* | 0.73 | 2.17 |

***$P < 0.001$; *$P < 0.05$.
L, left; R, right; C, standardized for magnification and age.

From the reproducibility tests it seems reasonable to conclude that there were no systematic or random errors in the method that would undermine the results of the investigation.

The maxillary canine does not follow a direct path from its position at the age of 5 years until it reaches full occlusion. The 30 cases studied were quite consistent, with all following a general path with wavering variations in the antero-posterior and bucco-lingual directions.

In the horizontal plane, movement was mostly posterior although initial variation between negative and positive movement was recorded. Between 7 and 13 years of age, statistically significant posterior movement occurred. On average the greatest annual movement occurred between 9 and 12 years of age. The greatest annual movement in the vertical plane also occurred between 9 and 12 years of age. After 13 years the annual movement was less than 1 mm.

Movement in the lateral plane between 5 and 9 years of age was small and mainly in a palatal direction. Thereafter buccal movement occurred. This buccal movement was greatest between 10 and 12 years of age. The discrepancy between the ages of significant buccal movement between left and right canines was smoothed in the dental stage data, which showed consistent levels of significance in the year prior to eruption, the year of eruption and the year following eruption.

It seems that the maxillary canine tooth does have a long eruptive pathway, moving an average of 11.48 mm posteriorly, 18.56 mm vertically and 2.67 mm laterally. Since movement in the antero-posterior plane was mainly posterior and in the vertical plane was always downward, the above figures give a good indication of total movement in these directions. In the lateral plane, however, because initial movement was palatal and subsequent movement was buccal, the figure of 2.67 mm only represents the average difference in position between the canine tip at 5 and 15 years of age. There was an average difference of 5 mm between the most palatal and the most buccal recorded positions of the canine tip.

The long eruptive pathway described in the literature by Broadbent (1941), Dewel (1949), Kay (1977), Hovell (1966) and Moss (1972) can

**Table 6** Annual movement of canine teeth in the horizontal ($x$) plane—dental stage data. +1 is the year of eruption

| Year | | Mean (mm) | SD (mm) | No. of canines | $t$-value |
|---|---|---|---|---|---|
| Left canine | | | | | |
| –8 | LXD–8 | 0.17 | 0.15 | 2 | 1.55 |
| –7 | LXD–7 | 0.33 | 2.12 | 2 | 0.22 |
| –6 | LXD–6 | 0.43 | 0.63 | 4 | –1.34 |
| –5 | LXD–5 | –0.41 | 0.99 | 12 | –1.41 |
| –4 | LXD–4 | –0.26 | 1.22 | 22 | –1.00 |
| –3 | LXD–3 | –0.35 | 1.07 | 29 | –1.75 |
| –2 | LXD–2 | –0.96*** | 1.06 | 30 | –5.05 |
| –1 | LXD–1 | –1.82*** | 1.32 | 30 | –7.58 |
| 0 | LXD 0 | –2.15*** | 1.71 | 30 | –6.94 |
| +1 | LXD+1 | –3.54*** | 1.80 | 30 | 10.73 |
| +2 | LXD+2 | –1.99*** | 1.63 | 28 | –6.42 |
| +3 | LXD+3 | –0.36 | 0.98 | 28 | –2.00 |
| +4 | LXD+4 | 0.04 | 0.16 | 26 | 1.33 |
| +5 | LXD+5 | 0 | 0 | 0 | 0 |
| +6 | LXD+6 | 0 | 0 | 0 | 0 |
| +7 | LXD+7 | 0 | 0 | 0 | 0 |
| Right canine | | | | | |
| –8 | RXD–8 | 0 | 0 | 0 | 0 |
| –7 | RXD–7 | 0.71 | 0.81 | 3 | 1.51 |
| –6 | RXD–6 | –0.13 | 1.04 | 14 | –0.30 |
| –5 | RXD–5 | 0.27 | 0.77 | 24 | 1.29 |
| –4 | RXD–4 | –0.64** | 0.94 | 24 | –3.37 |
| –3 | RXD–3 | –0.63 | 1.64 | 28 | –2.03 |
| –2 | RZD–2 | –1.02** | 1.63 | 30 | –3.40 |
| –1 | RXD–1 | –1.74*** | 1.27 | 30 | –7.57 |
| 0 | RXD 0 | –2.18*** | 1.81 | 30 | –6.61 |
| +1 | RXD+1 | –3.14*** | 1.96 | 30 | –8.72 |
| +2 | RXD+2 | –1.89*** | 1.67 | 30 | –6.10 |
| +3 | RXD+3 | –0.50** | 0.91 | 27 | –2.78 |
| +4 | RXD+4 | –0.08 | 0.30 | 24 | –1.33 |
| +5 | RXD+5 | –0.18 | 0.73 | 16 | –1.00 |
| +6 | RXD+6 | 0 | 0 | 0 | 0 |
| +7 | RXD+7 | 0 | 0 | 0 | 0 |

