The extraction of permanent second molars and its effect on the dentofacial complex

A thesis submitted in partial fulfilment of the requirements for the degree
of Master of Dental Surgery

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2. Abstract

The extraction of permanent second molars, particularly lower second molars, as an adjunct in the treatment of malocclusion, has attracted some debate within the orthodontic profession. The aim of this retrospective investigation was to assess the dentofacial changes in a group of patients treated with extraction of permanent second molars according to the protocol of one specialist orthodontic practitioner.

The sample consisted of forty-five patients, twenty-six females and nineteen males. The age ranges before treatment were 12.1 – 17.7 years for the female group (mean 13.7 years) and 12.1 – 15.6 years for the male group (mean 13.9 years). All four permanent second molars were extracted immediately prior to, or during, active orthodontic treatment. Orthodontic treatment consisted of full upper and lower fixed appliance therapy with the exclusive application of the Differential Straight - Arch® Technique (Tip - Edge®). Lateral cephalograms were available before active treatment and immediately before removal of the fixed appliances. Dental study casts were taken before active treatment and immediately following fixed appliance removal.

Measurement analysis of both the lateral cephalograms (cranial base and mandibular superimpositions) and the dental casts provided information on the skeletal, dental and soft tissue changes which occurred during treatment. Double-determinations were completed for both cephalometric and study model measurements to test for both random and systematic error. Comparisons of the results were made with published data from longitudinal growth studies. Standard descriptive statistics were applied to analyse the data and test for statistical significance for any differences both pre-treatment and post-treatment for both groups.

The results revealed statistically significant differences and changes between males and females for both radiographic and study model parameters. Cephalometric variables which exhibited pre-treatment significant sex differences included SNA, U1-NA (angular), SNB, lower and total face heights, nasolabial angle and upper lip length. At post-treatment, sex differences were demonstrated for SNA, mandibular length, several facial height parameters (both hard and soft tissue), nasolabial angle and upper lip length.

For the cast analysis, pre-treatment differences between males and females were noted for several variables including inter-canine, premolar and molar widths, tooth size, arch depth and arch length. The same variables exhibited significant sex differences and changes post-treatment (except tooth size and upper arch inter-canine width).

Overall, the pattern of correction exhibited by the current sample group included dental, skeletal and soft tissue changes. Males tended to have greater mean increases in mandibular skeletal and overall soft tissue variables compared to females. Both males and females had increases in all inter-dental variables measured from the study casts. Both sexes demonstrated a small but statistically insignificant distalising of the lower buccal segments. Sagittally, the lower incisors post-treatment showed a mean tendency to remain in their pre-treatment positions with some individual variation.

A thorough analysis of the pre- and post - eruption patterns of the third molars is not yet possible due to the early morphogenetic state of these teeth. A follow-up study could provide invaluable information as to the "final" eruptive positions of the third molars and the medium to long -term stability of the treated malocclusions.

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My father and mother, John and Shirley. It is rare to have the opportunity to requite the love and encouragement freely given over many years by my parents. I hope that this dissertation, in a small way, is a reflection of their enduring guidance.

Statement

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person except where due reference has been made in the text.

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4. Introduction and Aims

4.1 Introduction

The extraction of teeth as an adjunct to orthodontic treatment is a well-documented procedure. Debate remains, however, as to which teeth will provide the best conditions and opportunity to achieve both dental arch space gain and dentofacial harmony. Historically, the most common extraction pattern is that of four permanent first or second premolars.

While this often achieves the required dental arch space gain, several investigators have questioned the post-treatment consequences of extracting anteriorly and the possible detrimental effects on the dentofacial profile (Liddle, 1977; Drobocky and Smith, 1989).

In recent years, the extraction of one or more second permanent molars has been advocated as a possible alternative to the traditional bicuspid extraction pattern (Richardson, 1996). A good deal of comment and controversy has arisen mostly based on anecdotal evidence (Haas, 1986). A paucity of data based on minimal research and small sample sizes has added to the disquiet within the orthodontic profession as to the efficacy of such an extraction regime (Bishara, 1986).

The current study was in the form of an observational cohort study drawing on patients treated in a private orthodontic practice having had four permanent second molars extracted and fixed appliance therapy. The data was drawn from:

- patient written records;
- pre- and post-treatment lateral cephalograms;
- pre- and post-treatment dental study casts.

A comprehensive linear and angular cephalometric analysis was performed. Linear measurements have been derived from standardised photographs of the study models.

4.2 Aims

- to develop a method to analyse selection criteria and treatment responses in orthodontic patients treated with extraction of second molar teeth;
- to investigate factors which might influence the treatment responses;

- to analyse dentofacial changes contributing to correction of the malocclusion;
- to evaluate changes in the dental arch form in relation to available space conditions;
- to prepare data allowing a long-term follow-up of future dentofacial changes particularly that of the eruption status of the permanent third molars.

4.3 Hypothesis

The null hypothesis for the current investigation is that the extraction of four second permanent molars, followed by full fixed orthodontic appliance therapy, neither allows distalisation of the buccal segments nor prevents proclination of the lower incisors.

5. Literature Review

5.1 The Effects of Lower Second Molar Extraction on Lower Incisor Crowding

Late lower arch crowding in the untreated mandibular dentition has been reported widely in the literature (Humerfelt and Slagsvold, 1972; Moorrees *et al.,* 1979; Richardson, 1983; Sampson *et al.,* 1983; Sinclair and Little, 1983; Bishara *et al.,* 1989). The extraction of lower second permanent molars has been advocated to provide both the prevention (Tulley, 1959) and relief (Bishara and Burkey, 1986) of lower incisor imbrication. Proffit (1993) claims that the extraction of one second molar provides two millimetres of incisor crowding relief and one millimetre of incisal retraction. However, many of the reports are based on anecdotal evidence and case presentations.

Tulley (1959) wrote that the extraction of lower second molars "may minimize the deterioration of incisor alignment which tends to occur in the middle and late teens period." It was his belief that this particular extraction regimen minimized the potential for the deterioration in lower incisor alignment but that no significant space to alleviate existing crowding was gained.

Wilson (1966) stated that some "spontaneous alignment" of the lower labial segment occurred following the extraction of lower second permanent molars.

In an assessment of sixty-six orthodontically treated patients with one or both lower second molars extracted, Cryer (1967) found that "the degree of lower arch crowding that can be relieved by lower second permanent molar extraction is limited." However, he did believe that some degree of alignment was possible. Of the sixty-six cases studied, lower incisor alignment remained the same in twenty-seven patients, slightly improved in twenty-one and greatly improved in six. A slight deterioration was found in eleven cases with a severe deterioration in only one case. Cryer (1967) believed the main benefit of this form of treatment was in preventing lower anterior crowding. Brenchley and Ardouin (1968) felt that lower second molar extraction reduced the tendency to late lower labial segment imbrication.

Lehman (1979) believed the extraction of lower second permanent molars increases the stability of the treated occlusion. He found, based on largely anecdotal evidence, that the lower first permanent molars were uprighted and distalised because of "interocclusal forces." The long axis of the first molar moved perpendicular to the occlusal plane with the resultant of occlusal forces crossing the centre of resistance and contributing to stability. Lehman (1979) believed that this molar movement provided sufficient space in the lower arch and subsequent uprighting of the lower anterior teeth with the incisal edges of the lower incisors reaching the facial plane and the lower incisal inclination "approaching 90° to the mandibular plane." He believed these factors lead to increased lower labial segment stability.

