ASSESSMENT OF TOOTH MOVEMENT IN THE MAXILLA DURING ORTHODONTIC TREATMENT USING DIGITAL RECORDING OF ORTHODONTIC STUDY MODEL SURFACE CONTOURS

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KEYWORDS

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ABSTRACT

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The aim of this project was to measure changes in dimensions of the first three primary rugae and to evaluate tooth movement in the maxilla during orthodontic treatment in patients treated with and without premolar extractions. Pre- and posttreatment records of 110 Caucasian patients treated by one orthodontist were selected according to the orthodontist's treatment plan. Three treatment groups were selected: 'NE' (nonextraction, 43 cases), group '4s' (maxillary and mandibular first premolar extractions, 34 cases) and group '4&5s' (maxillary first and mandibular second premolar extractions, 33 cases). The mean age of the patients was 12.6 years at commencement of treatment and mean duration of treatment was 1.8 years.

Rugal and dental landmarks were identified on the pre- and posttreatment orthodontic study models of each case. Images of the occlusal surfaces of paired study models were scanned at 300dpi resolution onto the hard drive of a computer and analysed using Adobe Photoshop 4.0 computer programme. Pre- and posttreatment images were superimposed using specified points on the rugae as reference. All measurements were made directly on the computer screen after magnification of the images (2:1). One examiner did all the measurements and the intra-observer reliability was high.

The results of the changes in rugal measurements and tooth movement changes in all treatment groups were characterized by large variation in individuals. Many of the parameters exhibited significant differences between the left and right sides. The perpendicular widths of the posterior rugae did not change significantly during treatment ($p<0.05$). There were small but significant increases in the distances from the most posterior points of the posterior rugae to the midpalatal plane for all treatment groups during treatment ($p<0.05$). The rugae on the right side were significantly larger than those on the left side. During orthodontic treatment greater changes were observed for the rugae on the left (smaller) side.

There were distinct differences between the changes in the transverse dimensions of the first three rugae in all treatment groups. The transverse dimension of the second ruga on the right side was the only transverse dimension that did not change significantly in any of the treatment groups ($p>0.05$). The anteroposterior distances between the lateral ends of the three rugae did not change significantly during treatment in groups ‘4&5s’ and ‘NE’ on the right and left sides, and in group ‘4s’ on the left side ($p>0.05$). The anteroposterior distances between the medial ends of the three rugae on the right side exhibited no significant change during treatment in any of the groups ($p>0.05$). Only group ‘NE’ had no significant changes in the lateral and medial anteroposterior distances on both sides of the palate ($p<0.05$).

The largest intercanine and intermolar width changes occurred in group ‘NE’, whereas the largest interpremolar width changes were in groups ‘4s’ and 4&5s’ respectively ($p<0.05$). The results indicated that significant differences in the amounts, directions and types of tooth movement occurred among the treatment groups and on both sides of the palate.

The conclusions from this research indicate that certain landmarks on the palatal rugae are stable and may be used to measure tooth movement during orthodontic treatment, depending on whether nonextraction or premolar extraction treatment is done. Furthermore, large individual variations were found and significant differences in measurements occurred on the right and left sides of the palate.

November 2006

DECLARATION

I declare that *Assessment of Tooth Movement in the Maxilla during Orthodontic Treatment using Digital Recording of Orthodontic Study Model Surface Contours* is my own work, that it has not been submitted before for any degree or examination at any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Angela Manbre Poulter Harris November 2006

Signed:……………………….

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CHAPTER 1

INTRODUCTION

An important part of any orthodontic treatment is the placement of teeth in the correct anteroposterior positions (Lindquist 1985, Creekmore 1997). Until recently usually only cephalometric superimposition methods have been considered reliable enough to measure the relative anteroposterior and vertical changes in tooth movement (Geron *et al* 2003). Reliability of cephalometric superimposition is, however, compromised by difficulties in defining valid and reliable reference structures, and the method's susceptibility to unnoticed differences in stable reference landmarks (Ghafari, Baumrind & Efstratiadis 1998, Ghafari, King & Tulloch 1998). The estimation of treatment changes can be made more difficult when the treatment changes of interest are small relative to the error of the cephalometric method (Richmond 1987, Jones 1991, Mavropoulos 2005).

Unfortunately the use of cephalometric radiographs exposes patients to radiation and although this is minimal, most orthodontists would not routinely consider using a series of cephalometric radiographs as a method of evaluating tooth movement during orthodontic treatment (Hoggan and Sadowsky 2001). Furthermore, identification of cephalometric landmarks, and accurate superimposition techniques may also make the results less reliable (Houston 1983, Hoggan and Sadowsky 2001, Mavropoulos 2005). When serial headfilms are taken at relatively long intervals and changes are evaluated, measurements due to growth have to be taken into account and the true dynamics of the changes could be obscured, especially when the measurements of change are averaged over several years (Tulloch *et al* 1997, Keeling *et al* 1998). Finally, the economic cost of exposing multiple radiographs also has to be considered.

Recent publications in the literature have suggested that there can be clinically and statistically significant differences between left and right side measurements of the effects of orthodontic treatment on the teeth and surrounding structures, and some of these would not be evident should only cephalometric analyses be used (Mavropoulos *et al* 2005). Unilateral tooth movements would be difficult to assess as the images of teeth on both sides of the dental arch are projected onto the midsagittal plane (Mavropoulos *et al* 2006).

Although the use of study model comparisons or the superimposition of images of study models to evaluate tooth movement has been attempted, results of these studies have been difficult to interpret because of the lack of available evidence of stable landmarks (Van der Linden 1974, Van der Linden 1978, Jones 1991, Rossouw *et al* 1991). Recently some researchers have focussed on the use of palatal rugae as suitable landmarks, but the results of these studies are not consistent (Peavy and Kendrick 1967, Van der Linden 1978, Simmons et al 1987, Grove and Christensen 1988, Almeida *et al* 1995, Bailey *et al* 1996, Hoggan and Sadowsky 2001, Ong and Woods 2001, Miller *et al* 2003, Mavropoulos *et al* 2004, Mavropoulos *et al* 2006). There are also indications in the literature that various types of orthodontic treatment may have different effects on the rugae, e.g. nonextraction treatment, premolar extraction treatment (and the different combinations of extraction sequences) and orthopaedic maxillary expansion (Hoggan and Sadowsky 2001, Ong and Woods 2001).

The technique of superimposition of scanned images of study models used in this study is a new idea in orthodontics, but has been used successfully in forensic dentistry (Wood *et al* 1994, Wood 1996). Scanners have become relatively cheap, are easy to use. Computerised images allow permanent storage of study models images in two dimensions and a considerable amount of storage space could be saved if fewer plaster study models have to be kept.

The aim of this research was to describe changes in the dimensions of the first three primary rugae during nonextraction and premolar extraction orthodontic treatment. A futher objective was to measure the amount of tooth movement relative to certain rugal landmarks. A technique of scanning the palatal surfaces of maxillary studymodels and measuring pre- and posttreatment differences in measurements which has not been used before in orthodontics was developed for this study.

The literature review in Chapter 2 provides the reader with a background about the state of knowledge regarding various aspects of orthodontic treatment, methods of measuring movement of teeth on study models and the possible uses of the palatal rugae in orthodontics. In Chapter 3 the research design and methodology are explained and the research hypotheses stated. The results and discussion of these results are presented in Chapter 4. The first part of Chapter 4 describes the pre- and posttreatment changes in the dimensions of the rugae and the inter-tooth width changes which occurred during treatment. The pretreatment tooth-to-ruga measurements are then presented and discussed. The results of the analyses regarding the differences between pre- and posttreatment measurements follow this discussion. The final part of Chapter 4 is a discussion about the effects of orthodontic treatment with respect to alignment of the teeth. In Chapter 5 a brief overview of the results of this research project is given and certain recommendations about possibilities of further research are presented. The research hypotheses as stated in Chapter 2 are evaluated and the overall conclusions of this research are summarized.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The first parts of this chapter present an overview of some of the most important decisions the orthodontist has to make during orthodontic treatment planning, namely the decision to extract premolar teeth or to treat nonextraction, and planning how to achieve the ideal anchorage requirements for the case during treatment (Tweed 1968, Root 1985, Proffit 1993, Creekmore 1997). Once the treatment has been started the orthodontist needs to ascertain that certain tooth movements are taking place during treatment and that the treatment goals (teeth positions) have been achieved at the end of orthodontic treatment (Sadowsky and Sakols 1982, Shields *et al* 1985). The problems associated with the determination of stable reference points on study models in three-dimensions which could be used to measure tooth movement using superimpositions and other techniques are then discussed. Some articles concerning the use of the palatal rugae as a method of measuring tooth movement during orthodontic treatment have appeared in the literature over the last three to four decades and there has been an increase in interest in this topic during the last five to ten years. An overview of the development of the palatal rugae, methods of classification of rugae and some epidemiological aspects relevant to orthodontics is presented. This is followed by a review of the literature about rugae and their relationship to teeth during normal development and during orthodontic treatment. The methods of measuring the rugae and tooth movement relative to the rugae that have been presented in the literature are summarized. Finally, as it has become evident that left-right side differences exist in the size and morphology of the palate and dental arches, and that the effects of orthodontic treatment are also not always symmetrical, aspects of asymmetry of the dentition are also discussed.

2.2 Historical aspects of nonextraction and premolar extraction orthodontic treatment

Extraction of teeth as part of orthodontic treatment planning is one of the oldest and most controversial subjects in Orthodontics. The decision whether to extract teeth is considerably more difficult than the practical clinical extraction of teeth (Delabarre 1815 cited Haas 1986). In the late 19th century the extraction of malaligned teeth was common orthodontic practice (Proffit 1994).

Edward Angle (1899, 1907) was ardently opposed to extractions for orthodontic reasons and this was the basic precept of his "new school" in orthodontics. Calvin Case countered with his "rational school", the basis for which was that "new bone cannot be induced to grow beyond its inherent size", and that there are indications for extractions in certain malocclusions (Baker 1957, Case 1964, Dewel 1964). During the early 1900's this controversy reached a peak with Edward Angle and Calvin Case representing opposite viewpoints on this matter. The "Case-Dewey-Cryer extraction debate of 1911" was a lively discussion about this critical issue at the time, namely first premolar extractions in orthodontics (Pollock 1964).

Despite many of Angle's publications and lectures opposing the extraction of teeth in orthodontics, it is interesting to note that in the 6th edition of his book "Treatment of malocclusion of the teeth and fractures of the maxillae" published in 1900, he describes the treatment of some extraction cases and his extraction preferences (Bernstein 1994). Unfortunately this book was subsequently withdrawn from publication by Dr Angle himself without explanation (Bernstein 1994). In the 7th edition of the book, published in 1907, Angle once again defends his uncompromising position against extraction treatment.

Angle thought that orthodontic treatment should aim to remove the causes of malocclusion while retaining a full complement of teeth (Angle 1907). He felt that extraction procedures never overcome faulty oro-muscular function and that extraction of premolars arrests facial development and expression, destroying the possibility of ideal occlusion or ideal esthetics (Weinberger 1950, Proffit 1994). Angle based his ideas on the German philosopher Wolff's work. Wolff demonstrated that the bony trabeculae are arranged in a pattern, which is determined by the stress lines in the bone (Proffit 1993). He felt that normal function of the teeth would stimulate new bone growth, and that the teeth would stabilize in their new positions when the space had been created by bone growth. He realized that tipping movements were not stable and used his "Bone growing appliance" to try to get bodily tooth movement, which he thought would be more stable. In cases where stability was not obtained using these criteria, Angle ascribed the relapse to operator error. Angle was also concerned about facial esthetics and had frequent discussions on this topic with Professor Wuerpel, a well-known artist (Wuerpel 1931 cited Bernstein and Edward 1992). Professor Wuerpel was of the opinion that ideal facial esthetics could not be achieved for every case, because of the extensive variation in facial characteristics. Angle argued that ideal facial esthetics would follow orthodontic treatment when all the teeth had been placed in their correct positions.

Angle's influence dominated Orthodontics for many years, until the development of gnathostatic evaluation of dental occlusions and the introduction of cephalometrics by Broadbent and Hofrath in 1931, which brought new dimensions to Orthodontics (Proffit 1993). Today cephalometric superimpositions are the accepted means for assessment of orthodontic tooth movement.

The "nonextraction" philosophy follows the theory that orthodontic appliances can enhance bone growth. Natural expansion occurs with normal growth and development (Friel 1927). It is doubtful that any meaningful growth can be induced in tooth-bearing bones using orthodontic appliances (Brodie 1940a, Strang 1949). Brodie (1940b) demonstrated that once the growth pattern of the facial bones is established, whether normal or abnormal, it is virtually constant and resistant to change. Haugh (1949) stated that little or no space could be created by lateral expansion, and that extractions should be done when there is a dentoalveolar discrepancy exceeding the capacity of the basal bone.

Since the 1920's there has been more interest in the extraction of premolars (Case 1964). Many orthodontists, including Case, Tweed (1946), Nance (1947), Dewel (1959) and Begg (1956), resisted Angle's concept of nonextraction treatment regardless of the type of malocclusion being treated. An "Extraction Panel" debate was held by the American Association of Orthodontists in 1944. Under the chairmanship of George Hahn, prominent orthodontists including Tweed, Hellman, Grieve and Brodie discussed the indications for extractions in orthodontics (Hahn 1944). The extraction/nonextraction trends have also been linked to developments in orthodontic techniques. In the mid- twentieth century, Tweed's modifications of the edgewise appliance technique provided enough control of root position to allow successful management of extraction spaces. When other techniques were used, e.g. removable appliances, more non-extraction treatment was done. With the introduction of the Begg appliance in the 1960's, the frequency of extraction treatment reached a peak (Proffit 1994). Since then, extraction frequencies have decreased (Proffit 1994, Turpin 1994). Reasons for this decrease in extraction percentage may be the increase in frequency of two-phase orthodontic treatment, differing esthetic guidelines, concern about temporomandibular dysfunction and technique changes.

Tweed (1944, 1946) maintained that tooth position remained relatively stable once it reached that state in the development of a malocclusion in which the forces, originally responsible for initiating the malocclusion, became neutralized. He felt that any treatment that forced the teeth into a protrusive relationship relative to the supporting bony base tends to be followed by collapse of the dental arches which in a normal occlusion is in harmony with its skeletal apical bases. Many modern malocclusions have deficient and/or deformed apical bases (Howes 1947). Tweed (1944) was very disappointed with nonextraction treatment in some of his bimaxillary protrusion cases and subsequently retreated these cases after first premolars had been extracted. In a study of 100 extraction and 100 nonextraction cases examined 25 years post-retention, Tweed concluded that the extraction cases were more stable than the nonextraction cases (Tweed 1968).

Historically the first premolars were selected for extraction when it was realized that retention of all the permanent teeth was impossible (Grieve 1944, Cole 1948, Logan 1973, De Castro 1974, Dewel 1976). Hays Nance (1947, 1949) was the first person to describe the indications for second premolar extractions, i.e. moderate bimaxillary protrusion cases. Carey (1949) and Dewel (1955) also published articles on second premolar extractions, but it was only in the 1970's that this treatment approach became accepted orthodontic practice. This probably coincided with the increasing awareness of the effectiveness of modern fixed appliances to conserve anchorage. Second premolar extractions avoid the negative effects of overretraction of incisors in "borderline cases" (Williams and Hosila 1976). Nel (1991) concluded that Class II division I malocclusions with moderate crowding in patients with profiles which are not very convex, can be successfully treated orthodontically after upper first and lower second premolar extractions. Although he used a different fixed appliance technique (Bioprogressive Therapy), Nel agrees with Steyn *et al* (1997) that not all Class II division I cases require orthopaedic correction and can often be treated without the use of extraoral traction.

De Castro (1974) stated that when a second premolar is extracted in the middle of the posterior segment, this segment alone is shortened. When a tooth is removed at the point where the segments meet, the posterior segment and the transitional area are affected. De Castro (1974) considered these transitional areas to be functionally important for the integrity of the dentition. De Castro (1974) suggested that second premolars be removed when the molars need to be moved forward more than 2.5mm per side; where the patient does not need a great change in facial profile; where posterior crowding of second or third molars occurs; and where there is an arch-length discrepancy of 5mm or more in a patient with a good profile.

The frequency of extraction treatment varies considerably among orthodontists. Peck and Peck (1979) reported an average prevalence of ± 42.1% (north-western USA) and Weintraub *et al* (1989) reported an average frequency of 39% ± 18.3% (range 5% to 87.5%) for orthodontists in Michigan, USA. The frequency of self-reported extraction rates did not correlate with the actual extraction rates, nor with the orthodontist's age, number of years in practice, or the university programmes from which they graduated (Weintraub *et al* 1989). According to Peck and Peck (1979) ethnic and socio-economic differences also influence the decision to extract or not. Japanese and Chinese orthodontists extract premolars to treat many bimaxillary protrusion cases, and the National Health Scheme in England also seems to favour extraction therapy (Peck and Peck 1979). In the Soviet Union where marked negative patient attitudes towards orthodontics exists and orthodontic treatment is not widely available, the extraction frequency is low and treatment plans involving extractions are discouraged (Peck and Peck 1979). There are indications that extraction treatment on average takes longer to complete than nonextraction treatment (Vig *et al* 1990). During the early 1990's there was a definite downward trend in the extraction rate worldwide (Luppanapornlarp and Johnston 1993).

Numerous studies have debated whether extraction or nonextraction therapy produces the best long-term stability. Bishara *et al* (1994) concluded that extractions do not significantly alter the direction of the overall posttreatment trends observed in many arch parameters, e.g. interincisor and intercanine widths, arch length and tooth size-arch length discrepancy. The trends for intermolar width, however, are different in the extraction and nonextraction cases. Generally, the posttreatment trends are similar in males and females, and in the maxillary and mandibular arches. Rossouw (1993) concluded that extraction of teeth does not necessarily assure stability of the dentition and that the extraction versus nonextraction debate will continue.

Incisor position (Downs 1948, Steiner 1953, Tweed 1954, Ricketts 1981), facial profile (Holdaway 1983) and tooth-arch size analysis are used to make a decision about whether extraction or nonextraction treatment should be planned. Since there is no clear and convincing evidence to support extraction versus nonextraction decisions, ultimately clinical experience and skill in producing the desired outcome gradually allows the orthodontist to develop his/her own philosophy in this regard (Salzmann 1949, De Castro 1974, Proffit 1994).

2.3 Anchorage considerations during extraction treatment

Schoppe (1964) described that when mandibular second premolars are extracted, half of the extraction space is taken up by anchorage loss. He found a mean mesial mandibular molar positioning of 3.1mm in first premolar extraction cases and 3.45mm in the second premolar extraction cases where anchorage was deliberately lost. Williams and Hosila (1976) found that about 66.5% of the available extraction space was taken up by retraction of the anterior segment, in cases where the four first premolars were extracted. In cases where the upper first and lower second premolars were extracted, 56.3% of the available extraction space was taken up by retraction of the anterior segment.

Nel (1991) described a 6.4 degree increase in the interincisor angle after the removal of maxillary first and lower mandibular premolars and orthodontic treatment (Bioprogressive technique) in 62 patients. He ascribed most of this change to distal tipping of the maxillary incisors following the use of Class II intermaxillary elastics. There was a slight increase (< 1 degree) in lower incisor proclination relative to the APo line, but a very significant distal tipping of the upper incisor (7.3 degrees) relative to this line. The maxillary first molar moved mesially about 3.1mm relative to the PTV line.

Creekmore (1997) reported that when first premolars are extracted, the posterior teeth move forward approximately one-third of the space, leaving two-thirds of the space for the relief of crowding and incisor movement; and that one-half of the space would be taken up by forward movement of the posterior teeth when second premolars are extracted. Bishara *et al* (1994) compared 91 treated Class II division I cases (27 non-extraction, 44 first premolar extractions) cephalometrically to a group of untreated normal individuals. Besides the overall "normalization" of dentofacial characteristics in the treated patients, they showed that the extraction decision had a significant differential impact on the dental relationships. The maxillary incisors uprighted considerably more in the extraction group (mean -5.1mm) than in the non-extraction (mean -2.0mm) and normal (mean -0.6mm) groups. The mandibular incisors became more upright in the normal and Class II extraction groups, but moved labially in the nonextraction group.

Luppanapornlarp and Johnston (1993) reported a mean of 2-3mm retraction of maxillary incisors with first premolar extractions.

Ong and Woods (2001) studied maxillary arch dimensional changes when first and second premolars are extracted during orthodontic treatment in 71 patients with a mean age of 163.9 months at the start of treatment. There were wide ranges of individual variation in all of the groups, but no statistically significant differences between treatment results for males and females. In all groups there was a mean increase in maxillary arch width across the most anterior premolars, which was not statistically significant. The only statistically significant difference among the groups was for reduction in intermolar width, especially when maxillary second premolars are extracted. The mean forward movement of the molars for the groups ranged from 3.7 to 4.7mm. The mean maxillary incisor retraction was 2.5±1.9mm (first premolar extraction) and 1.6±1.6mm (second premolar extraction). These results were similar to those reported by Saelens and De Smit (1998), who reported a mean retraction of the maxillary incisors of 2.1±2.5mm (first premolar extraction) and 1.9±2.4mm (second premolar extraction). Ong and Woods (2001) did not find that there was greater forward movement of molars when maxillary second premolars were extracted, compared cases where first premolars were extracted. They concluded that differential extractions are only one of the methods which can be used to provide anchorage control.

Staley *et al* (1985) demonstrated that arch widths in male adults with normal occlusions are larger than those in normal female adults. In the Class 11 division 1 malocclusions these differences did not occur, and the males had larger dimensions only in the maxillary and mandibular alveolar widths, but not in the dental widths. Staley *et al* (1985) postulated that the malocclusion may minimize or eliminate the differences normally found between the genders. Cassidy *et al* (1998) studied the dental arches of 320 Caucasian adolescents from 155 sibships and demonstrated that the arch widths in males were 3% to 5% larger than those in females, and that there was consistent gender dimorphism in these measurements.

Nelson *et al* (1999) found that the maxillary molars remained basically in their original positions in 20 males with Class ll division 1 malocclusions treated nonextraction with Begg fixed appliances and Class ll elastics. The mean age of the groups was 13.5 years and treatment duration was 1.3± 0.24 years.

BeGole *et al* (1998) analysed 38 cases of nonextraction and extraction to determine changes in arch form, in patients with treatment starting at a mean age of 10.5 years, and lasting an average of 39 months. All their measurements showed high variability. The maxillary nonextraction arches showed significant arch width expansion, with the second premolars showing the most expansion, followed by the first premolars, the molars and the canines. The maxillary extraction cases showed no significant changes for any dimension.

Bishara *et al* (1997) evaluated the changes in intercanine and intermolar widths of normal persons from 6 weeks to 45 years of age. They determined that intercanine and intermolar widths increase significantly between 3 and 13 year of age in both dental arches. After complete eruption of the permanent teeth, the dental arch widths decreased slightly, with a greater decrease in the intercanine than the intermolar widths. In males there were no significant changes in intermolar widths between 13 and 26 years of age. In females aged between 13 and 26 years old there was a slight decrease in intermolar widths both dental arches, but this was only statistically significant in the maxillary intermolar width measurements.

Taner *et al* (2004) evaluated dental arch widths changes after nonextraction orthodontic treatment combined with headgear in 21 Class ll Division 1 patients. The mean age of the patients at the start of treatment was 11.7±1.6 years and the mean treatment time was 3±1.4 years. The widths between all maxillary teeth (except intercentral width) increased significantly during orthodontic treatment, with the greatest increase between the first premolars (4.33±1.91 mm). The second premolar width increased with a mean of 3.95±2.36 mm, and the intermolar width increased with a mean of 3.34±3.06mm.

2.4 Problems of identifying stable reference points for superimposition of serial studymodel data in three planes of space

The need for evidence-based orthodontics is increasing, and the accuracy and reproducibility of different measurement methods must be evaluated, so that clinical decisions can be justified (Baumrind 2002). Some factors influencing the accuracy and reproducibility of measurements of individual teeth within the dental arch are the existing space condition, inclination of the teeth, rotations, interproximal contact positions, and anatomical variation.

An alternative approach to the use of cephalometric analysis to measure tooth movement is to measure changes in tooth position with a series of study models. Some advantages of using study models for this purpose include having an accurate reproduction of the teeth and surrounding oral structures, being able to take impressions at regular intervals, having preserved information that is three-dimensional, and being able to use various measurement techniques to collect spatial data from the models (Kuroda *et al* 1996). Furthermore, unilateral tooth movements can be evaluated more easily on study models than on cephalometric radiographs (Mavropoupos *et al* 2006). Recent advances in computer technology have made it possible to assess the relationships between craniofacial variables obtained from cephalometric radiographs and study models (Biggerstaff 1969, Biggerstaff 1970, Walker 1972, Suzuki 1980, BeGole *et al* 1981).

Traditionally, measurements on study models are performed using Vernier calipers or pointed dividers. Both these methods have clinically-significant measurement error (Shellhart *et al* 1995). Measurements on photocopies, photoholograms, or digitization of points from study models also have significant measurement errors (Ryden *et al* 1982, Rossouw *et al* 1991, Champagne 1992, Lowey 1993, Romeo 1995, Schirmer and Wiltshire 1997, Mok and Cooke 1998).

Ryden (1982) used superimposition to do two-dimensional measurement of tooth movement during orthodontic treatment, using a study model and a holographic image representing different treatment stages superimposed within a plane by a mechanical X-Y stage.

Despite the development of various systems, e.g. reflex metrograph (Takada *et al* 1983), the traveling microscope (Bhatia and Harrison 1987), and laser scanners (Alcaniz *et al* 1999, Okumura *et al* 1999), accurate three-dimensional analysis of study models is still a problem. The initial orientation of the models and the bias of measured values caused by variation of human performance when using the devices are problematic.

The reflex metrograph consists of an object table, semi-reflecting mirror, mirror mount and a light source carried on a slide system (Richmond 1987). A point is digitized by superimposing the light spot of the metrograph onto the marked area of the study model to obtain the best fit of the two-dimensional points. Coordinates in three planes are digitized and stored for analysis by the computer. Takada *et al* (1983) described the use of this system and maintain that the three-dimensional coordinates can be measured with an accuracy of ±0.1mm. Richmond (1987) found the error to be less than 0.27mm (<0.3%) with an angular error of less than 0.76%. Differences in the relative locations of the object to the mirror and/or in anatomic shape did not significantly influence the variance of the recorded coordinates. Drage *et al* (1991) reported that the reflex microscope had become a standard instrument for measurement of casts, but noted that operator training is advisable. Considerable initial variation exists in the precision of landmark identification and the mean errors are greatest in the z-axis, i.e. along the axis of the eye, which is a problem in individuals with astigmatism. Jones (1991) compared orthodontic treatment changes measured from study models and cephalometric radiographs using the reflex metrograph. He found no statistically significant differences in the assessment of treatment changes when using models and cephalographs.

The travelling microscope consists of a microscope fitted to a carriage which moves along a bridge mounted on the mainframe of the appliance (Bhatia and Harrison 1987). The cast is placed on the glass top of the box and viewed through the eyepiece of the microscope or on the monitor of a closed-circuit television connected to the apparatus. Point-to-point recordings are recorded by alignment of the features of the object with a simple graticule in the optical system of the microscope. Movement of the carriage in the horizontal plane provides the X and Y coordinates, and of the microscope in the vertical plane the Z coordinates. The coordinates are recorded on a computer for subsequent analysis. A light box with diffuse illumination is fitted at the base of the frame so that radiographs can also be analyzed. These authors noted that this system is more accurate than the reflex micrograph and that with the anticipated prospect of motorization of the microscope the scanning of a study model could become a computer controlled automated process.

Model measuring techniques using the reflex microscope have been widely used (Bhatia and Harrison 1987, Richmond 1987, Orton *et al* 1996). Orton *et al* (1996) described how the upper model is fixed, and the lower attached to a translator driven and controlled by a motorized circuit. A software program records points in a predetermined sequence. X,Y and Z coordinates can be recorded for all points. Orton *et al* (1996) drew attention to factors that influence the accuracy of this technique, i.e. slight movement of the casts when the upper and lower models are separated, operator experience. Orton *et al* (1996) concluded that direct comparisons with the reflex metrograph technique are not possible, and that when describing the accuracy of these various techniques, a standard Dahlberg method error must be included for comparison purposes.

Yamamoto *et al* (1991) described an optical method for creating 3D computerized models using a laser beam on a cast. Several researchers have tried to transfer the study model into a 3-D virtual model (Kuroda *et al* 1996, Wakabayashi *et al* 1997, Yamamoto *et al* 1998, Alcaniz *et al* 1999, Motohashi and Kuroda 1999, Sohmura *et al* 2000). Kuroda *et al* (1996) found the measurement error to be less than 0.05mm for the X,Y and Z coordinates in their study using a laser scanning technique of studymodels. Other researchers have shown that measurements made on computer images of study models generated by surface laser scanners are very accurate when compared to measurements done directly on study models (Hayashi *et al* 2003, Quimby *et al* 2004, Mavropoulos *et al* 2005). Hayashi *et al* (2003) described a palatal reference plane (corresponding to A-PNS on a lateral radiograph and to J-J' plane on a frontal radiograph) which could be used in conjunction with the 3-D shape of a study model and thereby integrate cephalometric and study model data.

Yamamoto *et al* (1991) followed long-term tooth movement during orthodontic treatment based on superimposition within a computer after digitizing the shape of study models. They developed an automatic optical measuring system equipped with a laser and image sensor to obtain three-dimensional measurement of a study model. Yamamoto *et al* (1991) found the palate profile to be appropriate as an immovable reference to use during superimposition studies. The average discrepancy in palatal depth before and after orthodontic treatment was only 0.05 - 0.13mm, excluding the data around realigned teeth (orthodontic treatment times from 6-21 months in 9 patients).

Commer *et al* (2000) have tried to create an apparatus for intraoral direct scanning.

Computerized models can be used for calculating distances and estimating treatment effects and tooth movements using software programmes, e.g. OrthoCAD (Marcel 2001). The performance of 3D virtual models for validity and reproducibility has not been thoroughly studied yet. Zilberman *et al* (2003) found OrthoCAD's accuracy to be clinically acceptable, although measurement with digital calipers on plaster models showed the highest accuracy and reproducibility. Miller *et al* (2003) reported on the use of computer software developed by the manufacturer of an orthodontic material/technique ("Invisalign"), which they used to evaluate superimposed digital study model images of orthodontic treatment outcome. Their results indicated that the method of digital superimposition used in this research was reliable (the mean error measurements after 10 trials was 0.2±0.15mm for translation movements and 1±0.7° for rotation movements.)

2.5 Palatal rugae pattern as a method of superimposition

As early as 1732 Winslow wrote about the rugae, but only in 1889 did Allen first relate the rugae to teeth (Lysell 1955, Peavy and Kendrick 1967).

2.5.1 Development of the palate and histology

Hauser *et al* (1989) demonstrated that human rugae occupy most of the length of the palatal shelves at the time of their elevation. At the 550mm stage of embryonic development, there are 5-7 relatively symmetrical ridges, with the anterior ones beginning at the raphe. Towards the end of intrauterine development, the pattern of rugae becomes more irregular, with some of the posterior ones disappearing and the anterior ones becoming more pronounced and compressed (Lysell 1955). Lund (1924 cited Peavy and Kendrick 1967) observed that a connective tissue core is deeply embedded between the submucosal fatty tissue and stratum reticulum of the palate. This core represents a foundation over which the substance of the rugae builds up to form a fold-like projection in the palate. Wood and Kraus (1962) described a noticible scantiness of adipose tissue in the anterior palate in the region of the rugae in human foetuses. They quote Lund (1924 cited Wood and Kraus 1962) who attributed the involution of rugae through life to a decrease of submocous fat. Lund described the rugae as best developed in the foetus, regressing later and sometimes absent in the adult. Thomas and Van Wyk (1987) studied 23 specimens of human palatal mucosa aged 3 months to 80 years, and reported that non-sulphated glycoaminoglycans (GAGs) are the main structural element of rugae, not elastic tissue or collagen. These authors concluded that GAGs have hydrophilic characteristics which cause the tissue to swell and contribute to the maintenance of the shape of rugae throughout life. It has been shown experimentally (in rats) that anomalous rugal patterns can occur in fetuses exposed to teratogenic drugs known to be associated with cleft palate induction (Ikemi *et al* 2001). In rats anomalous rugal patterns occur after exposure to lower doses of these substances than what would induce cleft palates, and therefore could be taken as a warning sign or an indicator of teratogenicity of a substance/drug.

Carrea (1937) cited by Lysell (1955) found that the rugae pattern had been formed by the 12th to 14th week *in utero.* Carrea stated that rugae remained stable from this time throughout life and that orthodontic treatment and extractions had no effect on the shape of the rugae. The rugal pattern, therefore, appears to be established early in life and the size of the ridges in relation to the size of the palate does not decrease from fetal to adult life, but may even increase in size (Schultz 1949 cited Lysell 1955). Lysell (1955) reported that the total number of rugae remains unchanged up to the age of 23 years and then decreases after this age. Yamazaki (1962 cited Hauser *et al* 1989) found that there is a marked reduction in the mean ridge counts from the age group 35 to 40 years onwards.

Lysell (1955) recorded an increase in primary rugae length from 5 to 10 years of age, of 11% for males and 9% for females. Changes from 6 to 16 years in a mixed longitudinal study indicated a small continuous increase in the distances between the medial borders of paired rugae (Van der Linden 1974, 1978). Van der Linden noted that this also happens with the lengths of the three paired rugae, with the exception that after the age of 10 years the anterior pair of rugae no longer increase in length.

Lysell (1955) reported that the rugal features return following surgery or trauma. Hausser (1950 cited Hauser *et al* 1989) indicated that severe finger-sucking during infancy may change the pattern of the rugae, and that orthodontic treatment which moves the molars and premolars in a sagittal direction causes displacement of the rugae.

The incidence of change in rugal shape from the primary through to the permanent dentition appears to be low (Kapali *et al* 1997). Lysell (1955) described a tendency for the backward direction of the rugae to decrease with age, which he attributed to the increase in width of the palate and forward movement of the teeth in relation to the rugae. Another explanation could be the forward movement of the lateral parts of the rugae as the dental arch develops in an anterior direction. Kapali *et al* (1997) disagreed with Lysell's findings and described that 53% of the rugae that changed direction in their sample of Aborigine people, moved backwards. These authors speculated that different ethnicity could explain the differences between the studies, and this would influence the pattern and growth of the palate, genetic variations, and differing patterns of tooth movement related to crowding and tooth wear.

2.5.2 Classification of rugae

Although much research that has been done since Lysell's publication in 1955, most has been confined to making superficial observations about the number, direction and prominence of rugae. Attempts at classifying the rugae have been relatively unsatisfactory (Lysell 1955, Thomas 1981).

Probably the most important and useful classification is that of Lysell (1955). Rugae are measured in a straight line between origin and termination and grouped into three categories (primary: 5mm or more, secondary: 3-5mm, fragmentary: 2-3mm). Rugae under 2mm are disregarded. The rugae of each side are numbered separately from anterior to posterior and classified according to shape and position relative to the median palatal raphe and unifications. Lysell named the most obvious rugae "primary O rugae" (numbering about four on each half of the palate). He described three categories of unification, and classified the incisive papilla according to one of seven shapes.

A method of analysis which distinguishes between primary and secondary rugae was developed by Szilvassy and Hauser (1983 cited Hauser *et al* 1989) and has been used in comparative studies of different population groups.

Thomas and Kotze (1983b) concluded that in a comparative study, the results of comparisons and accuracy of technique are more important than the systems of classifications of rugae. The features of rugae patterns are very complex and open to individual interpretation. Thomas and Kotze (1983c) reported that a single operator alone (eliminating inter-observer error), using his own classification could successfully apply it to a comparative project.

2.5.3 Epidemiology

Studies on the average number of rugae by gender, side of the palate and ethnicity report differing results.

Kogon and Ling (1973) reported that men have greater development of the rugae pattern than women, but that each person's pattern is highly individualized. Simmons *et al* (1987), using a Caucasian sample, reported that more rugae are found in males than females, and more rugae are present on the left side in both genders. Shetty *et al* (2005) found that males in Mysorean and Tibetan populations had more rugae on the left side of the palate. Longer and wider incisive papillae have been reported in females (Nilles 1950 cited Lysell 1955). Thomas and Kotze (1983c) reported no sexual dimorphism of the rugae in six different population groups of southern Africa. Dohke and Osata (1994) reported similar findings in a Japanese sample and Hauser *et al* (1989) in Greeks. Kapali *et al* (1997) found no significant differences in the number of rugae between the genders, or any differences between the number of rugae on the right and left sides of the palate in their sample of Aborigines. These authors reported that the mean number of primary rugae was significantly higher in Aborigines than in Caucasians. They also noted a significant association between rugae forms and ethnicity, with straight forms being more common in Caucasians and wavy forms more common in Aborigines.

It is important to remember that different studies have used varying methodologies, and that this may explain the differing results to some extent. Dohke and Osato (1994) included the seconday rugae in their study, whereas Kapali *et al* (1997) only studied the primary rugae. Dohke and Osato (1994) claimed that the tendency for the development of fewer rugae in the right side of the palate, and that females have fewer rugae than males, could be related to the phenomenon of regressive evolution dominating the right side of the palate and being more evident in females. Many of the morphological changes they found were in the secondary and fragmentary rugae. Thomas and Kotze (1983) concluded that primary rugae do not possess strong discriminatory ability between different human populations. Trends in the mean number of rugae between different population groups show that there may be greater ridge development (size and number of rugae) in populations with broader palates (Kapali *et al* 1997, Hauser *et al* 1989). Hauser *et al* (1989) found that the number of primary rugae in Swazi was significantly higher than in their Greek sample. The contrary was evident for the seconday ridges of the rugae. They also found significant gender differences, with the Swazi having a significant difference in the number of primary rugae between the genders, while in the Greeks the gender differences occurred in the secondary ridges only. They found significant symmetry between the right and left sides, regarding the number of primary and secondary ridges within each population group. Hauser *et al* (1989) concluded that there is an inverse proportion within and between the populations regarding the amounts of primary and secondary rugae. The presence of many primary rugae may imply fewer secondary rugae, and *vice versa*. The midline structures also differ among population groups, e.g. large incisive papillas, and more forking of the midpalatal plane in the Swazi compared to the Greek samples. Hauser *et al* (1989) also found significant associations between arch shape in the sagittal plane and numbers of primary and secondary rugae.

The numbers of primary rugae differ among various populations groups. Hauser *et al* (1989) provided a summary of mean numbers of primary rugae from other studies, and their own: Swazi 4.01-4.96; Greek 3.7-3.94; Austrian 4; Swedish 4.25; North American Whites 4.28; Japanese 4.12; South American Negro 3.71; Chilieans 4.15. They concluded that there seemed to be a tendency for more primary rugae development in populations with broader palates. These associations may suggest that the rugae may be the result of a common growth process with palatal development, or may be functionally involved in some way with the growth processes in the palatal region.

Heredity may play a role in the number, shape, direction and prominence of rugae, but it is difficult to prove anthropologic heredity using only palatal rugae (Lysell 1955). Parameters such as the length and shape of the rugae show definite racial differences (Shetty *et al* 2005). Thomas *et al* (1985) used the ruga pattern to develop cartoon faces, based on a method of representing multivariate data which was developed by the artist, Chernoff. Each variable is assigned to a facial feature. This method is useful as an overview of a set of data, can be used to show changes over time, and can indicate clustering of data and outliers. It is not an easy method to use for data analysis and requires a considerable amount of expertise in statistics and computation of data. Thomas *et al* (1985) converted the complex data of rugae patterns into Chernoff faces, and then tried to establish family groupings and possible parentage of a child. They found that matching was easier in certain families and that observers tended to be consistent in their matching (right or wrong), but the trends they recognized could not classify the children 100% correctly and were therefore not of any practical importance.

Thomas and Kotze (1983d) studied ethnic inter-group relationships using ruga patterns, and found dissimilar ruga patterns between ethnic groups. These authors concluded that this dissimilarity in ruga patterns indicated that the genetic origins of these population groups differed. Their results indicated that certain parameters of the ruga pattern could possibly be used as genetic markers, and they suggested that this be studied further. In 1987 Thomas *et al* described "an improved" statistical technique for the racial classification of humans, using palatal rugae.

2.5.4 Rugae and the positions of teeth

Friel (1949) demonstrated that the posterior teeth move forward in relation to the rugae, in conjunction with the growth of the jaws. He reported that the posterior limit of the rugae in relation to the teeth tends to move backward until the age of twenty. Sillman (1951) noted that there is still uncertainty about whether teeth move through the bone, with the bone, or by means of a combination of these two processes. Sillman (1951) conducted a longitudinal study on healthy children from birth to 12 years and described the individual growth and developmental changes in 4 individuals. He used “the most posterior point on the rugae” (R), which he maintained would eliminate many of the variables affecting accuracy of measurement when the alveolus is used in the measurements. “This point can be traced throughout the series with almost pin-point accuracy” (Sillman 1951). He measured the vector distance between Point R and Point I. Sillman described Point I as a point located at the intersection of the “sagittal plane with the everted edge” in the maxillary edentulous infant’s dental arch. He maintained that a remnant of the “everted edge” could always be traced as the dental arches developed. Sillman believed that dimension R could be used as an index of the basal structure of the maxillary dental arch, which he used to try to get an approximation of changes in the dimension of the apical base width.

Hausser (1950, 1951 cited Bailey *et al* 1996) suggested that the lateral edges of the palatal rugae move forward about half the distance of the forward migration as the adjacent teeth during orthodontic treatment, while the medial ruga points are not affected. Leontsinis (1952 cited Peavy and Kendrick 1967) ascertained that rugae are unchangeable from the time they develop until the oral mucosa degenerates after death. Lebret (1962) studied the distances between rugae landmarks and found that the distances between points near the median raphe are relatively constant on successive study models of individual cases. She concluded that the rugae could be used as study model reference points for measuring mesiodistal changes in tooth position.

Schwarze (1969, 1972, 1973 cited Bailey *et al* 1996) advocated the use of posterior medial rugae to evaluate anteroposterior changes of buccal teeth, particularly changes for first permanent molars.

Paevy and Kendrick (1967) evaluated 15 patients treated with extraction of maxillary first premolars and retraction of the anterior teeth. They found that the lateral ends of the rugae terminate close to the teeth and tended to follow the movement of the teeth in the sagittal plane, but not in the transverse plane. These authors did not measure the effects of orthodontic treatment on the medial terminations of the rugae. They suggested that, while the rugae may be of value as an aid in the orientation of recording devices when evaluating dental changes in longitudinal studies, they were of limited value in determining the magnitude and direction of tooth movement. They concluded that the rugae are not appreciably altered after orthodontic treatment.

Van der Linden (1974, 1978) studied changes in rugae, interruga dimensions, and relationships between teeth and rugae, as projected on the functional occlusal plane and analyzed in the sagittal direction, in 65 children with normally developing dentitions from 6-16 years old. He observed that little or no change took place in the length of the individual rugae and interruga distances as projected onto the functional occlusal plane. The distal site points of the upper canines maintained a constant anteroposterior relationship with the adjacent lateral ruga points. The lower canines seemed to move slightly distally, particularly during transition of the posterior teeth. Van der Linden (1978) concluded that the ruga points show a remarkable stability in their antero-posterior relationships to each other and may be used in the analysis of the changes in mesiodistal locations of buccal teeth in normally developing dental arches.