***$P < 0.001$; **$P < 0.01$.
+, anterior; –, posterior; L, left; R, right; X, $x$-coordinate; D, dental stage data.

now be quantified using Pythagoras' theorem to be 21.99 mm on average.

Mills (1987) described buccal movement of the canine passing over the line of the arch at age 3–4 years. As this present study did not cover this age range, we can only speculate about such movement. It would seem unlikely, in view of the fact that between 5 and 9 years of age movement was more often palatal than buccal; the most marked buccal movement occurring in the year prior to eruption and the year of eruption into the oral cavity.

Williams (1981) suggested buccal movement occurring from the of age 8 years. Jacoby (1983) also expected buccal movement from age 8 onwards in normally erupting canines. The present study supports buccal movement from 9 years of age onwards, the most significant buccal movement occurring between 10 and 13 years of age. Ericson and Kurol (1988) were unable to confirm that the maxillary canine is normally palpable in the buccal sulcus at 8–9 years of age. They stated that spontaneous correction of palatally placed canines up to the age of 10 years was highly probable. The findings of this study would support their assertion in that movement prior to age 9 years is still predominantly in a palatal direction, with movement after 9 years of age being buccal. The maxillary canine appears to move buccally from age 9 onwards, this

**Table 7** Annual movement of canine teeth in the vertical (*y*) plane—dental stage data. +1 is the year of eruption.

| Year | | Mean (mm) | SD (mm) | No. of canines | *t*-value |
|---|---|---|---|---|---|
| Left canine | | | | | |
| –8 | LYD–8 | 1.38 | 0.49 | 2 | –4.06 |
| –7 | LYD–7 | –1.72 | 1.63 | 2 | –1.50 |
| –6 | LYD–6 | –1.11 | 0.95 | 4 | –2.31 |
| –5 | LYD–5 | –1.20*** | 0.56 | 12 | –7.50 |
| –4 | LYD–4 | –1.26*** | 0.64 | 22 | –9.00 |
| –3 | LYD–3 | –1.48*** | 0.77 | 29 | –10.57 |
| –2 | LYD–2 | –1.81*** | 1.01 | 30 | –10.06 |
| –1 | LYD–1 | –2.22*** | 1.17 | 30 | –10.57 |
| 0 | LYD 0 | –3.79*** | 1.61 | 30 | –10.06 |
| +1 | LYD+1 | –4.80*** | 2.30 | 30 | –11.43 |
| +2 | LYD+2 | –2.61*** | 1.99 | 28 | –6.87 |
| +3 | LYD+3 | –0.30* | 0.60 | 28 | –2.73 |
| +4 | LYD+4 | –0.24 | 0.70 | 26 | –1.71 |
| +5 | LYD+5 | 0 | 0 | 0 | 0 |
| +6 | LYD+6 | 0 | 0 | 0 | 0 |
| +7 | LYD+7 | 0 | 0 | 0 | 0 |
| Right canine | | | | | |
| –8 | RYD–8 | 0 | 0 | 0 | 0 |
| –7 | RYD–7 | –1.84 | 1.63 | 3 | –1.96 |
| –6 | RYD–6 | –0.99* | 0.67 | 6 | –3.54 |
| –5 | RYD–5 | –1.33*** | 0.63 | 14 | –7.82 |
| –4 | RYD–4 | –0.86*** | 0.70 | 24 | –6.14 |
| –3 | RYD–3 | –1.39*** | 0.81 | 28 | –9.27 |
| –2 | RYD–2 | –1.88*** | 1.17 | 30 | –8.95 |
| –1 | RYD–1 | –2.35*** | 1.18 | 30 | –10.68 |
| 0 | RYD 0 | –3.68*** | 1.75 | 30 | –11.50 |
| +1 | RYD+1 | –4.46*** | 2.06 | 30 | –11.74 |
| +2 | RYD+2 | –2.18*** | 2.51 | 30 | –4.74 |
| +3 | RYD+3 | –0.45* | 0.92 | 27 | –2.50 |
| +4 | RYD+4 | –0.25 | 0.73 | 24 | –1.67 |
| +5 | RYD+5 | –0.18 | 0.71 | 16 | –1.00 |
| +6 | RYD+6 | 0 | 0 | 0 | 0 |
| +7 | RYD+7 | 0 | 0 | 0 | 0 |