A continuing ten-year longitudinal investigation into the effects of lower second molar extraction on late lower arch crowding was first reported in a pilot study by Richardson (1983). A small sample of ten subjects (four males; subject ages not disclosed) had lower second permanent molars extracted as part of their orthodontic treatment. Three subjects had unilateral and seven bilateral extractions. This group was compared with a non-extraction group for the change in lower arch space condition (arch length minus tooth size) and change in the antero-posterior position of the lower first molar after five years. The results revealed a significant difference between the two groups for the change in space condition and the change in the first molar position. The non-extraction group showed a mean increase in crowding and a mean mesial movement of the first molar. The extraction group showed an average decrease in crowding with a distal movement of the lower first molar. Richardson (1983) believed the results showed a "very clear trend which suggests that there may be some justification for extraction at the back of the lower arch as a prophylactic measure against the development of late crowding."

In 1990, Richardson and Mills reported results form a larger sample of thirty (thirteen males) subjects who had lower second molar extractions with no lower arch appliance therapy. Again, the data revealed in the extraction group a slight decrease in crowding in the lower arch and bilateral distal movement of the lower first molars. Richardson and Mills (1990) believed the decrease in crowding was due either to distal uprighting of the lower first molars or the prevention of crowding by providing space for a crowded third molar to develop and "eliminating its influence on the rest of the arch." She stated that the extraction of lower second molars would "be useful as an interceptive measure in patients whose third molars are developing in reduced space and who have an acceptable occlusion or mild malocclusion for which they are unwilling to undergo mechanical orthodontic treatment."

Richardson (1996) reported the ten-year findings on the same sample of thirty patients who had four second molar extractions at an average age of thirteen years, nine months. Little change was noted in lower arch space condition between the five and ten year investigations indicating stability "of lower arch alignment in second molar extraction cases in the later part of the second and in the early stages of the third decade of life". However, the possibility of lower incisor crowding at a later date cannot be discounted. Any future reports would be of great interest to the orthodontic profession as this longitudinal investigation continues.

5.2 The Effects of Second Molar Extraction on the Buccal Occlusion

An exhaustive discussion of the role of second molar extractions in orthodontic treatment was presented via a series of case presentations by Liddle (1977). An advocate of this extraction pattern, he claimed that ninety-one percent of his patients at that time had second molars extracted. He stated that: "Patients have told me many times that after all four second molars had been removed they felt relieved of the apparent pressure that had existed in the posterior areas of their dentition." This anecdotal response to second molar extraction has been elucidated by other clinicians (Twelftree 1999). Liddle (1977) theorised that following second molar extraction, the first molars move distally as a response to pressure exerted from the mesial dentition.

In an early investigation, Brenchley and Ardouin (1968) examined a small sample of eight patients who had lower second molars extracted with no lower arch treatment and upper arches with distalisation of the buccal segments or pre-molar extractions. The authors found a "temporary check" of the mesial drift of the lower buccal segments and indeed a distal "drifting" of the lower first molars. This may have been substantiated by a corresponding increase in arch length and inter-molar width. The investigators believed that lower second molar extraction responses may result from the direction of maxillary tooth movements having an influence on mandibular dental movements.

Wilson (1971, 1974) reported the treatment of over five hundred patients with the extraction of second permanent molars and rated "good buccal functional occlusion higher than a mere aesthetic improvement." He believed this could be achieved in many cases without lower appliances. In a rather vague assessment of the buccal occlusion of two-hundred and eight treated cases, one-hundred and ninety-eight were found to have “good results” where the buccal occlusion may not have been ideal (for example, exhibiting a slight postnormal occlusion).

Huggins and McBride (1978) also claimed correction of mild buccal segment crowding without appliances occurred following lower second molar extraction. Detailed data to support this claim were not published but the authors stated that “several cases showed eruption of impacted premolars.”

The concept of intermaxillary forces influencing lower first molar position has been mooted by Lehman (1979). In an analysis of case reports he claimed the lower first molars are uprighted and distalised. A possible explanation for this included “the resultant of occlusal forces crossing the centre of resistance and contributing to stability.” A further benefit of extracting distally to correct an anterior space deficiency would include the reduction of relapse through a re-opening of premolar extraction spaces.

Several authors have commented on the potential for the over-eruption of lower second molars if the upper second molars are extracted (Liddle, 1977; Smith, 1996). In an assessment of lower second molar eruption following upper second molar extraction, Smith(1996) found over-eruption of the distal aspect of the lower second permanent molars. The antero-posterior position of the upper first molar prevented the over-eruption of the mesial aspect of the lower second molar. Houston and Tulley (1986) felt that the lower second molars would not over-erupt if the upper first molars were in a “correct” occlusal relationship with the lower second molar.

5.3 The Effects on the Lower Third Molar following Lower Second Molar Extraction

The most oft-cited reasons in the literature for the removal of lower permanent second molars is to facilitate the disimpaction (Smith, 1957; Reid, 1957; Wilson, 1966; Richardson, 1974; Liddle, 1977; Cavanaugh, 1985), eruption into an acceptable position (Cryer, 1967; Wilson, 1974; Quinn, 1985) and possible early eruption (Halderson, 1959; Quinn, 1985) of the lower third molars. Others have questioned the rationale behind this particular extraction pattern (Chipman, 1961; Brown, 1974; Haas, 1986; Gooris *et al.*, 1990; Staggers, 1990).

Breakspear (1967) proposed "clinical guides" for the eruption of lower third molars following lower second molar extraction based on his experience:

- the direction of growth of the lower third molar remains constant until contact is made with the neighbouring tooth where a 'billiard ball' action ensues allowing the third molar to upright;
- the distance between the lower second molar and the anterior border of the ascending ramus increases (with growth) providing space for the developing lower third molar;
- providing there are no interferences (distal 'settling' of the lower first molars or over-eruption of the upper second molar) the lower third molar will follow a constant path of eruption (contradicted by McBride and Huggins, 1970).

Breakspear (1967) stressed that the eruption pattern of the lower third molar should be monitored biennially with lateral oblique radiographs.

In an investigation of sixty-six cases who experienced lower second molar extractions, Cryer (1967) analysed the final lower third molar positions. It was found that when the lower second molars were extracted between twelve and fifteen years of age, fifty-six percent of the lower third molars erupted into a "good" position (the third molar vertical and in good relations with the adjacent and opposing teeth). When the lower second molar extractions coincided with the full crown formation of the lower third molar, seventy percent of lower third molars were found to be in a "good" final position. The third molars more frequently erupted into a good position when the angulation of the tooth relative to the first molar was less than thirty degrees at the time of lower second molar extraction. However, Cryer (1967) noted that "modern surgical techniques and antibiotics make it unnecessary to extract the lower second molars merely to avoid the probable need for later surgical removal of the third molars."