Van der Linden's (1978) orthodontically-treated sample consisted of only 6 cases with different types of malocclusions and treatment initiated at various stages of dental development. He suggested that the lateral ruga points moved in the same direction as the adjacent teeth, and that preference should be given to medial ruga points to evaluate tooth changes in the sagittal direction. Van der Linden (1978) did not evaluate changes in tooth position relative to the medial ends of the rugae. He suggested that if actual molar shift was being evaluated, the tipping of the occlusal plane should be compensated for. He found that the relationship between the canine and the lateral end of the first ruga was stable, and that the first molar moved mesially relative to the lateral end of the third ruga in untreated cases followed up for 10 years. Van der Linden (1978) suggested that further research about the tooth-to-ruga relationships could provide a relevant diagnostic tool in clinical orthodontics. He suggested that an "orthodontic site measuring grid" developed by Schmuth (1955 cited Van der Linden 1978) be used to determine changes in the ruga pattern and the alterations in tooth-to-ruga relationships.

Simmons *et al* (1987) identified distinctive anterior and posterior rugae on both sides of the palatal raphae for 41 individuals (20 females and 21 males), and measured the anteroposterior distances between each pair of rugae on four successive study models of every individual. The time intervals selected for measurement were from the stage where all primary teeth were erupted (T1), earliest model with first permanent molars erupted (T2), earliest model with canines and premolars erupted (T3), and models from ages 16-22 years old (T4). They found that the medial rugal region increases significantly in anteroposterior length, between the genders and over time. These increases do not occur in a uniform manner. Females show more early growth and an earlier peak of growth compared to males. Significant growth for females was measured between ages 7.6. to 13.3 years (T2-T3), and for males between ages 7.8 through to 18.9 years (T2-T3, T3-T4). The male peak was higher than that for females, and males also had more actual growth than females. These authors suggested that the changes observed were characteristic of the craniofacial growth in this region, and that the rugal region was therefore responding to the differential growth of the underlying bone. Simmons *et al* (1987) concluded that medial rugal landmarks are not stable reference points to use in tooth migration studies.

Grove and Christensen (1988) determined the locations of the lateral borders of the right and left first primary rugae, relative to a canine-to-canine baseline. The transverse line of reference was drawn through the distal contact points of the maxillary canines (x-axis), at a right angle to the y-axis which passed through the contact points of the maxillary central incisors. The first rugae were located on anterior and posterior sides of the baseline, with average distances of about 1mm from the baseline. Right and left first rugae located anterior to the baseline showed a "minute asymmetry in the topography", whereas there was better symmetry of the right and left rugae situated on the posterior side of the baseline.

In a clinical study of the mechanics of retraction of maxillary canines Ziegler and Ingervall (1989) measured the amount of canine movement on maxillary study models. They photographed the model with the central projection perpendicular to the occlusal plane, with a millimeter scale in the occlusal plane. The contact point between the first molars and the second premolar was identified and projected onto the medial palatal plane. The distance from this point to the projected position of a “distinct” medial ruga point was measured as an indication of the movement of the first molars in their study. Ziegler and Ingervall (1989) found that the stability of the rugae was good, and that the average difference between the pre- and posttreatment measurements of the rugae was within the limits of the error of measurement (they compared right and left sides of the maxilla, one side being the control side). They also noted that the mean duration of this study was only 103 days and that relatively little change in the rugae due to growth could be expected during this time.

Yamamoto *et al* (1991) evaluated the morphological stability of the palate as a means of reference, and measured the deformation of the palate during orthodontic treatment in nine patients aged 8-14 years of age, over treatment periods of 6-21 months. They developed a method of three-dimensional measurement using a personal computer and an optical system (laser and image sensor), which they found to be very accurate. These authors emphasized that actual measurement accuracy is mostly determined by the reproducibility of the plaster casts during the various stages of orthodontic treatment.

Almeida *et al* (1995) digitized dental study models of 94 Class II treatment cases in three dimensions using the reflex metrograph in a study to determine if the palatal rugae are affected by treatment with headgear or functional appliances, as compared to an untreated control group. The measurements were done at enrollment and 15 months later. Perpendicular measurements from certain ruga points to the median palatal plane (MPP) were done, and transverse distances between medial and lateral points on the rugae measured. Anteroposterior distances between the first, second and third rugae were measured. The MPP to rugae distances and linear distances between the medial points of the first rugae were stable in all the groups. The anteroposterior distances between the medial points of the second and third rugae were also stable in all groups. Significant changes were observed for the lateral points of the rugae, particularly in the headgear group. Almeida *et al* (1995) concluded that the medial points of the rugae, especially the first rugae, appeared to be suitable anatomic landmarks for the construction of stable reference planes for serial study model analyses. These landmarks also did not change significantly in the control group during the 15 months of their study. The lateral ruga points were less stable, and showed differences in the treatment and the control groups. These results concur with those of others regarding the stability of the lateral points of rugae during orthodontic treatment (Hausser 1950, 1951 cited Peavy and Kendrick 1967, Peavy and Kendrick 1967, Van der Linden 1978).

Bailey *et al* (1996) compared the positional changes of the palatal rugae between patients treated orthodontically with extraction of maxillary premolars with those treated without extractions (57 adults, 18-36 years old, treatment times from 8-43 months). They concluded that the amount of tooth movement seemed to have some influence on the stability of the rugae. Their main conclusions were the following:

- the lateral points of the first rugae changed in extraction cases
- none of the medial points of the first rugae were affected in extraction cases
- changes in medial points of first rugae occurred in the nonextraction group; these points may not be stable references for evaluating tooth movement in nonextraction cases
- posterior movement of the maxillary anterior teeth did not affect the medial and lateral points of the second and third rugae in either extraction or nonextraction groups. They attributed this to a decrease in arch circumference, which affected the anterior part of the palate.
- anteroposterior changes were different for the extraction group only, suggesting that the mechanics of space closure had an effect on the stability of rugae, especially the second rugae (closest to the premolars).
- medial and lateral points of third rugae appeared stable in all transverse, linear and anteroposterior measurements in extraction or nonextraction cases. They therefore concluded that the medial portion of the third rugae could be used as stable reference areas when evaluating orthodontic treatment that does not depend on retraction of anterior teeth.

Abdel-Aziz and Sabet (2001) agreed with the latter authors, and found that the lateral third ruga points could be used as reference points for superimposition of scanned study models. They studied 50 orthodontically treated adult patients who had extraction of first premolars.

Hoggan and Sadowsky (2001) studied 33 cases where maxillary first premolars were extracted as part of the orthodontic treatment, to assess mean horizontal molar and incisor movement relative to palatal ruga landmarks on study models, compared to these tooth movements measured cephalometrically. They concluded that there were no significant differences in molar movement relative to the medial and lateral ends of the first and second rugae, or to the medial end of the third ruga, using these two methods. There were no differences between mean incisor movement relative to the medial and lateral ends of the third ruga. These authors recommended the use of the medial end of the third ruga as a suitable landmark to use for study model analysis of molar and incisor tooth movement.

Ashmore *et al* (2002) developed a mathematical approach for using homologous structures on studymodels to orient models in a common frame of reference. Unique anatomic landmarks selected on the palatal rugae were registered, and these were superimposed using subsequent models to analyse tooth movement during headgear treatment compared to that of untreated controls. The mathematical model proposed by Ashmore *et al* (2002) has the advantage that the best fit of the digitized rugae can be determined despite variations in the special configuration of the rugae caused by measurement error, growth, or treatment effects. It could also help quantify the accuracy of the superimposition of the rugae points. The superimposition used in their mathematical model assumed that the palatal rugae are stable landmarks. Ashmore *et al* (2002) used the Euclidean distance matrix analysis, a method of shape comparison that is invariant to changes in translation, rotation, reflection and scaling, as the matrix of Euclidean distances between landmarks (rugae points). Comparison of the form of two sets of landmarks was achieved by taking the ratio of each element of the matrix of distances. The form dissimilarity indexes were calculated and compared to each other statistically. Ashmore *et al* (2002) also evaluated whether form differences of rugae occurred in the treatment group. Form change was described as lack of fit after superimposition. Translating the form dissimilarity index into millimeters is not possible, because the form dissimilarity matrix is composed of ratios.

Ashmore *et al* (2002) found statistically detectable changes in the rugae configuration for patients who were untreated and those who wore headgear. Euclidean distance matrix analysis indicated that the distance between measured rugae points changed only an average of 2% over the 2-year treatment period in the headgear group. They recommended that this change in form be considered in evaluating the results of studies using this method. They also suggested that future investigators could consider using a weighted Procrustes superimposition method (Rohlf 1990 cited Ashmore *et al* 2002) so that greater statistical emphasis could be placed on rugae points known to be the least susceptible to treatment induced changes (e.g. medial aspects) and less emphasis placed on the areas known to change more with treatment (e.g. lateral and anterior aspects).

Results from Ashmore *et al*'s (2002) study showed substantial between-subject variation in the magnitude of tooth movement, and in the pattern of movement over time. Many authors have reported on the existence of a wide range of individual differences from a uniform treatment modality, and have encouraged research into the possible reasons for this effect (Baumrind et al 1996, Tulloch *et al* 1997, Ghafari *et al* 1998). To investigate individual variation Baumrind (1998) recommended that the dependent variable be measured frequently and precisely, and that "additional measures should be taken during treatment that may account for the individual variations in outcome".

The appearance of the palatal rugal pattern has been used in the early diagnosis of submucous cleft palate, in children too young to undergo nasoendoscopy and videofluoroscopy (Park *et al* 1994). One or more of the rugae curved towards the region of the bony notch in the posterior border of the hard palate in 14 of the 17 cases (87.5% of the cases) of submucous cleft palate these authors investigated. This was a unique feature, and the two cases without this rugal pattern did not have a detectable bony notch. In all of the isolated cleft palate cases, one or more of the rugae curved towards the anterior end of the cleft. This feature was not seen in any of their non-cleft controls.

Other researchers have relied on the physical superimposition of palatal rugae using impression materials to construct a template of the rugae that could be transferred over serial study models (Bar-Zion *et al* 1998, McDonald *et al* 2001). They noted that any inconsistencies in the dental cast could reduce the stability of the template, and the accuracy of the superimposition. They concluded that changes in the rugae may require the fabrication of another template that would better fit in a sequence of study models.

2.6 Methods of measurement of palatal rugae on studymodels

Kogon and Ling (1973) described a technique to compare palatal rugae patterns for forensic purposes. Palatine rugae (longer than 2 mm long), the palatine raphe and palatine papilla were outlined on each study model using a medium soft pencil. The study model was placed in a dental surveyor in such a manner that the rugal area was as parallel to the film in the camera as possible. A scale was placed beside the study model. Tracings were made on transluscent acetate film and all sheets were positioned in a standardized manner. The acetate sheet was positioned on an easel with the centre of the palatine papilla at the intersection of a "cross mark", and the median raphe aligned along the long axis of the cross. A photographic enlarger projected a twice-enlarged image of the photographic negative onto the sheet on the easel, and the rugae pattern could then be traced onto the acetate sheet. Kogon and Ling (1973) reported that the test for reproducibility "showed that there is a natural variability in the tracings made by different examiners and by the same examiner at different times. These variations were so slight that in no way did they nullify comparisons."

A method used in forensic bitemark comparison analysis is a transparent overlay technique described by Wood *et al* (1994). A photocopied image of the plaster cast of a bitemark is made with an accuracy of 99.5%, by placing the cast face down on the copier. The image is copied onto a transparency with a Boley gauge for reference, and then superimposed on the scaled 1:1 photograph of the bitemark. Wood *et al* (1994) concluded that computerized image editing is useful in forensic odontology.

A study making photocopies of study models with the occlusal surface face down produced no measurable distortion, and when teeth were positioned apical to the occlusal plane, there was some reduction in size in the order of a reduction of 1% at 10mm from the occlusal plane (Cassidy *et al* 1998). BeGole *et al* (1998) reported similar results, confirming that photocopies are a reliable method for measuring study models.

2.7 Left-right side differences in dental measurements

Craniofacial asymmetry was probably first recorded by an artist, Hasse, who noticed that early classic Greek sculptors who duplicated nature showed asymmetries in their work (Hasse 1887 cited Mulick 1965).

The lack of symmetry of the dentofacial complex has been well documented (Lundstrom 1961, Van der Merwe 1989, Bishara *et al* 1994, Kula *et al* 1998, Maurice and Kula 1998). Dental arch asymmetry has been shown to be more prevalent in persons with malocclusions than persons with normal occlusions (Alavi *et al* 1988, de Araujo *et al* 1994a, de Araujo *et al* 1994b, Rose *et al* 1994). Some dentoalveolar asymmetry has been described in the shape of the dental arch interpolated using mathematical formulae (Alavi *et al* 1988, Richards *et al* 1990). Dentoalveolar asymmetry has also been demonstrated on photographs of dental study models, and the anteroposterior and transverse linear measurements done directly on these photographs (Alavi *et al* 1988).

Cassidy *et al* (1998) found that the left side of the dental arch is slightly but systematically larger than the right side for most lengths, widths and tooth angulations. There were significantly more Class ll buccal segment relationships on the right side than the left, which the authors surmised could be caused by the slightly longer left side of the mandible compared to the right side. In their study of 155 sibships Cassidy *et al* found that arch size, especially arch width, is under considerable genetic control, with a mean transmissibility of 50%. They found little evidence for genetic control of asymmetry, and even less for familial clustering of the magnitude of asymmetry. Woo (1931, 1938 cited Cassidy *et al* 1998) noted that the right side of the calvarium is larger than the left side, probably to accommodate the greater size of the right brain hemisphere due to function of the brain. Woo found that the malar processes and the maxillae, including the palate, demonstrated opposite directionality. He speculated that the larger left side tendencies probably compensated for side differences elsewhere, or because of acquired lateralities, e.g. chewing side preference. Shah and Joshi (1978) reported that the total facial structures were larger on the right side of the face, and that the lateral maxillary area showed greater asymmetry than other parts of the face. They described relative symmetry on both sides for the dentoalveolar region and the mandibular region, which they attributed to the function of the labial and lingual musculature. Peck *et a*l (1991) analysed skeletal asymmetry in subjectively recognized esthetically pleasing faces, and described a tendency towards right sided dominance which was not statistically significant. Other researchers have found that the left sides of the craniofacial skeleton were larger in their studies of asymmetry (Vig and Hewitt 1975).

There seem to be differing reports concerning the relative extent of asymmetry in the anteroposterior versus the transverse dimensions, with some studies reporting larger anteroposterior than transverse asymmetries (Alavi *et al* 1988, Proffit 1993), and others reporting the opposite findings (Maurice and Kula 1998).

Reports of dental asymmetry are also not consistent in their conclusions about right and left side differences. Maurice and Kula (1998) reported that about 25% of their sample of 52 9-year old children had transverse asymmetries greater than 2mm at any one landmark; and about 11.5% had anteroposterior asymmetries greater than 2mm. Their results indicated that any one-sidedness they found had small mean arithmetic differences, were inconsistent and were probably unimportant clinically. Although they recorded low values, the left sides were larger for three transverse measurements: between upper primary canine cusp tips to MPP left and right, upper second primary molar mesiobuccal tips to MPP left and right, and for upper first permanent molar mesiobuccal tips to MPP left and right. The mean absolute differences were slightly greater in the transverse dimension (1-1.48mm), compared with the anteroposterior dimension (0.42-1.14mm). The mean absolute differences were slightly greater in the transverse dimension (1.00±0.71mm to 1.31±0.93mm) compared to the anteroposterior dimension (0.42±0.91mm to 1.14±0.80mm), but these differences were not statistically significant.

The prevalence of anteroposterior asymmetry in the mixed and permanent dentitions increases the more posterior the measurements, and some researchers attribute asymmetric molar relationships to this tendency (Maurice and Kula 1998, Alavi *et al* 1988, Lundstrom 1961). Lundstrom (1961) described how asymmetric rotation orientation of the upper dental arch within the skull could result in the molars being at different anteroposterior levels on the left and right sides, and subdivisions in Angle's Classes II and III. Lundstrom studied the symmetry of the dental arch relative to the midpalatal raphe in 139 13-year old boys with nearly ideal or anatomically correct occlusion. He found that the greatest asymmetry of the dentition was located at the first molars, compared to the premolars and incisors. Lundstrom noted that the first molar on the left side was often more anterior to the same tooth on the right side, than vice versa. The average difference of 0.45 - 0.14mm was statistically significant. Azevedo *et al* (2006) reported that dentoalveolar discrepancies, usually distal positioning of the first mandibular molar on the Class II side and secondarily mesial positioning of the first maxillary molar on the same side, and not skeletal factors are usually the components of Class II subdivision malocclusions.

Ferrario *et al* (1993) studied the position and symmetry of all permanent teeth (up to second molars) in 50 males and 45 females aged 20-27 years with normal dentitions, and concluded that a certain degree of asymmetry could be considered to be a normal finding, and that perfect symmetry is a difficult and "abnormal" goal. No significant gender differences were found in their sample.

Vig and Hewitt (1973) speculated that the dentoalveolar region is adaptive and has a high degree of symmetry than the rest of the face because of compensatory growth of the alveolus.

De Araujo *et al* (1994a) studied the frequency of asymmetries on study models of 20 subjects with normal occlusions, whose mean age was 22.4 years. They found that the maxillary and mandibular midlines, and palatal raphe were nearly coincident with the medial sagittal plane on frontal cephalometric radiographs. Half of their sample presented asymmetries of the first molars greater than 1mm in the anteroposterior and transverse planes. No gender differences were evident.

Can the midpalatal raphe be used as an ideal reference plane for evaluating dental arch asymmetry? The midpalatal raphe has been defined as a line connecting an anterior point on the raphe anterior of the incisive foramen and a second point on the posterior part of the raphe at the depth of the second molars (Cassidy *et al* 1998). Many studies reported in the literature have used the midpalatal raphe as a standard reference plane when making transverse comparisons of the position of bilateral dental landmarks (Hunter 1953, Lundstrom 1961, Alavi *et al* 1988, de Araujo *et al* 1994 a), de Araujo *et al* 1994 b)), but Lundstrom (1961) illustrated a case to show that there are occasions where the midpalatal raphe could be primarily responsible for dental arch asymmetry.

Differences in the direction of rugae on the right and left sides have been described. Lysell (1955) showed that the rugae on the right side are directed more outward-backward than the rugae on the left side. Lundstrom (1961) and Lysell (1955) concluded that, although differences between the right and left sides could be associated with the influence of the external environment, some right-left differences could be linked to nonspecific differences between body halves in the internal environment, i.e. a genetically guided symmetric development of the individual could result in small differences between bilaterally located organs that cannot be ascribed to the influence of external factors. It seems that the precision of genetic guidance is not perfect, even when the external environment may favour symmetrical development.

Huddart *et al* (1971) described a method of measuring photocopy diagrams by computer of the maxillary arches of children at birth, and found that the landmark postgingivale was more difficult to locate on the left side than on the right side. They had no explanation for this finding, as it appeared that landmark identification had been done accurately.

Van der Merwe (1989) studied differences between the left and right side mesio-distal tooth sizes in a sample of 200 South African Caucasian patients, and found the following statistically significant asymmetries: maxillary canines R>L; maxillary second premolars R>L; mandibular second premolars R<L; maxillary first molars R>L. Van der Merwe (1989) also described consistently larger mesio-distal tooth measurements in males than in females, the greatest difference being the four canines, where the difference was approximately 0.4mm. Garn et al (1966) found that the asymmetry (mean magnitude was 0.24mm) in their sample was larger for males than females, greater for larger teeth, and larger for the more distally placed tooth in each morphological class. They concluded that bilateral asymmetry regarding mesiodistal and buccolingual tooth size is governed by developmental factors in the tooth morphological classes, and is also affected by gender (less effective genetic control of tooth size in the XY compared to the XX chromosomes) and tooth position within each class. Other studies, however, have reported that there are no statistically significant tooth size differences between right and left sides of the dentition, either within individuals or in their study samples as a whole (Garn *et al* 1967).

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Aim of the study

This project aimed to measure changes in certain dimensions of the first, second and third primary rugae during orthodontic treatment, and to evaluate the changes in tooth movement during orthodontic treatment in patients treated without extraction of premolar teeth (nonextraction) and with premolar extractions, using the palatal rugae pattern observed on orthodontic study models, in two stages:

- At commencement of orthodontic treatment, and before any premolar extractions
- At removal of orthodontic appliances once the desired positions of teeth had been reached (end of active orthodontic phase).

3.2 Research hypotheses

The following hypotheses were tested or evaluated:

1. The rugae themselves possess internal dimensional stability between pretreatment and posttreatment conditions.
2. The rugae positions relative to one another are dimensionally stable between pretreatment and posttreatment conditions:
    a) in nonextraction orthodontic cases
    b) in maxillary and mandibular first premolar extraction cases
    c) in maxillary first and mandibular second premolar extraction cases
3. Soft tissue rugae are not stable landmarks for use in assessment of tooth movement in orthodontic treatment.
4. The relative positions of the palatal rugae are affected by orthodontic treatment involving extraction of maxillary teeth.

5. Rugae to dental unit distances change equally on the right and left sides during orthodontic treatment.

3.3 Sample description

The records of 110 Caucasian subjects who had undergone conventional edgewise orthodontic therapy during their pubertal growth spurts were analysed. Caucasian subjects were used because that was the study group where material was readily available. Three groups of patients were selected according to the treatment regime followed: treatment without extraction of premolar teeth (group 'NE'); extraction of four first premolar teeth (group '4s'); and extraction of maxillary first premolar teeth and mandibular second premolar teeth (group '4&5s'). Previous research has indicated that nonextraction and various premolar extraction treatment plans result in different effects on the rugae (Van der Linden 1978, Almeida *et al* 1995, Bailey *et al* 1996). Due to the fact that orthodontically treated cases were used in this research it was impractical to include a control group. This was therefore a longitudinal study with patients acting as their own controls. All the materials used in this study were held in secure format and no identifying particulars of these patients were shared with anyone.

The following treatment criteria were used during the selection process:

- All the cases had been treated by one operator (an orthodontist in private practice) using the same Edgewise technique. Complete pre- and posttreatment records were available. All the study models had been cast in orthodontic plaster as soon as possible after the alginate impressions had been taken. The orthodontic treatment received by each individual patient was not randomized. A specific treatment plan was devised by the orthodontist for every patient, based on clinical records and examination, and the operator's own clinical expertise.
- All malocclusions were treated with .018" standard edgewise attachments. The treatment technique was based on the use of .016 x .022 stainless steel

archwires with/ without closing loop arches in both jaws. Four ounce Class II elastics were used when required. Second molars were excluded from the appliance. The occlusions were finished with ideal .017 x .025 archwires. All subjects had an Angle Class 1 occlusion with a normal overjet (1-2mm) and overbite (1-3mm), and no spaces in the arches at the end of treatment.

- Cleft lip and palate, and other craniofacial deformity patients, and subjects where palatal expansion or orthognathic surgery was part of the treatment plan were excluded, as were cases with gross dental anomalies (e.g. congenitally missing teeth, supernumerary teeth, toothsize aberrations).

Orthodontic study models representing two stages of treatment were analysed:
Pretreatment, before extractions had been done and before orthodontic treatment had been started (T1)
Posttreatment, after removal of the fixed appliances (T2).
T1 - T2 was the active treatment phase involving the wearing of fixed orthodontic appliances.

3.4 Identification of rugae and tooth landmarks, and measurement of the maxillary study models

This method of study model analysis has not been used previously in orthodontics. The digital imaging system has been used for bite mark analysis in forensic dentistry (Wood 1994, Wood 1996). Such bite mark analysis involves and requires the accurate metric recording of the dentition and associated soft tissue (Wood 1994, Wood 1996, Sweet *et al* 1998). The application of computer technology for measurement of dental study models is a modern trend, and the technique is rapid and highly reproducible. Some disadvantages of this method include the high cost of fast and powerful computer hardware, and the need for the examiner to be computer literate. Most orthodontic offices, however, have modern computer equipment and scanners, and this system or other similar one could easily be integrated into existing facilities in orthodontic offices.

One examiner did all the landmark identification, scanning and measurements. Paired, marked study models (pretreatment and posttreatment) were positioned on a flat bed reflective scanner surface with the occlusal plane held parallel to the glass surface of the scanner. After some pre-testing done on forensic cases the study models were scanned at 300 dpi resolution. An ABFO #2 bitemark scale[1] was placed on the scanner surface, parallel to the occlusal plane to assure accurate recording of measurements (left-right laterality and life-sized reproduction). Information was scanned onto the hard drive of the computer[2] and transferred to 100 MB ZIP drives. Adobe Photoshop 4.0 computer programme[3] was used for analysis of the models. The palatal rugae were digitally enhanced to improve their visibility by a single operator experienced in the use of Photoshop 4.0 (Figs 3.1 a, b and c representing examples of '4s' extraction and '4&5s' extraction cases and nonextraction cases respectively; Fig 3.2). Pre- and posttreatment images were superimposed using specified points on the rugae as reference. After enhancing, the images via changing the contrast, density, and brightness controls, the superimposition of the scaled images was done on the computer using "cut" and "paste" commands. This created layered images. By controlling the translucency/opacity of the top image using the "paste controls" command, one can see partially or totally through the top image onto the bottom one. The superimposition was done by using the cursor arrows to move the pasted, partially opaque, top image over the completely opaque bottom image. Any model which did not allow acceptable viewing of the anatomical areas of interest was not included in the study. In all such cases this occurred because of problems with the models themselves rather than imaging problems.

[1] Lightning Power Co., Salem, Oregon, USA
[2] Apple Macintosh, Cupertino California, U.S.A.
[3] Adobe Systems Inc., 1585 Charleston Road, Mountain View, CA, 94039-7900

Figure 3.1a
Example of scanned images of pre- and posttreatment studymodels of a maxillary and mandibular first premolar extraction case (group '4s')

Figure 3.1b
Example of scanned images of pre- and posttreatment studymodels of a maxillary first premolar and mandibular second premolar extraction case (group '4&5s')

All landmarks were marked on each model with the "brush" tool (Fig 3.2) which was 2 pixels in size and all measurements were made directly on the computer CRT screen[4]. All measurements were made using the rulers set to millimeters and using the computer mouse as the measuring tool. Measurements were made from

[4] High resolution 21" Sony Trinitron (Sony S.A., Edenvale, 1610, South Africa)

one point to another by placing the cursor on the first point of interest and then dragging it to the second point of interest with the mouse button depressed. When the cursor arrived at the second point of interest the mouse button was released and the metric changes were displayed in a sub menu of the program. All measurements were made on magnified images (2:1) to allow easier visualisation of the landmark points and accurate recording of the measurements. Following this, the measurements were recorded on paper and then the data for images were entered into the appropriate groups using a spreadsheet on the Excel computer program[5].

Figure 3.2
Example of a nonextraction case (NE) with identification of landmarks on images

[5] Microsoft Corporation, Microsoft (S.A.) (Proprietary) Limited, Rivonia, 2128, South Africa)

3.4.1 Description of the landmarks and measurements used in the study

1. Measurements of the pre-and posttreatment perpendicular widths and transverse lengths of the first three primary rugae, and anteroposterior distances between the lateral points and medial points of these rugae were done. To determine the perpendicular width of a ruga a perpendicular line was constructed from the median palatal plane to the most posterior point of the ruga. The perpendicular then constructed from this point across the ruga was measured as the perpendicular width of the ruga.

2. The following interdental transverse (archwidth) dimensions were measured pre- and posttreatment:
   - Maxillary intercanine widths: measured as the distance between the cusp tips or estimated cusp tips in the cases of wear facets (Walter 1962)
   - Maxillary premolar widths: measured as the distance between the tips of the lingual cusps of the first or second premolars (Howes 1957)
   - Maxillary intermolar widths: measured as the distance between the cusp tips of the mesiobuccal cusps or estimated cusp tips in cases of wear facets (Walter 1962).

3. The following landmarks were identified on the study models (Fig 3.3) and measurements entered onto the spreadsheet:
   - A median palatal plane (MPP) was constructed on the median palatal raphe. A midline point in the region of the anterior rugae and a midline point in the dorsal part of the palate was used for the determination of the midsagittal plane according to the method used by Van der Linden (1974) and Bailey *et al* (1996).
   - The most posterior point on the posterior ruga on the right and left sides was identified (points a and b, respectively), as well as the most anterior point of the incisive papilla on MPP (point c).

- Perpendicular distances from ruga points a and b to the median palatal plane were constructed. The right and left intercepts on the MPP were represented by points d and e, respectively.
- Individual tooth positions were measured to each of the five rugal landmarks (points a to e) described above:
    - mesio-lingual cusp tips of 16 and 26
    - disto-buccal cusp tips of 16 and 26
    - lingual cusp tips of 14/15 and 24/25
    - cusp tips of 13 and 23
    - mesial incisal tips of 11 12 21 22
    - distal incisal tips of 11 12 21 22

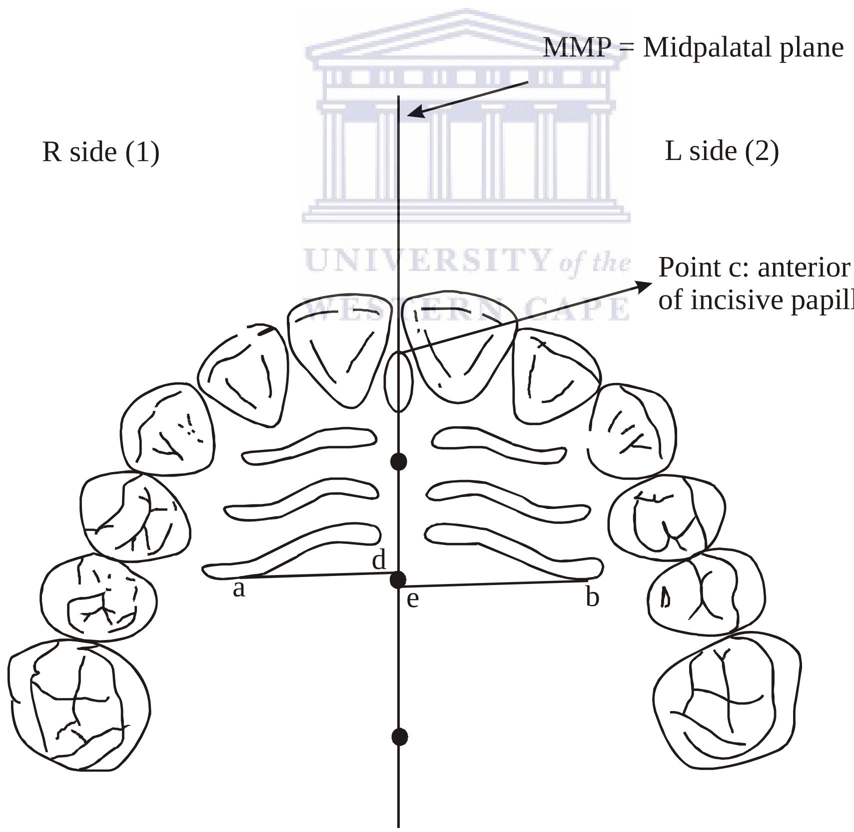


Figure 3.3
Rugal landmarks (points a-e) used in the study

a) most posterior point on posterior ruga on right side
b) most posterior point on posterior ruga on left side
c) anterior point on incisive papilla
d) perpendicular projection of point (a) onto midpalatal plane
e) perpendicular projection of point (b) onto midpalatal plane

3.5 Intra-observer error

To test whether the researcher located the landmarks reliably and that the measurements made were reliable, 45 measurements were re-measured on 5 sets of study models two weeks after the original measurements had been done. The mean difference between the first and second measurements was 0.142±0.192mm. The error of the method was also calculated using the Dahlberg technique (Dalberg 1940). The formula was $Se = \sqrt{\sum d^2 / 2\mu}$ where $\sum d^2$ is the sum of the squared differences between pairs of measurements and μ is the number of duplicate measurements. The value for Se was 0.131mm. These results indicate a high degree of intra-observer reliability.

3.6 Pilot study to test for magnification of objects at distances from the scanner surface

When scanning in the models allowance was made for differences in the curves of Spee and Wilson. The curves of Spee and Wilson could be verified to be constant by direct measurements of the models or by using circles of known dimension on the occlusal surface of posterior teeth, which could be used for scaling of the objects. If there was no appreciable magnification of the images of these circles then there would be no need to make allowances for the curves of Spee or Wilson. A trial test was done by placing an American Board of Forensic Odontology bite mark ruler on the scanner surface and at 1.5mm, 3.0mm, 4.5mm, 6.0mm, 7.5mm and 10.5 mm from the surface. The results indicated that at 7.5 mm from the scanner surface the magnification was only 0.1mm and was uniform in the XY plane. At 10.5 mm the magnification was 0.2-0.3mm. This meant that as long as the position of any tooth was less than 10.5 mm from the occlusal plane it could be scanned successfully (Fig 3.4). No palatal arch in this series was anywhere near 10.5 mm from the occlusal plane.

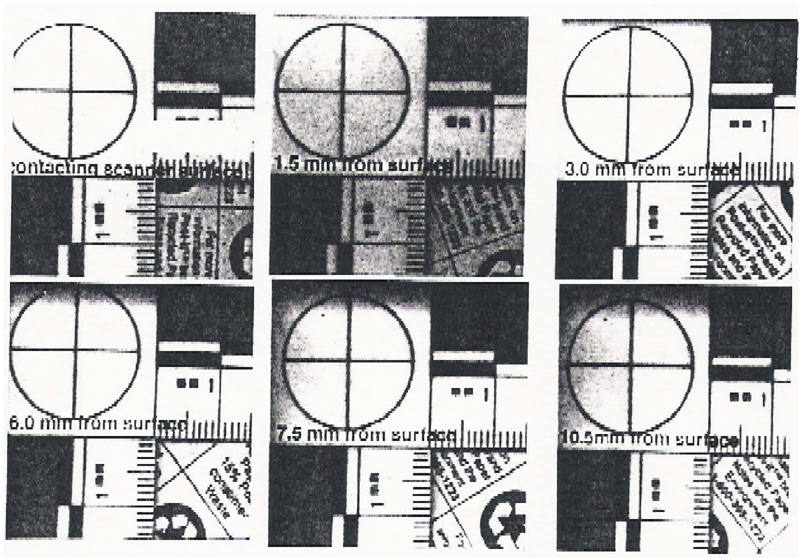


Figure 3.4
Scanned images of ruler markings at distances from the surface of the scanner

3.7 Statistical analysis of the data

The data was captured by means of a spreadsheet package, Excel®. Descriptive statistics were calculated for the complete sample for the beginning and end of treatment, and for the nonextraction and two types of extraction groups separately. The male and female gender groups were only analyzed separately when necessary. Descriptive statistics were also calculated in Excel®, and the data was investigated for unusual (outlying) observations. These outliers could have been due to incorrect recordings or measurements that did not fit in with the three treatment groups and therefore may have a misleading influence on the descriptive statistics.

The Number Cruncher Statistical System (NCSS) package was mostly used for graphical displays of the univariate distributions (NCSS 1955). Violin plots were used to gain insight into the approximate empirical distributions (Chambers *et al* 1983, DuToit *et al* 1986). The violin plot is an improvement on the box-andwhisker plot, in that it provides an empirical density estimate of the distribution. The parameters of the box plot are included in the body of the violin plot, the median and the two quartiles. The violin plot provides a symmetric display of the density and usually tapers off to the maximum and minimum observations. If local modes (e.g. bimodality) occur they would be clearly visible in this symmetrical display of the density.

The correlation structure was also studied. Inferential statistical analyses were used to test for significant differences among the three treatment groups. The tests included paired t tests to evaluate the significance of the differences between the two stages (T1 and T2), done at the $p = 0.05$ level of significance.

CHAPTER 4

RESULTS: PRESENTATION AND DISCUSSION

4.1 Introduction

The descriptive statistics of age and duration of treatment are given in Table 4.1, and a graphical display of the distributions of these variables is shown in Figure 4.1.

Table 4.1
Descriptive Statistics of Age (in Years) and Duration of Treatment (in Years)

	Age	*Duration of Treatment*
Count	110	110
Mean	12.6	1.8
Median	12.6	1.7
Standard Deviation	1.7	0.5
Range	11.9	2.9
Minimum	8.5	0.9
Maximum	20.3	3.7

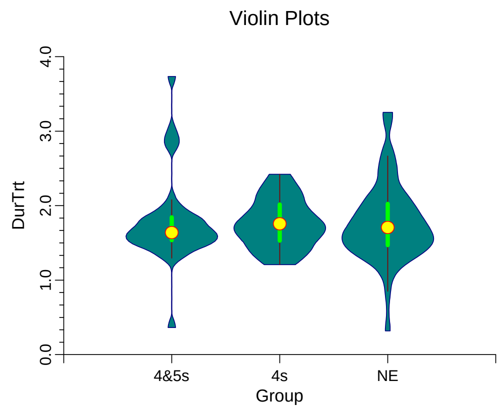


Figure 4.1
Violin Plots of Age and Duration of Treatment for the three groups '4&5s', '4s' and NE

The median ages and the age distributions in the three treatment groups were similar, except for the presence of an outlier (age of 20.5 years) in the 'NE' group. The shapes of the age distribution for the three groups were relatively similar except for the '4&5s' and the 'NE' group. For the '4&5s' the distance from the first quartile to the median was larger than the distance from the median to the third quartile. The '4s' group was approximately symmetrical in distribution. The distribution of the 'NE' group was also slightly skewed in that the distance from the median to the third quartile was larger than the distance from the first quartile to the median.

The median duration of treatment was similar for the '4s' group and the 'NE' group, and the median duration of the '4&5s' group was somewhat shorter. The '4&5s' group contained the overall minimum (0.9 year or 11 months) and overall maximum (3.7 years).

The gender distribution of the sample was 52 males and 58 females. The gender distributions in the groups were: group 'NE' – 18 males and 25 females; group '4s' - 18 males and 16 females; group '4&5s' – 16 males and 17 females.

4.2 Changes in Rugal Measurements during Orthodontic Treatment

The rugae dimensions were studied within the three treatment groups. All the measurements were made in millimetres. The pretreatment measurements are presented in Tables 4.2.1, 4.2.3, 4.2.5, 4.2.7, 4.2.9, 4.2.11, 4.2.13, 4.2.15, 4.2.17, and 4.2.19, and the differences between pretreatment and posttreatment measurements in Tables 4.2.2, 4.2.4, 4.2.6, 4.2.8, 4.2.10, 4.2.12, 4.2.14, 4.2.16 and 4.2.18.

4.2.1 Perpendicular Widths of the Posterior Rugae

Table 4.2.1
Descriptive statistics for each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Perp. Width Right Post Ruga			*Perp. Width Left Post Ruga*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	0.79	0.77	0.75	0.72	0.75	0.74
Median	0.70	0.80	0.70	0.70	0.70	0.70
Standard Deviation	0.24	0.19	0.19	0.21	0.19	0.20
Range	0.00	0.08	1.00	0.80	0.70	1.00
Minimum	0.05	0.40	0.50	0.40	0.50	0.40
Maximum	1.50	1.20	0.15	1.20	1.20	1.40

From the above table it can be seen that the perpendicular widths were as wide as 1.5mm. There were no statistically significant differences between the mean perpendicular widths of the posterior rugae in any of the treatment groups, or between the left and right sides, before orthodontic treatment.

Table 4.2.2
Descriptive statistics for each treatment group of the differences between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Perp. Width Right Post Ruga Differences			*Perp. Width Left Post Ruga Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	-0.08	-0.04	0.04	0.06	-0.04	0.01
Median	0.00	0.00	0.05	0.00	0.00	0.00
Standard Deviation	0.25	0.18	0.24	0.21	0.20	0.25
Range	1.00	0.90	1.10	0.90	0.80	1.30
Minimum	-0.70	-0.60	-0.50	-0.40	-0.40	-0.70
Maximum	0.30	0.30	0.60	0.50	0.40	0.60
Confidence Level (95.0%)	0.1170	0.2235	0.2636	0.1616	0.2733	0.7884

Most of the mean differences after orthodontic treatment were very small and five of the six differences were negative, indicating that the perpendicular width of the rugae decreased slightly during the treatment period. The last line of the above table indicates a confidence level and it can be used to determine whether the mean difference was statistically different from zero. As is evident from this data, none of the group means (of the differences) differed significantly from zero. The slight changes in perpendicular widths during the treatment period may be related to growth changes, measurement error, and/or changes due to orthodontic treatment. It is unlikely that growth changes could have contributed to any significant change during the mean orthodontic treatment time of 1.8 years. Researchers who have described and/or measured morphological changes in the rugae have indicated that many of the changes they noted were in the secondary and fragmentary rugae (Thomas and Kotze 1983, Dohke and Osato 1994). This study concentrated on measurement of the primary rugae only. Some authors have noted that the shape of palatal rugae do not change throughout life (Leontsinis 1952, Carrea 1937, cited Peavy and Kendrick 1967, Kapali *et al* 1997).

4.2.2 Rugal Landmarks Projected onto the Midpalatal Plane and to the Incisive Papilla

Table 4.2.3
Descriptive statistics for each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	MPP-a			MPP-b		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	9.82	9.76	10.21	9.44	8.93	10.04
Median	9.80	9.90	10.55	9.60	8.90	10.35
Standard Deviation	1.99	1.71	2.16	1.57	1.72	1.78
Range	8.00	6.70	0.90	6.30	5.70	9.20
Minimum	5.30	6.10	4.10	6.10	6.10	3.70
Maximum	13.30	12.80	5.00	12.40	11.80	12.9

It can be observed from the above table that the MPP-a (median palatal plane to point a) and the MPP-b (median palatal plane to point b) distances were the largest for the ‘NE’ group.

Table 4.2.4 **Descriptive statistics for each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)**						
	MPP-a Differences			**MPP-b Differences**		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	1.08	1.24	1.80	1.03	1.46	0.99
Median	1.00	1.30	1.75	0.80	1.40	0.80
Standard Deviation	1.80	1.56	1.80	1.38	1.90	1.65
Range	11.30	7.10	7.90	5.60	9.70	9.30
Minimum	-4.00	-1.40	-1.00	-1.60	-2.10	-2.90
Maximum	7.30	5.70	6.90	4.00	7.60	6.40
Confidence Level (95.0%)	0.0033	0.0000	0.0000	0.0003	0.0000	0.0001

In the above table all of the six mean differences were positive, indicating that all the MPP-a and MPP-b distances increased significantly during the treatment period. This could likely be ascribed to natural growth and/or a treatment effect, i.e. expansion of the maxillary dental arch during treatment. The mean increases were statistically significant, but small in magnitude.

Rugal length and transverse palatal region width increase up to about 16 years of age has been described in both genders (Lysell 1955, Sillman 1956, 1964), although Van der Linden (1973, 1978) noted that the anterior pair of rugae did not increase in length after 10 years of age. Lebret (1962) studied growth changes of the palate in 13 boys and 17 girls, between ages 5 and 18 years, and found that the shape of the top of the palatal vault remained essentially constant except for an increment in breadth at the apex of the palatal vault in 75% of the sample. Lebret (1962) could not ascribe this increment (widening) to growth at the mid-palatal suture, or to bone remodeling, or to both. Lebret determined the symmetry in the total breadth of the palate, and for both dentitions the left side was slightly wider than the right. She ascribed this finding to three possibilities, namely: 1) the sample selected had wider palates on the left side than on the right side 2) error of measurement, and 3) deformation of the impression. As in this study, Lebret (1962) found large individual variation in all measurements of the dental arches and palate. In their study of the growth in length of the maxilla in boys between 6 and 20 years, Linder-Aronson *et al* (1975) found a relatively stable growth increment occurring over this period. They recorded growth increments of 0.76mm per year in the 9-12 age group and 0.80mm per year in the 12-14 year age group.