***$P < 0.001$; *$P < 0.05$

–, downward; L, left; R, right; Y, *y*-coordinate; D, dental stage data.

movement being significant at the 1 per cent level in the year prior to eruption, at the 0.1 per cent in the year of eruption into the oral cavity and at the 5 per cent level in the year after eruption.

Broadbent (1941) commented that by the 7th year the maxillary canine tooth had not moved far from its site of origin. This study can confirm that movement recorded between the ages of 5 and 7 years was less than in subsequent years, the only significant movement being in the vertical plane. Broadbent (1941) also referred to the 'ugly duckling' stage corresponding to the age of 8–12 years; the uprighting of the maxillary lateral incisor being dependent on canine eruption. This study can confirm that between the ages of 9 and 12, posterior, vertical and buccal movement of the canine occurs. Becker (1984) hypothesized two processes in the palatal impaction of the maxillary canine: absence of initial early guidance from an anomalous lateral incisor, and later failure of buccal movement of the canine at an unspecified age. This study can confirm that substantial buccal movement does occur from the age of 9 years onwards in canines that erupt normally.

Although estimates of the age of canine eruption from models taken at 6 monthly intervals must inevitably be later than the first appearance of the canine in the oral cavity, it was felt worthwhile to relate data to this event

**Table 8** Annual movement of canine teeth in the lateral (*z*) plane—dental stage data. +1 is the year of eruption

| Year | | Mean (mm) | SD (mm) | No. of canines | *t*-value |
|---|---|---|---|---|---|
| Left canine | | | | | |
| –8 | LZD–8 | –1.09 | 2.15 | 2 | –0.72 |
| –7 | LZD–7 | 0.70 | 0.98 | 2 | 1.00 |
| –6 | LZD–6 | –0.27 | 0.21 | 4 | –2.45 |
| –5 | LZD–5 | –0.34 | 0.58 | 12 | –2.00 |
| –4 | LZD–4 | –0.02 | 1.28 | 22 | –0.07 |
| –3 | LZD–3 | –0.27 | 0.97 | 29 | –1.50 |
| –2 | LZD–2 | –0.17 | 0.09 | 30 | –0.85 |
| –1 | LZD–1 | –0.39 | 1.39 | 30 | –1.56 |
| 0 | LZD 0 | 1.02** | 1.84 | 30 | 3.00 |
| +1 | LZD+1 | 1.85*** | 1.93 | 30 | 5.29 |
| +2 | LZD+2 | 0.68* | 1.62 | 28 | 2.19 |
| +3 | LZD+3 | 0.06 | 0.52 | 28 | 0.60 |
| +4 | LZD+4 | –0.13 | 0.72 | 26 | –0.93 |
| +5 | LZD+5 | 0 | 0 | 0 | 0 |
| +6 | LZD+6 | 0 | 0 | 0 | 0 |
| +7 | LZD+7 | 0 | 0 | 0 | 0 |
| Right canine | | | | | |
| –8 | RZD–8 | 0 | 0 | 0 | 0 |
| –7 | RZD–7 | 0.05 | 0.89 | 3 | –1.00 |
| –6 | RZD–6 | 0.87* | 0.58 | 6 | 3.63 |
| –5 | RZD–5 | –0.16 | 0.88 | 14 | –0.70 |
| –4 | RZD–4 | 0.11 | 1.02 | 24 | 0.52 |
| –3 | RZD–3 | –0.02 | 0.96 | 28 | –0.11 |
| –2 | RZD–2 | 0.49 | 1.38 | 30 | 1.96 |
| –1 | RZD–1 | 0.13 | 1.66 | 30 | 0.43 |
| 0 | RZD 0 | –0.76** | 1.45 | 30 | –2.92 |
| +1 | RZD+1 | –1.97*** | 1.68 | 30 | –6.35 |
| +2 | RZD+2 | –0.73* | 1.56 | 30 | –2.61 |
| +3 | RZD+3 | –0.17 | 0.61 | 27 | –1.42 |
| +4 | RZD+4 | –0.17 | 0.67 | 24 | –1.21 |
| +5 | RZD+5 | –0.13 | 0.50 | 0 | 1.08 |
| +6 | RZD+6 | 0 | 0 | 0 | 0 |
| +7 | RZD+7 | 0 | 0 | 0 | 0 |