Following their earlier investigation (McBride and Huggins, 1970), Huggins and McBride (1978) assessed the eruption of lower third molars following lower second molar extraction in a longitudinal cephalometric study of twenty females and seven males. Rotated cephalograms were taken before treatment, eight to ten months and two to four years after the extraction of the lower second molars. The angles formed by the occlusal plane of the lower molars and the cusps of the lower third molars were measured as described by McBride and Huggins (1970). An angle formed of between twenty and sixty degrees had been found to indicate the likelihood of satisfactory lower third molar eruption. All fifty teeth examined were found to have erupted with a range of eruption times of thirty-six to one hundred and seven months. The relationship of the third molars with the first molars and the opposing teeth was assessed by three variables:

OCCLUSION

Forty-three teeth had 'excellent' and seven teeth 'good' occlusion (based on an arbitrary and unexplained grading of 'excellent', 'good', 'fair' or 'poor').

CONTACT POINT RELATIONSHIP

Forty-two teeth exhibited 'excellent' contact point relationship, three 'good', two 'fair' and three 'no contact' with the lower first molar. The over-eruption of the upper molars caused the gingivally positioned contact points of the lower third molars in the 'fair' and 'good' groups. The authors believed that with mesial drift, the 'no contact' teeth would eventually exhibit some form of proximation.

AXIAL INCLINATION of the TEETH

This was assessed by the analysis of the long axes of the lower first and third molars and graded as 'excellent' (parallel within five degrees), 'good' (five to fifteen degrees), 'fair' (fifteen to twenty-five degrees) and 'poor' (greater than twenty-five degrees). None of the teeth showed excellent inclination, five had a good angulation, sixteen fair and twenty-nine poor. The curve of the roots of the lower third molars made categorising parallelism difficult. The authors believed that fixed appliances would be required to achieve root parallelism. Figs 1, 2.

Richardson (1974) analysed the eruption patterns of lower third molars over a seven year period. Early eruption of lower third molars was found in subjects who had posterior extractions and, in particular, first or second molar extractions as compared to first or second premolar extractions. She also noted that the initial angulation of the third molar to the mandibular plane was significantly lower in the group exhibiting early lower third molar eruption. There was also evidence of a greater change in the angulation of the third molar in this early eruption group. The amount of mandibular growth in the early eruption group was also the highest of all the subjects which would correlate with the findings of Björk (1956) and perhaps indicated an increased sagittal growth component in these individuals. Richardson (1975a), however, believed it is not possible to predict which third molars will become impacted but that one can conclude that "a very steeply angled developing third molar has a greater than average chance of becoming impacted." Fig 3

In an analysis of over nine hundred second permanent molar extraction cases, Wilson (1971, 1974) assessed the final position of the third molars by clinical appearance and unstandardised lateral oblique radiographs. The final positions were classified as:

- *Excellent*: molars in good occlusion, good contact with the first molar and near parallel roots of the first and third molars;
- *Very Good*: clinical appearance satisfactory and no more than twenty degrees of root divergence;
- *Good*: contact between the first and third molars with tilting of the crown and up to twenty degrees root divergence;
- *Poor*: some degree of impaction between the first and third molars. Fig 4

Of the one hundred and seventy-eight erupted third molars, one-hundred and eleven were excellent, thirty-one were very good, thirteen were good and twenty-three were poor. Wilson (1974) believes that many of the 'poor' group would be expected to improve spontaneously (as compared with Brown, 1974).

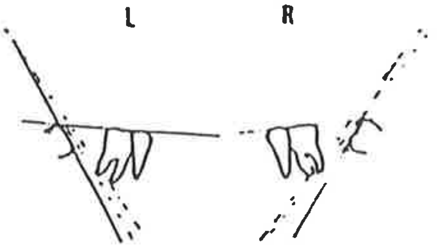


Figure 1 Superimposition of three films over an 18 month period showing continuing decrease in the angle of 38,48 to occlusal plane (McBride and Huggins, 1970).

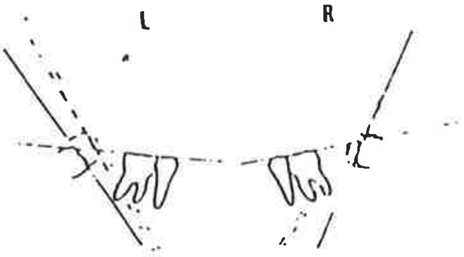


Figure 2 Illustration of 48 becoming more favourable and 38 less favourable to the occlusal plane

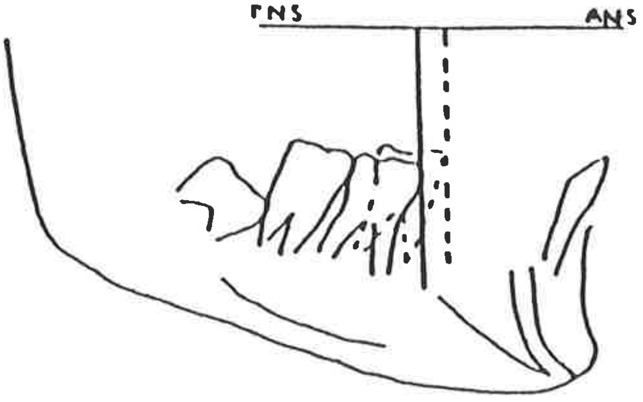


Figure 3 Tracings of 60° rotated cephalometric radiographs superimposed on the inner outline of the mandibular symphysis and inferior dental canal showing the measurement of change in position of the first molar. *Solid line,* age 13 years; *broken line,* age 18 years (from Richardson, 1975)

Figure 4 Classification of final positions of third molars

(from Wilson, 1974).

Liddle (1977) believed the potential trauma inflicted on a lower second molar by the surgical removal of an impacted third molar justifies the extraction of second molars. He claimed that he "has never seen third molars fail to erupt into good, useful occlusion without appliances…or drifting or loose contact areas."

Rindler (1977) investigated whether the position and status of the lower third molar in a subject was 'satisfactory' following lower second molar extraction. Based on an undefined clinical scale of 'poor' to 'very good' status, seventy-seven percent of the lower third molars examined were deemed, after treatment, to have a 'good' or 'very good' status. It was concluded, based on subjective evidence from unstandardised, lateral oblique radiographs and study models, that "in the majority of cases both the status and axial inclination of the lower third molars were such that these teeth could function as adequate substitutes for the extracted second molars." The definition of the term 'adequate substitute' was not apparent.

In a five-year follow-up investigation of sixty patients, Lawlor (1978) assessed the proportion of lower second molar extraction cases who exhibited successful third molar eruption. A lower third molar was considered to be in good position "if it erupted into a good contact with the first molar and occluded with its opposing tooth in the upper jaw." From standardised lateral oblique radiographs and dental casts, the angulation of the lower third molars, root formation of these teeth and the space between the third molar crypt and the second molar were analysed to see if these factors influenced the eruption pattern of the lower third molars. Fourteen of the eighty-four erupted lower third molars were considered to be in an 'unsatisfactory' position. Of these, eight originally had a space between the anterior border of the crypt of the third molar and the distal lamina dura of the second molar. The third molars were found to have uprighted by an average of twenty-one degrees in ninety-three of the one hundred and fourteen sites. It was noted that of the fourteen unsatisfactory lower third molars, thirteen showed no initial root formation. In contrast to Breakspear (1967), Lawlor (1978) found only four third molars erupted in a straight line.