The results of this study indicate that probably both normal growth and orthodontic treatment were responsible for the increases in the distances. The results show a large range of values, indicating considerable variation among the responses of individual patients in all the treatment groups. If the maximum increase in length is studied it will be observed that for MPP-a all the maxima were larger than 5.7mm and for MPP-b all the maxima were larger than 4.0mm. This is considerable if they are compared to the values of the six means and medians. The existence of a wide range of differences in response in individuals for uniform treatment modalities is a common finding in the literature, and is also very evident in the results of this study (Ghafari *et al* 1998, Baumrind 1995, Tulloch *et al* 1997).

Table 4.2.5
Descriptive statistics for each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	d-c Differences			e-c Differences		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	17.88	16.46	17.62	16.76	16.05	17.18
Median	17.80	16.50	18.60	16.70	16.20	17.05
Standard Deviation	2.07	2.28	3.34	2.20	3.54	3.14
Range	7.80	9.60	13.3	7.70	15.50	13.20
Minimum	14.50	11.70	9.80	12.50	6.50	11.60
Maximum	22.30	21.30	23.10	20.20	22.00	24.80

From the above table it can be observed that there were no distinct differences in the means of the pre-measurements: d to c (distance between most posterior point on the right posterior ruga projected onto midpalatal plane, and a point on the anterior aspect of the incisive papilla) and e to c (distance between most posterior point on the left posterior ruga projected onto midpalatal plane, and a point on the anterior aspect of the incisive papilla) amongst the three treatment groups. It is clear that the distributions of these measurements were fairly symmetrical as can be seen in the similarity of the means and medians. It can be concluded that the anteroposterior distances of the left and right posterior rugae to point c are similar, therefore relatively symmetrical. There was, however, a large range of values. These results partially concur with those found by Maurice and Kula (1988), but differ from other studies which have reported greater anteroposterior than transverse asymmetry of the palatal region (Alavi *et al* 1988, Proffit 1993). This study has demonstrated a significant amount of asymmetry in both the transverse and anteroposterior dimensions of the rugal area of the palate.

Table 4.2.6
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	d-c Differences			e-c Differences		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46			
Mean	-1.68	-2.16	0.04			
Median	-1.20	-2.20	0.20			
Standard Deviation	1.56	2.97	2.20			
Range	6.30	11.60	10.40			
Minimum	-5.00	-8.30	-4.80			
Maximum	1.30	3.30	5.60			
Confidence Level (95.0%)	0.0001	0.0001	0.9029			

Two of the three mean differences in the above table were significantly different from zero and indicated a shortening of the d-c distance in the extraction groups during the treatment period. The ‘NE’ group did not show any definite shortening or lengthening. From the minimum and maximum values it could be seen that ’4s’ and ’4&5s’ groups displayed a definite shortening in some cases (-5.0mm and -8.3mm). The ‘NE’ group had d-c differences as small as –4.8mm and as large as 5.6mm. The shortening of the anteroposterior distance in the extraction groups can be explained by the extractions done during orthodontic treatment. Once again, the wide range of different values for individuals is evident in all three groups. The wide range of results may indicate different responses to treatment or possible growth in this region.

Lebret (1962) and Korkhaus (1959) noted the constancy of a section of the mid-sagittal contour, which they noted could be used as a line of superimposition when comparing serial cephalograms. This approximately 8mm section is located “a few millimeters behind the foramen incisivum up to the region of the palate in the region of the first molars”.

4.2.3 Changes in Dimensions of the First Three Rugae (Transverse Length Changes, and Anteroposterior Distances between Medial and Lateral Ends of these Rugae)

The descriptive statistics of the transverse lengths of the first three rugae are presented in the following Tables. Schematic representations of these changes for each treatment group are illustrated in Figures 4.2 a – c.

Table 4.2.7
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Transverse1 ruga Right			*Transverse1 ruga Left*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	8.68	8.24	9.01	7.62	7.62	7.84
Median	8.50	8.50	8.85	7.30	7.50	7.75
Standard Deviation	1.36	1.73	1.28	1.32	1.87	1.27
Range	5.80	8.70	6.60	4.70	9.30	5.80
Minimum	6.00	3.50	5.00	5.40	4.50	5.30
Maximum	11.8	12.20	11.60	10.1	13.80	11.10

The transverse distance of the first ruga on the right was consistently larger than the comparative distance on the left for all three groups. The standard deviations on the right were also larger than the standard deviations on the left. It is generally accepted that there is no bilateral symmetry in the relative size or number of primary rugae (Simmons *et al* 1987). In Lebret (1962)’s study sample the rugae were larger on the left side. The differences in first primary rugal lengths between the right and left sides also characterized this study sample, but the rugae were larger on the right side compared to the left side in Lebret’s study.

These factors could explain at least some of the left-right side differences found in this sample of patients.

Table 4.2.8
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Transverse1 ruga Right Differences			*Transverse1 ruga Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	-0.25	0.13	-0.54	1.06	0.83	0.92
Median	-0.10	0.20	-0.60	1.00	0.90	0.90
Standard Deviation	1.12	1.15	1.47	1.04	2.09	1.04
Range	5.50	5.80	8.20	4.20	9.90	4.80
Minimum	-3.60	-2.40	-3.80	-1.00	-4.20	-1.90
Maximum	1.90	3.40	4.40	3.20	5.70	2.90
Confidence Level (95.0%)	0.2742	0.5358	0.0137	0.0000	0.0296	0.0000

Of the six differences in the above table four means were statistically different from zero. On the right the difference associated to the 'NE' group was significant and indicated shortening. Surprisingly all the differences on the left were significant and pointed towards a lengthening of the rugae. Rugal length has been shown to increase with age in both genders (Lysell 1955, Sillman 1956, 1964), although Van der Linden (1973) reported that anterior rugae do not increase in length after age 10. The results indicated in Table 4.2.8 may, therefore, be caused by normal growth, the orthodontic treatment done and/or factors associated with the measurement technique. Although the mean changes are relatively small, there is a large range of differences. These results suggest that the use of the first rugae as stable landmarks for 'NE' cases is questionable, but may be used in premolar extraction cases if the rugae on the "dominant" side (side with largest rugae; in this study the right side) are used.

It is interesting to note that the relatively greater changes occurred on the left side, which was the side where the first rugae were significantly shorter that those on the right before orthodontic treatment. Dental arch asymmetry has been shown to be greater in persons with malocclusions than those with relatively normal occlusions (Hunter 1953, Lundstrom 1961, Rose *et al* 1994). An effect of orthodontic treatment would usually be an improvement in dental arch asymmetry. In this study the treatment mechanics would probably have resulted in relatively more "expansion" on the left side, this side being smaller than the right side.

Table 4.2.9
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Transverse 2 ruga Right			*Transverse 2 ruga Left*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	8.18	7.98	8.79	5.79	6.27	6.79
Median	8.10	8.50	9.00	5.70	6.00	6.35
Standard Deviation	2.57	2.21	2.31	1.70	2.04	2.10
Range	8.80	8.00	9.60	5.80	7.60	9.90
Minimum	3.30	3.70	3.80	3.20	2.30	2.90
Maximum	12.10	11.70	13.40	9.00	9.90	12.80

As was the case with the first rugae, the mean transverse lengths of the right rugae were longer than those of the first rugae on the left side, for all three treatment groups. The lengths of the first and second rugae on the right side are relatively similar, whereas the lengths of the second rugae on the left side are considerably shorter than the lengths of the first rugae on the left.

Table 4.2.10
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Transverse 2 ruga Right Differences			*Transverse 2 ruga Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	-0.40	-0.84	-0.39	1.33	0.44	1.16
Median	-0.20	-0.50	-0.10	1.20	0.90	1.10
Standard Deviation	1.69	2.25	1.77	1.33	1.96	1.90
Range	9.00	11.50	10.40	6.20	8.80	10.40
Minimum	-6.20	-4.90	-7.20	-1.80	-5.20	-5.70
Maximum	2.80	6.60	3.20	4.40	3.60	4.70
Confidence Level (95.0%)	0.2462	0.0409	0.1394	0.0000	0.2189	0.0000

On the right side none of the mean differences of the treatment groups were significant, but all the groups showed some shortening. On the left side, the mean differences of the '4s' group and the 'NE' group lengthened significantly. On comparison the mean difference associated with the '4&5s' group was not different from zero, but the group contained individual differences as small as –5.2mm and differences as large as 3.6mm.

It can be noted that the mean differences that were (statistically) significant were on the left side, which was the side with the shorter rugae, compared to the right side changes and relatively larger rugae. The mean changes on the right side in all groups were clinically insignificant. These results indicate that the second ruga on the side of the palate with the largest rugae could be used as reference landmarks for superimposition/ tooth measurements during nonextraction and premolar extraction orthodontic treatment.

Table 4.2.11
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Transverse 3 ruga Right			**Transverse 3 ruga Left**		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	30	46
Mean	9.27	8.28	9.01	6.16	6.46	6.57
Median	9.10	8.70	9.20	5.50	6.45	6.65
Standard Deviation	2.85	2.56	2.72	1.83	2.06	2.18
Range	11.20	9.20	9.70	6.80	6.90	8.20
Minimum	3.3	3.80	4.00	3.40	2.90	2.30
Maximum	14.50	13.00	13.70	10.20	9.80	10.50

As before the mean lengths of the third right rugae were significantly longer than those of the third left rugae.

The asymmetry in lengths of the first three primary rugae was consistent in that the rugae on the right side were all significantly longer than those on the left side.

Table 4.2.12
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Transverse 3 ruga Right Differences			*Transverse 3 ruga Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	24	31	45	24	30	46
Mean	-1.12	-0.19	0.54	1.80	1.24	2.15
Median	-1.00	-0.20	0.20	1.70	1.00	1.85
Standard Deviation	2.33	1.69	2.75	1.68	1.59	2.27
Range	11.80	6.80	12.40	7.30	5.80	13.00
Minimum	-6.60	-3.60	-4.80	-2.40	-1.40	-3.20
Maximum	5.20	3.20	7.60	4.90	4.40	9.80
Confidence Level (95.0%)	0.0212	0.538	0.1927	0.0000	0.0000	0.0000

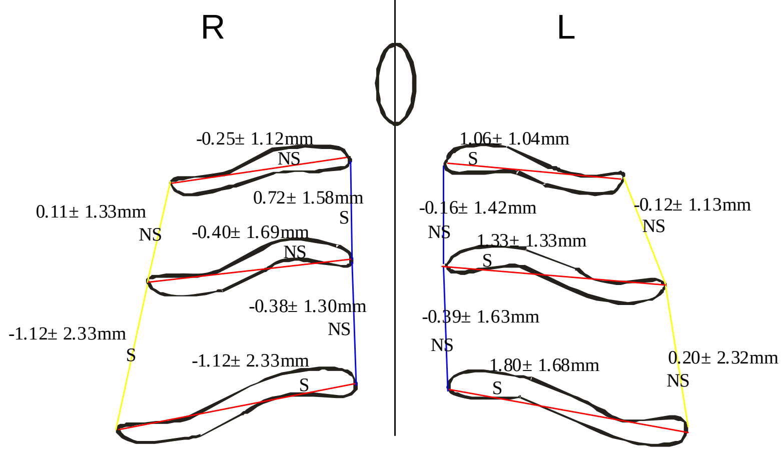
On the right side the ‘4s’ group showed a significant shortening of the transverse dimension of the third rugae during treatment, whereas the changes in the transverse lengths for the ‘4&5s’ and the ‘NE’ groups were not significant. On the left side all the mean differences indicated a definite lengthening of the transverse distances for all three treatment groups ($p<0.05$). This trend for the length of the rugae on the “smaller” side of the palate (left side in this sample) to increase relatively more during the treatment time than the longer rugae on the opposite side is similar to the changes of the lengths observed for the second rugae (see Table 4.2.10).

In conclusion, these results indicate that the transverse lengths of the first three rugae on the dominant side (right side) of the palate were more stable during nonextraction and extraction orthodontic treatment. For the ‘NE’ group the second and third rugae on the right side had no significant differences occurring during treatment, but there was a significant difference for this group for transverse measurement of the first ruga. Both extraction groups exhibited no significant changes in transverse dimensions of the first and second rugae on the right side. The ‘4s’ group, however, showed significant change of the right third ruga, whereas there was no significant change for the ‘4&5’ group. It seems that various premolar extraction sequences may affect the third rugae on the dominant side of the palate, and/or that other characteristics of these cases (e.g. pretreatment characteristics, orthodontist’s biomechanics, etc) may lead to the changes observed in the transverse dimensions of these rugae.

All the differences in the transverse lengths of the first three rugae on the non-dominant side (left side) were significant, except for group ‘4&5’ on the second ruga, indicating that nonextraction and premolar extraction orthodontic treatment resulted in increased transverse dimension of these rugae.

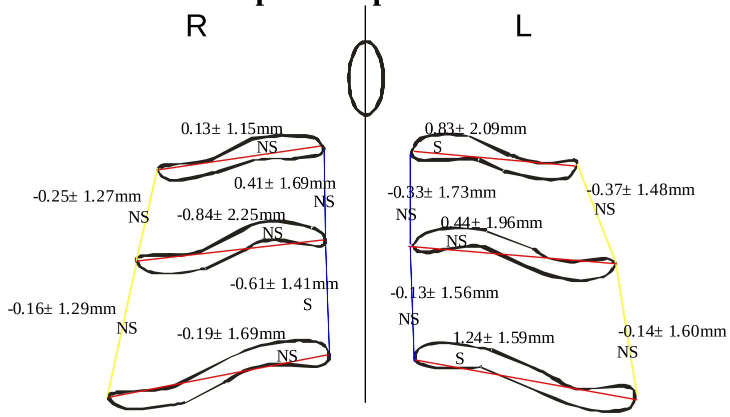
The descriptive statistics of the anteriorposterior distances between the medial and laterial ends of the first three rugae are presented in the following tables. Schematic representations of these changes are illustrated in Figures 4.2 a – c.

Figure 4.2a
Group '4s': Graphical representation of descriptive statistics for differences between pre- and posttreatment measurements



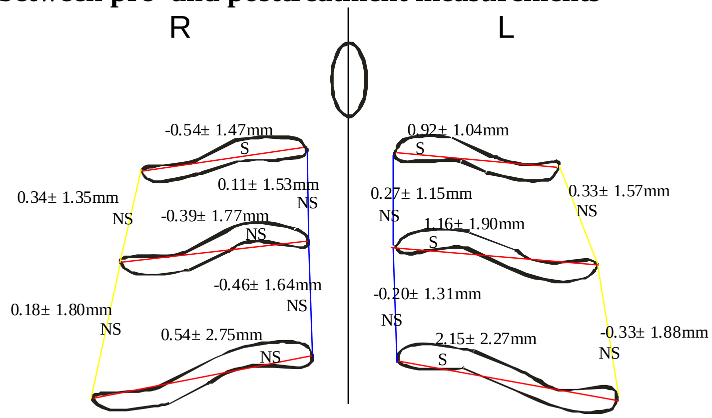
------ **Transverse dimension of ruga**
------ **Anteroposterior medial rugae points**
------ **Anteroposterior lateral rugae points**
S **Statistically significant difference between pre- and posttreatment measurements ($p<0.05$)**
NS **No statistically significant difference between pre- and posttreatment measurements ($p>0.05$)**

Figure 4.2b
Group '4 & 5s': Graphical representation of descriptive statistics for differences between pre- and posttreatment measurements



------ **Transverse dimension of ruga**
------ **Anteroposterior medial rugae points**
------ **Anteroposterior lateral rugae points**
S **Statistically significant difference between pre- and posttreatment measurements ($p<0.05$)**
NS **No statistically significant difference between pre- and posttreatment measurements ($p>0.05$)**

Figure 4.2c
Group NE: Graphical representation of descriptive statistics for differences between pre- and posttreatment measurements



------ **Transverse dimension of ruga**
------ **Anteroposterior medial rugae points**
------ **Anteroposterior lateral rugae points**
S **Statistically significant difference between pre- and posttreatment measurements ($p<0.05$)**
NS **No statistically significant difference between pre- and posttreatment measurements ($p>0.05$)**

Table 4.2.13
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Anterior Post 1_2 Lat Right			Anterior Post 1_2 Lat Left		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	4.47	4.14	4.95	3.28	3.50	3.76
Median	4.10	4.30	4.10	2.80	3.30	3.40
Standard Deviation	1.71	1.78	2.27	1.203	1.56	1.98
Range	5.80	7.00	8.30	4.50	7.00	9.50
Minimum	1.70	1.30	1.20	1.30	1.30	1.10
Maximum	7.50	8.30	9.50	5.80	8.30	0.60

The mean distance between the lateral points of the first two rugae on the right was consistently larger than the distance between the corresponding rugae points on the left for all three groups.

Table 4.2.14
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Anterior Post 1_2 Lat Right Differences			*Anterior Post 1_2 Lat Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	0.11	-0.25	0.34	-0.12	-0.37	0.33
Median	-0.20	-0.20	0.20	-0.10	-0.30	0.35
Standard Deviation	1.33	1.27	1.35	1.13	1.48	1.57
Range	6.80	5.40	8.60	5.40	6.90	9.40
Minimum	-1.90	-2.80	-2.00	-3.50	-3.70	-5.40
Maximum	4.90	2.60	6.60	1.90	3.20	4.00
Confidence Level (95.0%)	0.6853	0.2809	0.0911	0.6029	0.1709	0.1585

None of the six mean differences in the above table were statistically significant different from zero, therefore none of the three treatment groups showed a consistent change for the above measurements over the treatment period. The '4s' group had the lowest mean differences on both left and right sides. The sets of differences were not free from excessive individual changes, for example, some rugae shortened as much as 5.4mm and lengthened as much as 6.6mm. A wide range of variation was observed in all the groups. Therefore, even though the mean changes are small this physical landmark may not always be suitable as a stable reference point. It is possible that this reference point could be used to describe changes in a group of patients, but is probably not reliable on its own for measurement in individual cases. Using more than one reference point or looking at a change in the pattern of the palatal rugae to evaluate treatment changes is therefore probably preferable, a concept which has been debated in the literature (Ashmore *et al* 2002, Baumrind 2002).

The lateral rugal region increases in the anteroposterior dimension with growth until about 16 years of age (Lysell 1955). In this study there could have been some growth in the anteroposterior dimensions of the rugae. Other research has shown that the maxillary canines maintain a relatively constant anteroposterior relationship with the adjacent lateral rugae (Van der Linden 1978). Peavy and

Kendrick (1967) described how lateral rugal movement closely followed canine movement in 92% of their orthodontically treated cases (first premolar extractions and canine retraction), but unpredictably followed premolar movement in 50% of their cases.

The maxillary arch length normally increases by 4.0mm in males and 2.4mm in females from 3- to 13 years (Bishara *et al* 1998). Between 13 and 45 years the maxillary arch length decreases by an average of 5.7mm in males and 4.6mm in females, and this usually manifests as an increase in the tooth size-arch length discrepancy unless interproximal attrition occurs. In this study the arch length would probably have been stable, and any significant changes noted been caused by orthodontic treatment and not by growth.

4.3 Descriptive statistics within the Three Defined Treatment Groups (pre-treatment)

The following is only a superficial discussion of the pretreatment measurements, concentrating on graphical comparisons of the distributions. The three treatment groups were: The group in which the maxillary first premolar and mandibular second premolar teeth were extracted (abbreviated as '4&5s'); the group in which all four first premolar teeth were extracted (abbreviated as '4s'); and the group in which no extractions were done (abbreviated as 'NE'). Differences in location (the median) with respect to the right and left sides and the three treatment groups are mentioned, but no statistical inference was applied to see whether these differences were statistically significant. Only extreme distributional characteristics and differences are mentioned. All distances indicated on the violin plots were measured in millimetres.

Table 4.2.15
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Anterior Post 2_3 Lat Right			*Anterior Post 2_3 Lat Left*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	30	46
Mean	5.03	3.88	4.26	3.66	3.90	4.83
Median	5.00	3.70	4.10	3.70	3.35	4.65
Standard Deviation	1.68	1.59	1.71	1.29	1.95	2.23
Range	7.30	5.90	7.10	5.20	8.20	9.90
Minimum	1.40	1.40	1.00	0.80	1.10	0.70
Maximum	8.70	7.30	8.10	6.00	9.30	10.6

No definite pattern could be observed with respect to the means in the different treatment groups and the left and right sides.

Table 4.2.16
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Anterior Post 2_3 Lat Right Differences			*Anterior Post 2_3 Lat Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	24	31	45	24	30	46
Mean	-0.86	-0.16	0.18	0.20	-0.14	-0.33
Median	-0.75	0.00	0.00	-0.10	-0.40	-0.10
Standard Deviation	1.36	1.29	1.80	2.32	1.60	1.88
Range	6.40	6.60	9.70	12.10	8.70	10.40
Minimum	-4.70	-3.50	-4.00	-3.40	-4.90	-6.70
Maximum	1.70	3.10	5.70	8.70	3.80	3.70
Confidence Level (95.0%)	0.0024	0.4969	0.5071	0.6793	0.6375	0.239

Only the ‘4s’ group showed a significant shortening of the above distance on the right, whereas the mean differences of the other two groups were not significantly different from zero. On the left none of the three treatment groups displayed mean differences that were significantly different from zero. The difference on the right side only for the ‘4s’ group is confusing, and contrasts with the findings of the anteroposterior differences between the first and second rugae, and with the measurements for the group ‘4&5’. The mean changes were small, but there was a wide variation of values.

Table 4.2.17
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Anterior Post1_2 Med Right			*Anterior Post 1_2 Med Left*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	3.02	3.27	3.74	3.85	3.83	3.84
Median	3.10	2.70	3.75	3.90	4.10	3.75
Standard Deviation	1.46	1.77	1.70	1.18	1.53	1.29
Range	5.40	8.30	8.40	5.30	7.50	5.00
Minimum	0.00	0.70	1.00	1.60	0.00	1.70
Maximum	5.40	9.00	9.40	6.90	7.50	6.70

No definite pattern could be observed with respect to the means in the various treatment groups and the left and right sides, for anteroposterior measurements between the medial points of the first and second rugae.

Table 4.2.18
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Anterior Post1_2 Med Right Differences			*Anterior Post 1_2 Med Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	31	46
Mean	0.72	0.41	0.11	-0.16	-0.33	0.27
Median	0.40	0.40	-0.10	-0.20	-0.50	0.20
Standard Deviation	1.58	1.69	1.53	1.42	1.73	1.15
Range	6.00	7.70	8.10	7.20	9.70	5.10
Minimum	-1.50	-2.70	-2.40	-4.10	-4.30	-2.20
Maximum	4.50	5.00	5.70	3.10	5.40	2.90
Confidence Level (95.0%)	0.0256	0.1839	0.6296	0.581	0.2961	0.1153

Only the ‘4s’ group showed a significant widening of the above distance on the right (compare to Table 4.2.16), whereas the mean differences of the other two groups were not significantly different from zero. The widening of this distance in the ‘4s’ group may be due to canine retraction during orthodontic treatment. On the left none of the three treatment groups displayed mean differences that were significantly different from zero. Once again the ‘4s’ group has demonstrated change, which could be because of the proximity of the rugae to the first premolars and the extraction areas. These differences were not observed in the other extraction group. It is possible that the orthodontist's decision-making process for extracting four first premolars and for extracting upper first and lower second premolars shows a definite consistent pattern (e.g. type of malocclusion, amount of canine retraction desired etc) and/or that the treatment mechanics used in these two groups is consistently different.

Table 4.2.19
Descriptive statistics of each treatment group of rugae measurements before treatment (relevant measurement indicated in the layout heading)

	Anterior Post 2_3 med Right			*Anterior Post 2_3 Med Left*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	25	31	46	25	29	46
Mean	4.25	4.26	4.75	4.16	3.80	4.20
Median	4.20	4.00	4.40	3.70	3.6	4.30
Standard Deviation	1.79	1.51	2.01	1.48	1.25	1.36
Range	7.40	6.20	9.40	6.10	5.60	5.20
Minimum	1.50	1.00	0.00	2.40	1.50	1.70
Maximum	8.90	7.20	9.40	8.50	7.10	6.90

No definite pattern could be observed with respect to the means in the various treatment groups and the left and right sides.

Table 4.2.20
Descriptive statistics of each treatment group of the difference between rugae measurements before and after treatment (relevant measurement indicated in the layout heading)

	Anterior Post 2_3 med Right Differences			*Anterior Post 2_3 Med Left Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	24	31	45	24	29	46
Mean	-0.38	-0.61	-0.46	-0.39	-0.13	-0.20
Median	-0.10	-0.60	-0.30	-0.25	-0.30	-0.20
Standard Deviation	1.30	1.41	1.64	1.63	1.56	1.31
Range	6.10	5.30	1.00	7.5	8.1	7.8
Minimum	-4.10	-3.10	-6.50	-2.80	-3.20	-4.60
Maximum	2.00	2.20	4.50	4.70	4.90	3.20
Confidence Level (95.0%)	0.1610	0.0178	0.0628	0.2512	0.6592	0.3058

All of the six differences in the above table indicated a shortening on the left and right side within all three treatment groups. Only the right mean difference associated with the '4&5s' group was statistically significantly different from zero.

These mean values were small indicating that minimal changes in the medial distance measurements occurred, although a wide range of values was measured. Additionally, the statistical significance of these results does not mean that they are clinically significant, as most of the differences were relatively small. (The fact that this study had a large number of measurements and many statistical tests were done could mean that some of the results are going to be statistically significant just because of that).

Generally the changes in the anteroposterior dimensions between the lateral points of the first three rugae showed small mean changes during treatment in all the treatment groups. It may be advisable to use a "best fit" model to evaluate changes, which would include more than one landmark position as reference points if researchers wanted a higher degree of accuracy (Ashmore *et al* 2002).

In conclusion, the anteroposterior distances between the lateral points of the first and second rugae on both sides of the palate did not change significantly during nonextraction and extraction orthodontic treatment. In the 'NE' group there were no significant changes between the anteroposterior distances between any of the lateral points of the rugae or between any of the medial points of the rugae on both sides of the palate. These distances could therefore be used as reference points for superimposition/ tooth movement measurement purposes in nonextraction cases. It is interesting to note that all the lateral and medial anteroposterior distances were stable on the smaller (left) side of the palate for the three treatment groups. In the extraction groups there were significant differences in the anteroposterior distances between the medial points of the first and second rugae on the right side ('4s') and medial points of the second and third rugae on the right side ('4&5s'), indicating that various premolar extraction sequences have different effects on the medial aspects of rugae on the larger side of the palate, and that these landmarks are not stable during extraction orthodontic treatment. The anteroposterior distance between the second and third rugae on the right side changed significantly for group '4s', but not for group '4&5s'. These landmarks may therefore also not be suitable for superimposition or tooth movement measurement purposes in extraction cases.

Table 4.3.1
Descriptive statistics of each treatment group of inter-cusp tip measurements before treatment (relevant measurement indicated in the layout heading)

	13-23 Cusp Tips			**Inter-Premolar Cusp Tips**			*16-26 Cusp Tips*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	16	25	37	21	29	39	25	31	46
Mean	33.92	34.00	32.62	28.05	28.31	29.37	48.46	48.31	48.89
Median	34.00	33.50	32.40	28.20	27.80	29.10	49.10	48.10	49.30
Standard Deviation	2.98	2.97	1.91	2.48	3.01	2.47	3.51	3.62	3.13
Range	10.30	12.40	8.60	9.80	13.60	11.40	16.40	14.30	13.80
Minimum	27.90	26.70	28.00	23.00	23.00	12.30	38.10	40.40	41.80
Maximum	38.20	39.10	36.60	32.80	36.60	36.70	54.50	54.70	55.60

No significant treatment group differences for the "Cusp Tips" measurements could be observed. The "14-24 Cusp Tips" measurements were the smallest of the three "Cusp Tips" measurements.

Table 4.3.2
Descriptive statistics of each treatment group of the difference between inter-cusp tip measurements before and after treatment (relevant measurement indicated in the layout heading)

	13-23 Cusp Tips Differences			*Inter-Premolar Cusp Tips Differences*			*16-26 Cusp Tips Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count	16	25	37	21	29	39	24	31	46
Mean	1.83	1.27	2.01	5.68	4.83	3.13	1.51	1.27	4.06
Median	1.05	1.00	1.80	5.40	5.30	2.80	1.05	0.90	3.85
Standard Dev	1.95	2.04	1.71	1.85	2.11	1.76	2.76	2.72	2.59
Range	5.60	8.90	8.30	7.70	10.30	7.60	13.40	12.80	14.80
Minimum	-0.50	-2.30	-0.90	1.30	-1.60	-0.20	-2.30	-3.70	-3.20
Maximum	5.10	6.60	7.40	9.00	8.70	7.40	1.10	9.10	1.60
Confidence Level (95.0%)	0.0003	0.0023	0.0000	0.0000	0.0000	0.0000	0.0087	0.0106	0.0000

All the above differences indicated a significant widening of the inter-cusp tip measurements during the treatment period. These findings are supported by results of many other studies of orthodontically treated cases (Sillman 1964, Uhde *et al* 1983, Pacquette 1992, Sadowsky *et al* 1994, Lee 1999, Ong and Woods 2001, Hoggan and Sadowsky 2001, Taner *et al* 2004).

Intercanine width: Longitudinal studies of arch width changes in untreated cases indicate that maxillary intercanine width increases until about 13 years, after which age there is no further significant growth (Sillman 1964, Knott 1972). Knott (1972) described a mean intercanine width increase of 2mm from mean ages of 9.4 years to 13.6 years in his study sample. The mean increase from 13.6 to 25.9 years in Knott's sample was 0mm. Knott (1972) also observed considerable individual variation in the total amount of intercanine width changes. Bishara *et al* (1997) found significant increases in maxillary intercanine widths between between ages 3 to 5.5 to 8, and 8-13 years in males and females. Between 13 to 26 years they recorded a small decrease in the mean intercanine width in both genders, which was not significant. In the group of patients in this study, therefore, it can be concluded that most of the increase in intercanine width may be attributed to the orthodontic treatment received by these patients. The mean increase in intercanine width was largest for the 'NE' group, followed by the '4s' and '4&5s' groups respectively. There was a statistically significant difference between the mean intercanine differences of the two extraction groups, but the millimeter measurements were small and probably not clinically significant.

Interpremolar width: The distance “14-24 Cusp Tips” showed the largest widening of the three distances, almost always double the change that occurred in the distances “13-23 Cusp Tips” and “16-26 Cusp Tips”. However, the absolute distances associated to these measurements were the smallest of the three “Cusp Tips” measurements. The interpremolar widths in the three treatment groups were significantly different from one another, indicating that the treatment effects were different for the groups.

Lundstrom (1969) found minimal change in interpremolar width in a longitudinal study of untreated males and females ranging from 9 to 30 years of age, and Lee (1999) stated that little change in interpremolar arch width occurred after age 12 years. Any significant width changes in the premolar area, as noted in this study, may therefore be largely attributed to orthodontic treatment. The relatively greater increase in the interpremolar width (especially the first premolars) than in the intercanine and intermolar widths has been found in studies evaluating dental arch width and form changes after orthodontic treatment (Elms *et al* 1996, Ong and Woods 2001, Taner *et al* 2004). Some expansion of the maxillary dental arch in Class ll division 1 cases is expected in orthodontic treatment where anteroposterior movement is likely to have occurred, and this expansion seems to be stable in the longterm (Lee 1999, BeGole *et al* 1998).

The significant difference in interpremolar widths between the extraction groups ‘4s’ and ‘4&5s’ is interesting, and indicates that the orthodontic treatment effect in these two groups was different. Geron *et al* (2003) noted that although most studies about considerations of anchorage in orthodontics have concentrated mainly on biomechanical effects, many other factors should also be taken into account. They investigated five factors playing a role in orthodontic anchorage planning, and described a pattern of influence where the amount of crowding was more important than mechanics, and extraction site was more influential than age and overjet. In the '4s' and '4&5s' groups in this study the mandibular first and mandibular second premolars, respectively, were extracted. The resulting effect of orthodontic treatment is influenced by the orthodontist's decision to do a specific extraction sequence, along with the many other factors influencing his treatment planning, including type of malocclusion (amount of crowding, overjet), amount and type of tooth movement desired, anatomy of tooth roots and crowns, skeletal and growth patterns in the patient, periodontal considerations, pathology and anomalies (e.g. missing teeth), patient factors (e.g. compliance, age, gender) to name a few (Wientraub *et al* 1989, Baumrind *et al* 1996, Gottlieb *et al* 1996, Saelens and De Smit 1998, Ong and Woods 2001). This multifactorial response to all aspects of orthodontic treatment planning and treatment is probably one of the reasons why many studies on treatment effect note a wide range of individual responses to orthodontic treatment.

Intermolar width: In a longitudinal study Sillman (1964) found that from the deciduous dentition stage until eruption of the second molar the intermolar distance increased about 0.5mm per year until age 14 years, after which there were further no significant changes. Lundstrom's (1969) study of twins found little increase in arch width from an initial age of between 12-15 years of age to a final age of between 26-30 years of age. Intermolar widths increased significantly in males between 3 and 13 years in a sample of normal individuals (Bishara *et al* 1997), after which there were no significant changes between 13 and 26 years of age. In females there was a similar increase up to 13 years, after which there was a slight, but statistically significant, decrease in maxillary intermolar width between 13 and 26 years of age. Lee (1999) found that intermolar widths increase to a considerable extent in untreated cases between ages 7 and 18, especially in males. Moorrees (1959 cited Lebret 1962) measured the breadth of the dental arches between 6 and 18 years of age, and found a mean increase of 3.54mm in the intermolar distance (between mesio-lingual cusps of the permanent first molars). Longterm studies indicate that expansion of the interpremolar and intermolar widths may be stable in nonextraction cases (Sadowsky *et al* 1994, Elms *et al* 1996). These studies show that mean interpremolar expansion of

2.7mm and mean intermolar expansions of 4.5mm (Sadowsky *et al* 1994), and 3mm (Elms *et al* 1996) can be maintained at least 6 years after completion of orthodontic treatment.

There were increases in the mean intermolar widths in all three treatment groups in this study, with the 'NE' group showing the largest increase and the two extractions groups smaller mean increases of 1.51mm(4s) and 1.27mm(4&5s). The results for the extraction groups in this study differ from other research which has indicated that the intermolar widths decrease in premolar extraction groups, with different responses for various extraction sequences (Ong and Woods 2001, Hoggan and Sadowsky 2001). These differences could probably be attributed to the treatment mechanics used by the orthodontist who treated these cases.

Table 4.3.3
Descriptive statistics of each treatment group of inter-labial tooth surface measurements before treatment (relevant measurement indicated in the layout heading)

	13-23 Labial Points			*Inter-Premolar Labial Points*			*16-26 Labial Points*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count				18	25	35	12	13	25
Mean				24.16	24.94	25.42	50.49	50.35	49.79
Median				24.55	24.00	25.40	51.90	50.7	50.20
Standard Deviation				2.39	2.73	2.57	4.77	3.48	2.91
Range				9.20	10.70	11.40	15.80	9.40	10.50
Minimum				18.80	21.70	20.80	42.20	46.10	44.60
Maximum				28.00	32.40	32.20	58.00	55.50	55.10

There was considerable difficulty in making the measurements mentioned in the above table as could be seen from the counts (or frequencies). This may be related to the technique used. The labial surface at the gingival margin could not always be identified adequately on the scanned models because of the inclination of the teeth. Only the obvious could be stated from this table; that the distance "14-24 Labial Points" was smaller than the distance "16-26 Labial Points".

Table 4.3.4
Descriptive statistics of each treatment group of the difference between inter-labial tooth surface measurements before and after treatment (relevant measurement indicated in the layout heading)

	13-23 Labial Points Differences			*Inter-Premolar Labial Points Differences*			*16-26 Labial Points Differences*		
Treatment Group	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**	**4s**	**4&5s**	**NE**
Count				17	25	35	12	13	24
Mean				5.11	4.27	2.61	1.66	1.57	3.70
Median				4.90	4.80	2.20	0.65	2.40	3.65
Standard Dev				1.49	1.78	1.84	3.37	2.95	2.59
Range				5.20	7.40	9.70	11.80	9.50	14.20
Minimum				2.70	-0.90	-0.60	-1.70	-2.60	-2.80
Maximum				7.90	6.50	9.10	10.10	6.90	11.40
Confidence Level (95.0%)				0.0000	0.0000	0.0000	0.1023	0.0652	0.0000

No deductions could be made for the "13-23 Labial Points" due to the small counts for which pre- and post-measurement were both measured. Within all the treatment groups the measurement "Inter-Premolar Labial Points" increased considerably (p<5%), however the difference in the 'NE' group was the smallest. Only the 'NE' group displayed a significant increase in the measurement "16-26 Labial Points". In the other two treatment groups this measurement also increased but not significantly.

4.4 Descriptive statistics within the Three Defined Treatment Groups (pre-treatment)

The following is only a superficial discussion of the pretreatment measurements, concentrating on graphical comparisons of the distributions. The three treatment groups were: The group in which the maxillary first premolar and mandibular second premolar teeth were extracted (abbreviated as '4&5s'); the group in which all four first premolar teeth were extracted (abbreviated as '4s'); and the group in which no extractions were done (abbreviated as 'NE'). Differences in location (the median) with respect to the right and left sides and the three treatment groups are mentioned, but no statistical inference was applied to see whether these differences were statistically significant. Only extreme distributional characteristics and differences are mentioned. All distances indicated on the violin plots were measured in millimetres.

Discussion of graphical results of the three treatment groups.

Please refer to the template attached to the manuscript (Fig3.3) for a diagram of the landmarks. The code that follows 'T' refers to the tooth number, 'M' or 'D' to the mesio-lingual or disto-buccal cusp respectively, and a, b, c, d, e to the rugal landmarks.

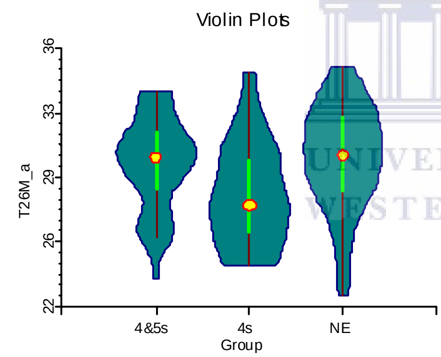


Figure 4.3.1a
Violin Plots of T26M_a for the three groups '4&5s', '4s' and NE

The median of T26M_a within the '4s' group was the smallest. The interquartile ranges of the three groups were very similar. The '4&5s' and the 'NE' groups displayed long tails towards the smaller values (there were less individuals with smaller distances less than the first quartile within these two groups). The '4s' group showed a longer tail for distances larger than the third quartile. The skewness of the '4&5s' and 'NE' groups was therefore in the opposite direction to that of the '4s' group.

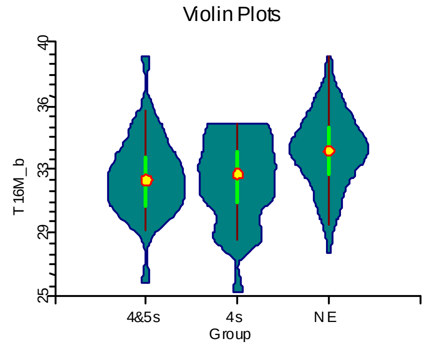


Figure 4.3.1b
Violin Plots of T16M_b for the three groups ‘4&5s’, ‘4s’ and NE

The medians of T16M_b of the ‘4&5s’ and the ‘4s’ groups were similar, but the median of the ‘NE’ group was higher than those of the first mentioned groups. The median of the ‘NE’ group was equal to the third quartile of the ‘4&5s’ and ‘4s’ groups, thus considerably higher than the medians of these two groups. The interquartile ranges were similar to each other in the three groups.

Comparison of the two sides

It was clear from the two graphical displays above, that the distances between the mesiolingual cusp tips of 16 and 26 to the most posterior points on the last rugae on the left and right sides of the palate respectively, differed considerably with respect to location and the distribution. The differences between the left and right medians within the ‘4&5s’ group were 2.0mm, 5.0mm for the ‘4s’ group and 3.4mm for the ‘NE’ group. It is important to note that the left side measurements were larger for all three treatment groups. These findings are in agreement with results of other studies measuring asymmetry of the dentition (Lundstrom 1961, Cassidy *et al* 1988, Kula *et al* 1998, Maurice and Kula 1998), and showing that dentoalveolar asymmetry is more prevalent in persons with malocclusions (Alavi *et al* 1988, de Araujo *et al* 1994, Rose *et al* 1994, Azevedo *et al* 2006). It has also been shown that the rugal patterns on the right and left sides of the palate are usually asymmetrical (Lysell 1955).

Due to the mathematical principle that the median of the difference is not equal to the difference of the medians, the left-right symmetry was studied by means of the differences between the left and right orthodontic measurements separately.

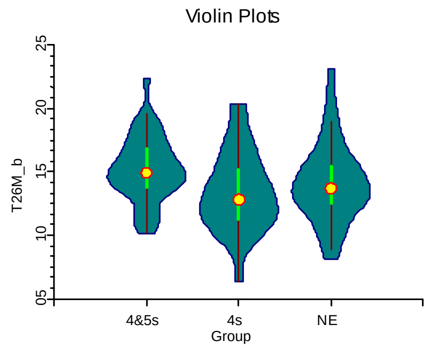


Figure 4.3.2a
Violin Plots of T26M_b for the three groups '4&5s', '4s' and NE

The median of T26M_b of the '4&5s' group differed from the other two groups. The interquartile ranges of the three groups were comparable to one another.

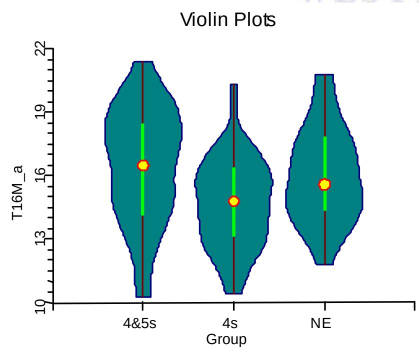


Figure 4.3.2b
Violin Plots of T16M_a for the three groups '4&5s', '4s' and NE

The same pattern as with the left side occurred with T16M_a measurement (right side).

Comparison of the two sides

It was clear from the two graphical displays that distances between the mesiolingual cusp tips of 16 and 26 to the most posterior points on the last rugae on the right and left sides respectively, were similar. For all three groups, however, the median distances were somewhat higher on the right side compared to those on the left side.

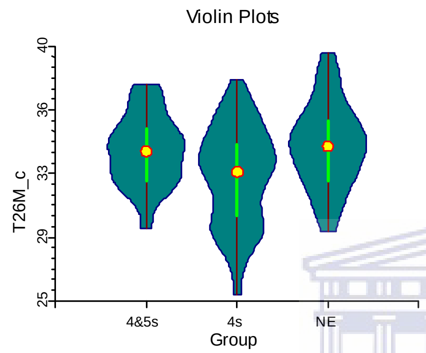


Figure 4.3.3a
Violin Plots of T26M_c for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the lowest and the distribution of this group had a long tail towards the lower values. The interquartile range of the '4s' group was the widest of the three distributions.