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.
Left canine: +, buccal; –, palatal.
Right canine: –, buccal; +, palatal.
L, left; R, right; Z, *z*-coordinate; D, dental stage data.

especially in relation to the *z*-plane. Compared with movement in the horizontal and vertical planes, movement in the lateral plane did not reach such a high level of statistical significance when the chronological data were analysed. Movement in the lateral plane proved to be statistically significant when the data were rearranged. Statistically significant movement was recorded in the year prior to appearance of the canine in the oral cavity at the 1 per cent level, in the year of appearance in the oral cavity at the 0.1 per cent level, and in the following year at the 5 per cent level.

Further research is required into maxillary canine impaction. The next step might take the form of a study to trace the eruption pathway of maxillary canines that failed to erupt in order to determine the stage at which their eruption pathway deviates from normal. Of course, it is a matter of chance whether impacted canines occur in subjects having longitudinal radiographs. Only a small number are present in the Belfast study and there is a strong case for collaborative research involving all growth studies worldwide in this project. If all maxillary canines that become impacted deviated from the normal eruption pathway at a similar developmental stage, it would take us one step closer to

identifying causative factors, and open up further possibilities for interceptive treatment.

## Conclusions

1. In the antero-posterior plane, maxillary canines show significant ($P < 0.001$) annual movement in a posterior direction, between 7 and 12 years of age and at a diminished level between 12 and 13 years.
2. In the vertical plane, maxillary canines show significant ($P < 0.001$) annual movement between 5 and 12 years of age. This movement is always towards the oral cavity. Between 12 and 13 years there is still significant vertical movement, although at a diminished level.
3. In the lateral plane, maxillary canines show significant ($P < 0.001$) annual movement in a buccal direction, between 11 and 12 years of age.
4. In the three planes of space, maxillary canines travel almost 22 mm from their position at the age of 5 years to their position at 15 years.
5. Maxillary canines show posterior horizontal movement which is statistically significant ($P < 0.001$) in each of the 3 years prior to their appearance in the oral cavity, in the year of their clinical eruption and in the following year.
6. Maxillary canines show vertical movement which is statistically significant ($P < 0.001$) in each of the 6 years prior to appearance of the tooth in the oral cavity, in the year of their clinical eruption and in the following year.
7. Maxillary canines show buccal lateral movement which is statistically significant ($P < 0.001$) in the year of their eruption into the oral cavity, in the previous year ($P < 0.01$) and in the following year at a diminished level ($P < 0.05$).

**Address for correspondence**

Professor Andrew Richardson
Division of Orthodontics
School of Clinical Dentistry
Royal Victoria Hospital
Belfast BT12 6BP
UK

**Acknowledgement**

We are very grateful to Dr Chris Patterson for advice on statistical management of the data.

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