Quinn (1985) believes that third molar development and eruption can be likened to a plant in a pot which is too small for it to allow root formation and growth. He recommends removal of second molars to provide space for the developing third molars “in an environment that provides good trabeculation and sufficient space for unimpeded growth’. It also facilitates the early eruption of the third molars. Basing his opinion from “over twenty years of experience”, Quinn (1985) believes the third molars will “assume their position in juxtaposition to the first molar in over seventy-five percent of cases” but he was unable to accurately predict which mandibular third molars would erupt into an upright position.

Cavanaugh (1985) examined the panoramic radiographs of twenty-five private practice patients for whom all four second molars were extracted. Follow-up time was twenty-two to eighty-four months. The investigation found all third molars erupting with changes in angulation relative to a long axis through the bifurcation of the lower first molars ranging from zero to forty-nine degrees. The second molars were extracted before evidence of root formation in the third molars. However, Gaumond (1985) advocated the enucleation of the second molar tooth bud “as soon as the presence of a non-ectopic and sound third molar germ was confirmable by radiography.” The twenty-two extractions produced nineteen satisfactory or very satisfactory (?) positioning of the third molars. Gaumond (1985) believes that as the third molar migrates mesially, the first molar distalises under the influence of the canines and premolars. He describes “systematically straightening lower third molar tooth buds” where a thirty degree inclination is present between the third molar cusps and the mandibular plane. One can only assume this is achieved surgically at the time of second molar enucleation although this is not explained. He also places a lower lingual arch in the mixed dentition to prevent mesial migration of the lower permanent first molars.

Dacre (1987) recalled one hundred and ten patients who, five years previously, had lower second molars extracted. Right and left lateral oblique radiographs and study casts were taken and compared with the initial records. The axial angulation of the lower third molar, the crown/root development of the lower third molar, the shortest distance between the developing lower third molar and the root of the adjacent second molar (Lawlor, 1978) and a space width ratio to determine the space available for third molar eruption were all measured in order to determine criteria to allow the clinician to predict the potential for adequate eruption of the lower third molars. Fig. 5. The results indicated that:

- The successful eruption of the third molar can occur from a wide range of sagittal angulations;
- The need for treatment at follow-up seemed to occur unilaterally and more often on the right;
- Full crown development of the lower third molar prior to second molar removal yielded the highest proportion of well-placed lower third molars. However, if other indications are evident, the clinician "should not be deterred by any stage from 'cusps joined' to 'distal root start'" Fig 6;
- The posterior position of the lower third molar indicated by the space between the developing third molar and the root of the second molar was the best predictor for the final third molar position in the radiograph;
- The amount of space available following loss of a lower second molar did not influence the final position of the third molar.

Dacre (1987) believes extracting premolars and having to close residual space anteriorly would, in some cases, be better treated with the extraction of second molars and the "less challenging" scenario of the mechanical uprighting of third molars.

Others have portrayed a less than favourable outcome for lower third molars following lower second molar extractions. Chipman (1961) does not recommend clinicians utilising this technique routinely. He believed that "adverse negative angles" followed by the erupting third molar, would often lead to a poor occlusal position and less than ideal interproximal contacts.

Brown (1974) presented a case which clearly described the progressive impaction of a third molar following lower second molar extractions. Interestingly, the contralateral lower third molar, which had a similar initial axial inclination to the occlusal plane, erupted uneventfully. He postulated that the loss of alveolar bone from the distal surface of the extracted lower second molar may be responsible for the mesial tilting of the lower third molar.

Haas (1986), in a scathing attack on the proponents of four second molar extractions, believed that any orthodontic technique should "withstand biologic scientific investigation or, for that matter, even the test of common sense." In a clever analogy, he described the extraction of second molars to allow uneventful eruption of the third molars as being "akin to someone disposing of a new Mercedes to make room for a Mini import rendered asymmetric by several accidents during shipment." He stated that the lower third molar "pivots" about the cortical plate provided by the root socket of the lower second molar and if this tooth is extracted the lower third molar will invariably tip as it erupts. Gnathologically inspired clinicians will also be tempted to extract any third molars which display a less than ideal occlusion leading to the removal of eight permanent teeth in total.

Gooris *et al.* (1990) analysed from consecutive panoramic radiographs the posteruptive position of the mandibular third molar relative to the position of the second molar at the time of extraction. In a sample of ninety-five patients, one hundred and forty sites were evaluated. The authors found that lower third molars would invariably erupt into a mesially tilted position. A discrepancy was observed in the tooth contact relationship between the first and third molars in over half of the sites evaluated. Indeed, eight percent of these sites exhibited open contacts. The implications for the health of the periodontium in this area is not clear. In conclusion, the investigators found that the lower third molars rarely erupted with proper angulations and tooth contacts following mandibular second molar extractions.

Staggers (1990) examined the records of twenty-two maxillary and mandibular second molar and twenty-two maxillary and mandibular first premolar extraction cases. From the evaluation of pre- and post-treatment panoramic radiographs, she found the mandibular third molar long axis to occlusal plane angle increased in the second molar group (as it did in the premolar group) indicating a poorer mandibular third molar angulation. As such, she could find no advantage to extracting second molars as opposed to first premolars to improve third molar angulation.

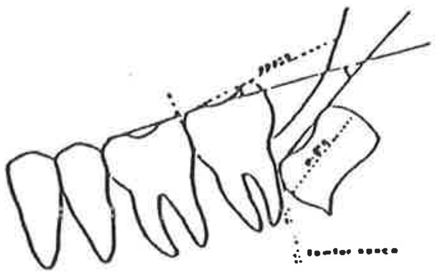


Figure 5 An illustration of how the shortest distance between the developing lower third molar and the adjacent second molar (Lawlor space) was measured by Dacre (1987)

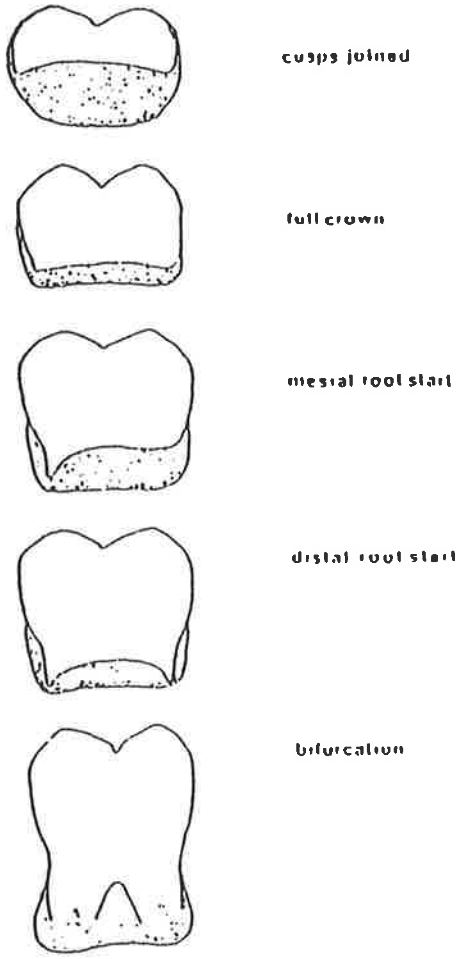


Figure 6 Crown-root developmental stages as determined radiographically by Dacre (1987)

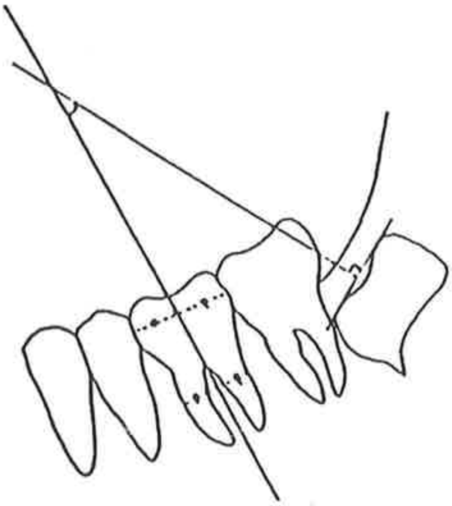


Figure 7 The method used by Cryer (1967) to determine the changes in angulation of 38 and 48 relative to the long axes of the bifurcations of 36 and 46

5.4 The Effect of Second Molar Extractions on Upper Third Molars

Goldberg (1967) believed that the extraction of maxillary second molars would help avoid the impaction of maxillary third molars.