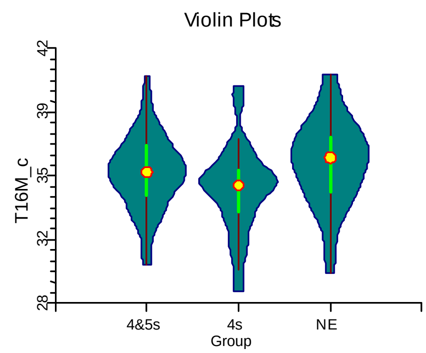


Figure 4.3.3b
Violin Plots of T16M_c for the three groups '4&5s', '4s' and NE

The same pattern occurred with T16M_c as with the left side (T26M_c).

Comparison of the two sides

It was clear from the two graphical displays above that the distances between the mesiolingual cusp tips of 16 and 26 to the anterior border of the incisive papilla respectively, were similar with regard to location and distribution. However, the observations of the '4s' group were concentrated around the median. The distributions of the two sides of the '4s' group differed in that the left side displayed the widest interquartile range and for the right side the interquartile range was the narrowest of the three groups.

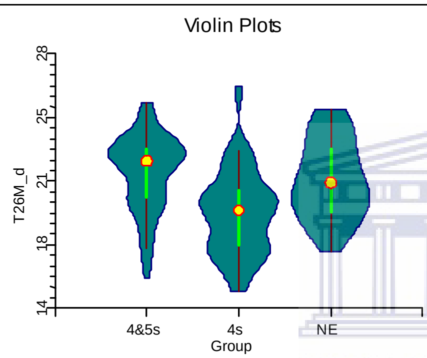


Figure 4.3.4a
Violin Plots of T26M_d for the three groups '4&5s', '4s' and NE

The '4s' group had a much lower median compared to the other two groups. With respect to the interquartile range the '4&5s' and the '4s' groups were skewed towards the lower values, whereas the interquartile range of the 'NE' group was slightly skewed towards the larger distances.

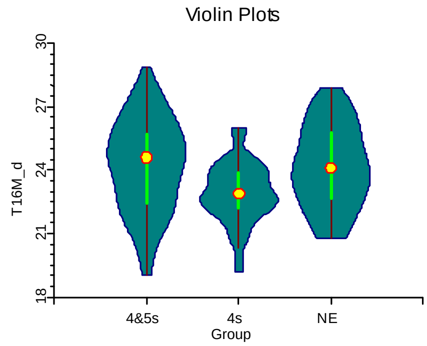


Figure 4.3.4b
Violin Plots of T16M_d for the three groups '4&5s', '4s' and NE

The pattern of the medians on the right side was similar to that on the left side.

Comparison of the two sides

The most prominent difference between the two sides was that the range of the '4s' group on the right side was smaller than the corresponding range on the left side.

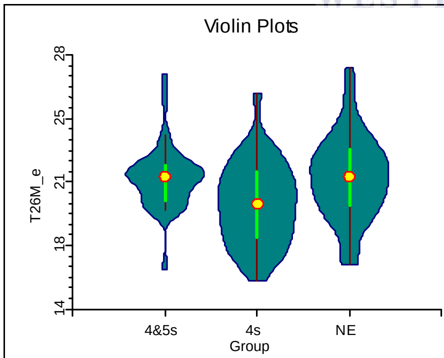


Figure 4.3.5a
Violin Plots of T26M_e for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the lowest of the three groups and the medians of the '4&5s' and the 'NE' groups were very similar. The only interquartile range that was skewed towards the smaller measurements was that of the '4&5s' group. Furthermore, it was clear that the interquartile range of the '4s' group was the largest of the three groups.

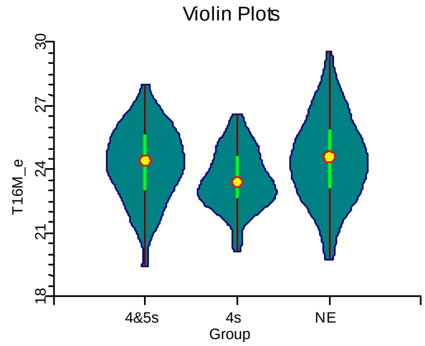


Figure 4.3.5b
Violin Plots of T16M_e for the three groups '4&5s', '4s' and NE

The median of the '4s' group was again the lowest of the three groups. The medians of the '4&5s' and the 'NE' groups were very similar but somewhat larger than the medians on the left side.

Comparison of the two sides

The range of the '4s' group on the right side was smaller than the corresponding range of the left side. Furthermore, it could be observed that the median of the '4s' group on the left side was the highest of the three groups, but this group had the lowest median on the right side.

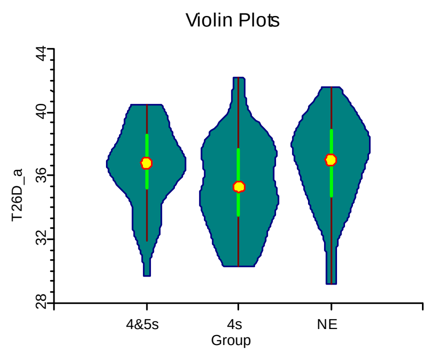


Figure 4.3.6a
Violin Plots of T26D_a for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the lowest and the interquartile ranges of the three groups were similar.

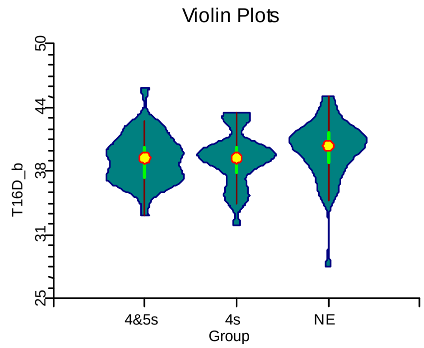


Figure 4.3.6b
Violin Plots T16D_b for the three groups '4&5s', '4s' and NE

The 'NE' group had a higher median than the other two groups.

Comparison of the two sides

The minimums of the three groups for the right side were larger than the corresponding minimums of the left side. The ranges of the three groups on the right side were smaller than the corresponding ranges on the left side. The main reason why the scale of the two figures was so different is that the 'NE' group had an extreme outlier towards the smaller measurements. In the '4s' group the observations were concentrated in the vicinity of the median.

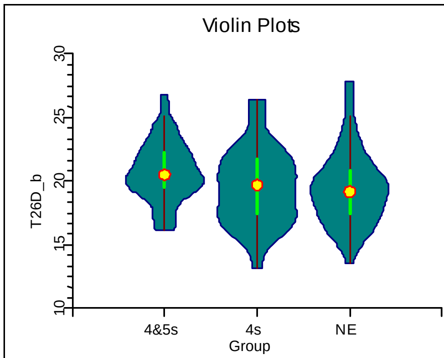


Figure 4.3.7a
Violin Plots of T26D_b for the three groups '4&5s', '4s' and NE

This measurement was similar for the three groups.

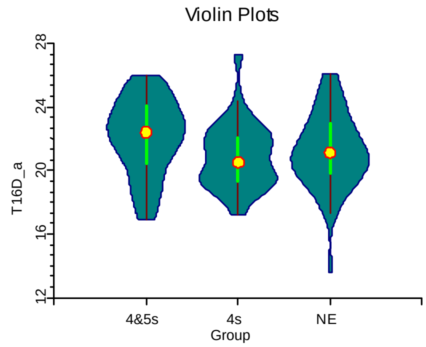


Figure 4.3.7b
Violin Plots of T16D_a for the three groups '4&5s', '4s' and NE

From the graphical display it was evident that the median of the '4&5s' group was the highest of the three medians.

Comparison of the two sides

The median of the '4&5s' group was higher than that of the other two groups on the right side, compared to the pattern of the medians on the left side, whereas the distribution (dispersion) on the right side of '4s' group was more concentrated than that on the left side (see Fig 4.3.8a).

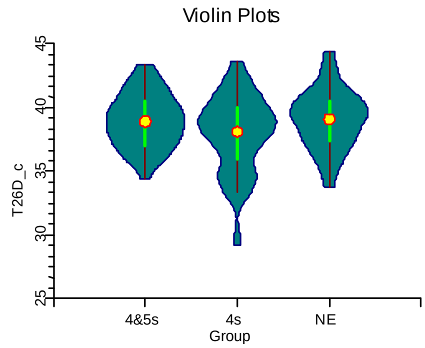


Figure 4.3.8a
Violin Plots of T26D_c for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar except for the '4s' group, which had a long tail towards the lower values.

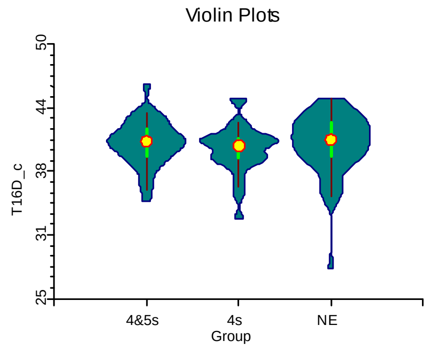


Figure 4.3.8b
Violin Plots of T16D_c for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar and there was a strong central tendency for all three groups. The 'NE' group displayed an outlier towards the lower values.

Comparison of the two sides

The interquartile ranges on the right and left sides were approximately similar for the '4&5s' group and the 'NE' groups. However, the '4s' group had a smaller dispersion and interquartile range on the right side compared to the left side.

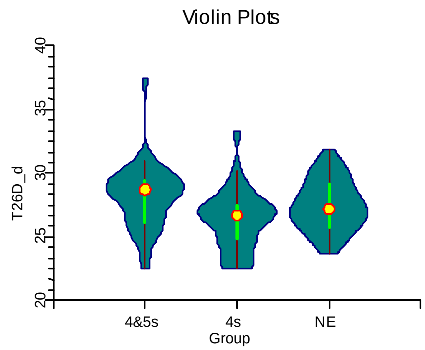


Figure 4.3.9a
Violin Plots of T26D_d for the three groups '4&5s', '4s' and NE

The medians of the '4s' and 'NE' groups were similar, but the '4&5s' had a higher median. The '4&5s' group was clustered just above its median.

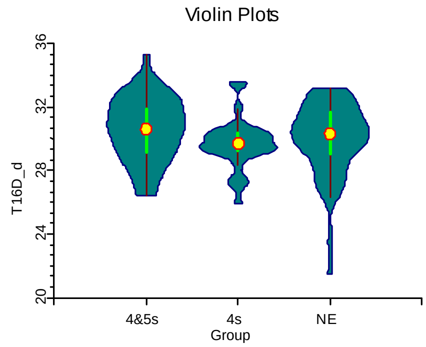


Figure 4.3.9b
Violin Plots of T16D_d for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar and the observations of the '4s' group were clustered around the median.

Comparison of the two sides

The single outliers present in group '4&5s' (left) and group 'NE' (right) created a confusing graphical display (pattern) of the distributions of the two sides and hid the similarity between the two sides. However, observations in the '4s' group were highly concentrated at the right side around the median compared to the left side.

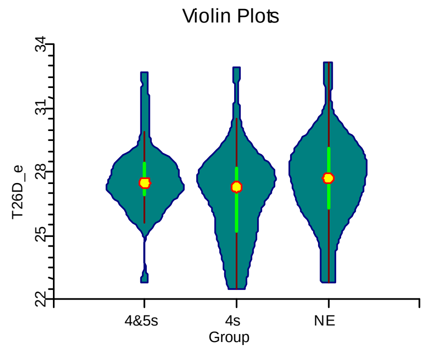


Figure 4.3.10a
Violin Plots of T26D_e for the three groups '4&5s', '4s' and NE

The three groups were similar with respect to their medians. The '4&5s' group had the smallest interquartile range.

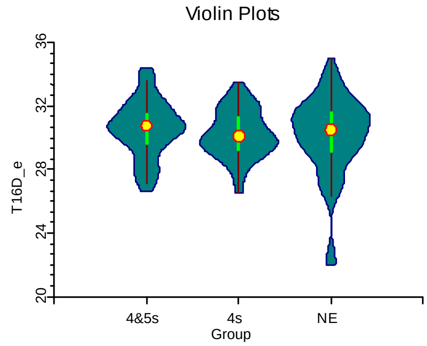


Figure 4.3.10b
Violin Plots of T16D_e for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar and the observations of the '4&5s' and '4s' groups were clustered around the corresponding medians.

Comparison of the two sides

A difference with respect to the range of the medians was that for the left side medians of the three groups were between 27 and 28mm and that the right side medians were between 30 and 31mm. Another prominent difference between the two sides was that the matching ranges of the right side were smaller than those of the left side.

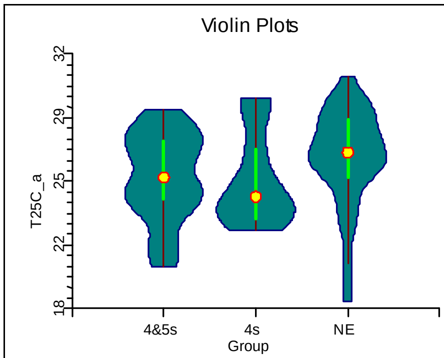


Figure 4.3.11a
Violin Plots of T25C_a for the three groups '4&5s', '4s' and NE

The three groups could be ranked with respect to their medians from lowest to highest: '4s', '4&5s' and then the 'NE' group.

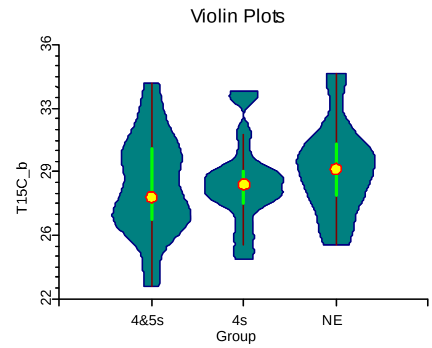


Figure 4.3.11b
Violin Plots of T15C_b for the three groups '4&5s', '4s' and NE

The three groups could be ranked with respect to their medians from lowest to highest: '4&5s', '4s' and then the 'NE' group.

Comparison of the two sides

As can be seen from the above deductions, the ranks of the medians of the three groups differed for the right and left sides. The distributions of the '4s' group differed for the left and right sides: on the left side the '4s' group had a heavy tail towards the longer measurements whereas, on the right side the '4s' group showed heavy tails above the median and below the median.

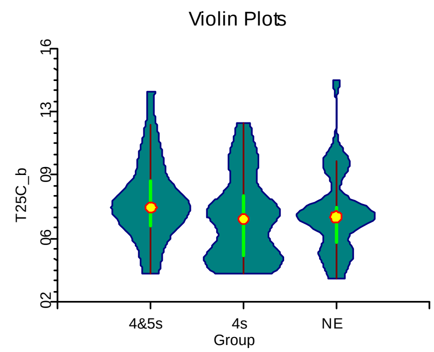


Figure 4.3.12a
Violin Plots of T25C_b for the three groups '4&5s', '4s' and NE

There was a strong possibility for multi-modal distributions within the '4s' and the 'NE' groups. The '4&5s' had only a single mode that corresponded to the median. The '4s' group had a mode near to the first quartile and another one corresponding to the median. The 'NE' group had two definite modes: the first one corresponding to the median and the other mode nearer to the maximum.

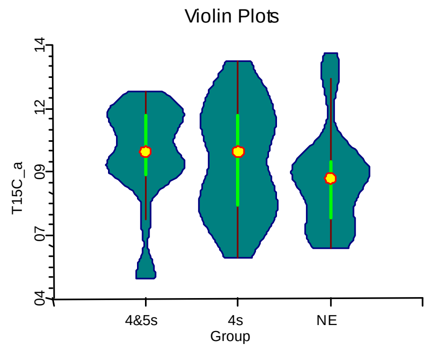


Figure 4.3.12b
Violin Plots of T15C_a for the three groups '4&5s', '4s' and NE

The 'NE' group had the lowest median of the three groups. The skewness of the '4&5s' group and the 'NE' group was in opposite directions. The observations of the '4s' group had an extremely flat distribution.

Comparison of the two sides

The medians of the three sub-groups formed a different pattern on the right side compared to the left side. The medians on the right side appeared to be higher than those on the left side.

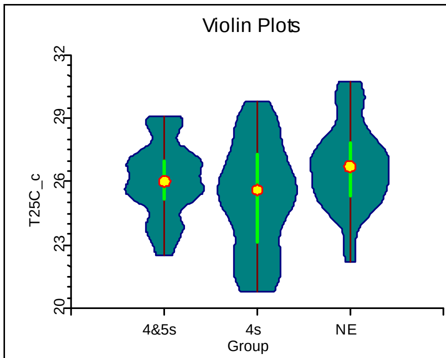


Figure 4.3.13a
Violin Plots of T25C_c for the three groups '4&5s', '4s' and NE

The ‘NE’ group had a higher median compared to the other two groups. The ‘4s’ group had a distribution that was near to uniformity.

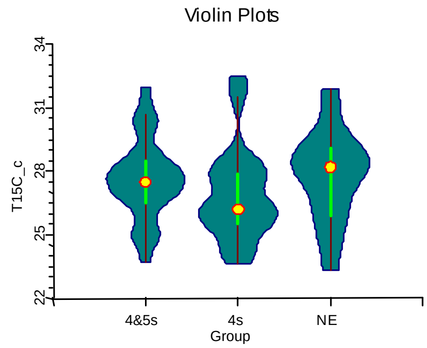


Figure 4.3.13b
Violin Plots of T15C_c for the three groups ‘4&5s’, ‘4s’ and NE

The median of T15C_c with respect to the ‘4s’ group was lower than that of the two remaining groups.

Comparison of the two sides

The pattern formed by the medians for the two sides was different.

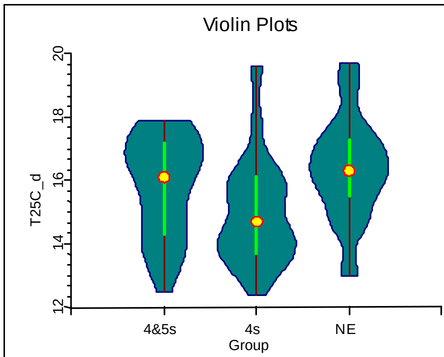


Figure 4.3.14a
Violin Plots of T25C_d for the three groups ‘4&5s’, ‘4s’ and NE

In this case the ‘4s’ group had the lowest median compared to the other two groups.

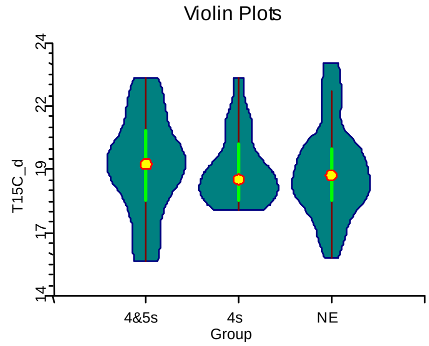


Figure 4.3.14b
Violin Plots of T15C_d for the three groups '4&5s', '4s' and NE

The medians of the three groups on the right side were approximately equal.

Comparison of the two sides

The patterns formed by the medians of the two sides were different from each other. For the '4s' group on the right side the tail below the first quartile was absent compared to that on the left side. The range formed by the medians on the left side was much wider than that of the right side.

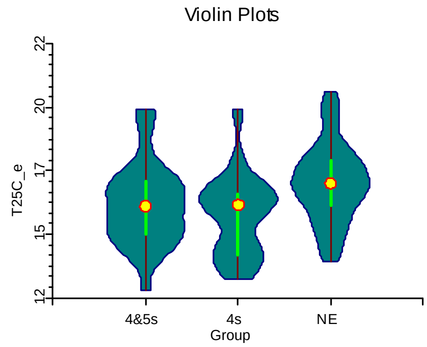


Figure 4.3.15a
Violin Plots of T25C_e for the three groups '4&5s', '4s' and NE

The 'NE' group had a higher median compared to the other two groups. The '4s' group had two modes – the smaller one corresponding approximately to the lower quartertile.

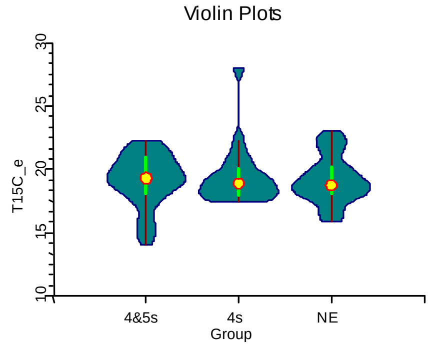


Figure 4.3.15b
Violin Plots of T15C_e for the three groups '4&5s', '4s' and NE

The large outlier present in the '4s' group distorted the side-by-side violin plots. The '4&5s' group was skewed towards the lower values and the '4s' group skewed extremely towards the higher values.

Comparison of the two sides

In general the medians on the right side were larger than those on the left side.

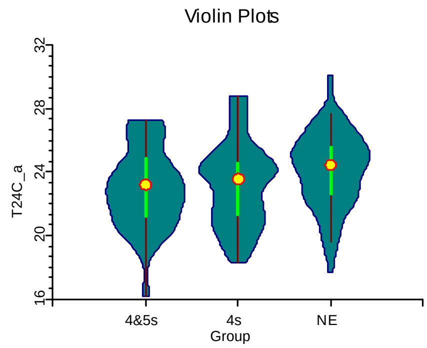


Figure 4.3.16a
Violin Plots of T24C_a for the three groups '4&5s', '4s' and NE

The medians of the three groups could be ranked from lowest to highest: '4&5s', '4s' and 'NE'.

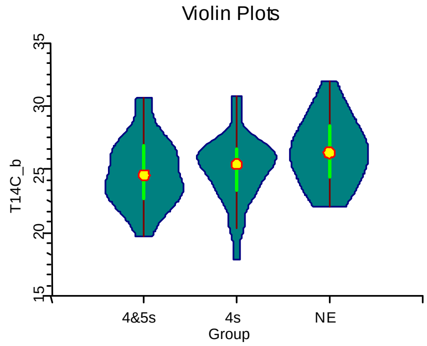


Figure 4.3.16b
Violin Plots of T14C_b for the three groups ‘4&5s’, ‘4s’ and NE

The ranking of the medians was the same on the right side as on the left side.

Comparison of the two sides

The two sides appeared to be approximately similar.

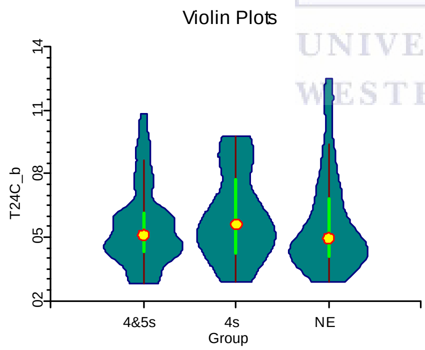


Figure 4.3.17a
Violin Plots of T24C_b for the three groups ‘4&5s’, ‘4s’ and NE

All three distributions had long tails towards the higher values. The median of the ‘4s’ group was the highest.

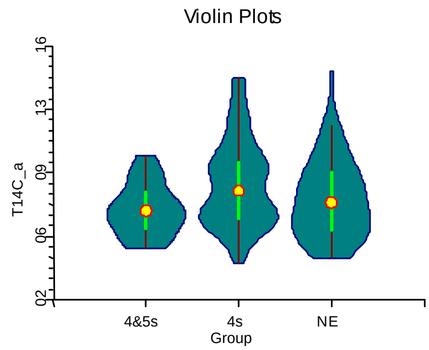


Figure 4.3.17b
Violin Plots of T14C_a for the three groups ‘4&5s’, ‘4s’ and NE

The three groups also had tails towards the larger values on the right side.

Comparison of the two sides

The corresponding medians on the right appeared to be higher than those on the left side.

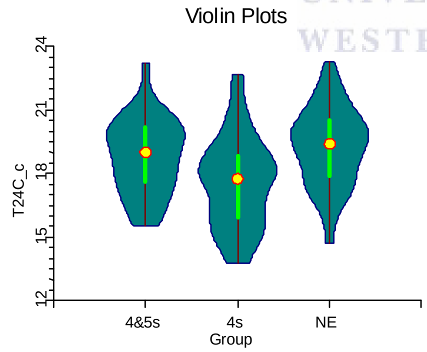


Figure 4.3.18a
Violin Plots of T24C_c for the three groups ‘4&5s’, ‘4s’ and NE

The median of the ‘4s’ group was the lowest. The interquartile ranges of the three groups were very similar.

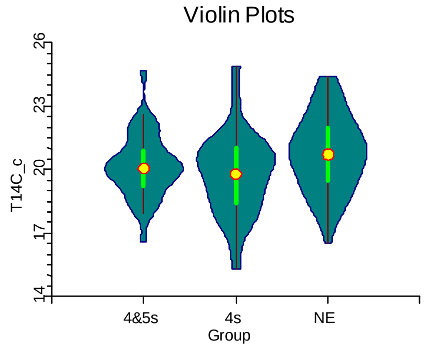


Figure 4.3.18b
Violin Plots of T14C_c for the three groups '4&5s', '4s' and NE

The 'NE' group had the highest median of the three groups and the interquartile range of the '4&5s' group was lower than that of the two remaining groups.

Comparison of the two sides

The pattern formed by the medians on the left side differed substantially the pattern on the right side.

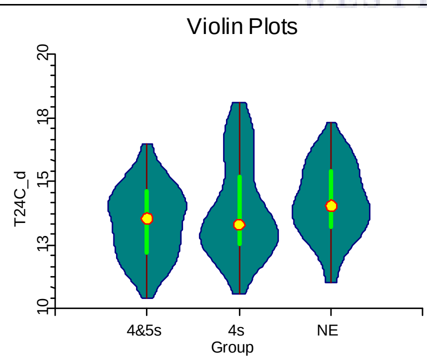


Figure 4.3.19a
Violin Plots of T24C_d for the three groups '4&5s', '4s' and NE

The median of the 'NE' group was higher than the medians of the other two groups. The '4s' group had a heavy tail towards the higher measurements.

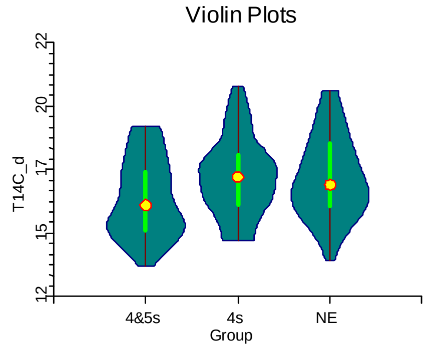


Figure 4.3.19b
Violin Plots of T14C_d for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups. The interquartile ranges of the three groups were similar.

Comparison of the two sides

The median of the '4s' group was the lowest on the left side, whereas the median of the '4s' group was the highest of the three groups on the right side. This phenomenon was not expected. The range described by the minimum and maximum medians of the left side was (13.7mm – 14.2mm) compared to that of the right side (15.9mm – 16.9mm), resulting in higher medians on the right side.

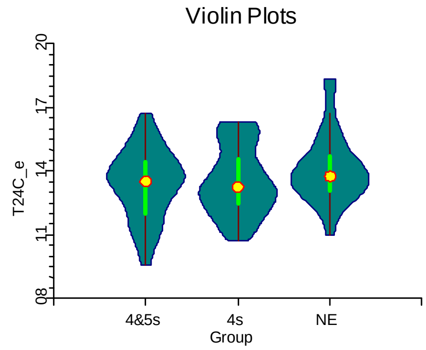


Figure 4.3.20a
Violin Plots of T24C_e for the three groups '4&5s', '4s' and NE

The medians of the three groups were very similar and displayed a strong measure of central tendency.

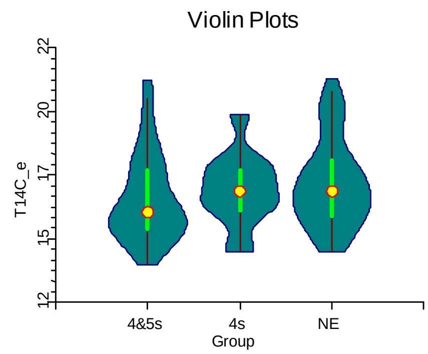


Figure 4.3.20b
Violin Plots of T14C_e for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest of the three.

Comparison of the two sides

The distribution of the '4&5s' group was different for the two sides in that the skewness was in opposite directions. In general the medians were higher on the right side.

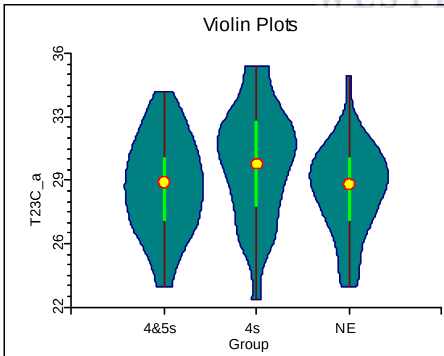


Figure 4.3.21a
Violin Plots of T23C_a for the three groups '4&5s', '4s' and NE

For this measurement the '4s' group displayed the highest median and the medians of the other two groups were similar.

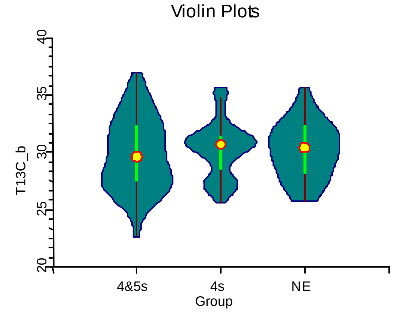


Figure 4.3.21b
Violin Plots of T13C_b for the three groups '4&5s', '4s' and NE

The '4s' group had a strong tendency to cluster around the median compared to the other two groups.

Comparison of the two sides

Of the six distributions compared, the distribution of the '4s' group displayed the smallest range and the most clustering around the median.

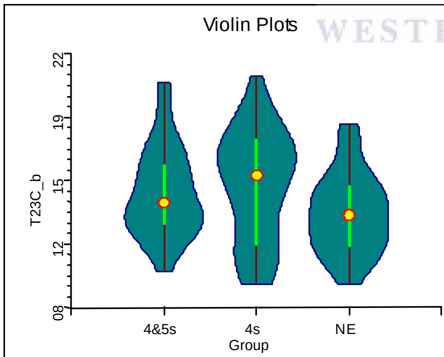


Figure 4.3.22a
Violin Plots of T23C_b for the three groups '4&5s', '4s' and NE

For this particular measurement the distribution of the '4s' group was platocurtic (i.e. showed a very flat, uniform distribution) and displayed the highest median of the three groups.

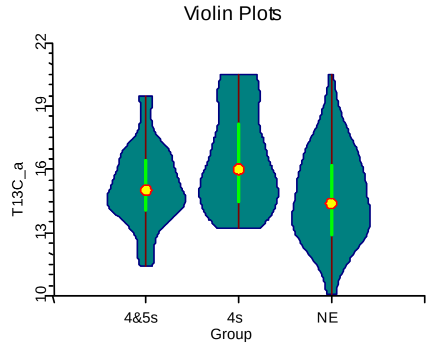


Figure 4.3.22b
Violin Plots of T13C_a for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

The right and left sides appeared to be similar except that the skewness of the '4s' group was in opposite directions.

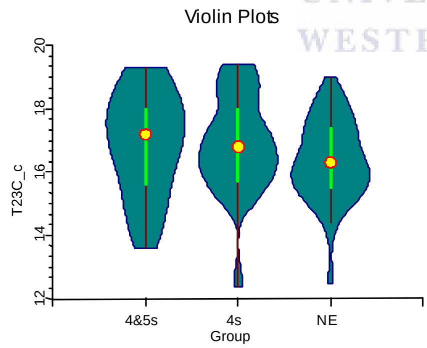


Figure 4.3.23a
Violin Plots of T23C_c for the three groups '4&5s', '4s' and NE

The medians of the three groups could be ranked from lowest of highest as follows: 'NE', '4s' and '4&5s'. The distribution of the '4&5s' group was platocurtic.

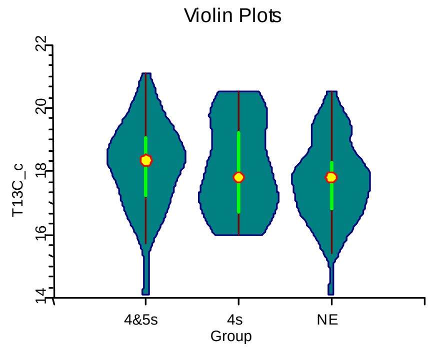


Figure 4.3.23b
Violin Plots of T13C_c for the three groups '4&5s', '4s' and NE

The medians of the three groups could be ranked in a similar order to those on the left side.

Comparison of the two sides

The distribution of the '4s' group of the right side was atypical with respect to the absence of a tail towards the smaller values.

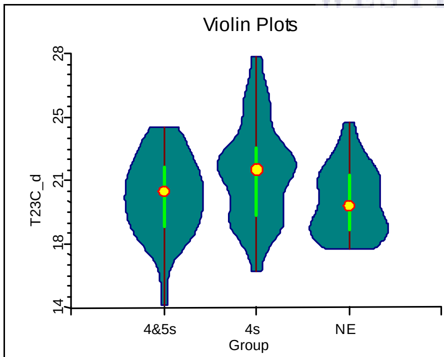


Figure 4.3.24a
Violin Plots of T23C_d for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups.

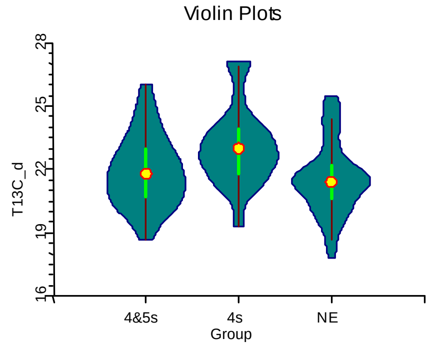


Figure 4.3.24b
Violin Plots of T13C_d for the three groups "475S', '4S' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

A stronger degree of clustering occurred around the median on the right side compared to the left side.

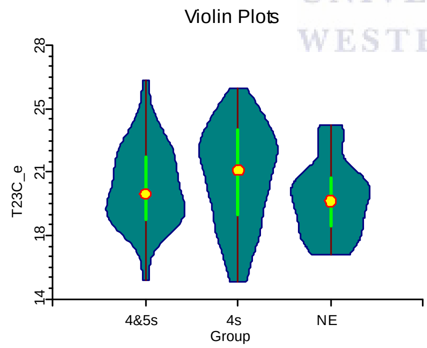


Figure 4.3.25a
Violin Plots of T23C_e for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups.

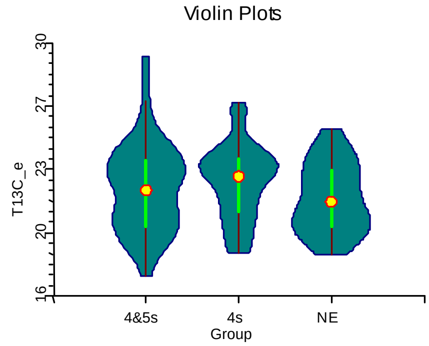


Figure 4.3.25b
Violin Plots of T13C_e for the three groups ‘4&5s’, ‘4s’ and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

No definite differences between the two sides could be observed.

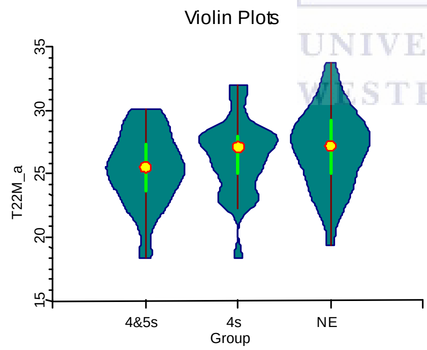


Figure 4.3.26a
Violin Plots of T22M_a for the three groups ‘4&5s’, ‘4s’ and NE

The median of the ‘4&5s’ group was the lowest of the three groups.

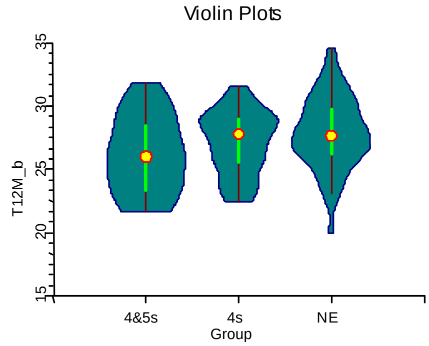


Figure 4.3.26b
Violin Plots of T12M_b for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

No clear-cut difference between the two sides could be observed.

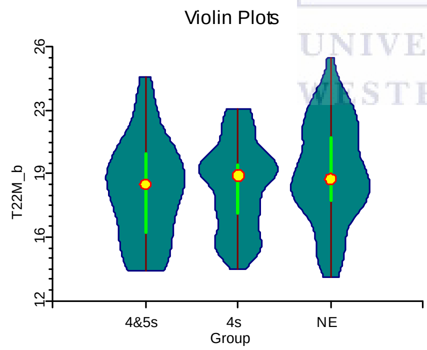


Figure 4.3.27a
Violin Plots of T22M_b for the three groups '4&5s', '4s' and NE

The three medians were similar and the distribution for this measurement was platocurtic in all three groups.

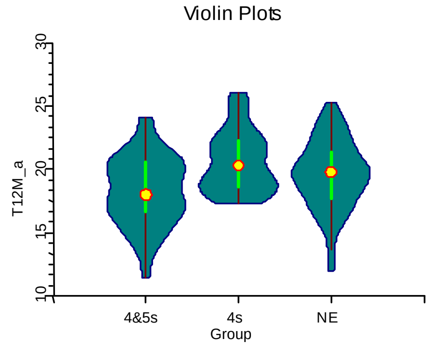


Figure 4.3.27b
Violin Plots of T12M_a for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest of the three medians.

Comparison of the two groups

The distribution of the '4s' group was atypical in that lower values were absent.

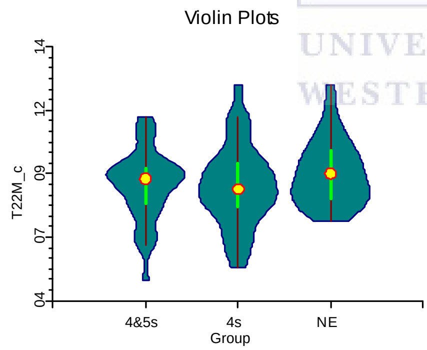


Figure 4.3.28a
Violin Plots of T22M_ c for the three groups '4&5s', '4s' and NE

The medians and the interquartile ranges of the three groups were similar.

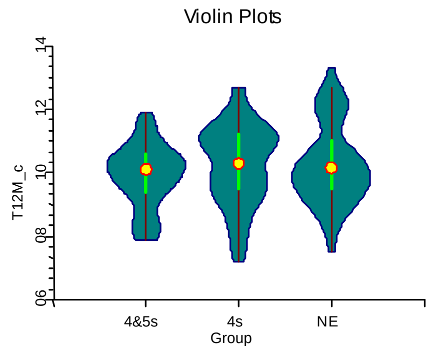


Figure 4.3.28b
Violin Plots of T12M_c for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

No definite differences between the two sides could be observed.

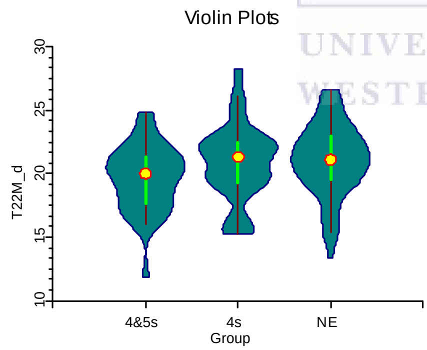


Figure 4.3.29a
Violin Plots of T22M_d for the three groups '4&5s', '4s' and NE

The median of the '4&5s' was the lowest of the three groups.

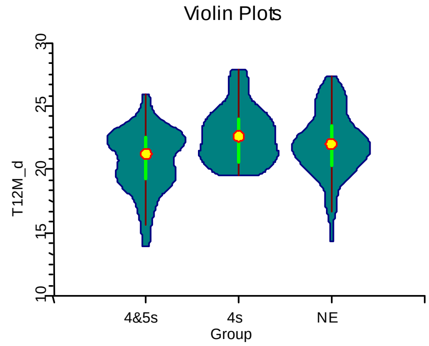


Figure 4.3.29b
Violin Plots of T12M_d for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

No definite differences between the two sides could be observed.

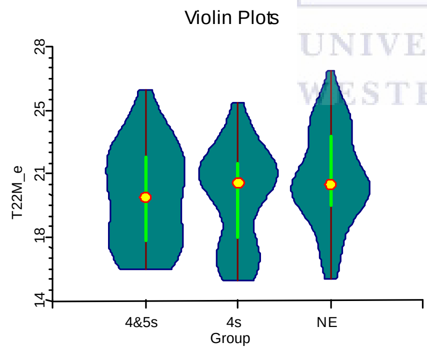


Figure 4.3.30a
Violin Plots of T22M_ e for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest and the three distributions displayed various degrees of platocurticness.

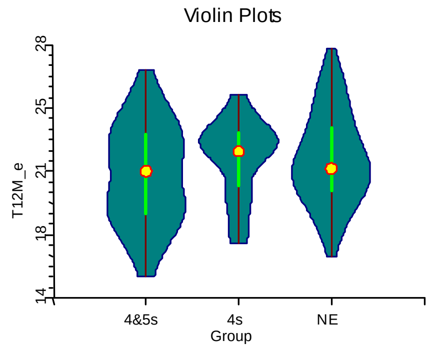


Figure 4.3.30b
Violin Plots of T12M_e for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar. The distributions of the three groups differed in that the distribution of the '4s' group was strongly clustered around the median.

Comparison of the two groups

The distributions on the right sides were less platocurtic compared to the distributions on the left sides.

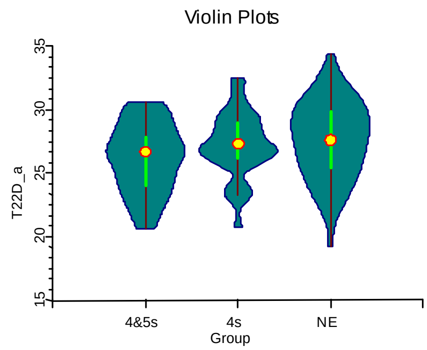


Figure 4.3.31a
Violin Plots of T22D_a for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest and the distribution of the '4&5s' group was the most platocurtic of the three groups.

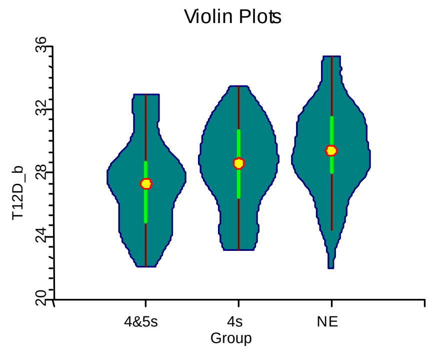


Figure 4.3.31b
Violin Plots of T12D_b for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

The '4s' group had the most leptokurtic patterns (i.e. showing a short concentrated distribution, making a very high peak) on the left sides.

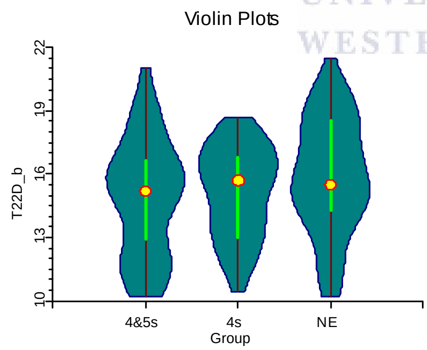


Figure 4.3.32a
Violin Plots of T22D_b for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest and all three distributions displayed considerable platocurticness.

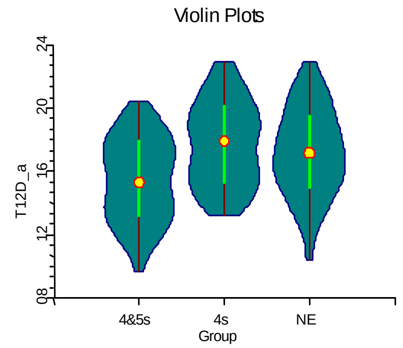


Figure 4.3.32b
Violin Plots of T12D_a for the three groups '4&5s', '4s' and NE

The median of the '4&5s' was the lowest of the three groups.

Comparison of the two sides

All three distributions on the right sides were more platocurtic than the distributions on the left sides, notwithstanding the wider combined distributions of the three groups.

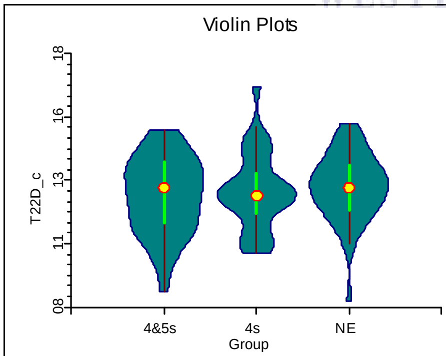


Figure 4.3.33a
Violin Plots of T22D_c for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar. The '4s' group and the 'NE' group displayed strong measures of central tendency.

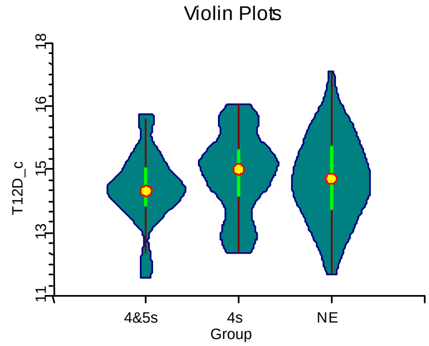


Figure 4.3.33b
Violin Plots of T12D_c for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest of the three groups and the distribution of this group was leptocurtic.

Comparison of the two groups

Most of the six distributions differed from each other with respect to shape of the distributions. For example, on the left side the '4 & 5s' group had the lowest median and the '4s' group had the highest median of the three groups.

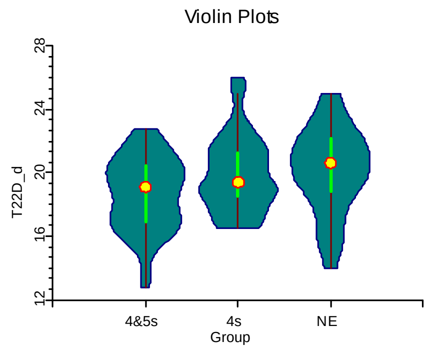


Figure 4.3.34a
Violin Plots of T22D_d for the three groups '4&5s', '4s' and NE

The 'NE' group had the highest median of the three groups and the skewness of the '4&5s' and '4s' groups was in similar directions.

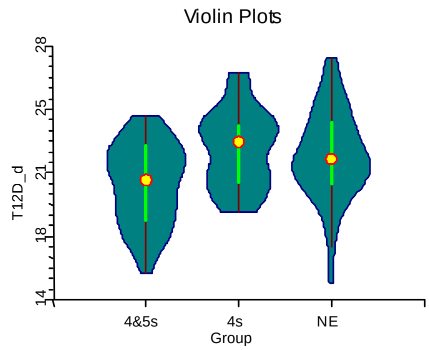


Figure 4.3.34b
Violin Plots of T12D_d for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups.

Comparison of the two sides

The pattern of the medians was different for the two sides. On the left and right sides the '4 & 5s' had the lowest medians. On the left side the 'NE' group had the highest median and on the right side the '4s' group had the highest median.

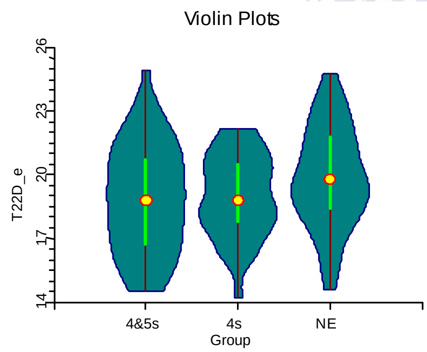


Figure 4.3.35a
Violin Plots of T22D_e for the three groups '4&5s', '4s' and NE

The median of the 'NE' group was the highest of the three groups. The distributions of the '4&5s' and '4s' groups were much more platocurtic compared to the distribution of the 'NE' group.

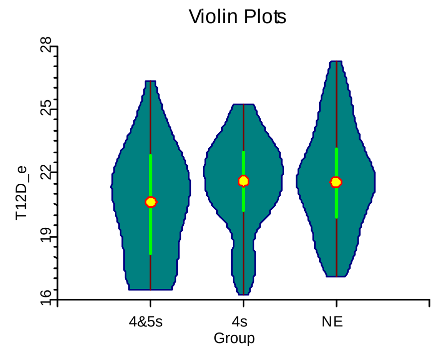


Figure 4.3.35b
Violin Plots of T12D_e for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was lower than the medians of the other two groups.

Comparison of the two sides

The patterns of the medians differed between the two sides in that all three medians on the right sides were larger than the three medians on the left sides.

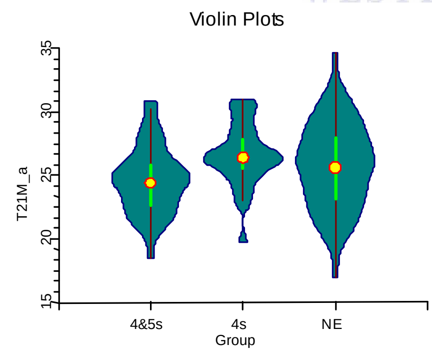


Figure 4.3.36a
Violin Plots of T21M_a for the three groups '4&5s', '4s' and NE

The '4s' group had the highest median of the three groups and displayed the strongest measure of central tendency.

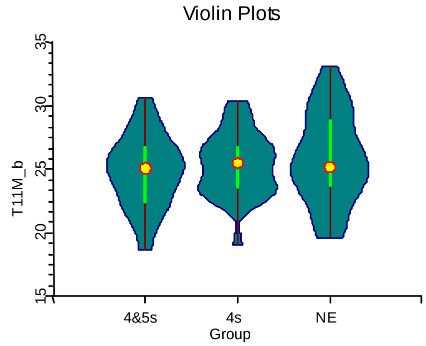


Figure 4.3.36b
Violin Plots of T11M_b for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side. The interquartile ranges of the three groups were not different for the three groups.

Comparison for the two sides

The distribution of the '4s' group on the left side was more leptocurtic than the distribution of this group on the right side.

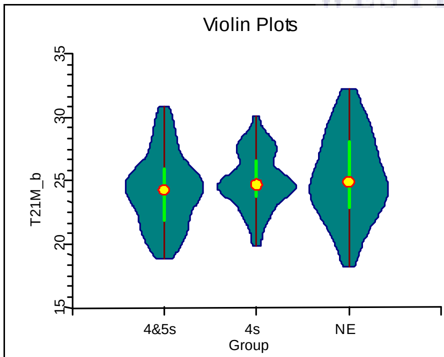


Figure 4.3.37a
Violin Plots of T21M_b for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar. The tendency for the observations to cluster around the median was the strongest in the '4s' group.

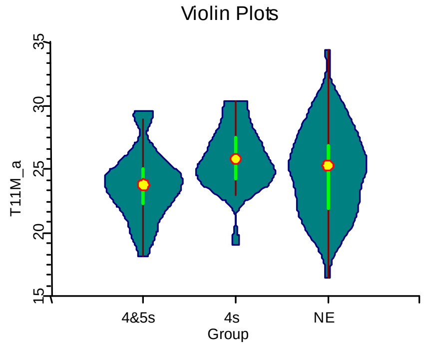


Figure 4.3.37b
Violin Plots of T11M_a for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups.

Comparison of the two sides

No major differences between the left and right sides were observed for the three groups.

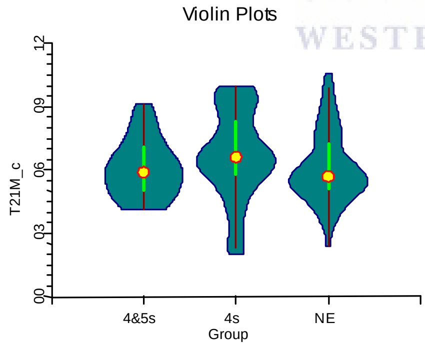


Figure 4.3.38a
Violin Plots of T21M_c for the three groups '4&5s', '4s' and NE

The '4s' group had the highest median of the three groups. The range of the '4&5s' group was the smallest.

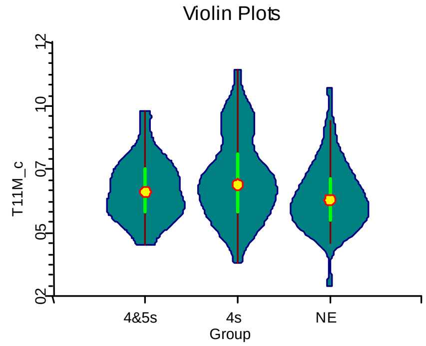


Figure 4.3.38b
Violin Plots of T11M_c for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the right side.

Comparison of the two sides

The skewness of the '4s' group was in opposite directions on the two sides. The range described by the medians on the left side was similar to that on the right side.

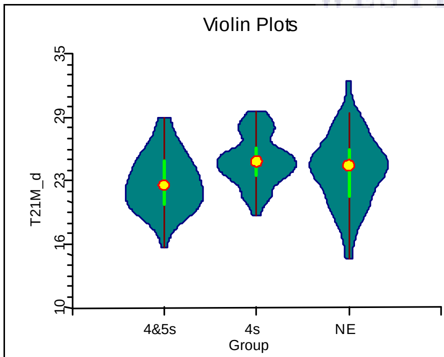


Figure 4.3.39a
Violin Plots of T21M_d for the three groups '4&5s', '4s' and NE

The median of the '4s' group was the highest of the three groups. The distribution of the '4s' group also displayed the strongest central tendency.

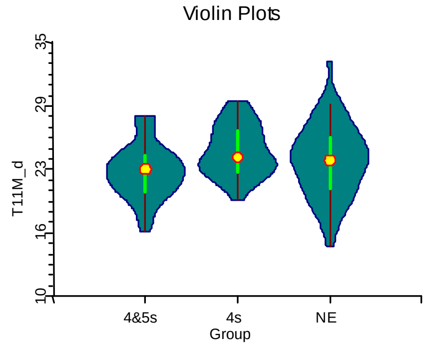


Figure 4.3.39b
Violin Plots of T11M_d for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar for this side compared to the pattern on the left side.

Comparison for the two sides

No distinct difference with respect to the corresponding distributions could be observed between the right and left sides.

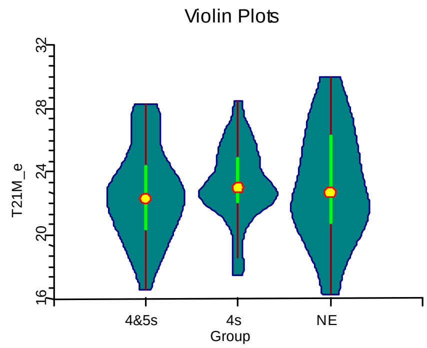


Figure 4.3.40a
Violin Plots of T21M_e for the three groups '4&5s', '4s' and NE

Compared to Figure 40 the median of the '4s' group was the largest for the three groups. The distributions of the three groups were much more platocurtic compared to the distributions of measurements to point 'd'.

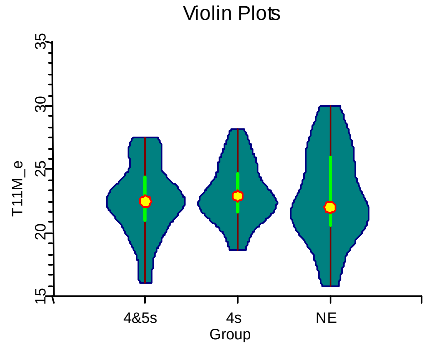


Figure 4.3.40b
Violin Plots of T11M_e for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison of the two sides

The scale difference between the two plots creates the illusion that the distributions on the two sides were different. The pattern of the medians for the two sides was similar, as were the positions of the interquartile ranges.

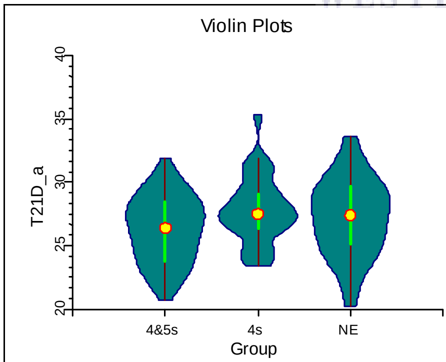


Figure 4.3.41a
Violin Plots of T21D_a for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group for this measurement was the lowest. However the interquartile range of the '4s' groups was considerably shorter compared to that of the other two groups.

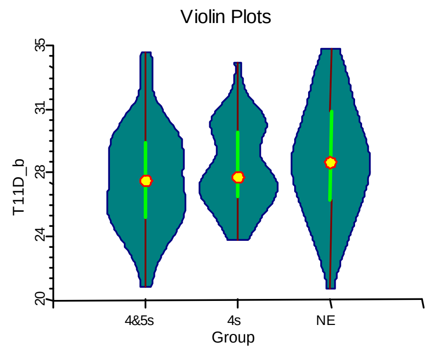


Figure 4.3.41b
Violin Plots of T11D_b for the three groups '4&5s', '4s' and NE

The pattern of the medians was approximately similar to the pattern on the left side.

Comparison of the two sides

No distinct differences with respect to the shapes of the distributions of the corresponding three groups could be observed, except that the interquartile range of the '4s' group was wider on the right side compared to the left side.

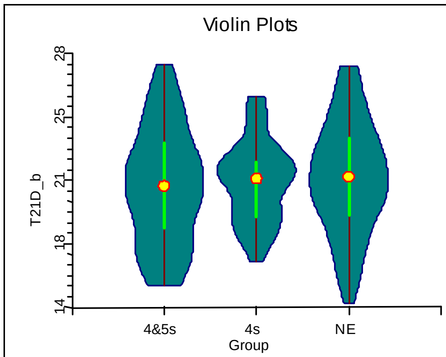


Figure 4.3.42a
Violin Plots of T21D_b for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar, but the interquartile of the '4s' group was much shorter than that of the other two groups.

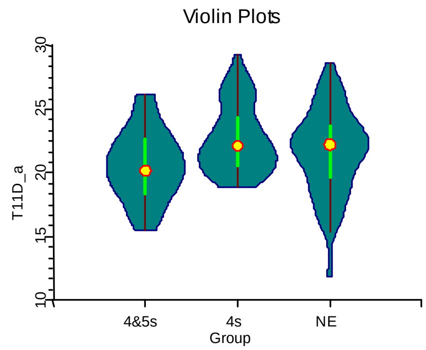


Figure 4.3.42b
Violin Plots of T11D_a for the three groups '4&5s', '4s' and NE

The median of the '4&5s' group was the lowest for this side.

Comparison of the two sides

The shapes of the three distributions on the left side appeared to be more platocurtic than those on the right side. The skewness of '4s' group was in opposite directions on the two sides.

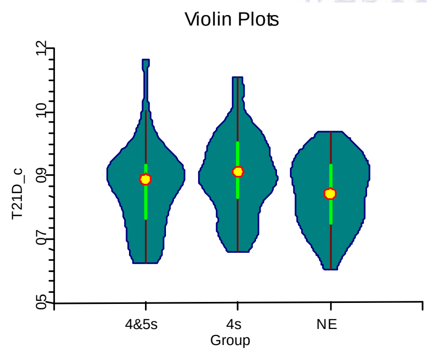


Figure 4.3.43a
Violin Plots of T21D_c for the three groups '4&5s', '4s' and NE

The median of the 'NE' group was the lowest. The skewness of the 'NE' and the '4&5s' groups was in opposite directions.

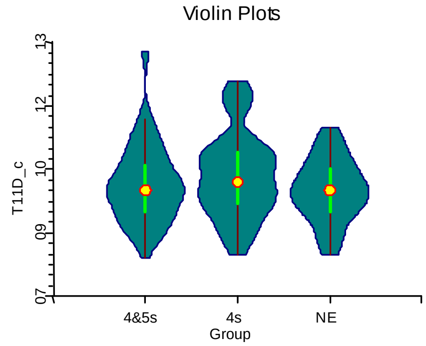


Figure 4.3.43b
Violin Plots of T11D_c for the three groups '4&5s', '4s' and NE

No distinct differences were observed in the pattern of the medians compared to the left side.

Comparison of the two sides

The corresponding distributions of the right and left sides were not different.

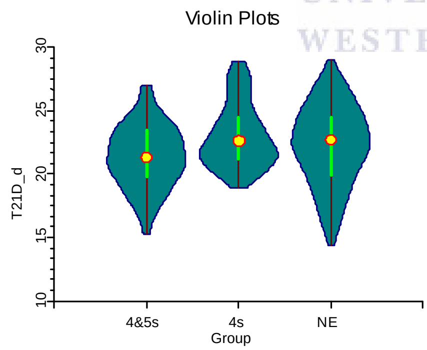


Figure 4.3.44a
Violin Plots of T21D_d for the three groups '4&5s', '4s' and NE

The '4&5s' group had the lowest median of the three groups.

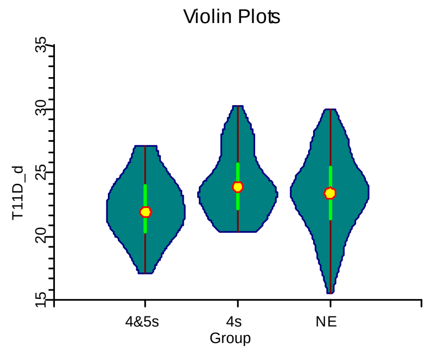


Figure 4.3.44b
Violin Plots of T11D_d for the three groups '4&5s', '4s' and NE

The pattern of the medians was similar to the pattern on the left side.

Comparison for the two sides

The pattern of the medians and the distributions of the corresponding groups appear to be similar for the two sides.

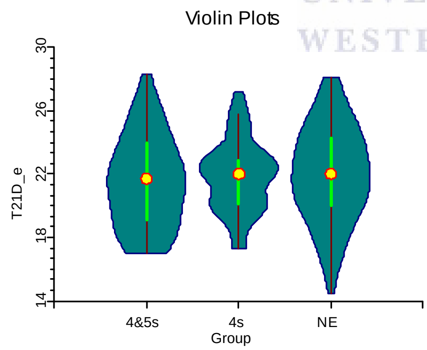


Figure 4.3.45a
Violin Plots of T21D_e for the three groups '4&5s', '4s' and NE

The medians of the three groups were similar. However, the interquartile for the '4s' group was the smallest.

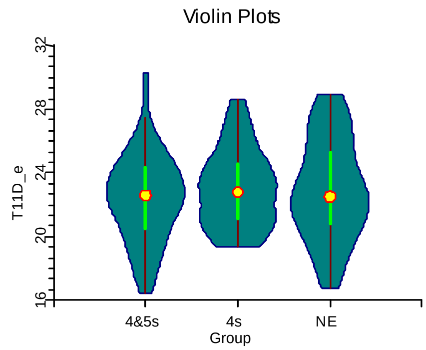


Figure 4.3.45b
Violin Plots of T11D_e for the three groups '4&5s', '4s' and NE

The pattern of the medians of the three groups was similar to the pattern on the left side and the range of the '4s' group was the smallest.

Comparison of the two sides

No distinct differences could be observed between the two sides.

Overview of pretreatment characteristics of the sample

The pretreatment graphical displays indicated that a wide range of variation occurred among the three groups for many measurements and on the right and left sides of the dentition. Often the medians among the three groups and on both sides were relatively similar, but the other graphical parameters were generally different among the groups and between the sides. No consistent characteristics of the pretreatment graphical patterns could be identified.

The orthodontist whose cases were used for this study determined the orthodontic treatment plan for each patient, i.e. the patients' treatment plans were not randomized. Literature regarding the consistency of intra-practitioner and inter-practitioner decisions to undertake certain premolar extraction sequences and nonextraction treatment plans has indicated that, although intra-practitioner agreement is usually higher than inter-practitioner agreement, many factors influence these decision-making processes (Baumrind *et al* 1996a, Baumrind *et al* 1996b, Ribarevski *et al* 1996, Luke *et al* 1998, Lee *et al* 1999). Some factors which have been discussed are the lack of adequate definitions of diagnostic criteria and treatment strategies (Luke *et al* 1998). Many factors may this have influenced the orthodontist in his decision to do a particular treatment on a patient and would therefore determine into which of the three treatment groups the patient was placed.

4.5 Discussion of the Differences Resulting from the Three Treatment Groups

4.5.1 Introduction

In this discussion inferential results were added to the graphical displays of the differences between the pre- and post-measurements ('pre-' was subtracted from 'post-'). The descriptive statistics are summarised in the tables with respect to the three treatment groups and for comparative purposes the left and right differences are placed next to each other. This was done in order to deduce whether the effects of the treatments were symmetrical with respect to the left / right sides of the palate. Distributional aspects of these differences can be seen in the side-by-side violin plots.

4.5.2 General comments on the Statistical Methods used

This novel method of measuring the position of teeth with respect to well-defined positions on the palate is still relatively new in dental science. A pilot study was done to learn more about the quality of the method of data collection. This was found to be insufficient to understand all the characteristics of this new method of taking measurements.

The total sample studied consisted of 112 individuals of whom two were lost due to missing and/or improbable measurements in some of the analyses, leaving 110 individuals in the sample. This sample was divided into groups '4&5s', '4s' and 'NE' according to the treatment applied. Most of the participants' ages were less than 15 years. The aim of this part of the study was to compare the three treatment groups in terms of the tooth movement relative to landmarks on the palatal rugae that had occurred after the orthodontic treatment for a mean duration of 1.8 years.

A descriptive approach was followed in the analysis and comparisons. An attempt was made to study the distributional forms within the treatment groups for the raw measurements, as well as the changes that had occurred after the treatment had been completed. All differences contain the abbreviation 'DIF'. Statistical inferential statements were made on whether the three different treatments made a significant difference in the measurements taken.

One of the problems present in this study was that numerous measurements had been made (more than 98 measurements before and the same number after treatment). This data-structure had the potential for multi-colinearity, so that some of the findings would be similar to others due to the interrelationships between the raw measurements and the calculated changes. For this reason the discussion of the results concentrated on the largest differences between treatment groups and the strongest relationships between measurements.

Treatment effects (movement due to treatment) were compared firstly using measurements crossing the midline, for example, Figure 4.4.1 comparing T26M_aDIF and T16M_bDIF; both the initial and follow-up measurements crossing the midline. Then measurements on the right and left sides of the palate were compared to each other, for example, Figure 4.4.2 comparing T26M_bDIF and T16M_aDIF, both the initial and follow-up measurements being separated by the midline.

Table 4.4.1
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26M _aDIF*	**4s** *T26M _aDIF*	**NE** *T26M _aDIF*	**4&5s** *T16M _bDIF*	**4s** *T16M _bDIF*	**NE** *T16M _bDIF*
Count	34	29	47	34	29	47
Mean	-0.54	-2.02	-3.49	-1.84	-1.17	0.30
Median	-0.30	-1.80	-3.20	-1.55	-1.20	0.60
Standard Deviation	1.83	1.94	1.84	2.12	1.59	2.10
Range	7.90	7.30	6.80	8.80	7.90	10.20
Minimum	-4.50	-5.80	-7.10	-6.80	-4.40	-5.50
Maximum	3.40	1.50	-0.30	2.00	3.50	4.70
Confidence Level (95.0%)	0.0901	0.0000	0.0000	0.0000	0.0001	0.3326

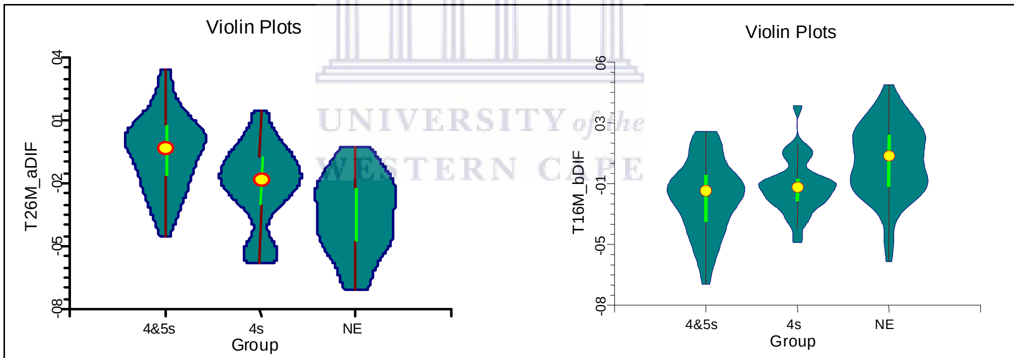


Figure 4.4.1
Side by side violin plots
T26M_aDIF and T16M_bDIF for the three groups '4&5s', '4' and NE

T26M_aDIF

Most of the distributions were skewed towards the larger negative movements. From Table 4.4.1 it is clear that there was hardly any movement for the '4&5s' group on average, but there was an individual who showed a decrease of this distance of 4.50mm (minimum of movements within this group) and another for whom the distance was increased by 3.40mm (maximum of movements within this group). These results indicate that not all the individuals in group '4&5s'

reacted in the same manner to this treatment. The range could measure this diversity of treatment effect (range= 7.90mm), or it could be measured by the standard deviation (1.83mm). For reasons of consistency the standard deviation values were used.

For the ‘4s’ group the average distance decreased by 2.02mm and for the NE group by 3.49mm. The standard deviation of the three groups was approximately the same. The movement created by the treatment was not statistically significant for group ‘4&5s’, but significant for groups ‘4s’ and NE on the left (2) side ($p < 0.05$).

The treatment effects were significantly different from each other for all three groups (Kruskal-Wallis Multiple-Comparison). Taking the pretreatment distributions into account this result did not appear to originate from differences in the three groups that might have been present prior to treatment.

T16M_bDIF

For groups ‘4&5s’ and ‘4s’ the mean distance was shortened significantly 1.84mm and 1.17mm respectively, whereas there was minimal change in the NE group. The standard deviations within the three groups fluctuated somewhat. The treatment effect of the NE group was significantly different from groups ‘4&5s’ and ‘4s’. The treatment effects in groups ‘4&5s’ and ‘4’ were not significantly different from each other ($p < 0.05$, Kruskal-Wallis Multiple-Comparison). As before, this result did not appear to originate from differences in the three groups that might have been present prior to treatment.

Comparison of the two sides

The right side responded totally differently to the left side to the treatment in all three groups of patients. The movement in the NE group was highly significant on the left (2) side but not significant on the right (1) side. However, the situation was the opposite for group ‘4&5s’. Furthermore the two extraction groups reacted differently to treatment and these differences were statistically significant.

Lundstrom (1961) indicated that the first molars could be positioned at different anteroposterior levels on the right and left sides due to asymmetrical maxillary skeletal orientation in the skull. Rugal patterns on right and left sides of the maxilla are not symmetrical and do not have the same dimensions, and this could also explain some of the right versus left side variations in measurements in this study (Simmons et al 1987). The rugae on the right side of the palate were all statistically significantly larger than the rugae on the left side in this sample of patients. These factors would probably complicate interpretation of tooth movement when measurements of tooth-to-ruga distances are done across.

Table 4.4.2
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26M _bDIF*	**4s** *T26M _bDIF*	**NE** *T26M _bDIF*	**4&5s** *T16M _aDIF*	**4s** *T16M _aDIF*	**NE** *T16M _aDIF*
Count	34	29	47	34	29	47
Mean	4.10	2.32	0.54	-5.11	-4.01	-2.82
Median	4.00	2.00	0.60	-4.90	-3.60	-2.40
Standard Deviation	2.66	2.28	2.29	2.91	1.68	2.36
Range	11.30	9.20	9.30	13.10	8.60	11.40
Minimum	-2.10	-1.50	-4.30	-11.80	-8.60	-11.00
Maximum	9.20	7.70	5.00	1.30	0.00	0.40
Confidence Level (95.0%)	0.0001	0.0001	0.1098	0.0001	0.0001	0.0001

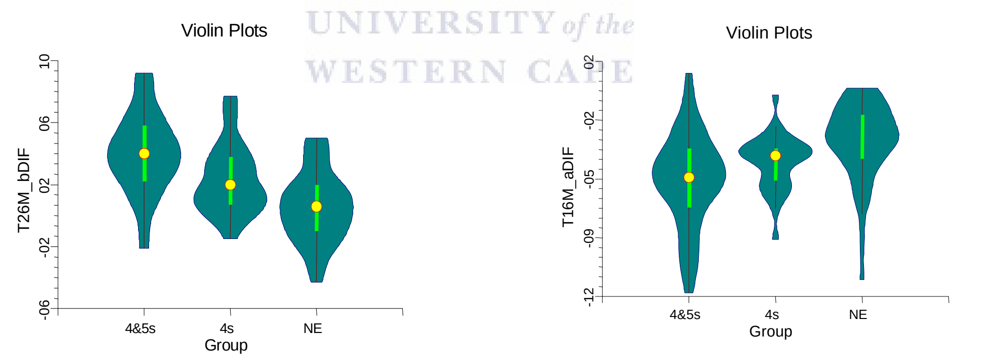


Figure 4.4.2
Side by side violin plots
T26M_bDIF and T16M_aDIF for the three groups '4&5s', '4' and NE

T26M_bDIF

This distance increased significantly for the '4&5s' group as well as for the '4s' group, but not significantly for the NE group. The standard deviations within the three groups were approximately equal.

T16M_aDIF

This distance decreased significantly for all three groups (see Table 4.4.2). The standard deviation within the '4s' group was somewhat smaller compared to the standard deviations of the '4&5s' and NE groups (see Table 4.4.2 as well as Figure 4.4.2).

Comparison of the two sides

The right side responded totally differently in comparison to the left side in all three treatment groups. The movement in the NE group was not significant on the left (2) side but shortened significantly on the right (1) side. This was similar to other deductions of left/right comparisons, in that the treatment effects for the two sides differed significantly.

These results indicate that there may be different reactions to orthodontic treatment, as the responses to treatment were significantly different on the right and left sides of the upper arch. This reaction occurred in all three groups, and therefore in orthodontic treatment with and without premolar extractions. It is interesting to note the all the distances decreased on the right (largest) side of the palate in all the treatment groups, whereas all the distances increased on the left (smaller) side of the palate in all the groups. This may be partly due to orthodontic treatment as archwires that are used during treatment are usually fitted to archforms which are symmetrical relative to the dental midlines (Tweed 1966, Root 1985). The relative effects of the symmetrical archwires on smaller and larger sides of the palate could therefore be expected to be different.

There was more movement of the first molars on both sides in the extraction groups than in the NE group. The reaction to orthodontic treatment in the two extraction groups also differed considerably, with more tooth movement occurring in the '4&5s' group.

Table 4.4.3
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26M _cDIF*	**4s** *T26M _cDIF*	**NE** *T26M _cDIF*	**4&5s** *T16M _cDIF*	**4s** *T16M _cDIF*	**NE** *T16M _cDIF*
Count	34	29	47	34	29	47
Mean	5.24	3.61	0.57	-5.86	-4.94	-1.73
Median	5.50	3.40	0.40	-5.70	-5.40	-1.90
Standard Deviation	1.91	2.94	2.23	2.25	1.67	2.11
Range	8.10	16.70	11.80	10.90	5.90	9.30
Minimum	0.20	-2.50	-5.10	-11.20	-7.50	-6.70
Maximum	8.30	14.20	6.70	-0.30	-1.60	2.60
Confidence Level (95.0%)	0.0001	0.0001	0.0830	0.0001	0.0001	0.0001

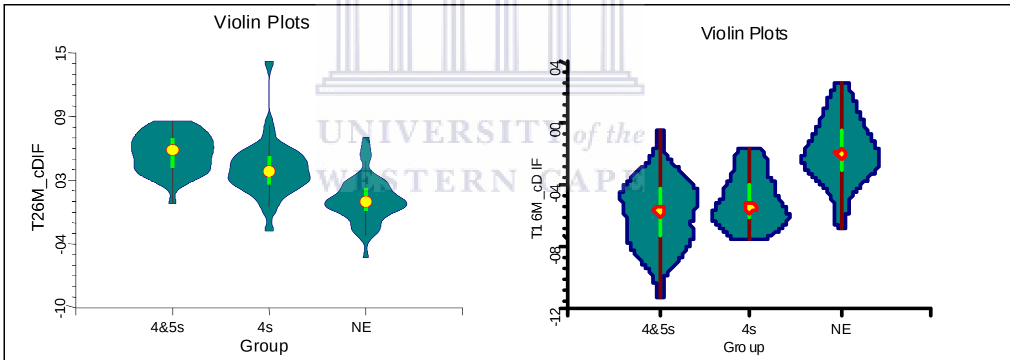


Figure 4.4.3
Side by side violin plots
T26M_cDIF and T16M_cDIF for the three groups '4&5s', '4' and NE

T26M_cDIF

This distance increased for all three treatment groups, significantly for the '4&5s' and the '4s' groups but not for the NE group. The standard deviations fluctuated between the three groups largely due to the positive outlier present in group '4s'.

T16M_cDIF

This distance decreased significantly for the three groups. The standard deviation fluctuated somewhat amongst the three groups, largely due to the truncated appearance of the '4s' group.

Comparison of the two sides

The same extensive differences in the treatment effects existed between the two sides as for T26M_bDIF and T16M_aDIF, i.e. increases in the distances on the left (smaller) side and decreases on the right (larger) side, with the larger differences occurring in the extraction groups compared to the NE group, and significant differences occurring between the two extraction groups.

Table 4.4.4
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26M _dDIF*	**4s** *T26M _dDIF*	**NE** *T26M _dDIF*	**4&5s** *T16M _dDIF*	**4s** *T16M _dDIF*	**NE** *T16M _dDIF*
Count	34	29	47	34	29	47
Mean	1.53	-0.34	-1.20	-3.31	-2.52	-0.89
Median	1.30	0.00	-1.40	-3.25	-2.50	-1.20
Standard Deviation	2.21	1.76	1.73	1.95	1.14	1.62
Range	10.30	8.10	9.50	8.80	4.80	8.00
Minimum	-3.40	-3.40	-4.90	-7.60	-5.20	-5.00
Maximum	6.90	4.70	4.60	1.20	-0.40	3.00
Confidence Level (95.0%)	0.0001	0.3067	0.0001	0.0001	0.0001	0.0002

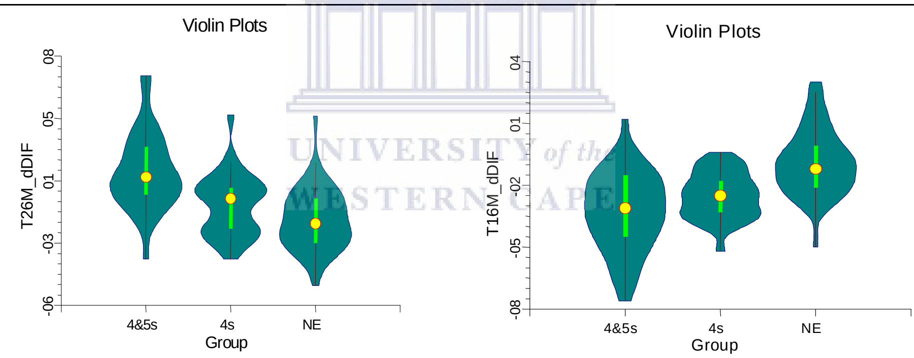


Figure 4.4.4
Side by side violin plots
T26M_dDIF and T16M_dDIF for the three groups ‘4&5s’, ‘4’ and NE

T26M_dDIF

The average movement (1.53mm) was positive (distance increased) in the case of the ‘4&5s’ group ($p<0.05$). The individual movements covered a wide range from –3.4mm to 6.9mm. For the ‘4s’ group the average movement was not significant ($p>0.05$), but the individual movements varied between –3.4mm and 4.7mm. Within the NE group the average movement was negative (distance decreased) ($p<0.05$).

T16M_dDIF

The average movement for all three groups was negative ($p<0.05$). All the individual movements were negative (decreased) in the '4s' group. The other two groups consisted of a mixture of increases and decreases. The standard deviation of the '4s' group was smaller than that of the remaining two groups.

Comparison of the two sides

The same differences in the treatment effects existed between the two sides as for T26M_bDIF and T16M_aDIF (mostly a reduction in the distance to 'point d').

Table 4.4.5
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26M _eDIF*	**4s** *T26M _eDIF*	**NE** *T26M _eDIF*		**4&5s** *T16M _eDIF*	**4s** *T16M _eDIF*	**NE** *T16M _eDIF*
Count	34	29	47		34	29	47
Mean	1.59	-0.14	-1.35		-3.38	-2.69	-0.83
Median	2.10	0.00	-1.70		-3.70	-2.90	-1.30
Standard Deviation	1.82	1.95	1.96		1.55	1.08	1.51
Range	6.80	8.10	9.30		6.40	5.10	6.90
Minimum	-2.50	-3.70	-5.30		-6.20	-5.60	-4.30
Maximum	4.30	4.40	4.00		0.20	-0.50	2.60
Confidence Level (95.0%)	0.0001	0.7040	0.0001		0.0001	0.0001	0.0002

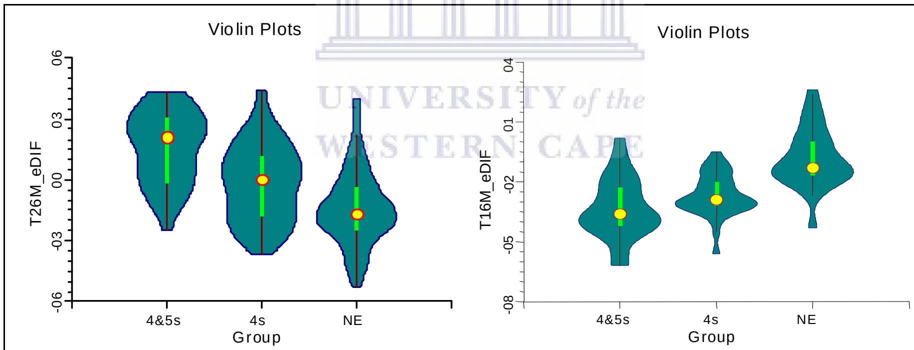


Figure 4.4.5
Side by side violin plots
T26M_eDIF and T16M_eDIF for the three groups '4&5s', '4' and NE

T26M_eDIF

The average movement was positive (increased) in the case of the '4&5s' group ($p<0.05$). For the '4s' group the average movement was not significant ($p>0.05$). Within the NE group the average movement was negative (decreased) ($p<0.05$).

T16M_eDIF

The average movement for all three groups was negative ($p<0.05$). All the individual movements were negative (distances decreased) in the '4s' group. The other two groups consisted of a mixture of increases and decreases. The standard deviation of the '4s' group was smaller than the standard deviations in the remaining two groups.

Comparison of the two sides

The effect of the three treatments on T26M_e and T16M_e was similar to the effect on T26M_d and T16M_d discussed above. There were no significant differences for left or right side midline measurements, i.e. left and right side measurements projected onto the midline (MPP) gave similar results. It would appear that these two midline measurements showed similar changes in tooth movement patterns within the three groups, and that measurements using projections of rugae points onto the midpalatal plane can therefore be used to evaluate first molar tooth movement during orthodontic treatment.

Table 4.4.6
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26D _Adif*	**4s** *T26D _aDIF*	**NE** *T26D _aDIF*	**4&5s** *T16D _bDIF*	**4s** *T16D _bDIF*	**NE** *T16D _bDIF*
Count	34	29	47	33	29	47
Mean	0.99	1.94	3.64	-1.22	-0.77	1.15
Median	0.90	1.60	3.60	-1.20	-0.90	0.80
Standard Deviation	1.77	1.91	1.71	1.97	1.76	2.71
Range	8.30	8.40	6.70	8.90	8.80	18.60
Minimum	-3.20	-2.50	0.80	-6.00	-4.20	-5.10
Maximum	5.10	5.90	7.50	2.90	4.60	13.50
Confidence Level (95.0%)	0.0013	0.0001	0.0001	0.0001	0.0206	0.0040

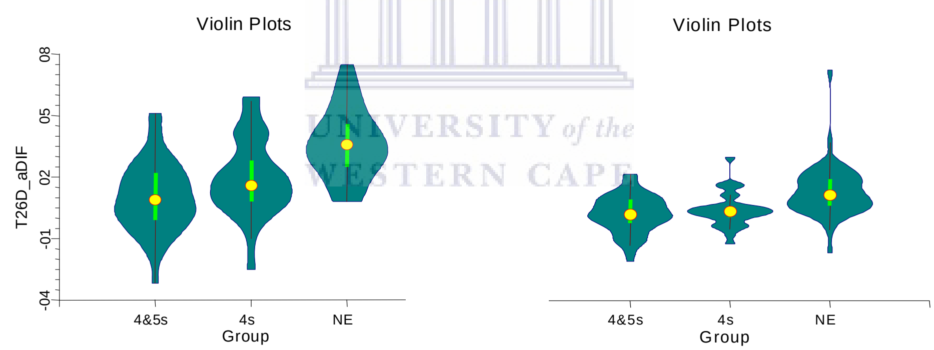


Figure 4.4.6
Side by side violin plots
T26D_aDIF and T16D_bDIF for the three groups '4&5s', '4' and NE

T26D_aDIF

The average movement was positive for all three treatment groups ($p<0.05$) and no large discrepancies occurred in the standard deviations. However, all the individual movements in the NE group were positive (increased) whereas the movements within the '4&5s' and the '4s' groups were positive as well as negative.

The increased measurements in the 'NE' groups may indicate distalization, expansion and/or rotation of the first molar teeth during orthodontic treatment.

T16D_bDIF

The average distance decreased significantly for the '4&5' and the '4s' groups, but increased for the NE group. This significant increase (average = 1.15mm, median = 0.80mm) in the NE group was largely due to a severe outlier (13.5mm). This severe outlier in the NE group complicated the comparison of the three groups. Nevertheless, there was extensive clustering around the median within the '4s' group.

Comparison of the two sides

The treatment effect was diverse within the three treatment groups and between the right and left sides. When compared to the results in Table 4.4.1 it is evident that the millimetre measurements of the movement of the mesial and distal surfaces of the left first molar were relatively similar, but in opposite directions, probably indicating some rotation of this tooth in all three groups (the mm measurements also relatively similar). The largest amount of change was for the NE group, followed by groups '4s' and '4&5s' respectively. On the right side the changes for the mesial and distal surfaces were in the same directions for all three groups, possibly indicating more translation/ tipping changes than rotation on this (the larger) side.