Graber (1955b) felt that the extraction of maxillary second molars would alleviate the untoward sequelae of upper third molar impactions following the use of extra-oral distalising mechanics. Graber (1955a,b; 1969) believed that maxillary second molar extraction expedited the correction of Class II, Div. I malocclusions but required the presence of maxillary third molars in good position and of "proper size and shape." The third molars come forward to "take up the slack" in the maxillary arch with the mandibular third molars to be removed at a later date. He recommended the use of a fixed lingual arch to prevent the lower second molars over-erupting and creating functional occlusal disturbances.

Chipman (1961), documenting thirteen cases of maxillary second molar extractions, described the pattern of third molar eruption as being downward and forward. Furthermore, the third molar reportedly "rotates and tips mesially as it descends" and the greater the original distal angulation, the greater the amount of rotation. The second molars should be extracted when the occlusal surface of the third molar is level with the vertical midline of the second molar root (Magness, 1986). The angulation of the long axis of the third molar to the occlusal plane should be between zero and thirty degrees and the third molars tipped distally. Chipman (1961) also believed that the mesial surface of the maxillary third molar should be "fairly in line horizontally with the distal surface of the mandibular second molar." Ideally, the erupting third molar should contact the maxillary first molar and occlude with the lower second molar simultaneously. Magness (1986) believed there was "ample published evidence" that the maxillary third molar will erupt with the roots nearly the size and shape of the extracted second molar.

Basdra and Komposch (1994, 1996) examined the results of thirty-two maxillary second molar extraction cases to evaluate the position and anatomy of the erupted third molars from orthopantomographs and study models. The third molars were found to have mesial contact and "acceptable" axial inclination. Thirty-one of the thirty-four molars examined were positioned "satisfactorily" in the arch without need for further active repositioning. The third molars exhibited good periodontal status with no pockets or mobility. There appeared to be an improvement in the maxillary third molar angulation with an increase in the angle between the upper third molar and the occlusal plane. The size and shape of the third molars were acceptable in thirty patients with the crown size ranging from eight to ten and a half millimetres mesio-distally. The authors felt that it was easier to assess the form and size of the third molar in the later stages of development. The best results were observed (good axial inclination, early eruption) when the extractions were performed when the third molar crowns were positioned at the level of the crown-root junction of the upper second molars. Extractions completed earlier resulted in postponed third molar eruption and evaluation of the third molar anatomy was not as accurate.

5.5 Timing for the Extraction of Lower Second Molars

Breakspear (1967) recommends the lower second molar not be removed in cases where the roots of the lower third molars are more than half formed even if the angle of the third molar is considered "favourable."

Cryer (1967), in his investigation of sixty-six lower second molar extraction cases, could not define an optimum age when the extraction of lower second molars would ensure success of the overall treatment. However, the highest proportion of successful overall treatment results occurred when the lower second molar extractions coincided with complete crown formation of the lower third molars. There was no apparent connection "between the developmental position of the lower third molar in the vertical plane at the time of lower second molar extractions and the success of the overall treatment result."

Wilson (1971) commenting on his clinical experience of treating over five hundred cases, believes the second molars should be extracted as early as possible since the eruption of the third molars was very good irrespective of the apparent developmental position of this tooth. He believes "the critical time is when the roots of the third molars begin to develop."

Liddle (1977) would ideally wish to enucleate lower second molars. Because overcrowding begins when the lower second molars are erupting, this is the time that these teeth should be extracted. He believes children eight to ten years of age should be assessed for "developmental irregularities." If the clinician believes there is insufficient arch length and overcrowding developing, “serious consideration of second molar extraction is essential.”

Lawlor (1978), in an assessment of one hundred and fourteen lower second molar extraction sites, found a poor result in fourteen sites. Thirteen of these exhibited lack of third molar root formation at the time of the removal of the lower second molars and space between the third molar crypt and the lamina dura of the second molar.

Lehman (1979) believes the best results are obtained when the second molars are removed when the crowns of the third molars are fully formed but before any radiographic signs of root formation are evident.

Marceau and Trottier (1983) state that the third molar crowns should be sufficiently calcified to determine their size and position relative to adjoining structures. The authors felt that the lower third molars are likely to ‘tip’ if more than one-third of the root is evident.

Cavanaugh (1985) evaluated twenty-five second molar extraction cases and found all third molars had erupted “satisfactorily.” The second molars were extracted after one-third molar crown formation but *before* root formation.

Dacre (1987) found that full crown formation of the lower third molars was associated with the highest proportion of good treatment results following the extractions of lower second molars in one hundred and ten patients. It is believed that tipping of the lower third molar may occur if the lower second molar is extracted when the third molar is developing root bifurcation.

5.6 The Predictive Value of the Initial Angulation of the Third Molar

Chipman (1961) believed the angulation of the upper third molar should range from zero to thirty degrees (distal tip), this being the angle formed between the occlusal surface of the tooth and the occlusal plane. Any maxillary third molars with mesial tip are poor candidates for uneventful eruption.

Cryer (1967) suggested a higher proportion of good results when the angulation of the lower first to lower third molar is less than thirty degrees at the time of lower second molar extraction. Although not entirely accurate, it appeared that the greater the initial angulation of the lower third molar the less likely is the final position to be vertical. If the initial angle is greater than forty-five degrees then there was the possibility of converting a potential mesio-angular impaction into a horizontal one (Fig. 7, p.28).

Huggins and McBride (1978) measured the angle between the occlusal plane of the lower molars and the cusps of the lower third molars (McBride and Huggins, 1970). An angle of between twenty to sixty degrees had been found to indicate the likelihood of satisfactory third molar eruption.

Lawlor (1978) found little relationship between the angles 'before' and 'after' of the lower third molars where the lower second molars had been extracted.

Lehman (1979) felt that the best results were obtained when the long axis of the developing mandibular third molar made an angle of fifteen to thirty degrees with the long axis of the first molar.

Dacre (1987) found that successful eruption of the third molars can occur from a wide range of sagittal angulations and found generally initial lower third molar axial angulation a poor predictor of the final lower third molar axial angulation.

Gooris *et al.* (1990) concluded (as did Lawlor, 1978) that there was no association between the initial inclination of the third molar and its posteruptive position in the arch.