Table 4.4.7
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26D _bDIF*	**4s** *T26D _bDIF*	**NE** *T26D _bDIF*		**4&5s** *T16D _aDIF*	**4s** *T16D _aDIF*	**NE** *T16D _aDIF*
Count	34	29	47		33	29	47
Mean	-2.79	-1.66	0.40		-4.11	-3.31	-1.73
Median	-3.00	-1.20	0.60		-4.10	-3.00	-1.50
Standard Deviation	2.27	2.17	2.14		2.50	1.79	2.88
Range	10.30	8.30	9.30		10.10	9.90	19.10
Minimum	-7.70	-6.60	-4.40		-8.90	-8.70	-8.50
Maximum	2.60	1.70	4.90		1.20	1.20	10.60
Confidence Level (95.0%)	0.0001	0.0001	0.2049		0.0001	0.0001	0.0001

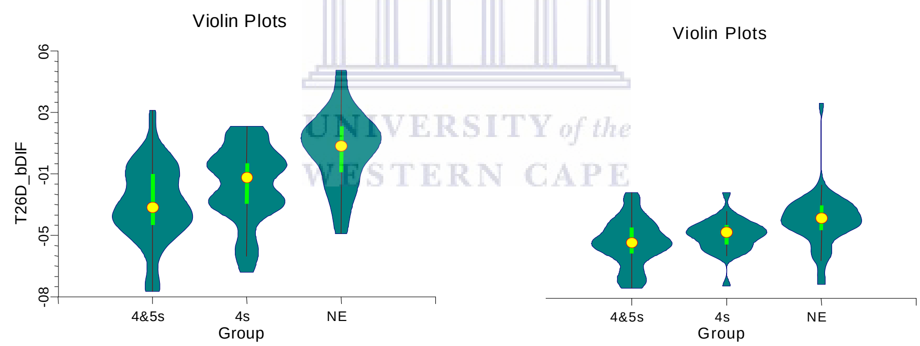


Figure 4.4.7
Side by side violin plots
T26D_bDIF and T16D_aDIF for the three groups '4&5s', '4' and NE

T26D_bDIF

This distance decreased significantly for the '4&5s' (greatest change) and the '4s' groups, but there was very little movement within group NE. There was some evidence of bimodality in the '4&5s' and the '4s' groups.

The first molar teeth probably moved forwards, and/or rotated inwards in the premolar extraction groups during treatment. When the results are compared to those in Table 2 it is probable that more rotation of the first molars occurred on the left side (movement in opposite directions) in the two extraction groups, with considerably more movement occurring in the '4&5s' group than in the '4s' group. The tendency for a bimodal response to treatment may indicate two distinctly different responses to orthodontic treatment in both of the extraction groups.

T16D_aDIF

This distance decreased significantly for all three groups. The severe positive outlier of 10.60mm influenced the standard deviation of the NE group. The possibility that this outlier could be a measurement error could not be excluded.

Comparison of the two sides

There was more tooth movement due to treatment on the right side than on the left side. The different responses between the left and right sides followed the trend noted for other measurements in all three groups. When the information in Tables 4.4.2 and 4.4.7 is compared it is apparent that the left first molar tooth rotated during treatment in groups '4&5s' and '4s', and that there was more movement of this tooth in the '4&5s' group. Very little tooth movement was noted for the left first molar tooth in the NE group. The right first molar tooth showed a decreased distance for all three groups, the largest distance decrease being for the '4&5s' group. When this information is compared to that in Table 4.4.2 it is evident that the right first molar tooth moved towards point a, and that other types of tooth movement probably occurred here, i.e. translation and/or tipping movements (less rotation) compared to the left first molar.

Table 4.4.8
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26D _cDIF*	**4s** *T26D _cDIF*	**NE** *T26D _cDIF*	**4&5s** *T16D _cDIF*	**4s** *T16D _cDIF*	**NE** *T16D _cDIF*
Count	34	29	47	33	29	47
Mean	-4.40	-2.70	0.29	-4.80	-4.04	-0.35
Median	-4.30	-2.70	0.70	-5.00	-.4.60	-0.80
Standard Deviation	2.55	2.42	2.14	2.12	1.69	2.73
Range	15.60	10.70	11.10	9.90	7.00	17.60
Minimum	-16.00	-7.10	6.50	-7.60	-7.10	-5.60
Maximum	-0.40	3.60	4.60	2.30	-0.10	12.00
Confidence Level (95.0%)	0.0001	0.0001	0.358	0.0001	0.0001	0.3846

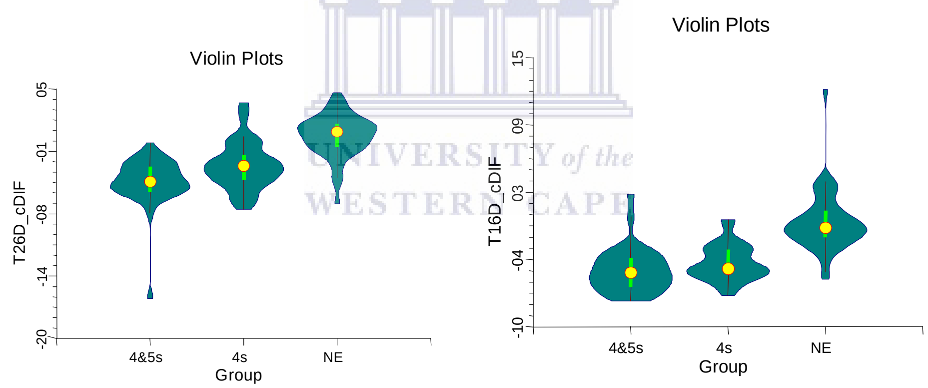


Figure 4.4.8
Side by side violin plots
T26D_cDIF and T16D_cDIF for the three groups '4&5s', '4' and NE

T26D_cDIF

This distance decreased within the '4&5s' and the '4s' groups, but there was no general movement within group NE. A severe negative outlier (-16mm) could be observed in the '4&5s' group.

T16D_cDIF

This distance decreased within the '4&5s' and the '4s' groups, but there was no general movement within group NE. A severe positive outlier (12mm) could be observed in the NE group.

Comparison of the two sides

For the two treatments in which teeth were removed (‘4&5s’ and ‘4s’) a definite shortening of this distance occurred. This effect was not present in the NE group. The midline projections of left and right side landmarks gave consistent results in the three groups. When these results are compared to those in Table 4.4.3 and Figure 4.4.3 it is evident that similar tooth movements as described for the changes relative to points a and b occurred relative to point c.

Table 4.4.9
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26D _dDIF*	**4s** *T26D _dDIF*	**NE** *T26D _dDIF*	**4&5s** *T16D _dDIF*	**4s** *T16D _dDIF*	**NE** *T16D _dDIF*
Count	34	29	47	33	29	47
Mean	-1.07	0.46	1.56	-2.65	-1.71	0.09
Median	-0.85	0.60	1.70	-2.80	-2.00	-0.60
Standard Deviation	2.41	1.68	1.52	1.78	1.79	2.35
Range	13.50	6.70	8.80	8.50	9.50	13.70
Minimum	-10.30	-3.50	-3.70	-6.20	-3.60	-3.20
Maximum	3.20	3.20	5.10	2.30	5.90	10.50
Confidence Level (95.0%)	0.0108	0.1474	0.0001	0.0001	0.0001	0.7950

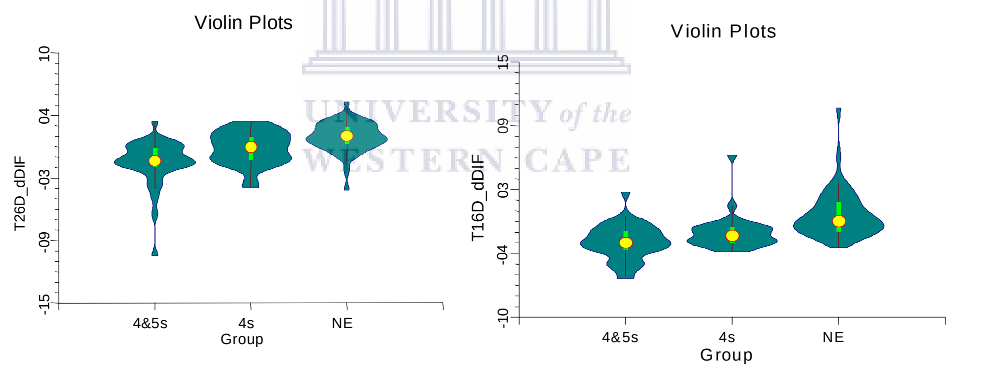


Figure 4.4.9
Side by side violin plots
T26D_dDIF and T16D_dDIF for the three groups ‘4&5s’, ‘4’ and NE

T26D_dDif

Within the ‘4&5s’ group there was a significant decrease of this distance; no significant movement for group ‘4s’ and a significant increase for the ‘NE’ group. The distribution associated with the‘4&5s’ group had a long tail in the negative direction.

The decrease in the ‘4&5s’ group could indicate inwards rotation of the first molars, shortened arch lengths and/or mesial movement of the first molars during treatment. The fact that no significant movement occurred in the '4s' groups may be related to the orthodontic technique used and/or the amount of space shortage in the cases. There could have been distalization of the first molars and/or upper arch expansion in the 'NE' group. When these results are compared to those in Table 4.4.4 and Figure 4.4.4 it can be seen that the first molars rotated during treatment, and that there were mesial and distal components in the movement aswell.

T16D_dDIF

For the '4&5s' and '4s' groups there was a significant decrease of this distance, but not for the NE group. A severe positive outlier (10.50mm) was present in the NE group as well as for the '4s' group (5.90mm). Extractions of premolars and the subsequent forward movement and rotation of the first molars could explain the results in the two extraction groups.

Comparison of the two sides

From the above table it could be seen that the effects were diverse for the three treatment groups as well as for the two sides. The possibility that measurements done on the same side of the palate where the amount of tooth movement is being measured may be more accurate than measurements done relative to landmarks across the midline should be investigated further. From the results of this study it can be concluded that the most posterior point on the most posterior rugae projected onto the midline may be used to evaluate movement of the first molars.

Table 4.4.10
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T26D _eDIF*	**4s** *T26D _eDIF*	**NE** *T26D _eDIF*	**4&5s** *T16D _eDIF*	**4s** *T16D _eDIF*	**NE** *T16D _eDIF*
Count	34	29	47	33	29	47
Mean	-0.80	0.30	1.72	-2.70	-1.86	0.06
Median	-0.95	0.40	1.90	-2.80	-2.20	-0.20
Standard Deviation	1.48	1.91	1.76	1.53	1.94	2.63
Range	6.40	7.20	8.90	6.80	10.50	19.10
Minimum	-3.50	-3.90	-3.60	-5.50	-3.90	-7.70
Maximum	2.90	3.30	5.30	1.30	6.60	11.40
Confidence Level (95.0%)	0.0020	0.4060	0.0001	0.0001	0.0001	0.8770

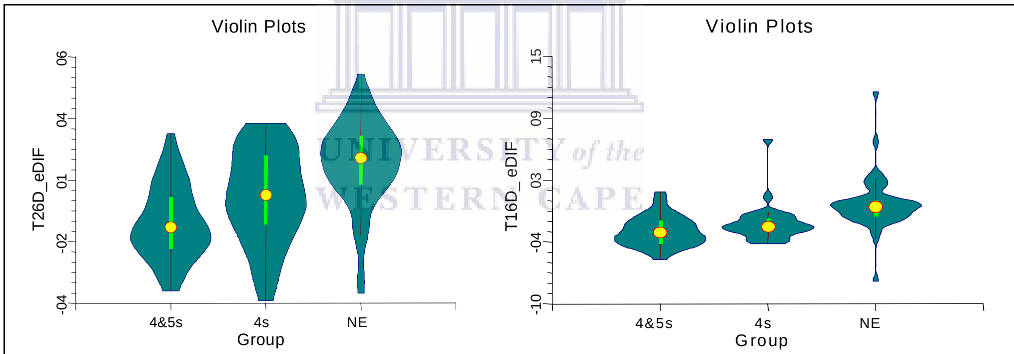


Figure 4.4.10
Side by side violin plots
T26D_eDIF and T16D_eDIF for the three groups '4&5s', '4' and NE

T26D_eDIF

There was a significant decrease of this distance in group '4&5s'; no significant change for group '4s', and a significant increase for the group NE.

These results are similar to those presented in Figure and Table 4.4.9. The insignificant change observed in the group '4s' may be attributed to the fact that these cases had more crowding in the anterior segments, or were bimaxillary protrusion cases, where conservation of orthodontic anchorage was an important part of treatment planning. The difference in the amount of first molar movement between the two extraction groups indicates that anchorage control differences and other differences related to the mechanics of orthodontic treatment existed between the group where maxillary and mandibular 4's were extracted (group '4s') and the group where maxillary 4's and mandibular 5's were extracted (group '4&5s') respectively. Other researchers have noted similar findings (Ong and Woods 2001).

T16D_eDIF

For both groups '4&5s' and '4s' there were a significant decrease in this distance and no definite movement within the NE group. Severe positive outliers occurred in the NE (6.6mm) as well as the '4s' (11.4mm) groups. A negative outlier (-7.70mm) was also present in the NE group. These outliers had a severe influence on the range as well as the standard deviation in the '4s' and the NE groups of side one. In both of the extraction groups the measurements done across the midline showed shortening of the distances.

Comparison of the two sides

The changes due to treatment were similar to those that occurred with respect to 'point d' (see section above for T26D_dDIF & T16D_dDIF supported by Table 4.4.9 and Figure 4.4.9). For both 'points d and e' there was a decrease in this distance on the right side that did not occur on the left side in treatment group '4s'. For the '4&5s' group, the treatment effect was stronger on the right compared to the left. A definite increase in these distances occurred on the left side but not on the right for the NE group. Once again, when these results are compared to those of the mesial points on the first molars (Table 4.4.5 and Figure 4.4.5) the rotation movement of the left molars and greater amount movement of the right molars during extraction treatment are evident.

The trend in the left/ right side differences in the data of rugae measurements may be influenced by the asymmetry of the rugae on the left/right sides of the palate, and the significant differences in the sizes of rugal measurements between the two sides (see Chapter 4.2). It may, therefore, be advisable to measure tooth movement relative to rugal points on the same side of the palate, rather than measuring changes in distances to rugal points on opposite sides of the palate. Furthermore, projections of rugal landmarks onto the midpalatal plane could also be useful landmarks to use to measure tooth movement. This finding concurs with the results of other studies regarding rugal to palatal midline measurements (Lebret 1962, Almeida *et al* 1995, Bailey *et al* 1996, Miller *et al* 2003).

Table 4.4.11
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T25C _aDIF*	**4s** *T25C _aDIF*	**NE** *T25C _aDIF*	**4&5s** *T15C _bDIF*	**4s** *T15C _bDIF*	**NE** *T15C _bDIF*
Count	27	18	29	33	29	47
Mean	2.14	2.56	4.24	7.43	9.02	9.61
Median	2.10	2.40	3.90	0.10	0.30	2.70
Standard Deviation	1.73	2.33	1.98	12.98	13.59	13.25
Range	7.70	9.80	7.80	35.40	35.80	37.60
Minimum	-0.60	-3.60	1.30	-3.50	-4.60	-2.90
Maximum	7.10	6.20	9.10	31.90	31.20	34.70
Confidence Level (95.0%)	0.0000	0.0000	0.0000	0.0012	0.0004	0.389

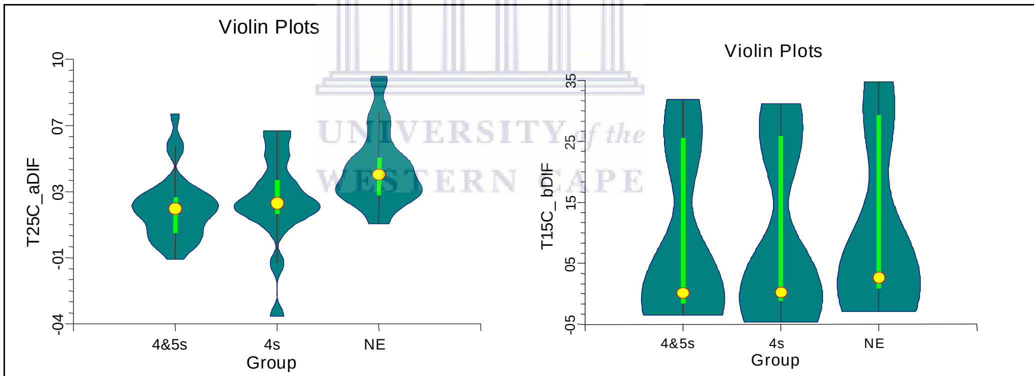


Figure 4.4.11
Side by side violin plots
T25C_aDIF and T15C_bDIF for the three groups '4&5s', '4' and NE

T25C_aDIF

For all treatment groups there were a significant increase in this distance and the distribution of the differences showed skewness towards the positive values. All the average movements, as well as the medians, were positive indicating an increase in the distance to the 'point a'. In the '4s' group an extreme outlier of –3.6mm with respect to this treatment was present.

These results are an indication that expansion or buccal tipping/ translation of the second premolars occurred. The interpremolar distance increased significantly in all treatment groups (Table 4.4.2). A mean increase in the interpremolar width during orthodontic treatment is a common finding, and occurs in nonextraction cases and extraction cases regardless of the extraction sequence (Ong and Woods 2001). There is very little change due to growth in interpremolar archwidth after the age of 12 years in normal untreated individuals (Lee 1999), so most of this change can be attributed to the orthodontic treatment.

T15C_bDIF

This increase for the three groups occurred also on the right. A definite bimodality occurred on this side as can be seen in the above violin plot. This bimodality had the effect that the means and the corresponding medians differed extensively from each other. The comparison of the treatment within the three groups in the presence of bimodality is problematic.

The bimodal pattern of these results indicates that there could probably be two types of reaction to the orthodontic treatment, and/or that the patients in all of the three groups did not react to orthodontic treatment in the same manner. The dramatic differences between the left and right side measurements may also indicate that important differences occurred on the two sides. This may, therefore, be another indication that using a rugal point on the same side of the palate as a reference may be more useful than using a point on the opposite side of the palate. These results may also indicate a measurement error across the midline, and not a treatment effect, but this does not explain why the increase of the distance on the right side was double that on the left side. There may have been differences (asymmetries) between the left and right sides in the positions of the premolars before treatment, which may have changed during treatment. Dental arch asymmetry has been shown to be more prevalent in persons with malocclusions (Alavi *et al* 1988, De Araujo *et al* 1994, Rose *et al* 1994) and improves after orthodontic treatment (Maurice and Kula 1998).

Comparison of the two sides

The skewness towards the positive values was much more pronounced on the right compared to the left, to such a degree that bimodalities occurred on the right. This may be indicative that there was a subgroup that showed an excessive increase of this distance on the right side. The mean increase on the right was more than double the increase measured on the left all three treatment groups. The standard deviations were consistantly higher on the right due to the presence of bimodality.

Table 4.4.12
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T25C _bDIF*	**4s** *T25C _bDIF*	**NE** *T25C _bDIF*	**4&5s** *T15C _aDIF*	**4s** *T15C _aDIF*	**NE** *T15C _aDIF*
Count	27	18	29	23	19	34
Mean	-0.91	-0.09	1.35	-3.37	-2.46	-0.79
Median	-1.30	0.45	1.40	-3.40	-1.90	-0.65
Standard Deviation	2.17	2.33	1.44	2.22	1.94	1.94
Range	8.80	7.70	7.00	7.50	7.40	9.90
Minimum	-.4.40	-4.90	-1.90	-6.80	-7.10	-5.50
Maximum	4.40	2.80	5.10	0.70	0.30	4.40
Confidence Level (95.0%)	0.0325	0.8735	0.0000	0.0000	0.0000	0.0193

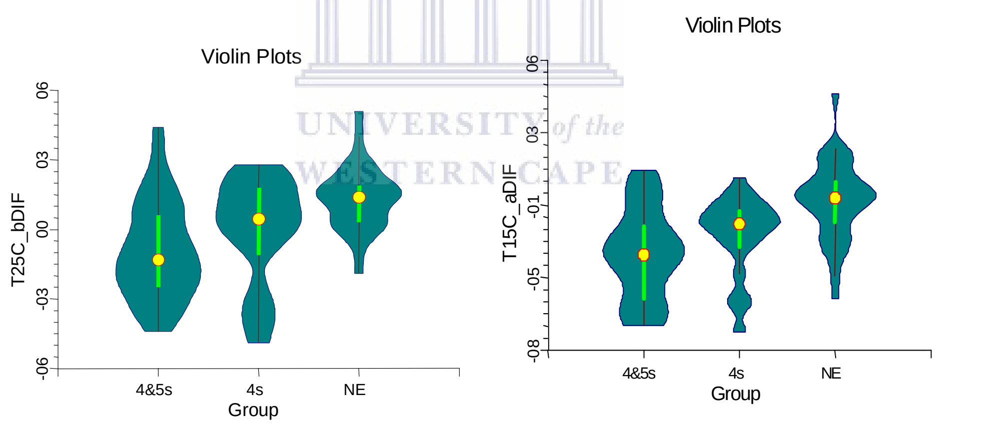


Figure 4.4.12
Side by side violin plots
T25C_bDIF and T15C_aDIF for the three groups '4&5s', '4' and NE

T25C_bDIF

Hardly any change appeared in groups '4&5s' (except for a small decrease) and '4s', whereas the mean change in group NE showed a definite increase in distance.

When measured to point b on the left side (same side), there was no indication that expansion had occurred in the extraction groups, whereas there was expansion of the dental arch in the second premolar area.

T15C_aDIF

A significant movement (shortening) of this distance occurred for the groups ‘4&5s’ and ‘4s’. A much smaller decrease (but still significant) occurred for the NE group.

Comparison of the two sides

The shortening on the right was much larger than the movement on the left. On the left for the NE group there was a significant increase that did not correspond to the right of the NE group. Comparing the two violin plots it was clear that the relative positions of the three corresponding groups for the two sides formed a similar pattern, but a major difference between the two sides was that the NE group showed a strong increase of the distance to ‘point b’ but a decrease of the distance to ‘point a’.

These results may indicate some instability in the rugal points used, and/or some measurement error. It does not seem to be advisable to use landmarks on the posterior rugae to measure movement of premolar teeth during extraction treatment. The same is probably true for nonextraction orthodontic treatment, to a lesser degree.

Table 4.4.13 **Descriptive Statistics of the differences for the three treatment groups both for the left and right side** **All units are in millimetres (mm)**						
Treatment Group	**4&5s** *T25C _cDIF*	**4s** *T25C _cDIF*	**NE** *T25C _cDIF*	**4&5s** *T15C _cDIF*	**4s** *T15C _ cDIF*	**NE** *T15C _ cDIF*
Count	27	18	29	23	19	34
Mean	-4.11	-2.84	0.12	-5.02	-4.08	-0.26
Median	-4.30	-2.95	0.40	-4.80	-4.40	-0.40
Standard Deviation	1.36	1.86	1.97	1.49	1.60	1.86
Range	5.00	6.90	9.80	6.40	6.80	8.70
Minimum	-6.70	-6.50	-6.20	-7.70	-6.90	-5.10
Maximum	-1.70	0.40	3.60	-1.30	-0.10	3.60
Confidence Level (95.0%)	0.0000	0.0000	0.7472	0.0000	0.0000	0.4220

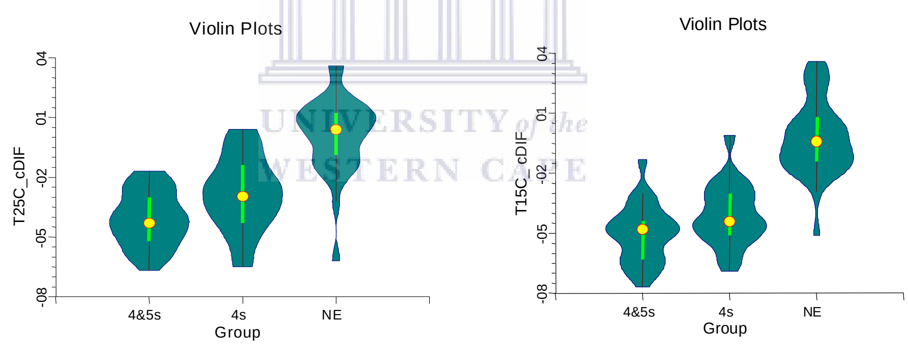


Figure 4.4.13
Side by side violin plots
T25C_cDIF and T15C_cDIF for the three groups '4&5s', '4' and NE

T25C_cDIF

Two of the treatment groups namely '4&5s' and '4s' showed a significant decrease in this distance, whereas the NE group had no definite movement (shortening or lengthening) but contained a minimum of –6.20mm (due to an excessive outlier) and a maximum of 3.60mm.

These results may indicate that rugal stability differs in individuals and/or that there was considerable individual variation in treatment response. The latter finding has been described in many studies of orthodontic treatment, irregardless of the treatment options followed, e.g. nonextraction, extraction, expansion, different orthodontic techniques etc. (Ghafari Baumrind & Efstratiadis 1998, Baumrind 1995, Tulloch *et al* 1997). This may explain why some outliers were seen in the group NE, although the mean change for the group as a whole was not significant.

T15C_cDIF

The effect of the different treatments was similar to that of the left side, except that the shortening within the '4s' group was larger. There was no significant change in the NE group, as before.

Comparison of the two sides

The shortening of this distance in the '4&5s' and the '4s' groups was more pronounced on the right compared to the left. Landmarks on the midpalatal plane may be used to measure tooth movement of premolars during orthodontic treatment. Points related to the incisive papilla may be considered for this purpose.

Table 4.4.14
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres(mm)

Treatment Group	**4&5s** *T25C _dDIF*	**4s** *T25C _dDIF*	**NE** *T25C _dDIF*	**4&5s** *T15C _dDIF*	**4s** *T15C _dDIF*	**NE** *T15C _dDIF*
Count	27	18	29	23	19	34
Mean	0.59	1.81	2.17	-2.13	-1.37	0.72
Median	0.60	1.50	2.20	-2.20	-1.30	0.40
Standard Deviation	1.36	1.63	1.16	1.34	1.13	1.60
Range	5.60	6.60	5.00	4.50	4.80	6.30
Minimum	-2.20	-0.90	-0.60	-4.40	-3.90	-2.50
Maximum	3.40	5.70	4.40	0.10	0.90	3.80
Confidence Level (95.0%)	0.0270	0.0000	0.0000	0.0000	0.0000	0.0097

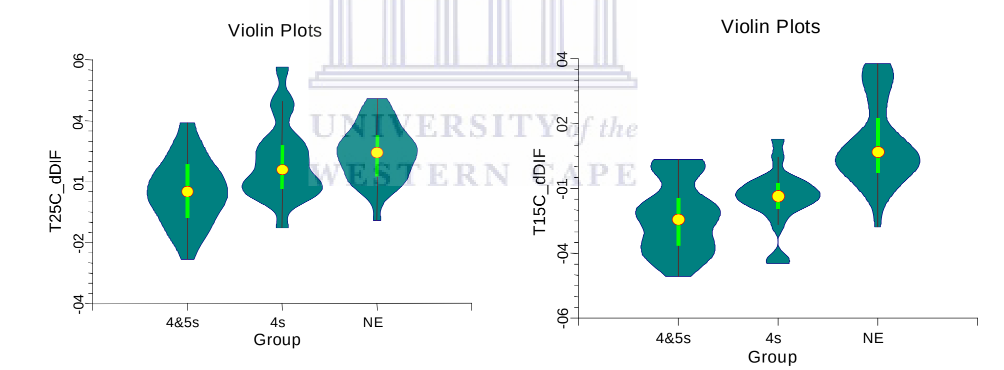


Figure 4.4.14
Side by side violin plots
T25C_dDIF and T15C_dDIF for the three groups ‘4&5s’, ‘4’ and NE

T25C_dDIF

Definite increases occurred in the ‘4s’ and NE groups, and a smaller, but still significant increase had taken place in the ‘4&5s’ group.

T15C_dDIF

Definite decreases (shortening) occurred in the ‘4&5s’ and the ‘4s’ groups, but a small lengthening ($p<0.05$) had taken place in the NE group.

Comparison of the two sides

As can be seen from the above table and figure the effect of the treatment within the three treatment groups was diverse. Once again, there were distinct differences between the right and left sides for these measurements.

These results indicate that selected rugal points projected onto the MPP may be used to measure premolar tooth movement during extraction and nonextraction orthodontic treatment.

Table 4.4.15
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T25C _eDIF*	**4s** *T25C _eDIF*	**NE** *T25C _eDIF*	**4&5s** *T15C _eDIF*	**4s** *T15C _eDIF*	**NE** *T15C _eDIF*
Count	27	18	29	23	19	34
Mean	0.80	1.39	2.28	-1.94	-1.84	0.68
Median	1.00	0.75	2.40	-2.00	-1.50	0.25
Standard Deviation	1.16	1.72	1.33	1.46	2.45	1.61
Range	5.80	6.30	5.80	6.40	12.20	7.00
Minimum	-2.40	-1.10	-1.40	-4.20	-11.20	-3.00
Maximum	3.40	5.20	4.40	2.20	1.00	4.00
Confidence Level (95.0%)	0.0004	0.0009	0.0000	0.0000	0.0014	0.0153

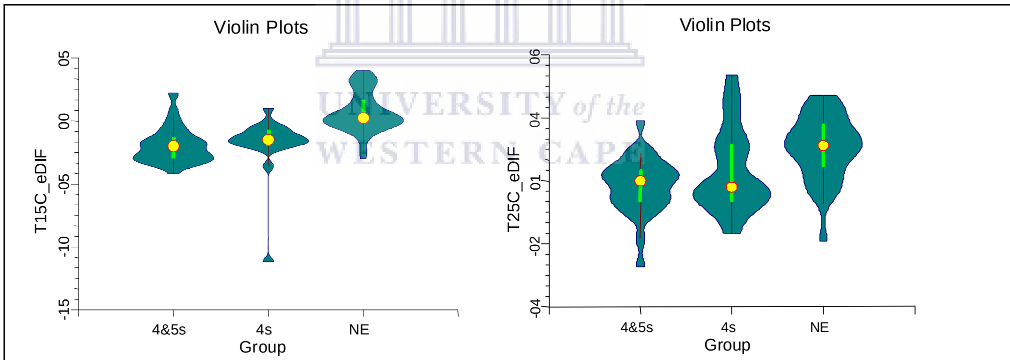


Figure 4.4.15
Side by side violin plots
T25C_eDIF and T15C_eDIF for the three groups ‘4&5s’, ‘4’ and NE

T25C_eDIF

On this side the effect was similar to the effect with respect to ‘point d’.

T15C_eDIF

On this side the effect was similar to the effect with respect to ‘point d’. This could be expected due to the proximity of ‘d’ and ‘e’ to each other.

Comparison of the two sides

This comparison was similar to that of 'point d' for the same reasons stated above. There were consistent differences between the measurements on the left and right sides of the palate.

Any analysis of the effects of orthodontic treatment related to the positions of teeth 24 and 14 was not possible in the extraction groups, as the first premolars had been extracted as part of the treatment planning in these two groups.

The movements (changes) with respect to the five reference points 'a' to 'e' in the NE group are provided in the Tables below. In general, the increases for the left side were greater than those for the right side.

Table 4.4.16
Descriptive Statistics of the differences for the three treatment groups both for the left and right side

All units are in millimetres (mm)

Treatment Group	**4&5s** *T24C _aDIF*	**4s** *T24C _aDIF*	**NE** *T24C _aDIF*		**4&5s** *T14C _bDIF*	**4s** *T14C _bDIF*	**NE** *T14C _bDIF*
Count			39				40
Mean	No	No	4.09		No	No	1.60
Median	Valid	Valid	3.70		Valid	Valid	1.30
Standard Deviation	Obser-vations	Obser-vations	1.92		Obser-vations	Obser-vations	2.17
Range			8.30				11.60
Minimum			1.20				-4.10
Maximum			9.50				7.50
Confidence Level (95.0%)			0.0001				0.0001

Both sides showed a significant increase for this distance, but the mean increase for the left side was more than twice that of the right. All the changes on the left side were positive (increased), whereas the changes on the right side consisted of a mixture of increases and decreases. Across the midline rugal measurements indicated larger differences than the corresponding measurement differences on the same sides.

Table 4.4.17
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres(mm)

Treatment Group	**4&5s** *T24C _bDIF*	**4s** *T24C _bDIF*	**NE** *T24C _bDIF*		**4&5s** *T14C _aDIF*	**4s** *T14C _aDIF*	**NE** *T14C _aDIF*
Count			39				40
Mean	No	No	0.86		No	No	-0.79
Median	Valid	Valid	1.10		Valid	Valid	-0.75
Standard Deviation	Obser-vations	Obser-vations	1.23		Obser-vations	Obser-vations	1.65
Range			6.10				8.00
Minimum			-2.50				-5.40
Maximum			3.60				2.60
Confidence Level (95.0%)			0.0000				0.0028

Small but significant changes occurred in both sides, the left increased and the right decreased. These results may not be reliable and this may be ascribed to the proximity of the rugal landmarks to the premolars.

Table 4.4.18
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres(mm)

Treatment Group	**4&5s** *T24C _cDIF*	**4s** *T24C _cDIF*	**NE** *T24C _cDIF*		**4&5s** *T14C _cDIF*	**4s** *T14C _cDIF*	**NE** *T14C _cDIF*
Count			39				40
Mean	No	No	1.13		No	No	0.31
Median	Valid	Valid	0.70		Valid	Valid	0.00
Standard Deviation	Obser-vations	Obser-vations	1.73		Obser-vations	Obser-vations	1.50
Range			7.10				6.10
Minimum			-2.00				-2.30
Maximum			5.10				3.80
Confidence Level (95.0%)			0.0000				0.1968

Small increases occurred in both sides, the left significant but not the right. Considering the relatively large increase in the interpremolar width it seems probable that there may have been a forward movement of the premolars and/or retraction of the anterior teeth during orthodontic treatment. This could explain the small increases in this measurement.

Table 4.4.19
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres(mm)

Treatment Group	**4&5s** *T24C _dDIF*	**4s** *T24C _dDIF*	**NE** *T24C _dDIF*	**4&5s** *T14C _dDIF*	**4s** *T14C _dDIF*	**NE** *T14C _dDIF*
Count			39			40
Mean	No	No	2.30	No	No	0.60
Median	Valid	Valid	2.00	Valid	Valid	0.70
Standard Deviation	Obser-vations	Obser-vations	1.09	Obser-vations	Obser-vations	1.21
Range			4.70			5.20
Minimum			-0.10			-1.30
Maximum			4.60			3.90
Confidence Level (95.0%)			0.0000			0.0020

Small increases occurred in both sides, the left showed a much larger increase than the right (both $p<0.05$). This result is similar to that indicated in Table 18 and Figure 18 (using a landmark in the anterior part of the palate), and the conclusion reached is that it is more likely that the greater differences occurred because of an increase in interpremolar width during treatment, rather than retraction of the anterior teeth.

Table 4.4.20 **Descriptive Statistics of the differences for the three treatment groups both for the left and right side** **All units are in millimetres(mm)**							
Treatment Group	**4&5s** *T24C _eDIF*	**4s** *T24C _eDIF*	**NE** *T24C _eDIF*		**4&5s** *T14C _eDIF*	**4s** *T14C _eDIF*	**NE** *T14C _eDIF*
Count			39				40
Mean	No	No	2.12		No	No	0.45
Median	Valid	Valid	2.20		Valid	Valid	0.60
Standard Deviation	Obser-vations	Obser-vations	0.97		Obser-vations	Obser-vations	1.38
Range			5.00				6.80
Minimum			-0.80				-3.30
Maximum			4.20				3.50
Confidence Level (95.0%)			0.0000				0.0417

Small increases occurred in both sides, the left showed a much larger increase (more than four times) than the right. These results agree with the results of the preceding Tables and Figures showing '14' and '24' measurements.

Table 4.4.21
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T23C _aDIF*	**4s** *T23C _aDIF*	**NE** *T23C _aDIF*	**4&5s** *T13C _bDIF*	**4s** *T13C _bDIF*	**NE** *T13C _bDIF*
Count	32	23	39	31	21	43
Mean	1.54	0.87	3.39	0.21	0.31	1.65
Median	1.05	0.60	3.10	-0.30	0.00	1.20
Standard Deviation	2.12	2.76	1.87	2.77	1.85	2.19
Range	10.50	12.30	7.70	13.00	7.60	9.30
Minimum	-3.90	-5.70	0.50	-5.10	-3.10	-2.80
Maximum	6.60	6.60	8.20	7.90	4.50	6.50
Confidence Level (95.0%)	0.0001	0.1393	0.0000	0.678	0.4536	0.0000

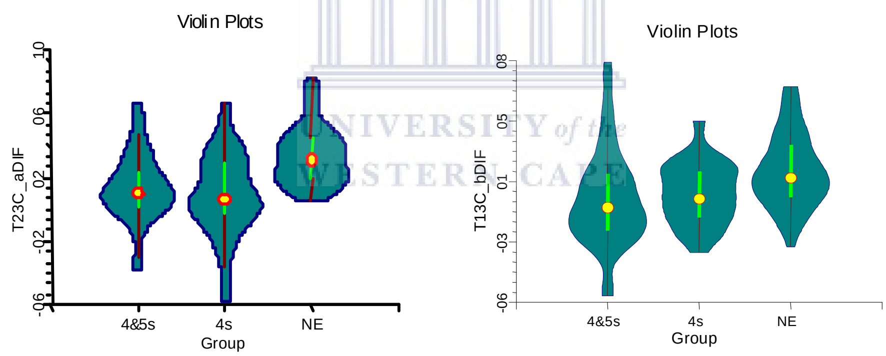


Figure 4.4.21
Side by side violin plots
T23C_aDIF and T13C_bDIF for the three groups '4&5s', '4' and NE

(Figures 4.4.16 – 4.4.20 do not exist; the numbering was changed to match the corresponding table numbers)

T23C_aDIF

The distance to point 'a' increased significantly after treatment for group '4&5s' and the NE group, but not in group '4'. The NE group did not contain any individual for whom a decrease of this distance occurred, whereas this was not the case for the two extraction groups.

These results indicate that growth and/or orthodontic treatment had contributed to expansion of the maxillary dental arch in the canine areas. Intercanine arch widths do not change significantly after age 13 years in females and age 16 years in males (Knott 1961, 1972, Sillman 1964, DeKock 1972). Although expansion in the mandibular intercanine width usually results in relapse, the likelihood of relapse in maxillary intercanine width after expansion is less (Bishara *et al* 1973).

T13C_bDIF

The distance to point 'b' increased significantly for the NE group but not for the other two groups. All three groups consisted of individuals for whom these distances increased or decreased.

Distance measurement differences across the midline indicated that dental arch expansion had occurred in the group NE. The dental arch expansion in nonextraction cases and considerable individual variation in treatment reponse for all three groups in this research is in accordance with the results of other studies about orthodontic treatment (Tuncay and Tulloch 1992, BeGole *et al* 1998, Taner *et al* 2004).

Comparison of the two sides

The corresponding treatment effects for the right and left were diverse; only the NE group showed a significant increase posttreatment for both sides, but the increase for the right side was much smaller.

Table 4.4.22
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T23C _bDIF*	**4s** *T23C _bDIF*	**NE** *T23C _bDIF*		**4&5s** *T13C _aDIF*	**4s** *T13C _aDIF*	**NE** *T13C _aDIF*
Count	32	23	39		31	21	43
Mean	-1.23	-2.13	0.35		-2.41	-2.71	-0.17
Median	-1.00	-1.80	0.20		-2.30	-3.00	-0.30
Standard Deviation	2.40	2.28	1.64		1.75	1.91	1.73
Range	2.00	6.90	6.80		8.50	6.90	9.70
Minimum	-8.40	-5.50	-2.60		-7.00	-0.6.30	-4.80
Maximum	3.60	1.40	4.20		1.50	0.60	4.90
Confidence Level (95.0%)	0.0043	0.0000	0.1883		0.0000	0.0000	0.5242

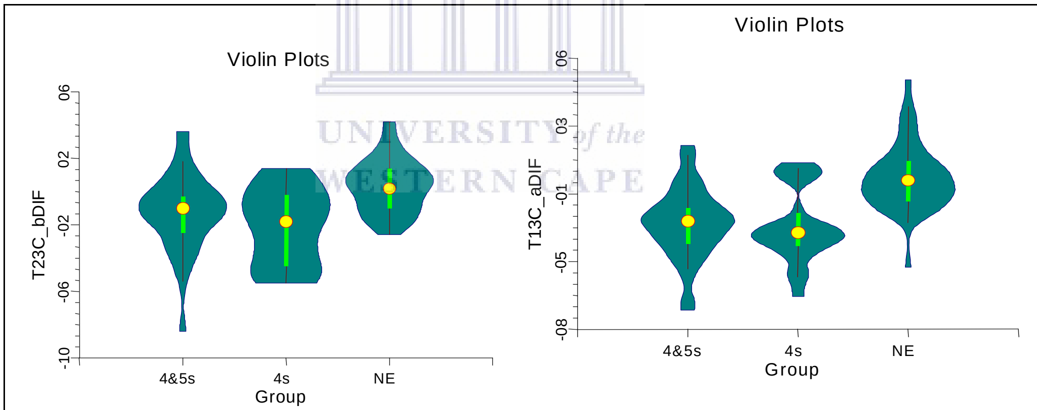


Figure 4.4.22
Side by side violin plots
T23C_bDIF and T13C_aDIF for the three groups '4&5s', '4' and NE

T23C_bDIF

The distance to point 'b' decreased significantly for the '4&5s' as well as the '4s' group. The distribution for the '4s' group was near to uniformity whereas the other two groups showed some central tendency. The two extraction groups differed significantly. In the extraction groups the dental arch dimension decreased (narrowed) in the canine areas. Expansion occurred in the group NE.

T13C_aDIF

The distance to point ‘a’ decreased significantly for the ‘4&5s’ as well as the ‘4s’ group. The distribution associated with the ‘4s’ group showed a definite bimodality.

Comparison of the two sides

The movement due to treatment was similar for the two sides. Weak evidence of bimodality was present on the left side for group ‘4s’, but it was very strong on the right, therefore it appeared that there was a subgroup of subjects for whom there was minimal movement.

When rugal points on the same side of the palate were used to measure the difference in distances, the dental arch dimensions decreased in the extraction groups, and increased in group NE. In addition to this, there was a bimodal tendency in the group ‘4s’, which may indicate that there were two distinct groups of cases being treated (e.g. crowded cases, and bimaxillary protrusions), or that the orthodontic treatment effect manifested in two distinct ways.

Table 4.4.23
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T23C _cDIFf*	**4s** *T23C _cDIFf*	**NE** *T23C _cDIF*	**4&5s** *T13C _cDIF*	**4s** *T13C _cDIF*	**NE** *T13C _cDIF*
Count	32	23	39	31	21	43
Mean	1.08	1.41	1.19	0.01	0.38	0.32
Median	1.20	1.30	1.10	0.20	0.30	0.10
Standard Deviation	0.98	1.17	1.16	1.66	1.08	1.40
Range	3.40	4.70	6.00	10.40	4.20	6.80
Minimum	-0.60	-0.70	-1.10	-7.40	-1.70	-2.30
Maximum	2.80	4.00	4.90	3.00	2.50	4.50
Confidence Level (95.0%)	0.0000	0.0000	0.0000	0.5093	0.1156	0.1385

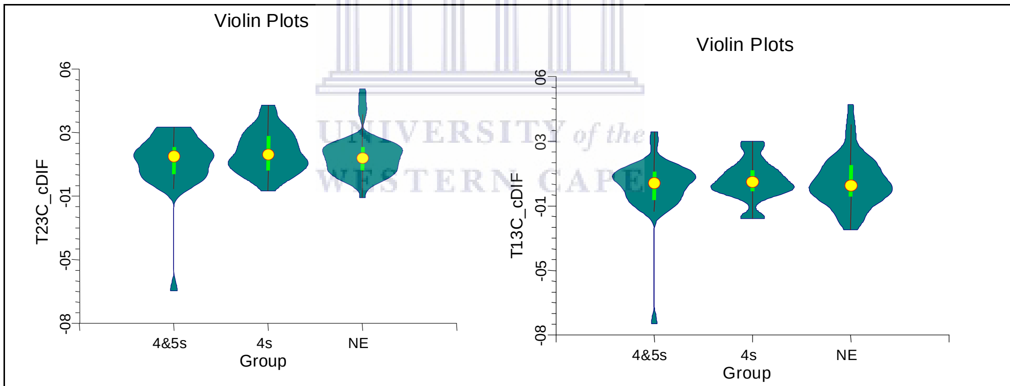


Figure 4.4.23
Side by side violin plots
T23C_cDIF and T13C_cDIF for the three groups '4&5s', '4' and NE

T23C_cDIF

All three treatment groups showed a significant increase of the distance; a severe outlier was present in the '4&5s' group.

T13C_cDIF

None of the differences were significant on this side and as with the left side a severe outlier was present in the '4&5s' group. These measurements indicate that there was no distinct movement of the canines relative to the anterior incisive point.

Comparison of the two sides

Significant differences in the distances measured took place on the left side, but not on the right side. This may indicate instability of the anterior incisive papilla point as a reference point, or that the effect of orthodontic treatment was asymmetrical in the canine regions. It is probable that the orthodontic treatment resulted in greater tooth movements on the left side as this side was the smaller side in this group of patients, as discussed previously. The results for the movement of the canines is in agreement with the results for the movement of other teeth on the left and right sides. Although statistically significant, the small differences are probably not clinically significant, and may therefore indicate that the intercanine distance was only slightly expanded during treatment in all three groups.

Table 4.4.24
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T23C _dDIF*	**4s** *T23C _dDIF*	**NE** *T23C _dDIF*	**4&5s** *T13C _dDIF*	**4s** *T13C _dDIF*	**NE** *T13C _dDIF*
Count	32	23	39	31	21	43
Mean	-0.06	-0.14	1.56	-1.23	-1.37	0.74
Median	0.00	-0.70	1.20	-1.20	-1.90	0.60
Standard Deviation	1.76	2.53	1.65	1.20	1.62	1.42
Range	9.20	0.60	7.50	5.90	5.30	6.90
Minimum	-4.00	-5.10	-1.30	-5.20	-3.80	-1.60
Maximum	5.20	5.50	6.20	0.70	1.50	5.30
Confidence Level (95.0%)	0.8495	0.7952	0.0000	0.0000	0.0002	0.0007

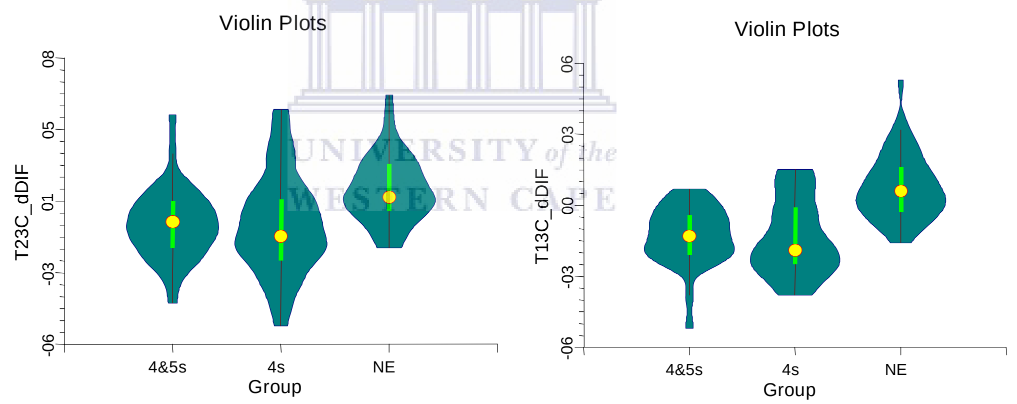


Figure 4.4.24
Side by side violin plots
T23C_dDIF and T13C_dDIF for the three groups '4&5s', '4' and NE

T23C_dDIF

The NE group showed a significant lengthening due to treatment, and all three distributions showed decreases as well as increases.

T13C_dDIF

The '4&5s' group as well as the '4s' group displayed a significant decrease in distance, but the NE group showed a significant increase.

Comparison of the two sides

The two sides showed some similarity except that two of the mean differences on the left were not significant. However, it was of great importance that the movements in the '4&5s' and the '4s' groups were significantly in an opposite direction to that of the NE group on the right side.

Table 4.4.25
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T23C _eDIF*	**4s** *T23C _eDIF*	**NE** *T23C _eDIF*	**4&5s** *T13C _eDIF*	**4s** *T13C _eDIF*	**NE** *T13C _eDIF*
Count	32	23	39	31	21	43
Mean	0.19	-0.33	1.27	-0.85	-1.25	0.51
Median	0.20	0.30	1.30	-1.10	-1.30	0.80
Standard Deviation	1.83	2.13	1.46	1.85	1.49	1.66
Range	8.60	6.70	6.00	7.80	6.20	6.20
Minimum	-4.60	-3.70	-1.10	-4.30	-4.20	-2.10
Maximum	4.00	3.00	4.90	3.50	2.00	4.10
Confidence Level (95.0%)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0465

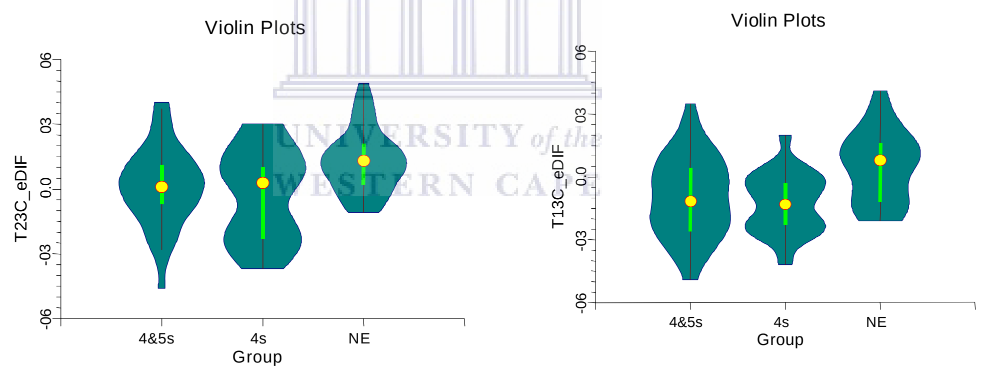


Figure 4.4.25
Side by side violin plots
T23C_eDIF and T13C_eDIF for the three groups '4&5s', '4' and NE

T23C_eDIF

As before with the distances to point 'd' this change in distance followed approximately the same pattern.

T13C_eDIF

The '4&5s' group as well as the '4s' group displayed a significant decrease in distance, but the increase of the NE group was not significant

Comparison of the two groups

The left and right sides displayed the same pattern as the changes in the distances to point ‘d’. As before with Figure 24, it was of great importance that the tooth movement in the two extraction groups differed significantly from that of the NE group on the right side.

By using the two midline refences (d and e) for comparison purposes, it is evident that definite right and left side differences occurred. This observation would support the observation that treatment effects were different on the right and left sides.

Table 4.4.26
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22M _aDIF*	**4s** *T22M _aDIF*	**NE** *T22M _aDIF*	**4&5s** *T12M _bDIF*	**4s** *T12M _bDIF*	**NE** *T12M _bDIF*
Count	33	29	47	34	29	46
Mean	1.22	1.73	2.51	0.45	0.21	0.78
Median	0.80	1.20	2.50	0.05	0.20	0.30
Standard Deviation	2.69	2.96	2.25	2.75	1.94	2.38
Range	11.20	15.60	9.70	10.60	6.70	11.30
Minimum	-4.00	-3.80	-2.30	-3.90	-3.40	-5.10
Maximum	7.20	11.80	7.40	6.70	3.30	6.20
Confidence Level (95.0%)	0.0103	0.0020	0.0000	0.9168	0.5668	0.0279

Table 4.4.27
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22D _aDIF*	**4s** *T22D _aDIF*	**NE** *T22D _aDIF*	**4&5s** *T12D _bDIF*	**4s** *T12D _bDIF*	**NE** *T12D _bDIF*
Count	33	29	47	34	29	46
Mean	2.33	1.50	3.05	1.11	0.52	1.06
Median	1.90	2.20	2.80	1.05	0.30	1.20
Standard Deviation	2.38	5.17	2.01	2.63	1.81	2.20
Range	9.50	30.80	9.20	10.60	6.80	0.40
Minimum	-1.80	-20.10	-1.40	-3.80	-2.80	-4.70
Maximum	7.70	10.70	7.80	6.80	4.00	5.70
Confidence Level (95.0%)	0.0000	0.1247	0.0000	0.0218	0.1285	0.0012

T22M_aDIF & T22D_aDIF

From the two tables above it was observed that five differences in tooth movements resulted in a significant lengthening due to the treatment; the one difference that was not significant, namely T22D_aDIF in group '4s', due to an outlier at the minimum.

T12M_bDIF & T12D_bDIF

On the right the lengthening of this distance was much smaller and not significant in three of the six instances. The '4s' group showed the smallest standard deviation of the three treatment groups and this showed that the movement had less variability than the movement in the other two groups.

The lateral incisors moved anteriorly (proclined) during treatment and/or were rotated during their orthodontic positioning. This is in accordance with the principle of aligning the anterior teeth on a dental arch form decided on by the orthodontist (Root 1985).

Table 4.4.28
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	4&5s *T22M _bDIF*	4s *T22M _bDIF*	NE *T22M _bDIF*		4&5s *T12M _aDIF*	4s *T12M _aDIF*	NE *T12M _aDIF*
Count	33	29	47		34	29	46
Mean	-0.42	-0.42	0.52		-1.11	-1.69	0.67
Median	-1.00	-0.50	0.40		-0.90	-1.60	0.55
Standard Deviation	3.08	2.44	2.18		2.48	2.09	2.24
Range	12.20	11.30	11.00		11.30	7.70	11.3
Minimum	-6.70	-4.60	-3.80		-6.50	-5.70	-4.30
Maximum	5.50	6.70	7.20		4.80	2.00	7.00
Confidence Level (95.0%)	0.4405	0.3624	0.1057		0.0371	0.0000	0.0448

Table 4.4.29
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	4&5s *T22D _bDIF*	4s *T22D _bDIF*	NE *T22D _bDIF*		4&5s *T12D _aDIF*	4s *T12D _aDIF*	NE *T12D _aDIF*
Count	33	29	47		34	29	46
Mean	0.04	-0.09	0.92		-0.86	-1.85	0.20
Median	-0.10	-0.20	0.70		-1.05	-2.00	0.10
Standard Deviation	2.77	2.46	2.35		2.30	1.96	2.09
Range	11.00	10.90	10.80		10.10	6.70	10.20
Minimum	-6.40	-4.40	-3.90		-5.70	-5.20	-3.90
Maximum	4.60	6.50	6.90		4.40	1.50	6.30
Confidence Level (95.0%)	0.9349	0.8465	0.0079		0.0000	0.0000	0.5209

T22M_bDIF & T22D_bDIF

It was observed that only one of the six considered movements resulted in a significant lengthening due to the treatment; the other five movements were very small.

T12M_aDIF & T12D_aDIF

On the right the treatment (significantly) shortened this distance in four of the six considered distances. In the NE group this distance was lengthened to a small extent.

Table 4.4.30
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22M _cDIF*	**4s** *T22M _cDIF*	**NE** *T22M _cDIF*		**4&5s** *T12M _cDIF*	**4s** *T12M _cDIF*	**NE** *T12M _cDIF*
Count	33	29	47		34	29	46
Mean	1.28	1.80	1.14		0.39	0.44	-0.12
Median	1.30	1.80	1.10		0.25	0.30	0.05
Standard Deviation	1.51	1.68	1.91		1.25	1.27	1.11
Range	8.70	7.30	13.30		4.80	5.70	5.90
Minimum	-3.40	-2.10	-1.90		-2.10	-1.90	-3.10
Maximum	5.30	5.20	11.40		2.70	3.80	2.80
Confidence Level (95.0%)	0.0000	0.0000	0.0000		0.2506	0.0668	0.4683

Table 4.4.31
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22D _cDIF*	**4s** *T22D _cDIF*	**NE** *T22D _cDIF*		**4&5s** *T12D _cDIF*	**4s** *T12D _cDIF*	**NE** *T12D _cDIF*
Count	33	29	47		34	29	46
Mean	1.55	1.22	0.79		0.42	0.32	0.02
Median	1.30	1.60	0.80		0.30	0.40	0.00
Standard Deviation	1.23	2.52	0.95		1.04	1.00	0.96
Range	5.90	11.40	4.10		3.50	5.00	5.70
Minimum	-0.70	-7.20	-1.40		-1.30	-2.50	-2.80
Maximum	5.20	4.20	2.70		2.20	2.50	2.90
Confidence Level (95.0%)	0.0000	0.0104	0.0000		0.0975	0.0904	0.8889

T22M_cDIF & T22D_cDIF

All six of the differences showed a significant lengthening of the corresponding distance.

T12M_cDIF & T12D_cDIF

Only one of the six differences showed a slight lengthening of the corresponding distance, whereas the other movements were very small.

Table 4.4.32
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres(mm)

Treatment Group	**4&5s** *T22M _dDIF*	**4s** *T22M _dDIF*	**NE** *T22M _dDIF*		**4&5s** *T12M _dDIF*	**4s** *T12M _dDIF*	**NE** *T12M _dDIF*
Count	33	29	47		34	29	46
Mean	-0.19	0.43	1.19		-0.94	-1.31	0.52
Median	-0.10	0.00	0.80		-1.05	-0.90	0.40
Standard Deviation	2.30	2.62	1.96		2.36	2.26	2.13
Range	10.80	9.10	8.30		10.60	11.00	11.60
Minimum	-4.40	-3.20	-2.60		-5.80	-8.70	-4.50
Maximum	6.40	5.90	5.70		4.80	2.30	7.10
Confidence Level (95.0%)	0.6403	0.3851	0.0000		0.0106	0.0022	0.1015

Table 4.4.33
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22D _dDIF*	**4s** *T22D _dDIF*	**NE** *T22D _dDIF*		**4&5s** *T12D _dDIF*	**4s** *T12D _dDIF*	**NE** *T12D _dDIF*
Count	33	29	47		34	29	46
Mean	1.00	0.99	1.64		-0.28	-0.98	0.53
Median	0.50	0.40	1.40		-0.30	-0.80	0.40
Standard Deviation	2.21	2.10	1.82		1.99	1.64	1.86
Range	8.20	7.90	8.40		8.00	5.80	9.30
Minimum	-1.90	-2.90	-1.80		-4.00	-4.00	-3.00
Maximum	6.30	5.00	6.60		4.00	1.80	6.30
Confidence Level (95.0%)	0.0105	0.0126	0.0000		0.3865	0.0016	0.0559

T22M_dDIF & T22D_dDIF

Four of the six movements indicated a significant increase in the corresponding distance.

T12M_dDIF & T12D_dDIF

Of the six movements three showed a significant decrease. The mean increases in the NE group were statistically significant, but relatively small.

Table 4.4.34
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22M _eDIF*	**4s** *T22M _eDIF*	**NE** *T22M _eDIF*	**4&5s** *T12M _eDIF*	**4s** *T12M _eDIF*	**NE** *T12M _eDIF*
Count	33	29	47	34	29	46
Mean	0.15	0.52	0.74	-0.54	-1.03	0.05
Median	-0.10	0.20	0.40	-0.75	-1.00	0.05
Standard Deviation	2.59	2.58	2.13	2.57	2.02	2.11
Range	9.30	11.40	10.70	9.10	9.30	10.40
Minimum	-4.80	-3.30	-3.40	-4.90	-4.90	-4.20
Maximum	4.50	8.10	7.30	4.20	4.40	6.20
Confidence Level (95.0%)	0.7432	0.2862	0.01846	0.0937	0.0000	0.8737

Table 4.4.35
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T22D _eDIF*	**4s** *T22D _eDIF*	**NE** *T22D _eDIF*		**4&5s** *T12D _eDIF*	**4s** *T12D _eDIF*	**NE** *T12D _eDIF*
Count	33	29	47		34	29	46
Mean	1.14	1.13	1.31		0.15	-0.94	0.15
Median	1.40	1.10	1.00		0.40	-0.90	0.15
Standard Deviation	2.30	2.04	1.99		2.19	1.74	1.95
Range	8.80	7.80	8.10		7.20	7.70	9.70
Minimum	-3.40	-1.70	-2.30		-3.60	-4.50	-3.90
Maximum	5.40	6.10	5.80		3.60	3.20	5.80
Confidence Level (95.0%)	0.0051	0.0034	0.0000		0.2941	0.0043	0.6058

T22M_eDIF & T22D_eDIF

Only one of the three mesial movements showed a significant increase (NE group). All three of the distal average movements showed a significant increase.

T12M_eDIF & T12D_eDIF

The distances T12M_e and T12D_e showed a significant decrease and the remaining four average movements were very small.

Table 4.4.36
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21M _aDIF*	**4s** *T21M _aDIF*	**NE** *T21M _aDIF*		**4&5s** *T11M _bDIF*	**4s** *T11M _bDIF*	**NE** *T11M _bDIF*
Count	34	29	47		34	27	47
Mean	-1.40	-1.66	0.41		-1.52	-1.74	-0.58
Median	-1.50	-1.70	0.70		-1.90	-1.30	-0.70
Standard Deviation	2.83	2.60	2.50		2.91	2.35	2.66
Range	10.70	12.10	11.30		11.30	9.10	11.20
Minimum	-7.30	-6.40	-5.20		-5.80	-6.30	-5.50
Maximum	3.40	5.70	6.10		5.50	2.80	5.70
Confidence Level (95.0%)	0.0045	0.0007	0.2660		0.0002	0.0000	0.1392

Table 4.4.37
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21D _aDIF*	**4s** *T21D _aDIF*	**NE** *T21D _aDIF*		**4&5s** *T11D _bDIF*	**4s** *T11D _bDIF*	**NE** *T11D _bDIF*
Count	34	29	47		34	27	47
Mean	-0.04	-0.09	1.76		-0.85	-0.98	0.24
Median	-0.35	-0.40	1.90		-1.05	-0.50	0.10
Standard Deviation	2.41	2.78	2.44		2.65	2.18	2.60
Range	9.30	12.80	11.10		11.10	8.30	12.00
Minimum	-4.40	-7.20	-2.90		-5.40	-6.00	-5.60
Maximum	4.90	5.60	8.20		5.70	2.30	6.40
Confidence Level (95.0%)	0.9240	0.8640	0.0000		0.0228	0.0219	0.5313

T21M_aDIF & T21D_aDIF

Of the three treatment groups the '4&5s' and '4s' had a significant decrease in distance while the NE group had a very small and non-significant increase in the measurement. The three distal measurements reacted differently; the '4&5s' and '4s' showed minute decreases compared to the significant increase (average increase equal to 1.76mm) for the NE group.

T11M_bDIF & T11D_bDIF

The mesial measurements decreased in all three treatment groups (two of them significant). For the distal measurements the movement was small and the only significant decreases were in the '4&5s' and '4s' group.

Table 4.4.38
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21M _bDIF*	**4s** *T21M _bDIF*	**NE** *T21M _bDIF*		**4&5s** *T11M _aDIF*	**4s** *T11M _aDIF*	**NE** *T11M _aDIF*
Count	34	29	47		34	27	47
Mean	-1.60	-2.16	-0.70		-1.56	-1.83	0.53
Median	-2.20	-1.80	-0.60		-1.85	-1.90	0.70
Standard Deviation	3.17	2.73	2.45		2.82	2.73	2.71
Range	12.60	12.60	11.80		11.50	11.7	12.70
Minimum	-6.60	-9.10	-5.90		-8.20	-6.70	-6.10
Maximum	6.00	3.50	5.90		3.30	5.00	6.60
Confidence Level (95.0%)	0.0037	0.0000	0.0526		0.0002	0.0006	0.1847

Table 4.4.39
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21D _bDIF*	**4s** *T21D _bDIF*	**NE** *T21D _bDIF*		**4&5s** *T11D _aDIF*	**4s** *T11D _aDIF*	**NE** *T11D _aDIF*
Count	34	29	47		34	27	47
Mean	-1.72	-1.74	-0.23		-2.08	-2.54	0.15
Median	-2.45	-1.90	-0.20		-2.60	-2.60	0.30
Standard Deviation	3.18	2.34	2.64		2.52	2.75	2.61
Range	11.70	9.10	11.50		12.80	9.40	13.9
Minimum	-6.80	-6.50	-5.40		-8.60	-7.50	-5.70
Maximum	4.90	2.60	6.10		4.20	1.90	8.20
Confidence Level (95.0%)	0.0019	0.0000	0.5546		0.0000	0.0000	0.6967

T21M_bDIF & T21D_bDIF

A significant decrease of this distance occurred for groups '4&5s' and '4s', but only a small change in the NE group. The same pattern was present in the distal measurements.

T11M_aDIF & T11D_aDIF

A significant decrease occurred for groups '4&5s' and '4s', but only a small average movement for the NE group. The same pattern was present for the distal measurements. The decreases for the distal measurements were somewhat larger than the mesial measurements. The latter observation could be explained by the orthodontic alignment of the incisors in the dental arch form used by the orthodontist during treatment.

Table 4.4.40
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21M _cDIF*	**4s** *T21M _cDIF*	**NE** *T21M _cDIF*		**4&5s** *T11M _cDIF*	**4s** *T11M _cDIF*	**NE** *T11M _cDIF*
Count	34	29	47		34	27	47
Mean	-0.64	-0.81	-0.72		-0.61	-0.76	-0.54
Median	-0.70	-0.80	-0.60		-0.65	-0.50	-0.40
Standard Deviation	1.09	1.95	1.40		1.36	1.33	1.17
Range	4.20	9.50	6.70		7.80	5.30	5.40
Minimum	-2.90	-6.40	-4.60		-3.40	-3.60	-3.60
Maximum	1.30	3.10	2.10		4.40	1.70	1.80
Confidence Level (95.0%)	0.0007	0.0279	0.0005		0.0060	0.0000	0.0017

Table 4.4.41
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21D _cDIF*	**4s** *T21D _cDIF*	**NE** *T21D _cDIF*		**4&5s** *T11D _cDIF*	**4s** *T11D _cDIF*	**NE** *T11D _cDIF*
Count	34	29	47		34	27	47
Mean	0.56	0.73	0.68		-0.47	-0.41	-0.45
Median	0.80	0.60	0.70		-0.40	-0.60	-0.40
Standard Deviation	1.15	1.07	0.97		0.89	0.90	0.65
Range	4.70	5.20	4.20		4.10	3.60	3.40
Minimum	-2.40	-1.50	-1.30		-2.60	-2.00	-1.80
Maximum	2.30	3.70	2.90		1.50	1.60	1.60
Confidence Level (95.0%)	0.0052	0.0003	0.0000		0.0098	0.0202	0.0000

T21M_cDIF & T21D_cDIF

For all three treatments the mesial measurements decreased significantly due to the treatment. For the distal measurements all average measurements increased. The differences between the mesial and distal movements could be due to correction of incisor tooth rotations during treatment.

T11M_cDIF & T11D_cDIF

All measurements decreased significantly for the three treatment groups, indicating that tooth 11 had been retroclined or retracted during treatment.

Table 4.4.42
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21M _dDIF*	**4s** *T21M _dDIF*	**NE** *T21M _dDIF*	**4&5s** *T11M _dDIF*	**4s** *T11M _dDIF*	**NE** *T11M _dDIF*
Count	34	29	47	34	27	47
Mean	-2.39	-2.58	-0.63	-2.41	-2.51	-0.48
Median	-2.80	-3.00	-0.50	-2.60	-2.90	-0.40
Standard Deviation	2.86	2.68	2.29	2.78	2.61	2.59
Range	9.80	10.10	10.60	10.70	9.90	13.00
Minimum	-7.30	-7.50	-6.20	-8.20	-7.80	-6.30
Maximum	2.50	2.60	4.40	2.50	2.10	6.70
Confidence Level (95.0%)	0.0000	0.0000	0.0621	0.0000	0.0000	0.2088

Table 4.4.43
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21D _dDIF*	**4s** *T21D _dDIF*	**NE** *T21D _dDIF*		**4&5s** *T11D _dDIF*	**4s** *T11D _dDIF*	**NE** *T11D _dDIF*
Count	34	29	47		34	27	47
Mean	-1.53	-1.34	0.38		-2.22	-2.40	-0.33
Median	-1.70	-1.70	0.30		-2.50	-2.00	-0.30
Standard Deviation	2.36	2.55	2.24		2.29	2.62	2.32
Range	9.50	8.00	9.70		11.30	9.00	12.60
Minimum	-5.70	-5.40	-4.00		-7.50	-7.10	-5.10
Maximum	3.80	2.60	5.70		3.80	1.90	7.50
Confidence Level (95.0%)	0.0002	0.0054	0.2499		0.0000	0.0000	0.3347

T21M_dDIF & T21D_dDIF

A significant decrease occurred for the mesial measurements in the '4&5s' and '4s' groups. Somewhat smaller decreases, but still significant, occurred for the distal measurements in the '4&5s' and '4s' groups. Small movements occurred for these two measurements with the NE group. These measurements indicate that tooth 21 retroclined during treatment, especially in the two extraction groups.

T11M_dDIF & T11D_dDIF

The same pattern of treatment effects occurred on the right side.

Table 4.4.44
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21M _eDIF*	**4s** *T21M _eDIF*	**NE** *T21M _eDIF*		**4&5s** *T11M _eDIF*	**4s** *T11M _eDIF*	**NE** *T11M _eDIF*
Count	34	29	47		34	27	47
Mean	-1.96	-2.53	-1.10		-1.98	-2.44	-0.88
Median	-2.65	-3.30	-1.40		-2.45	-2.60	-1.10
Standard Deviation	3.17	2.67	2.75		2.96	2.83	2.87
Range	12.70	13.30	12.50		11.20	13.00	11.70
Minimum	-7.60	-8.30	-5.80		-7.10	-8.20	-5.30
Maximum	5.10	5.00	6.70		4.10	4.80	6.40
Confidence Level (95.0%)	0.0004	0.0000	0.0067		0.0000	0.0000	0.0376

Table 4.4.45
Descriptive Statistics of the differences for the three treatment groups both for the left and right side
All units are in millimetres (mm)

Treatment Group	**4&5s** *T21D _eDIF*	**4s** *T21D _eDIF*	**NE** *T21D _eDIF*		**4&5s** *T11D _eDIF*	**4s** *T11D _eDIF*	**NE** *T11D _eDIF*
Count	34	29	47		34	27	47
Mean	-1.09	-1.32	-0.15		-1.76	-2.30	-0.61
Median	-1.00	-1.30	-0.10		-1.45	-2.10	-0.70
Standard Deviation	2.73	2.31	2.67		2.51	2.57	2.69
Range	11.50	9.40	11.80		10.60	8.80	11.40
Minimum	-6.30	-6.80	-5.20		-6.80	-7.80	-5.10
Maximum	5.20	2.60	6.60		3.80	1.00	6.30
Confidence Level (95.0%)	0.0218	0.0025	0.7032		0.0009	0.0000	0.124

T21M_eDIF & T21D_eDIF

A similar pattern occurred with the measurements to point ‘e’ as compared to the point ‘d’ due to the close proximity of the two points, except for the test for significance of the NE group.

T11M_eDIF & T11D_eDIF

The same similarities as above existed on the right, except that the shortening for the NE group was significant only for the mesial measurement.

4.5.3 Overview of differences resulting from the three treatment groups

The results indicate diverse reactions to orthodontic treatment, irrespective of the treatment group. This wide variation in response to orthodontic treatment modalities has been described in many other studies of treatment effects. There were also significant differences in the effects of treatment among the three groups compared to one another, including the results of the two extraction groups.

There were significant differences in treatment effects on the right and left sides of the dentition. These results indicate that it would probably be prudent to include measurements on both sides of the dentition to evaluate treatment effects more accurately.

Measurements between teeth and rugae points on the same side of the palate gave more consistent results than measurements between teeth and rugae points on opposing sides of the palate. Furthermore, measurements between teeth and midline landmarks (i.e. projections of rugae points onto the midline, or a point on the incisive papilla) also gave consistent results.

4.6 Evaluation of the Success of the Orthodontic treatment (Effect of the Three Treatment Options)

The various treatments were evaluated with respect to the alignment of the teeth. It was impossible to assess the treatment effect by means of the position and size of the teeth. Gaps or spaces between the teeth could not be measured because teeth sizes and arch lengths were not determined during the data collection phase. The alignment of the various teeth could be measured relatively easily for the anterior teeth due to the availability of mesial and distal distances to the fixed points 'd' and 'e'. It was assumed that the difference between the distal and mesial measurements to the rugae points provides a measure of the degree of alignment of the teeth. The average of these differences could be seen as a measure of alignment. The standard deviation (SD) could then be seen as a measure of the variability of the degree of alignment in the sample. If the treatment brought a reduction in the SD variable of the sample it could be considered to have improved the alignment of the teeth, i.e. produced a satisfactory result.

In this study no attempt was made to evaluate tooth position or tooth movement relative to any specific arch form. In a longitudinal study of 30 subjects with normal occlusion, Henrikson *et al* (2001) found that dental arch form changes from adolescence to adulthood in both arches, with large individual variations. No one specific arch form could be found to represent the sample in their study. During orthodontic treatment each patient is given an individualized arch form which is selected by the operator to best fit the patient's natural arch form (Fujita *et al* 2002). Attempts to classify dental arch forms from individuals with various types of occlusions into various mathematical forms has resulted in many descriptions of arch shape, e.g. polimonial curves, elliptic curves, conic sections, catenary curves, spline curves (Henrikson *et al* 1991).

Table 4.5.1
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 11 to Point 'd' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-0.009	-0.189	0.026	-0.041
Standard Deviation	1.606	2.003	1.516	1.667
Minimum	-2.6	-4.9	-3.2	-4.9
Maximum	3.6	3.9	6.3	6.3
Posttreatment Differences				
Count of Differences	33	26	47	106
Average	0.191	0.038	0.181	0.149
Standard Deviation	0.703	0.589	0.697	0.671
Minimum	-1.3	-1.3	-1.1	-1.3
Maximum	1.5	1.1	2.2	2.2
Difference between Pre- & Post-SDs	0.902	1.414	0.819	0.996
Percentage Change	56.2%	70.6%	54.0%	59.8%

It was hoped that the alignment could be measured by the difference between the mesial and distal distances to the fixed point 'd' and that the improvement in the alignment would be evident from the change in pre- and posttreatment average differences. This difference between distal and mesial distances to point 'd' (and 'e') need not be near to zero for perfect alignment for individuals or the average of a sample. Any distance measured from the teeth to a fixed point on the palate is affected by three-dimensional factors. The average differences were small before and after the treatments, indicating that the mesial and distal tooth positions were approximately on the dental arch.

The standard deviation (SD) measures the variation of the sample of differences from the mean difference (between the mesial and distal distances to the point 'd') for a sample. From Table 4.5.1 it is evident that the standard deviation of the pre-differences was larger than the post-treatment standard deviation. This reduction in the standard deviation could be largely attributed to the orthodontic treatment which had been done, therefore indicating an improved alignment of the tooth under consideration. For the complete group the standard deviation was reduced from 1.67 to 0.67 mm.

Table 4.5.2
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 11 to Point 'e' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-0.079	-0.061	-0.023	-0.050
Standard Deviation	1.555	2.007	1.216	1.541
Minimum	-3.1	-5.1	-2.9	-5.1
Maximum	3.2	4.1	2.7	4.1
Posttreatment Differences 11e				
Count of Differences	33	26	47	106
Average	0.158	0.173	0.249	0.202
Standard Deviation	0.705	0.541	0.723	0.672
Minimum	-1.6	-1.0	-1.3	-1.6
Maximum	1.6	1.2	2.3	2.3
Difference between Pre- & Post-SDs	0.850	1.466	0.493	0.869
Percentage Change	54.7%	73.0%	40.6%	56.4%

The above table can be seen as a validation of the results contained in Table 4.5.1, because points 'd' and 'e' are both on the midline of the palate and usually near to each other. The averages for the pretreatment differences were in the same range for both the distances to points 'd' and 'e', the same is true for the posttreatment differences. An interesting observation that could be made when the pre- and post-differences were compared was that the absolute average differences were much larger in the case of the posttreatment differences. The percentage change in the standard deviations associated with points 'd' and 'e' respectively were similar. The same trend could be observed in the absolute differences between the pre- and posttreatment standard deviations. The percentage change was calculated by dividing the "difference of the SDs by the "SD of the pretreatment differences".

Table 4.5.3
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 12 to Point 'd' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	46	107
Average	-0.358	-0.489	0.002	-0.237
Standard Deviation	1.122	1.222	0.778	1.031
Minimum	-2.7	-3.1	-1.8	-3.1
Maximum	1.8	1.6	2.0	2.0
Posttreatment Differences 12d				
Count of Differences	33	28	47	108
Average	0.303	-0.125	0.019	0.069
Standard Deviation	0.631	1.132	0.555	0.776
Minimum	-1.0	-2.4	-1.1	-2.4
Maximum	1.4	3.6	1.6	3.6
Difference between Pre- & Post-SDs	0.491	0.090	0.223	0.255
Percentage Change	43.8%	7.3%	28.7%	24.7%

The standard deviations associated with the pre- and post-differences changed in a different fashion compared to the changes for tooth 11, and were smaller. The changes in all three treatment groups showed a reduction in the SDs, indicating an improvement in the alignment of tooth 12.

Table 4.5.4
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 12 to Point 'e' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	46	107
Average	-0.318	-0.318	0.022	-0.172
Standard Deviation	1.042	1.204	0.804	1.000
Minimum	-2.8	-2.9	-1.5	-2.9
Maximum	1.3	1.7	1.9	1.9
Posttreatment Differences 12e				
Count of Differences	33	28	47	108
Average	0.373	-0.207	0.136	0.119
Standard Deviation	0.717	0.807	0.623	0.730
Minimum	-1.3	-2.3	-1.0	-2.3
Maximum	1.9	1.3	1.6	1.9
Difference between Pre- & Post-SDs	0.324	0.397	0.180	0.270
Percentage Change	31.1%	33.0%	22.4%	27.0%

The structure of the change of the SDs pre- and posttreatment was different within the three treatment groups; associated to point 'd' the smallest reduction occurred for the '4s' group whereas the reduction in the SDs was approximately similar for the three treatments. No explanation could be offered for this phenomenon and it could be partially due to the estimational instability of the SDs. However, an outlier was present in the posttreatment differences within the '4s' group (see maximum of 0.36, Table 4.5.3). Overall the reduction of the SD was similar with respect to points 'd' (24.7%) and 'e' (27.0%).

Table 4.5.5
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 21 to Point 'd' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-0.991	-1.429	-1.300	-1.239
Standard Deviation	1.705	1.657	1.486	1.595
Minimum	-4.1	-4.7	-3.8	-4.7
Maximum	4.0	1.7	2.0	4.0
Posttreatment Differences 21d				
Count of Differences	33	28	47	108
Average	-0.130	-0.186	-0.291	-0.215
Standard Deviation	0.639	0.581	0.740	0.669
Minimum	-1.9	-1.6	-1.9	-1.9
Maximum	0.9	1.0	1.9	1.9
Difference between Pre- & Post-SDs	1.066	1.076	0.747	0.926
Percentage Change	62.5%	64.9%	50.2%	58.1%

Table 4.5.6
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 21 to Point 'e' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-1.006	-1.339	-1.185	-1.170
Standard Deviation	1.705	1.658	1.630	1.650
Minimum	-4.0	-4.7	-4.0	-4.7
Maximum	3.9	1.9	3.5	3.9
Posttreatment Differences 21e				
Count of Differences	33	28	47	108
Average	-0.136	-0.132	-0.240	-0.181
Standard Deviation	0.638	0.620	0.783	0.697
Minimum	-1.7	-1.5	-1.7	-1.7
Maximum	1.0	1.1	2.0	2.0
Difference between Pre- & Post-SDs	1.067	1.038	0.847	0.953
Percentage Change	62.6%	62.6%	52.0%	57.8%

As was said before the distances and functions of these distances to point 'd' were validated by the corresponding distances to point 'e'. This was evident from Table 4.5.5, point 'd', where the overall reduction was equal to 58.1% and Table 4.5.6, point 'e', where the overall reduction was equal to 57.8% representing only a small difference of less than 0.4%. For both Tables 4.5.5 and 4.5.6 group 'NE' had the smallest reduction of the standard deviations 50.2% and 52.0%, respectively.

Table 4.5.7
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 22 to Point 'd' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-0.945	-1.021	-0.940	-0.963
Standard Deviation	1.010	1.667	0.954	1.182
Minimum	-3.5	-4.1	-2.7	-4.1
Maximum	1.0	2.6	1.5	2.6
Posttreatment Differences 22d				
Count of Differences	32	28	47	107
Average	0.184	-0.425	-0.491	-0.272
Standard Deviation	1.158	0.872	0.667	0.932
Minimum	-1.4	-2.2	-2.2	-2.2
Maximum	5.8	1.6	0.7	5.8
Difference between Pre- & Post-SDs	-0.149	0.795	0.287	0.250
Percentage Change	-14.7%	47.7%	30.1%	21.2%

Table 4.5.8
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 22 to Point 'e' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	-0.933	-0.861	-0.902	-0.901
Standard Deviation	0.987	1.693	0.915	1.173
Minimum	-3.7	-4.5	-3.0	-4.5
Maximum	0.6	2.7	1.7	2.7
Posttreatment Differences 22e				
Count of Differences	32	28	47	107
Average	-0.012	-0.221	-0.340	-0.211
Standard Deviation	0.537	0.770	0.670	0.670
Minimum	-1.1	-1.6	-2.1	-2.1
Maximum	1.2	1.2	1.1	1.2
Difference between Pre- & Post-SDs	0.450	0.923	0.245	0.503
Percentage Change	45.6%	54.5%	26.8%	42.9%

For Tables 4.5.7 and 4.5.8 the respective overall differences for all three treatment groups to points 'd' and 'e' were 21.2% and 42.9%. This difference between the reductions with respect to points 'd' and 'e' can possibly be ascribed to a relatively high maximum of 0.58 for the posttreatment differences associated with 'tooth 22' to point 'd', whereas, the maximum for the posttreatment differences associated with 'tooth 22' to point 'e' was only 0.12. The pattern of reductions did not correspond within group '4&5s' to points 'd' and 'e' respectively, for point 'd' the reduction (**increase**) was equal to –14.7% and for point 'e' the reduction was equal to 45.6%. A likely explanation was that the maximum of 0.58 previously mentioned occurred within the '4&5s' treatment group. The reductions associated with the distances to point 'd' for groups '4s' and 'NE' showed a strong similarity to the reductions associated with point 'e'.

Comparing the treatments for the two central incisors, the reductions (for both points' 'd' and 'e') showed a strong similarity for both sides. Contrasting right (12) and left (22) revealed that the reductions were smaller in the case of 'tooth 12' to points 'd' and 'e' compared to 'tooth 22' to points 'd' and 'e'.

The next set of tables (Table 4.5.9 to Table 4.5.14) differs from the previous set (Table 4.5.1 to Table 4.5.8) in that Table 4.5.1 to 4.5.8 measured the rotation for teeth '12', '11', '21' and '22' whereas Table 4.5.9 to Table 4.5.14 describe the change in the difference of the mid-distances to point 'd' (or point 'e') of adjacent teeth e.g. '12-11', '11-21' and '21-22'.

Table 4.5.9
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 12 and 11 to Point 'd' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	46	107
Average	-1.817	-1.782	-1.413	-1.634
Standard Deviation	1.261	1.540	2.082	1.721
Minimum	-4.5	-4.9	-5.9	-5.9
Maximum	0.9	1.9	5.3	5.3
Posttreatment Differences 12_11d				
Count of Differences	33	26	47	106
Average	-0.080	-0.423	-0.491	-0.347
Standard Deviation	0.753	0.773	0.872	0.826
Minimum	-1.7	-1.9	-4.2	-4.2
Maximum	1.5	1.2	0.9	1.5
Difference between Pre- & Post-SDs	0.508	0.767	1.210	0.895
Percentage Change	40.3%	49.8%	58.1%	52.0%

Table 4.5.10
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 12 and 11 to Point 'e' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	46	107
Average	-1.844	-1.557	-1.263	-1.519
Standard Deviation	1.216	1.513	2.123	1.733
Minimum	-4.3	-4.7	-6.3	-6.3
Maximum	1.3	2.1	5.0	5.0
Posttreatment Differences 12_11e				
Count of Differences	33	26	47	106
Average	-0.141	-0.092	-0.378	-0.234
Standard Deviation	0.790	0.805	0.942	0.866
Minimum	-1.7	-1.7	-4.2	-4.2
Maximum	1.4	2.1	1.5	2.1
Difference between Pre- & Post-SDs	0.426	0.707	1.181	0.867
Percentage Change	35.1%	46.8%	55.6%	50.0%

The overall reductions for the three treatment groups were similar with respect to points 'd' and 'e' 50.0% and 52.0% in the standard deviation, respectively. The relative improvement within the three treatment groups was similar with respect to points 'd' and 'e' and group 'NE' showed the best reduction. The difference in the average mid-distance between 'tooth 12' and 'tooth 11' to the point 'd' with respect to the pre-treatment measurements was negative, indicating that the distance to 'tooth 11' was larger than the distance to 'tooth 12' to the point 'e'. For the posttreatment measurements the average difference was much smaller. Together with the reduction in the standard deviations this indicated that the positions of 'tooth 12' and 'tooth 11' were much more even. This was also true for the distances with respect to the point 'e'.

Table 4.5.11
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 11 and 21 to Point 'd' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	0.412	0.520	0.478	0.469
Standard Deviation	0.808	0.927	0.971	0.905
Minimum	-1.7	-0.8	-3.2	-3.2
Maximum	2.2	2.7	3.3	3.3
Posttreatment Differences 11_21d				
Count of Differences	33	26	47	106
Average	0.058	0.102	0.200	0.132
Standard Deviation	0.307	0.370	0.309	0.327
Minimum	-0.9	-0.6	-0.4	-0.9
Maximum	0.6	0.8	1.1	1.1
Difference between Pre- & Post-SDs	0.501	0.557	0.662	0.578
Percentage Change	62.0%	60.1%	68.2%	63.8%

Table 4.5.12
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 11 and 21 to Point 'e' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	0.415	0.504	0.379	0.422
Standard Deviation	0.786	0.904	0.885	0.855
Minimum	-1.6	-0.7	-3.1	-3.1
Maximum	2.3	2.8	2.1	2.8
Posttreatment Differences 11_21e				
Count of Differences	33	26	47	106
Average	0.071	0.075	0.260	0.156
Standard Deviation	0.312	0.358	0.489	0.417
Minimum	-0.7	-0.6	-0.6	-0.7
Maximum	0.7	0.9	2.8	2.8
Difference between Pre- & Post-SDs	0.475	0.547	0.396	0.438
Percentage Change	60.4%	60.5%	44.8%	51.3%

The positions of the two central incisors are usually even, and this can be seen in the average difference of the mid-distances of these two teeth (see Tables 4.5.11

and 4.5.12). The orthodontic treatment in general gave rise to a 63.8% and 51.3% percentage change with respect to the distances to points 'd' and 'e', although the absolute changes were smaller than the changes for 'teeth 12 and 11' and 'teeth 21 and 22'. Within the three treatment groups there were no major differences with respect to the percentage improvement, except for group 'NE' which was affected by an outlier for the posttreatment distances (see maximum of 0.28 in Table 4.5.12 in the post-treatment section of the table).