5.7 Extraction of Second Molars and the Effects on the Soft Tissue Profile

"The patient must be considered as a whole and cannot be separated from his dentition…nor can we decide for others what they may consider as pleasing as far as appearance is concerned" (Goldberg, 1967).

Several practitioners have proclaimed that the extraction of second permanent molars would have a beneficial effect on the dentofacial profile when compared to the alternative of premolar extractions.

Williams and Hosila (1976) found less incisor retraction occurred the further posteriorly extraction sites were located.

Liddle (1977) would rather treat his patients and finish with slightly protrusive profiles rather than "a concave, 'dished-in' appearance with loose contact areas, an unnatural smile and short second premolars where larger, more beautiful premolars should be located."

Marceau and Trottier (1983) believed the extraction of second molars not only improved but maintained good facial aesthetics. Unfortunately, no evidence is presented to support this claim.

Quinn (1985) stated that the extraction of four second molars improves or maintains good facial aesthetics and lessens the problems of "dished-in" faces.

Staggers (1990) in a comparison of premolar and second molar extraction groups, found an insignificant difference between the changes in facial convexity of the two groups. A decrease in skeletal convexity in both groups could explain the decrease in the soft tissue convexity angle.

The data from both groups (Staggers, 1990) also indicated little relationship between changes in the incisors and lip changes. Indeed, maxillary incisor retraction was greater in the premolar group but this did not lead to a corresponding decrease in upper lip protrusion. However, mandibular incisor retraction in the premolar group did lead to a significantly greater decrease in lower lip protrusion.

Basdra and Komposch (1996) evaluated several soft tissue changes following upper second molar extractions. They found the upper lip retracted relative to E-plane which the authors believed showed maxillary second molar extraction influences the soft tissue profile.

5.8 The Effect of Second Molar Extractions on the Duration and Complexity of Orthodontic Treatment

"This is not a rote in-and-out-in-two-years proposition. Recommending a procedure with objectives that will not be realised for five or ten years means a commitment on the part of the doctor and patient alike to follow through" (Thurow, 1985).

McBride and Huggins (1970) found, in an assessment of twenty patients who had second molar extractions, that appliances were not required to achieve the slight relief of dental crowding which was required in their sample.

Wilson (1971, 1974) believed that extraction of second molars instead of premolars allowed the clinician to avoid the use of fixed appliances but this should not be used as an excuse for low standards. He also believed treatment times were shortened by the extraction of second molars. This was achieved with extra-oral traction and removable appliances and produced "results" in a "remarkably short time." The patients are not discharged until all the third molars are erupted but, unfortunately, many fail to return.

Richardson (1975a) extracted first molars "as a simple interceptive measure" and none had any mechanical treatment. In an era when first molars exhibited a high caries rate, extraction of first molars achieved good arch alignment without orthodontic appliances. This knowledge could possibly be applied to other posterior arch extractions, namely second molar extractions.

Dacre (1987) in his sample believes one in five patients may require third molar uprighting to finish the cases. An ongoing recall strategy is recommended. Interestingly, the need for treatment appeared to occur unilaterally and more often on the right hand side.

Lehman (1979) believed that the extraction of premolars "always necessitates fully banded appliances to close the extraction spaces and to permit root paralleling." This treatment time may take up to two years. With second molar extractions and extra-oral traction, he feels treatment time is seldom more than one year. Marceau and Trottier (1983) concurs but also states that fixed mechanics may be necessary if the third molar fails to erupt into an "acceptable position."

Quinn (1985) in an assessment of "over twenty years experience" of second molar extractions, has reduced treatment time by half with a concomitantly reduced amount and duration of appliance therapy and less likelihood of relapse. The investigator does concede that it may be necessary in some cases to upright or reposition the third molars.

Magness (1986) questioned the premise of shorter times in that the third molars may not erupt for some time following active treatment. He believed treatment could not be concluded until the lower third molars were in occlusion or banded and aligned. A longer treatment time could be the result.

Staggers (1990) found that the length of treatment time is dependent on mechanics, patient cooperation and patient motivation. She found no significant difference in treatment times between those who had premolar extractions and those with second molar extractions. Including the time required in monitoring and possibly aligning the third molars, the actual length of treatment time in the second molar group should not be underestimated.

Basdra and Komposch (1996) emphasized the importance of patient motivation and cooperation in extraction treatment especially where extra-oral traction is being utilized. Second molar extractions are advantageous in that if the patient interrupts treatment the extraction spaces will close. The authors found that treatment times were not significantly different between premolar and second molar extraction groups. This does not consider the observation time involved in third molar eruption.

5.9 Advantages and Indications for the Extraction of Second Molars

Much of the literature describing the extraction of second molars is based on clinical impressions and case reports which are largely anecdotal. The following provides a resumé of the claimed advantages and indications of this treatment modality.

Reid (1957) believed second molars could be extracted in a "few marginal cases." This included situations where the distal segments had drifted forward following early loss of a deciduous molar and the subsequent distalising of the first molar with the second molar being extracted. This treatment modality assists the reduction of overbite and potentially eliminates the impaction of the third molar.

Graber (1955b, 1969) stated that in Class II, Division I cases, the extraction of maxillary second molars expedited treatment provided there was:

- an existence of excessive labial inclination of the maxillary incisors with no spacing;
- minimal overbite; and
- third molars are present.

Graber (1955b, 1969) thought there was less disturbance of the upper labial segment with fewer root movements required. He felt that mandibular incisor crowding occurred less frequently when compared with the extraction of premolars. The control of overbite was considered to be "easier."

Chipman (1961) described a method capable of "relieving the congestion in the maxillary tuberosity thereby aiding in the stabilization of the denture and at the same time replacing often decalcified and carious molars with sound tooth structures." The extraction of maxillary second molars is possible in all types of malocclusion. He described several indications for the removal of second molars and replacing them with third molars:

- maxillary third molars of fair size and shape with the possibility of good root development;
- small, restricted tuberosities and the possibility of interference with distal movement in the maxillary posterior region;
- second molars erupted buccally;
- second molars decayed, badly decalcified or having large restorations;
- maxillary third molars in favourable position and angulation relative to the second molar and the maxillary tuberosity;
- maxillary third molars in favourable relation to the mandibular second molars;
- desirability of relieving the anchorage units of an overload.

Brenchley and Ardouin (1968) following observations of a small (eight) sample of second molar extraction cases felt that:

- the extraction of lower second molars reduced the tendency to late imbrication of the lower labial segment but had an uncertain prognosis for satisfactory eruption of lower third molars;
- lower second molar extractions *may* halt the tendency to mesial drift, allow distal drift to lessen lower arch imbrication and *may* result in the direction of maxillary tooth movements having some influence on mandibular tooth movements.

Wilson (1971, 1974) believed that excellent results could be obtained with the extraction of second molars by simple means where the alternatives may be a compromised or prolonged treatment. He was particularly influenced by the treatment of temporomandibular disturbances but does not describe in his papers his findings compared with premolar extraction. The treatment resulted in:

- a reduction in the amount and duration of appliance therapy;
- a good, functional occlusion;
- good mandibular arch form;
- reduction in incisal overbite;
- disimpaction of third molars;
- less likelihood of relapse.

In Class I cases, Wilson (1971, 1974) used removable appliances in conjunction with extra-oral traction.