Table 4.5.13
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 21 and 22 Point 'd' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	2.623	3.236	2.254	2.621
Standard Deviation	1.396	1.668	2.046	1.801
Minimum	0.1	-1.3	-4.2	-4.2
Maximum	6.2	6.5	5.6	6.5
Posttreatment Differences 21_22d				
Count of Differences	32	28	47	107
Average	0.272	0.548	0.711	0.537
Standard Deviation	0.665	0.752	0.783	0.758
Minimum	-1.8	-1.3	-0.5	-1.8
Maximum	1.5	1.9	4.2	4.2
Difference between Pre- & Post-SDs	0.731	0.916	1.264	1.043
Percentage Change	52.3%	54.9%	61.8%	57.9%

Table 4.5.14
Descriptive Statistics of Pre- and Post- Differences between mid-distances of teeth 21 and 22 to Point 'e' (Evaluating "evenness")

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	2.636	3.100	2.241	2.585
Standard Deviation	1.461	1.637	2.066	1.809
Minimum	-0.6	-1.4	-4.3	-4.3
Maximum	6.2	6.0	5.9	6.2
Pos-treatment Differences 21_22e				
Count of Differences	32	28	47	107
Average	0.464	0.327	0.593	0.485
Standard Deviation	0.642	0.754	0.854	0.771
Minimum	-0.9	-1.6	-1.1	-1.6
Maximum	1.4	2.0	3.9	3.9
Difference between Pre- & Post-SDs	0.819	0.883	1.211	1.038
Percentage Change	56.0%	54.0%	58.7%	57.4%

The most important feature of Tables 4.5.13 and 4.5.14 is that for comparative purposes the sign of all the differences in Tables 4.5.13 and 4.5.14 can be changed to the opposite because the subtraction has taken place in the opposite direction compared to Tables 4.5.9 and 4.5.10. The mid-distances were always subtracted in the same order not taking the position of the midline into account. The reductions with respect to the pre- and pos-treatment values were similar in Tables 4.5.13 and 4.5.14, and showed small differences between the three treatment groups. Tables 4.5.13 and 4.5.14 are the left side version of Tables 4.5.9 and 4.5.10 except for a '-1' multiplier difference between the two sets of tables. Reasonable symmetry with respect to the improvement of teeth positions occurred between the right (Tables 4.5.9 and 4.5.10) and left (Tables 4.5.13 and 4.5.14) sides.

In Tables 4.5.9 to 4.5.14 more weight was placed on the change in the average difference compared to the discussion of the preceding Tables 4.5.1 to 4.5.8. The improvement in the evenness of the four front teeth could also be measured by the six reductions of the average mid-distances differences (absolute values). It was concluded that for these six reductions the change in the average differences and the change in the standard deviations were equivalent in measuring the improvement of the evenness of the four front teeth.

The value of these three dental treatments on the positions and / or movements of the molars will now be discussed. The removal of tooth 14 and tooth 24 for the treatment groups ‘4s’ and ‘4&5s’ resulted in the impossibility of making posttreatment measurements to teeth 14 and 24. The improvement could therefore only be measured for treatment group ‘NE’. In Tables 4.5.15 to 4.5.18 the improvement in the evenness of these premolars was studied in a similar manner to the four anterior teeth (see Tables 4.5.9 to 4.5.14).

Table 4.5.15
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 25 and 24 to Point ‘d’

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	26	17	29	72
Average	2.385	0.771	2.052	1.869
Standard Deviation	1.754	2.011	1.461	1.799
Minimum	-1.2	-2.8	-0.8	-2.8
Maximum	4.7	4.0	4.9	4.9
Posttreatment Differences 25_24d				
Count of Differences			43	
Average			2.200	
Standard Deviation			1.373	
Minimum			-0.4	
Maximum			4.9	
Difference between Pre- & Post-SD's			0.088	
Percentage Change			6.0%	

Table 4.5.16
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 25 and 24 to Point 'e'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	26	17	29	72
Average	2.219	1.688	2.303	2.128
Standard Deviation	1.614	1.819	1.501	1.616
Minimum	-0.9	-1.3	-2.0	-2.0
Maximum	5.6	5.0	5.1	5.6
Posttreatment Differences 25_4e				
Count of Differences			43	
Average			2.591	
Standard Deviation			1.272	
Minimum			0.3	
Maximum			5.5	
Difference between Pre- & Post-SDs			0.229	
Percentage Change			15.2%	

As before, the differences in the distances to points 'd' (Table 4.5.15) and 'e' (Table 4.5.16) validated the results of each other. The reduction in the standard deviation associated with the pre- and posttreatment could again be interpreted as an improvement in the quality of the evenness of these premolars. The reduction associated with point 'd' was 6.0% and the reduction associated with point 'e' was 15.2%. This represented a considerable difference, but it is still acceptable in the light of the instability of this estimate of the dispersion.

Table 4.5.17
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 15 and 14 to Point 'd'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	22	18	34	74
Average	3.291	1.928	2.303	2.505
Standard Deviation	1.370	1.386	1.428	1.482
Minimum	0.0	-0.6	-0.8	-0.8
Maximum	5.1	4.8	5.2	5.2
Posttreatment Differences 15_4d				
Count of Differences			43	
Average			2.407	
Standard Deviation			1.013	
Minimum			-0.1	
Maximum			5.0	
Difference between Pre- & Post-SDs			0.416	
Percentage Change			29.1%	

Table 4.5.18
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 15 and 14 to Point 'e'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	22	18	34	74
Average	3.086	2.861	2.585	2.801
Standard Deviation	1.414	1.832	1.442	1.531
Minimum	-1.0	0.6	-0.7	-1.0
Maximum	4.9	8.6	5.8	8.6
Posttreatment Differences 15_4e				
Count of Differences			43	
Average			2.753	
Standard Deviation			1.070	
Minimum			0.5	
Maximum			5.5	
Difference between Pre- & Post-SDs			0.373	
Percentage Change			25.8%	

Tables 4.5.17 and 4.5.18 provide estimates of the difference in the distances from teeth 14 and 15 respectively to points 'd' and 'e'. The reduction associated with point 'd' was 29.1% and the reduction associated with point 'e' was 25.8%. These reductions were fairly similar to each other, but they were considerably more than the reductions experienced on the right side. This could be ascribed to the asymmetry which characterized the right/left side differences measured in the pretreatment data and the subsequent effects of the orthodontic treatment.

Table 4.5.19
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 25 and 26 to Point 'd'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	26	18	29	73
Average	-9.040	-7.817	-7.762	-8.231
Standard Deviation	1.521	1.563	1.002	1.462
Minimum	-12.7	-10.2	-9.5	-12.7
Maximum	-6.5	-4.8	-4.8	-4.8
Posttreatment Differences 2526dM&D				
Count of Differences	33	28	47	108
Average	-7.158	-6.348	-7.102	-6.924
Standard Deviation	1.200	1.259	1.082	1.205
Minimum	-9.4	-8.7	-10.0	-10.0
Maximum	-4.1	-3.6	-4.1	-3.6
Difference between Pre- & Post-SDs	0.321	0.304	-0.080	0.257
Percentage Change	21.1%	19.4%	-8.0%	17.6%

Table 4.5.20
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 25 and 26 to Point 'e'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	26	18	29	73
Average	-8.794	-8.281	-7.866	-8.299
Standard Deviation	1.281	1.168	1.355	1.330
Minimum	-12.3	-10.0	-9.6	-12.3
Maximum	-6.7	-6.1	-3.8	-3.8
Posttreatment Differences 2526eM&D				
Count of Differences	33	28	47	108
Average	-6.952	-6.884	-7.298	-7.085
Standard Deviation	1.231	1.142	1.204	1.200
Minimum	-9.6	-9.0	-10.4	-10.4
Maximum	-4.5	-3.6	-4.1	-3.6
Difference between Pre- & Post-SDs	0.050	0.026	0.151	0.130
Percentage Change	3.9%	2.2%	11.2%	9.8%

Comparing Tables 4.5.19 (with respect to point 'd') and 4.5.20 (with respect to point 'e') the argument that these two tables validate each other does not appear to hold because of the heterogeneity of the corresponding reductions.

Table 4.5.21
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 15 and 16 to Point 'd'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	22	18	34	74
Average	-8.268	-7.544	-7.897	-7.922
Standard Deviation	1.383	1.412	1.604	1.499
Minimum	-10.5	-10.1	-11.1	-11.1
Maximum	-4.4	-4.5	-2.5	-2.5
Posttreatment Differences 1516dM&D				
Count of Differences	33	28	47	108
Average	-7.350	-6.820	-7.018	-7.068
Standard Deviation	1.011	1.395	1.196	1.205
Minimum	-9.0	-11.5	-9.8	-11.5
Maximum	-5.3	-4.0	-4.4	-4.0
Difference between Pre- & Post-SDs	0.372	0.017	0.408	0.294
Percentage Change	26.9%	1.2%	25.4%	19.6%

Table 4.5.22
Descriptive Statistics of Pre- and Post- Differences between distances of teeth 15 and 16 to Point 'e'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	22	18	34	74
Average	-8.534	-7.656	-8.053	-8.099
Standard Deviation	1.764	2.418	1.787	1.951
Minimum	-14.0	-10.2	-11.8	-14.0
Maximum	-5.7	0.9	-2.9	0.9
Posttreatment Differences 1516eM&D				
Count of Differences	33	28	47	108
Average	-7.156	-7.223	-7.135	-7.164
Standard Deviation	1.174	1.267	1.437	1.306
Minimum	-9.5	-11.8	-9.9	-11.8
Maximum	-4.2	-4.9	-1.6	-1.6
Difference between Pre- & Post-SDs	0.589	1.151	0.350	0.645
Percentage Change	33.4%	47.6%	19.6%	33.0%

The reductions with respect to the right side were also diverse, but these reductions were mostly larger compared to those on the left side (see Tables

4.5.19 and 4.5.20). The reductions on the right side within the three treatment groups did not validate each other (see Tables 4.5.21 and 4.5.22).

The four tables above addressed the evenness of teeth 25 and 26 on the left, and teeth 15 and 16 on the right sides. Comparing the associated reductions calculated in these four tables to the reductions with respect to the evenness of teeth 22 to 12 (see Tables 4.5.9 to 4.5.14), it was clear that these two groups of reductions followed different patterns. The reductions in Tables 4.5.9 to 4.5.14 were more constant and validated each other, whereas the reductions in Tables 4.5.19 to 4.5.22 were extremely variable showing that the operator did not achieve the same measure of quality of improvement with respect to evenness on the premolars and molars.

Table 4.5.23
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 26 to Point 'd'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	6.761	7.068	6.453	6.706
Standard Deviation	1.723	0.663	0.622	1.108
Minimum	5.2	5.7	4.9	4.9
Maximum	15.9	8.7	7.7	15.9
Posttreatment Differences 26dM_D				
Count of Differences	33	28	47	108
Average	7.230	7.189	6.821	7.042
Standard Deviation	0.723	0.756	0.697	0.740
Minimum	5.7	5.6	5.4	5.4
Maximum	8.8	8.5	8.3	8.8
Difference between Pre- & Post-SDs	1.000	-0.094	-0.075	0.368
Percentage Change	58.1%	-14.1%	-12.1%	33.2%

Table 4.5.24
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 26 to Point 'e'

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	33	28	47	108
Average	6.464	6.975	6.438	6.585
Standard Deviation	0.532	0.690	0.621	0.651
Minimum	5.2	5.5	5.0	5.0
Maximum	7.4	8.3	7.5	8.3
Posttreatment Differences 26eM_D				
Count of Differences	33	28	47	108
Average	7.255	7.146	6.804	7.031
Standard Deviation	0.725	0.731	0.705	0.740
Minimum	5.8	5.5	5.2	5.2
Maximum	9.0	8.3	8.3	9.0
Difference between Pre- & Post-SDs	-0.193	-0.041	-0.084	-0.088
Percentage Change	-36.2%	-5.9%	-13.6%	-13.5%

The reductions in rotation measured to points 'd' and 'e' were all negative on the left side, except for '4&5s' measured to point 'd'. The reductions for group 'NE' were similar, but more divergent for the two extraction treatment groups. The greatest diversity in measurement of rotation change was in '4&5s'.

Table 4.5.25
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 16 to Point 'd' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	32	28	47	107
Average	6.447	6.771	5.768	6.234
Standard Deviation	0.766	0.733	2.013	1.501
Minimum	4.5	5.4	-5.2	-5.2
Maximum	8.2	8.3	7.6	8.3
Posttreatment Differences 16dM_D				
Count of Differences	33	28	47	108
Average	7.070	7.589	6.747	7.064
Standard Deviation	0.507	2.186	0.810	1.297
Minimum	5.9	5.0	4.8	4.8
Maximum	8.0	17.8	8.3	17.8
Difference between Pre- & Post-SDs	0.259	-1.453	1.202	0.204
Percentage Change	33.8%	-198.1%	59.7%	13.6%

Table 4.5.26
Descriptive Statistics of Pre- and Post- Differences between mesial and distal distances of tooth 16 to Point 'e' (Evaluating rotation)

Pretreatment Differences	**4&5s**	**4s**	**NE**	**Complete Group**
Count of Differences	32	28	47	107
Average	6.403	6.711	5.691	6.171
Standard Deviation	0.750	0.815	2.019	1.516
Minimum	4.6	5.3	-5.5	-5.5
Maximum	8.2	8.6	7.4	8.6
Posttreatment Differences 16eM_D				
Count of Differences	33	28	47	108
Average	7.039	7.554	6.589	6.977
Standard Deviation	0.531	2.152	1.274	1.451
Minimum	6.1	5.2	0.1	0.1
Maximum	8.2	17.6	8.2	17.6
Difference between Pre- & Post-SDs	0.219	-1.338	0.745	0.065
Percentage Change	29.2%	-164.2%	36.9%	4.3%

The reduction in rotation changes on the right side were in the same direction within all three groups, with '4&5s' showing relatively similar percentage changes for points ‘d’ and ‘e’. There were large negative percentage changes for points ‘d’ and ‘e’ in the ‘4s’ group. Because the pretreatment standard deviations for ‘4s’ and ‘4&5s’ were relatively small compared to group ‘NE’, they will have a greater influence on the percentage reduction for those two groups. The posttreatment standard deviations for ‘4s’ to both points ‘d’ and ‘e’ increased indicating that more rotation had taken place.

No reasons could be offered for the instability of the left side rotation measurements.

In conclusion, from these tables it is evident that the changes in rotation and evenness improved from pre- to posttreatment in the 12-22 areas, for all the treatment groups. The changes (“improvements”) that were calculated for the posterior areas were not as good as for the anterior areas, indicating a large diversity of results and therefore unpredictability of the results for the posterior areas. There were differing amounts of change for teeth on the left and right sides of the dentition.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

There are differing opinions about the use of palatal rugae on studymodels as reference landmarks for evaluating tooth movement during normal development and during orthodontic treatment. Many researchers have found certain landmarks on the rugae to be stable reference points for measuring tooth movements during orthodontic treatment, but there is still no concensus regarding which landmarks would be the most accurate and reliable ones to use for that purpose (Lebret 1962, Peavy and Kendrick 1967, Van Der Linden 1978, Almeida *et al* 1995, Bailey *et al* 1996, Abdel-Aziz and Sabet 2001, Hoggan and Sadowsky 2001, Miller *et al* 2003, Mavropoulos *et al* 2005, 2006).

Because of the current uncertainties about using palatal rugae as reference points for measuring tooth movements during orthodontic treatment, some researchers have concluded that the cephalometric method is more reliable as several reference points can be located and used for this purpose (Geron *et al* 2003). Hoggan and Sadowsky (2001) have, however, suggested that using palatal rugae on studymodels would be an easy and cheaper method of evaluating anteroposterior tooth movements than using lateral cephalograms, besides the fact that the patient need not be exposed to x-ray radiation. Ghafari, Baumrind & Efstratiadis (1998) described some of the problems associated with the accurate and reliable identification of certain skeletal landmarks on cephalograms and how these could influence the results of studies using cephalograms. It is not possible to measure tooth movements in the transverse dimension on cephalograms. Other problems with the use of lateral cephalograms are the relatively more time consuming process of cephalometric superimpositioning which requires some expertise, and higher cost of equipment and materials compared to the preparation of study models. The selection of a reference plane that will remain stable during orthodontic treatment has been a major concern in research using cephalograms (Isaacson 1996). In addition to the problems and difficulties related to the use of cephalometric radiographs, accurate measurement of left/right side parameters e.g. teeth on cephalograms is very difficult. More recent research using 3-D images and superimpositions of study models has also shown that significant differences can occur between measurements on right and left sides in the same patient (Mavropoulos *et al* 2005). Mavropoulos *et al* 2005 determined that cephalometric measurements of sagittal movement of first molars and second premolars were underestimated compared to the measurements done on 3D studymodel analysis. Mavropoulos *et al* (2006) found that measurement of sagittal and vertical tooth movements on study models that were 3-D digitized and superimposed on a certain area of the palate were more reliable than the cephalometric analyses of these tooth movements.

Although the rugae may be accepted as stable landmarks in certain circumstances, the measurement error associated with superimposition of images of palatal rugae on study models has not been researched in great detail. Miller *et al* (2003) determined that a single operator could achieve good reproducibility with digital superimposition on selected points on the palatal rugae, with a mean error of 0.2mm (±0.15mm) for translation measurements. Mavropoulos *et al* (2005) found the following errors of the method using Dahlberg's formula (Dahlberg 1940), namely 0.21mm for molar sagittal measurements, 0.21mm for premolar sagittal measurements and 0.16mm for incisal sagittal measurements. The error of the method in the present study was 0.131mm (Dahlberg formula) which compares very favourably with those of these other two studies.

When analyzing the results of research related to clinical orthodontics, the terms "statistically significant" and "clinically significant" do not always have the same meaning or interpretation. The term "statistically significant" means that an observed difference is unlikely to be merely the effect of chance, not necessarily that the difference is clinically important (Sterne and Davey Smith 2001). Many variables may have influenced the data making the results statistically significant;

however, it does not necessarily follow that because two groups are statistically significantly different that the difference has clinical significance. When RA Fisher introduced significance testing for hypotheses he recommended that the interpretation of the P value be done by the researcher, and not by simply dividing results into significant or not significant (Sterne and Davey Smith 2001). The researcher has to consider other factors influencing the statistical results, including the rate of Type ll error. The latter error could result in potentially clinically important differences seen in small studies being ignored (non-significant statistically), and the faulty attributing of all significant findings as results of the effects of treatment. These considerations have been taken into account in the interpretation of the results of this research.

The present study has direct relevance in evaluating the use of palatal rugae for the accurate and reliable measurement of orthodontic tooth movement during orthodontic treatment.

5.2 Inter-subject Variation of Measurements

Many of the results of this study are characterized by substantial inter-subject variation in the magnitude of the parameters measured. The existence of a wide range of individual responses and/or differences for a uniform treatment modality is confusing, but has been documented in many well-researched studies about the effects of various orthodontic treatment modalities (BeGole *et al* 1998, Hoggan and Sadowsky 2001, Ong and Woods 2001, Mavropoulos *et al* 2005). Research has been conducted into possible reasons for this phenomenon and certain recommendations regarding the process of orthodontic research have been made, including that the dependent variable be measured frequently and precisely (Tulloch *et al* 1997, Baumrind 1988, Ghafari *et al* 1998).

Wide ranges of results were seen in all treatment groups even though this study used the differences between pre- and posttreatment values to try to define the results of certain treatment modalities. The results of this study indicate that many other factors including treatment mechanics, other aspects of orthodontic treatment planning, and pretreatment patient characteristics must have played a role in achieving the wide range of individual variation that is evident in this research.

The choice of treatment plan the orthodontist decided upon may play a role in the wide range of individual treatment response, and it is possible that many variables could have influenced him during the decision-making process (Baumrind *et al* 1996, Luke *et al* 1998, Ong and Woods 2001). One of these influences would be the decision to extract premolars or treat nonextraction. This aspect of orthodontic treatment planning been extensively debated from Angle's time to today (Angle 1907, Baumrind *et al* 1996, Steyn *et al* 1997, Ong and Woods 2001). Some factors which have been shown to play a role in this decision-making process regarding premolar extractions are the pretreatment condition of the patient, e.g. amount of crowding, overjet, Class 11 molar relationships, incisor protrusion (Ong and Woods 2001), and aspects of the orthodontist's training, clinical opinion and other anecdotal factors (Steyn *et al* 1997, Creekmore 1997, Saelens and De Smit 1998).

Literature about the quantification of changes in the dimensions of the dental arches during nonextraction and premolar extraction orthodontic treatment has yielded confusing results (De Castro 1974, Williams and Hosila 1976, Nel 1991, Steyn *et al* 1997, Saelens and De Smit 1998, Lee 1999, Ong and Woods 2001). Results of the present study agree with the conclusions of these studies, and others, that different premolar extraction sequences do not result in specific amounts of tooth movement in the arches (Schoppe 1964, Burger *et al* 1993, Bishara *et al* 1994, Ong and Woods 2001). Ong and Woods (2001) emphasized that the wide range of variation in treatment effect that is found using different extraction sequences necessitates that each patient's treatment plan should be individually constructed. They recommended that the orthodontist should not rely on using values of mean changes in pre- and posttreatment tooth positions that have been published in the literature when making decisions about premolar extraction sequences. Analysis of the results of the present study support the recommendations stated by Ong and Woods (2001).

5.3 Changes in Rugal Measurements during Orthodontic Treatment (Chapter 4.2)

5.3.1 Perpendicular Widths of the Posterior Rugae

There were no clinically or statistically significant differences for the perpendicular (vertical) widths of the posterior rugae (measured from points a and b) between left and right sides, or among the three treatment groups before orthodontic treatment. These dimensions also did not change during the orthodontic treatment time in any of the three treatment groups ($p<0.01$). The perpendicular widths of the posterior rugae can therefore be considered to be stable during orthodontic treatment in the age range of this group of patients. These results agree with those from other studies which have found that the rugae are stable from the time they develop until death (Leontsinis 1952 cited Peavy and Kendrick 1967, Peavy and Kendrick 1967).

*5.3.2 Rugal Landmarks Projected onto the Midpalatal Plane and to the **Incisive Papilla***

All the perpendicular distances between the most posterior points (points a and b) of the posterior rugae and the midpalatal plane (MPP) increased significantly during the orthodontic treatment time (Table 4.2.4). This can be expected considering that the interpremolar and intermolar widths increased significantly in all groups during orthodontic treatment (Table 4.3.2). These changes could be attributed to orthodontic treatment and patients' growth during the time of treatment. The mean increases in the MPP-a and MPP-b distances were between 0.99mm and 1.80mm. In five of the six groups the range of differences was very large, indicating that considerable variation occurred in individual cases (Table 4.2.4). This is reasonable in as much as examination of other aspects of growth and development in this age group would vary widely as the subjects progress from childhood into adolescence and also because of the wide range of variation which is known to occur in studies of the effects of different orthodontic treatment modalities (Ghafari *et al* 1998, Baumrind *et al* 1996, Tulloch *et al* 1997, Baumrind 1998).

The pretreatment anteroposterior dimension measured along the MPP (perpendicular projections of points a and b to MPP, i.e. points d and e) to the anterior point on the incisive papilla (point c) were all relatively similar (Table 4.2.5). After treatment these distances had decreased significantly in the two extraction groups, but not in the nonextraction group (point d-MPP, Table 4.2.6). Once again, large individual variation occurred.

Lebret (1962) noted that rugae points near the midpalatal raphe were stable and other researchers have included the midpalatal raphe in their studies measuring tooth movement relative to palatal rugae points (Miller *et al* 2003, Mavropoulos *et al* 2005, 2006). The results of this study are in agreement with these findings. It may be concluded that the perpendicular projections of rugal landmarks onto the MPP on the posterior part of the palate and measurements to the incisive papilla may be used to measure tooth movement during orthodontic treatment.

5.3.3 Changes in Dimensions of the First Three Primary Rugae (Transverse Length Changes, and Anteroposterior Distances between Medial and Lateral Ends of these Rugae)

Transverse Rugal Lengths

The transverse lengths of the first three primary rugae on the right side of the palate were significantly larger than the corresponding lengths on the left side for all three groups of patients. Many researchers have reported lengths, widths and tooth angulations on one side of the dental arch being larger than those on the other side (Cassidy *et al* 1998) and asymmetry of intraarch landmarks occurs often (Lundstrom 1961, Alavi *et al* 1988, Maurice and Kula 1998).

All the differences between pre- and post-treatment measurements on the left side of the palate were statistically significant for the first and third rugae in all three treatment groups, and groups 'NE' and '4s' for the second ruga. On the right side of the palate all the changes for the three treatment groups were not significant, except for group 'NE' (first ruga) and group '4s' (third ruga). It can be concluded that the side of the palate with the largest rugae is the most stable one for measuring tooth movement and/or for using for superimposition purposes. The second rugae on the right side (with the largest rugae) were stable in the nonextraction and premolar extraction cases in this study group. It follows that overlays on this landmark could be used as a stable reference area from which to measure changes in tooth position during orthodontic treatment in individuals from a similar population. The reasons for the significant differences in all treatment groups on the other side of the palate are unclear. It could be argued that statistically significant differences may not necessarily mean that the millimeter differences are clinically significant. The scanning technique would probably not have played a significant role in left/right side differences as the pilot study showed that there was minimal distortion of images at distances of up to 10cm from the scanner surface. These results concur with results from another study which shows that the effects of orthodontic treatment differ on the right and left sides of the dentition (Mavropoulos *et al* 2005).

Anteroposterior Distances between Lateral and between Medial Rugal Points

There were no significant differences between the pre- and posttreatment anteroposterior measurements of the lateral points of the first and second rugae on both sides of the palate in any of the treatment groups. All the corresponding measurements for the anteroposterior distances between the second and third rugae were also not significantly different, except for one group ('4s' on right side). All the mean differences were less than 1mm, which is probably clinically acceptable and possibly within the range of human error. This would imply that orthodontic treatment does not change the anteroposterior distances between the lateral points of the first three primary rugae for nonextraction orthodontic treatment.

Extraction of premolars during orthodontic treatment can affect the anteroposterior dimensions, but the changes are small and probably clinically acceptable (less than 1mm). These results agree with those of Hausser (1950, 1951 cited Bailey *et al* 1996), Paevy and Kendrick (1967) and Van der Linden (1978) who reported that lateral rugae points follow tooth movement in the sagittal plane, and with results published by Bailey *et al* (1996) and Abdel-Aziz and Sabet (2001) who noted that lateral points on the third rugae are stable during orthodontic treatment. The greatest changes noted by other authors occurred where the lateral ends of the rugae ended closely to the associated teeth, i.e. the rugae ending closer to the canines were less stable than those related to the premolars and molars (Peavy and Kendrick 1967). The results of this study indicate that various premolar extraction sequences, i.e. extraction of maxillary and mandibular first premolars, or extraction of maxillary first and mandibular second premolars, may have different effects on the lateral edges of the rugae.

The mean differences between the pre- and posttreatment anteroposterior distances between the medial points of the first three rugae on both sides were not significant for all treatment groups, except for two groups ('4s' right side between first and second rugae; '4&5s' right side between second and third rugae – both these mean differences less than 0.75mm). It may be concluded that nonextraction orthodontic treatment does not affect the anteroposterior distances between the medial ends of the first three primary rugae. It is also probable that orthodontic treatment involving extraction of premolars does affect these dimensions, but the changes measured may not be clinically significant. Many other researchers have also recommended that medial rugae points be used to measure tooth movement during orthodontic treatment (Hausser 1950, 1951 cited Bailey *et al* 1996, Schwarze 1979, 1972, 1973 cited Bailey *et al* 1996, Van Der Linden 1978), specifically the medial rugae points on the first rugae (Almeida *et* *al* 1995, Bailey *et al* 1996) or on the third rugae (Almeida *et al* 1995, Bailey *et al* 1996, Hoggan and Sadowsky 2001).

The possibility the posterior primary rugae may be close enough to the first molars in some individuals to be affected by the movement of these teeth should be taken into consideration (Paevy and Kendrick 1967, Van der Linden 1978). Various studies that have investigated the anteroposterior movement of first molars using the posterior rugae as reference points have reached different conclusions. Some have concluded that the medial points on posterior rugae can be used successfully for these measurements (Hausser 1950, 1951 in Bailey *et al* 1996, Lebret 1962, Schwarze 1969, 1972, 1973 cited Bailey *et al* 1996, Ziegler and Ingervall 1989, Bailey *et al* 1996, Hoggan and Sadowsky 2001), while others have found that the lateral ends of the rugae terminating near the teeth tend to follow the movement of the teeth in the sagittal plane (Peavy and Kendrick 1967, Hoggan and Sadowsky 2001).

5.4 Pre- and Posttreatment Intraarch Dimensions

There were no significant differences for the pretreatment intraarch widths among the three treatment groups. During orthodontic treatment there was significant widening of the intercanine, interpremolar and intermolar distances in all three groups. These results concur with findings of other studies describing changes in inter-tooth distances during nonextraction and extraction orthodontic treatment (Bishara 1997, BeGole *et al* 1998, Ong and Woods 2001, Hoggan and Sadowsky 2001, Taner *et al* 2004).

The largest increase in intermolar width occurred in group 'NE' (4.06 ± 2.59mm). There were significant increases in the two extraction groups and it is interesting to note the relatively similar amounts of intermolar expansion in these two groups. It is evident that the extraction sequence chosen by the orthodontist and his treatment mechanics had similar effects on the intermolar widths in the two extraction treatment groups.

There were significant increases in the premolar widths of all the groups, but the largest amounts of expansion occurred in the two extraction groups. The '4s' group had the most expansion in the premolar area, significantly more so than group '4&5s'. The intercanine width increase was the largest for group 'NE', followed by group '4s' and group '4&5s'.

It is interesting to note the similarity in the increases in the intercanine and intermolar widths in the two extraction groups, namely a mean increase of 1.83mm ('4s' canine) and 1.51mm ('4s' intermolar), and 1.27mm ('4&5s' intercanine) and 1.27mm ('4&5s' intermolar).

Accurate identification of the labial surfaces at the gingival margin was not possible on many models, therefore the results related to these measurements were not analysed. As technology improves it may become possible to get accurate three-dimensional images of study models, which would make it possible to do measurements in all dimensions, including the buccal/ lingual gingival margins.

5.5 Tooth-Ruga Measurements

Pre-Measurements:

Many of the pretreatment measurements showed bimodal distributions in all three groups (Chapter 4.4). The posttreatment measurements did not show bimodal distribution tendencies. The changes in the distributions of the parameters were therefore probably a result of the effects of orthodontic treatment on movement of the teeth.

Post-Measurements:

First Molar Teeth Measured to the Five Rugal Landmarks

Most of the differences for measurements from the mesio-lingual cusps of 16 and 26 from pre- to posttreatment positions indicated shortening (negative movement) of the distances the rugal points (26M-a, 16M-b, 16M-a), except for 26M-b where the differences in the three treatment groups were all positive. There were significant differences between the left and right sides in all treatment groups for the amount of tooth movement and probably the type of tooth movement. The amount of change on the left side was significantly more than that on the right side for all groups. Greater amounts of tooth movement occurred in the two extraction groups compared to group 'NE'. As only two landmarks on the first molars were used it was not possible to comment on the types of tooth movement which occurred during treatment, e.g. translation or tipping, except for indications of some rotation movement. The movement of the molar teeth would include all the types of tooth movements that occur during orthodontic treatment, e.g. rotation, translation and/or tipping of the molars.

Most of the measurements from the distal-buccal cusps of the first molars to rugal landmarks a and b in the nonextraction group indicated lengthening of the posttreatment dimensions, and shortening of these distances in the two extraction groups (with definite differences between the two extraction groups as well). This makes clinical sense as these differences could indicate expansion in the molar areas in the nonextraction group, and narrowing of the dental arch in extraction groups; and/or rotation of molars when compared to the measurements of the mesio-lingual cusp tips. There appeared to be more translation/ tipping movements of the first molar on the right side in all three groups and more rotation movement of the first molar on the left side.

It was evident that the anatomical positions of points a and b, and consequent geometric measurement of points on the first molars to these points, could influence the accuracy of left and right side measurements. The results indicated that there was more agreement of tooth movement measurements when rugal projects onto the MPP were used, rather than individual landmarks on the left and right sides. Measurements of first molar tooth movement relative to midpalatal projections of rugal landmarks on the posterior part of the palate, and to midpalatal landmarks on the incisive papilla may be used as accurate and reliable methods of measurement of tooth movement. Some recent research has used superimposition of projections of the palatal rugae onto the midpalatal raphe to evaluate tooth movement (Almeida *et al* 1995, Bailey *et al* 1996, Miller *et al* 2003).

The changes in landmarks c,d,e were consistent with the changes noted for landmarks a and b, through all three treatment groups. The differences measured on the left side showed less agreement with each other than the measurements on the right side. It may be concluded that it is not possible or advisable to compare changes on the left and right sides of the palate using only single unilateral reference points. Furthermore, as these cases were all done by a single orthodontic practitioner perhaps it may also be reasonable to assume that all/most of his cases exhibited some "sidedness" to them.

Some researchers have noted that there is an increase in the prevalence of anteroposterior asymmetry the more posterior the measurements (Lundstrom 1961, Maurice and Kula 1998, Alavi *et al* 1988). This could imply that there is more variability in the rugal landmark position on the posterior part of the palate (points a and b), compared to the anterior part of the palate (first and second rugae). De Araujo *et al* (1994) and Ferrario *et al* (1993) reported on the asymmetry of the dental arches in the molar regions. These factors could partly explain the "outliers" for measurements related to points a and b found in the data set. Furthermore, the wide range of individual measurements could also be partly explained by the suggestion that the "degree" of stability of rugal landmarks differs in individuals. As noted previously, the amount of tooth movement in all three treatment groups was characterized by extensive individual variation of values.

Premolars measured to the five rugal landmarks:

The changes between pre- and posttreatment tooth movement were significantly different among the three treatment groups and between left and right sides of the palate. There was also evidence of bimodality of the results on the right side, which may indicate that there were two types of reactions to orthodontic treatment on this, the larger, side. The results for group 'NE' (for the first and second premolars) were generally more consistent than those for the extraction groups, showing positive changes (lengthening) of the measurements to the rugal landmarks. Other researchers have found that orthodontic movement after premolar extractions can influence the stability of the ends of the rugae in the premolar areas (Paevy and Kendrick 1967, Van der Linden 1978).

Canines measured to the five rugal landmarks:

As for the molar and premolar teeth, there were different patterns of tooth movement in the three treatment groups and on the left and right sides. Results of tooth movement changes measured relative to landmarks projected onto the MPP (d and e) seem to be more consistent with each other than with changes measured relative to unilateral landmarks (a and b). This may not be a valid conclusion, though, as points d and e are located relatively near to each other and this may explain their apparent "consistency". Results for tooth movement changes relative to point c (anterior incisive papilla point on MPP) did not correspond to results for point a and b in the extraction groups, but did agree with the other landmarks showing positive changes for group NE. Paevy and Kendrick (1967) reported that rugae in the anterior part of the palate could be affected by posterior movement of anterior teeth in premolar extraction treatment, and the results of this study regarding the stability of point c agree with this finding.

Incisors measured to the five rugal landmarks:

No definite trends regarding points a,b,c,d and e could be identified for changes in tooth movement for these teeth, except what had already been noted for the other teeth, i.e. differences among the groups, differences between the left and right sides of the palate, and large individual variations.

The results indicated that the central incisors had been retracted in the two extraction groups. Other researchers have reported on the effects of premolar extractions on the positions of the maxillary incisor teeth, but these measurements have mostly been done on cephalometric analyses of cases. Luppanapornlarp and

Johnston (1993) found that four first premolar extraction treatment resulted in 2.8mm retraction relative to the NA line, compared to nonextraction treatment, while Schwab (1963) reported a 2.6mm retraction relative to point Sella. Using the APo line as reference and Nel (1991) found 2.9mm retraction of maxillary incisors when maxillary first and mandibular second premolars were extracted. Steyn *et al* (1997) used NPo as a reference and reported a 4.7 ± 2.3mm retraction of incisors in four first premolar extraction cases and retraction of the upper incisors of 6.6 ± 2.5 in maxillary first and mandibular second premolar extraction cases.

5.6 Evaluation of Effect of Treatment

The changes in tooth positions (rotation and evenness) improved substantially from pre- to posttreatment in the incisor areas in all the treatment groups. The changes ("improvements") that were calculated for the posterior areas were not as good as for the anterior areas and indicating a large range of results. It could be concluded that the predictability of the results of treatment (i.e. tooth movement) for the posterior areas was not as accurate as the predictability of tooth movement in the anterior part of the dentition. In the posterior part of the dentition the extraction groups showed more rotation of the first molars than group 'NE'. There were differing amounts of change for teeth on the left and right sides of the dentition.

5.7 Research Hypotheses

The results of testing the research hypotheses which were constructed to evaluate the research problem can be summarized as follows:

Hypothesis 1: The rugae themselves possess internal dimensional stability between pretreatment and posttreatment conditions.

This hypothesis can be accepted. The transverse width of the right second ruga did not change significantly during nonextraction and extraction orthodontic treatment.

Hypothesis 2: The rugae positions relative to one another are dimensionally stable between pretreatment and posttreatment conditions

a) in nonextraction patients:

This hypothesis can be accepted as there were no significant differences between the lateral and medial anteroposterior dimensions of the first three rugae during nonextraction orthodontic treatment. There were also no significant differences in the transverse dimensions of the second and third rugae on the right (larger) side pre- and posttreatment.

b) in patients whereemaxillary and mandibular first premolars were extracted

This hypothesis can be accepted as there were no significant changes between the lateral and medial anteroposterior dimensions of the first three rugae on the left (smaller) side during first premolar extraction treatment. There were also no significant differences in the transverse dimensions of the first and second rugae on the right side.

c) in patients where maxillary first and mandibular second premolars were extracted

This hypothesis can be accepted as there were no significant changes between the lateral and medial anteroposterior dimensions of the first three rugae on the left (smaller) side during upper first and lower second premolar extraction treatment, and no significant changes for these dimensions on the right side except for the medial anteroposterior distance between the second and third rugae. There were also no significant differences in the transverse dimensions of the first and second and third rugae on the right side and the second and third rugae on the left side.

Hypothesis 3: Soft tissue rugae are not stable landmarks for use in assessment of tooth movement in orthodontic treatment.

This hypothesis can be rejected. The results from this research demonstrate that certain landmarks on the palatal rugae are stable during orthodontic treatment. There are differences regarding the stability of landmarks depending on whether nonextraction or premolar extraction treatment had been done. The patterns of stability of the rugae during treatment were different for all three treatment groups.

Hypothesis 4: The relative positions of the palatal rugae are affected by orthodontic treatment involving extraction of maxillary teeth.

This hypothesis can be accepted as there were differences in the transverse dimensions of the first three rugae and differences in the medial and lateral anteroposterior distances between these rugae between the two extraction groups. The differences in these dimensions in both these groups differed from those in the nonextraction group. It is interesting to note that the transverse dimensions of the first and second rugae on the right (larger) side did not change significantly during extraction treatment and that the medial and lateral anteroposterior distances between the rugae on the left (smaller) side also did not change significantly during treatment in both of the extraction groups.

Hypothesis 5: Rugae to dental unit distances changed equally on the right and left sides.

This hypothesis can be rejected. There were definite significant differences between the ruga to dental unit distances measured on the left and right sides of the palate. These differences occurred in individual patients and in all three treatment groups.

5.8 Areas Requiring Further Research

Methods to achieve more accurate and reliable superimposition of the palatal architecture is a topic that requires further research. Some researchers have recommended that a mathematical model be used to find the best fit of rugal landmarks on series of study model images to measure tooth movement (Ashmore *et al* 2002). Recent literature has started focusing on trying to measure the types of tooth movement that occur during orthodontic treatment more accurately, e.g. translation and rotation (Ashmore *et al* 2002, Baumrind 2002). This could involve using more points on the surfaces of teeth, for example computing a centroid using four points (Ashmore *et al* 2002), which has implications for errors of landmark location. These authors and others are optimistic that the development of technology to obtain more accurate 3D digitization of studymodels is probably not far off.

Research about combining information from cephalograms and study models using modern technology needs to be investigated further to develop programmes which could integrate changes in the pre- and posttreatment skeletal parameters and tooth positions, including measurement of tooth movement in all dimensions.

5.9 Conclusions

1. Scanned pre- and posttreatment images of the palatal rugae on orthodontic study models can be computerized and used to measure tooth movement during orthodontic treatment. The method described in this study is clinically and economically efficient, and has been shown to be valid and reliable.

2. Large individual variation occurred in the differences measured between pre- and posttreatment parameters in all three treatment groups and on both sides of the palate. This was the case for measurement of rugal dimensions, for ruga-tooth dimensions and for intraarch width measurements in all three treatment groups.

3. There were significant differences between the dimensions of the rugae on the left and right sides of the palate in the sample of patients selected for this study. The first three primary rugae on right side were significantly larger than those on the left side.

4. The transverse length of the second ruga on the right (larger) side of the palate was the only ruga that did not change significantly during nonextraction or extraction treatment. Although the mean changes for some of the other rugae were statistically significant, they were probably not always clinically significant.

5. There was minimal growth in the lateral (transverse) dimension of the palate in the region of the first, second and third primary rugae during the period of orthodontic treatment.

6. No changes occurred between the anteroposterior distances between the medial and lateral points of first three rugae during orthodontic treatment for group 'NE'. Small/no changes were noted for these dimensions on the left (smaller) side of the palate for both extraction groups. There were

significantly different responses for these measurements between the two extraction groups. It may be concluded that the anteroposterior dimensions between rugae are stable during nonextraction treatment and can be accepted to be stable on the left (smaller) side of the palate during premolar extraction orthodontic treatment.

7. As there were minimal/no significant changes in the anteroposterior dimensions between the rugae during treatment, it may be concluded that there was minimal anteroposterior growth of the soft-tissue palate during the period of orthodontic treatment.

8. Rugal landmarks identified on the left and right sides of the palate and/or projections of these landmarks onto the midpalatal plane can be used for measuring tooth movement in individuals. The interpretation of mean changes for groups of individuals using individual landmarks can be problematic because of the wide range of individual variation in these measurements and the effect this has on the statistical analysis of the data.

9. There were significant increases in the intermolar, interpremolar and intercanine widths for all three groups during orthodontic treatment. Group 'NE' exhibited the largest increase in intercanine and intermolar widths of the three groups, whereas the extraction groups had greater interpremolar width increases than group 'NE'. The increases in the intertooth widths were all larger in the '4s' group compared to the '4&5s' group, but these differences for the intercanine and intermolar distances were small and probably clinically insignificant.

10. Evaluation of success of treatment using rugae points to measure alignment ("evenness") indicated that better alignment occurred in the anterior parts of the dentition compared to the premolar and molar areas. Significant differences in the amounts and types of tooth movement occurred in the

extraction groups compared to group 'NE'. Significant differences also occurred between left and right sides of the dentition.

11. The technique of using superimpositions of the palatal rugae on serial study models described in this study may be used for evaluating tooth movement during orthodontic treatment. Depending on which tooth movements the clinician chooses to measure, this technique could replace or augment cephalometrically-measured changes in tooth position. Tooth movements such as tipping and vertical movements could not be evaluated, but as technology regarding 3D imaging improves these movements could probably be measured reliably in future.

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