In Class II cases, Wilson utilised extra-oral traction combined with distal tilting of the first molars by fixed appliances.

In Class III cases the behaviour of the lower third molar varies more widely and can erupt without making contact with the first molar. If the upper arch is crowded the treatment is to align the arch and correct the incisal relationship by intermaxillary traction.

He found that a perfect lower arch form is produced in "a very high percentage of cases", the reduction of the overbite and stable results occurred in "a remarkably short time."

Huggins and McBride (1978) claimed the advantages of lower second molar extractions were:

- relief of mild crowding in the lower premolar area by distal movement if the lower first molar;
- no need for mechanotherapy;
- natural contact point relationships are retained from canine to lower first molar;
- surgical removal of lower third molars is avoided;
- lower labial segment alignment is maintained *but* not necessarily improved where lower incisors were initially imbricated.

The authors believed that the extraction of lower second molars resulted in decreased chairside time and a well-aligned lower arch which formed the basis for maxillary arch alignment.

Lehman (1979) claimed the extraction of second molars led to:

- a reduction in treatment time and complexity;
- increased stability of the treated occlusion;
- prevention of flaring-out of the second molars after headgear treatment.

Certain preconditions are also required, including:

- existing or anticipated arch length deficiency in the distal part of the dental arch;
- all third molars present and of normal size and shape;
- no congenital absence or loss of teeth elsewhere in the arch;
- optimal timing of extractions.

Lehman (1979) described specific malocclusions which would benefit from second molar extractions:

1. Skeletal Class I malocclusions with arch length deficiency in the distal part of the arch.
2. Skeletal Class I malocclusions with mild crowding in the anterior part of one or both arches.
3. Skeletal Class II malocclusions with mild crowding in the lower dental arch.

Headgear therapy should be instituted during the pubertal growth spurt to make full use of any orthopaedic treatment effects, prevent linguo-version of the upper incisors and a slight Class II relationship in the buccal teeth at the end of treatment.

Marceau and Trottier (1983) believed second molar extractions could be considered when there exists:

- Likelihood of the third molar impaction;
- Class I malocclusion with lack of space for the eruption of the second premolars;

- Class II malocclusions where distal movement of the molars is required;
- Class III malocclusions in order to reduce mandibular growth and prognathism;
- Temporomandibular joint problems where the third molars are causing crowding of the dentition and/or interference with the functional movement of the coronoid process.

Quinn (1985) cites a wide range of applications for second molar extractions including Class I. II, and III malocclusions, anterior open bites, deep overbites and some prognathisms (except bimaxillary prognathism). The treatment of anterior open bites is possible by moving the mandibular "fulcrum" forward and overbites are more easily controlled compared with first premolar extractions.

In Class III malocclusions, second molars are extracted to allow the third molars to erupt. This is also advantageous in "pseudo" prognathisms in cleft lip and palate patients. He also believed there were fewer problems with extraction spaces or diastemas anteriorly. Interestingly, Quinn (1985) felt that the extraction of premolars and the movement of broader molars into the narrower premolar region could result in bony and gingival recession.

Richardson and Mills (1990) believed the extraction of second molars could reduce the need for the surgical removal of third molars and thus provide economic and humanitarian benefits. The authors felt that second molars should be removed as an interceptive measure where third molars are developing in reduced space and for patients who had "an acceptable occlusion or a mild malocclusion for which they are unwilling to undergo mechanical orthodontic treatment."

Several authors have commented on the efficacy of upper second molar extractions. Magness (1987) believed that the best results are achieved with patients who have "good" facial profiles, low convexities, brachycephalic growth patterns and "little remaining growth potential" (*a contradiction?).* A Class II subdivision case could be treated with unilateral extraction of the upper second molar.

Basdra and Komposch (1994, 1996) stated that following upper second molar extractions, the maxillary first molars move posteriorly to correct the Class II malocclusion and any remaining space is occupied by the erupting upper third molar.

The posterior location of the extraction space can allow the patient to interrupt treatment with the upper third molar drifting mesially and closing space. The authors summarised the advantages of maxillary second molar extraction as:

- Reduction in treatment time and appliance use;
- Faster and less problematic distalisation of the upper first molars;
- Promotion of bite opening;
- Less adverse profile effects;
- Easier and more predictable maxillary third molar eruption.

5.10 Disadvantages and Contraindications for the Extraction of Second Molars

"Second molar extraction is not a panacea. It is an option that must be evaluated in the light of a detailed diagnosis." So proclaimed Quinn (1985) in a salutary reminder of the necessity to avoid the dogma of extraction versus non-extraction and to treat each individual case as an individual. Certain situations would contraindicate the extraction of second molars:

- small or poorly formed third molars;
- oversized third molars;
- third molars associated with the maxillary sinus;
- horizontal third molars;
- missing third molars;
- congenitally missing premolars or incisors;
- severe bimaxillary protrusion;
- severe space deficiency;
- need for extended orthodontic supervision through to third molar eruption;
- possible need for third molar uprighting, primarily in the lower arch;
- possible failure of third molar eruption.

Chipman (1961) believed a consideration of the contraindications for upper second molar extraction treatment were paramount, as if they are not considered treatment failure could be the result. These considerations included:

1. Maxillary third molars too high in the tuberosity.
2. Maxillary third molars too low in relation to the second molars.
3. Poor angulation in relation to the second molar and the tuberosity.
4. The possibility of the third molar involving the maxillary antrum.
5. Small or poorly shaped third molars with small roots.

Graber (1969) also commented on the pitfalls of upper second molar extraction treatment. He believed the poorest prognosis was for those with "severe basal dysplasias with vertically inclined maxillary incisors, no spacing and severe overbite." He recommended the use of a fixed lower lingual arch to prevent the overeruption of the lower second molars as this may cause a functional disturbance (Smith, 1996; Basdra and Komposch, 1994; Magness, 1986; Huggins and McBride, 1978).

Wilson (1971) reported several preconditions which are required for successful second molar extraction treatment including:

- Estimated patient cooperation;
- Health of the oral tissues including the teeth;
- The patient's domestic environment.

It would seem that these criteria would be important in any consideration of orthodontic treatment. He also describes a little-mentioned problem of the unknown quality of unerupted teeth especially the possibility of poorly calcified second premolars (*or, for that matter, third molars!*). There is some concern that the decalcified premolars would be prone to decay before full eruption and partially impact against the first molars with poor interproximal contacts being the result. He recommends a "careful radiographic technique and…more careful prophylaxis."

Gooris *et al.*, (1990) in an analysis of one hundred and forty mandibular quadrants where second molar extractions had been performed, found that ideal posteruptive position with good root parallelism between the first and third molars "is the exception rather than the rule." The third molars were found to invariably erupt into a mesially tilted position (Brown, 1974) with the possible sequelae of food impaction, periodontal breakdown and occlusal disturbances.

Basdra and Komposch (1994) summarised the disadvantages of upper second molar extractions and subsequent treatment as:

- More loss of tooth substance;
- Increased distance of the extracted teeth from the location of the crowding;
- Tendency of the lower second molars to overerupt;
- More need for patient cooperation.

The authors provide responses for possible problems which may arise during treatment including:

1. Lower second molar overeruption. The authors recommend a "lower holding plate" or lower fixed appliances;
2. Poor patient cooperation. The patient may be required to wear headgear so consider an alternative regimen if the patient is unable or unwilling to cooperate.
3. Unfavourable third molar eruption. This is thought to be a rare occurrence in the upper arch (Staggers, 1990).
4. Prolonged patient contact. The patient should be reviewed annually for maxillary third molar eruption and the patient should be referred for lower third molar extractions.

5.11 The effect of occlusally directed forces on the dental arch following dental extraction

Several authors have reported the "spontaneous" resolution of crowding in both the labial and buccal segments of the dental arches following extraction of teeth without mechanical intervention (Cryer, 1967; Richardson and Mills, 1990). However there is a dearth of evidence in the dental literature regarding the precise influences on the force(s) which may be responsible for these changes.

The concept of "mesial drift" of the human dentition and particularly of the permanent molars has long been acknowledged by most investigators (Sved, 1955;

Moss et al, 1959; Biggerstaff, 1967). Unfortunately, the exact mechanism of this drift is not yet fully understood.

Lusterman (1958) believed a "growth centre" existed distal to the permanent molars which acts as a wedging force as the second molar erupts. Hinrichsen (1962) stated that with early extraction of deciduous teeth, the permanent molar loses support and tips forward. However, not all researchers noted mesial movement only.

Liu (1949) noted that space closure may have been achieved by the erupting permanent incisors pushing adjacent teeth *distally* when the extraction occurred prior to their emergence. Love and Adams (1971) found a small percentage of cases achieving space closure from distal movement while most closed from the mesial direction. Salzmann (1938) revealed that 13.6% of his cases closed from the distal, 5.8% from the mesial and 67.6% closed from a combination of mesial and distal closure. Turner (1947) believed that the distal inclination of primordial tooth buds in their crypts may explain any measured clinical distal tooth movement. Ng (1971) stated that the mesial drift theory (as advocated by Brash, 1953) "cannot be applied totally in man because the predominant directions of tooth migration during the development of the dentition in man are *distal* for the deciduous mandibular canine, first molar, second molar and the permanent canine, first premolar and second premolar and *mesial* for the permanent first molar and second molar." Richardson (1965), in an experiment on rhesus monkeys following tooth extractions, concluded that teeth distal to an extraction site could move mesially, teeth mesial could move distally and both could occur simultaneously. "*Distal bodily movement definitely occurred.*"

In a recent study, Battagel and Ryan (1998) described the changes that occurred in the lower arches of forty-one patients with Class I or mild Class II dental relationships, about half of whom had lower second molars extracted and no mechanical treatment in the lower arch. "En-masse" retraction of the upper labial segments was completed with the use of extra-oral traction. Study casts were assessed before treatment, after upper buccal segment retraction and at the completion of all initial treatment. At the completion of upper buccal segment retraction, all measured parameters (including lower labial segment crowding, lower arch total crowding) showed favourable alterations. The authors suggest two reasons for this: firstly, "sympathetic movement" of the lower arch may have occurred while the upper dentition was being expanded and distalised. Secondly, extraction of the lower second molar may have facilitated buccal and distal drift (Richardson and Mills, 1990) in the molar region, allowing arch expansion, arch length increase and perimeter increase. The question remains: what factors are responsible for the observed "sympathetic movement" and "distal drift" of the labial and buccal segments?

Hunter (1778) first noted the horizontal migration of human teeth when he described the "drift which occurs following extraction of the first permanent molar". This "drift" is more properly termed "approximal migration" in man as the process can be observed not only mesially but in all planes.

Picton (1976) considered horizontal drift under three headings:

- Physiological Drift

In the human intact arch, migration occurs in a mesial direction as a result of approximal wear. Distal drift can also occur, for instance, where the distally inclined lower second premolar may come into contact with the lower second molar following extraction of the first permanent molar. Those communities with highly abrasive diets exhibit good examples of dental drift (Begg, 1954). With ongoing attrition the anatomical crown is eventually lost *but mesial drift still occurred* even though spaces appeared between the worn tooth fragments seen in the aboriginal adult skulls.

Brash (1927) in his studies of the pig and elephant found horizontal migration principally mesially. However, distal migration of the dentition has been reported in the rat (Sicher and Weinmann, 1944) and hamster (Kronman, 1971).

- Experimental and Orthodontic Drift

It does appear that once occlusion is established a tooth is in a stable position when the sum of the forces acting on the tooth is zero but minor changes of these forces cause the tooth to be displaced to a new balanced position. There may be a relation between "the rate of drift to the magnitude of the force change, the presence or absence of contacts between adjacent and opposing teeth and to the age of the individual." The tendency for teeth to approximate following extraction has been widely reported. The effect on transseptal fibres following extraction has been the development of substantial fibre bundles connecting the teeth and relapse of orthodontically treated teeth has been reduced by severing these and other fibre bundles with a scalpel (Edwards, 1971). Joho (1973) studied the influence of opposing teeth when distally directed forces on the lower first molars of monkeys caused sympathetic distal migration of the upper molars.

- Pathological Drift

Chronic periodontitis can be responsible for the spacing of teeth in the dental arch. Following firm contact between the teeth, with the onset of this condition, the teeth migrate away from each other. Picton (1976) believed that there may be a loss of continuity of the transseptal fibres holding the teeth adjacent one another while contraction of the remaining intact fibres draws the teeth apart. One can only speculate that a similar sequence is responsible for the distal drift of a lower first permanent molar following extraction of the adjacent lower second permanent molar.

In general, the changes observed in response to a pathological condition in the jaws support those seen in physiological and orthodontic drift. That is, the addition or removal of a force from a set of balanced forces allowing a tooth or teeth to drift until a balanced set of forces is once more achieved. Approximal drift allows maintenance of interdental contacts which assists the support of the teeth during mastication and protects the interdental soft tissues from undue trauma.

It is undisputed that approximal drift occurs in humans but the exact force or forces responsible are not completely understood. Several theories have been advanced (Moss, 1976):

- The Anterior Component of Occlusal Force

When the jaws close, because of their mesial angulation, the force is transmitted in an anterior direction. Angle (1907) advocated correct positioning of teeth during orthodontic treatment to limit relapse and noted the mesial axial inclination of human teeth. The anterior component of occlusal force is thought by some authors to be responsible for the mesial migration of teeth (Stallard, 1923; Dewel, 1949) and subsequent dental malalignment. Sassouni (1969) believed that when the palatal and mandibular planes are inclined the dentition is "squeezed out of the mouth" and that when the planes are parallel the dentition may drift distally.

Southard et al (1989, 1990) designed an experiment to measure the anterior force generated by a single tooth under an axial load and to quantify the distribution and dissipation of the force as it progressed anteriorly. The authors found that the magnitude of the anterior component of occlusal force was large and that it progresses anteriorly through the proximal tooth contacts and can pass beyond the midline to the contralateral side of the arch. The research also sought to determine if a relationship existed between the anterior force and dental malalignment. They found that a relationship may exist in those that clench, brux or load the posterior teeth for extended periods. The mandibular canines may tip mesially and crowd the lower anterior teeth.

Moss and Picton (1967, 1970) in a series of experiments on monkeys, found that the removal of an opposing tooth did not prevent the migration of teeth. The teeth without opponents moved more rapidly than those with opposing teeth. Interestingly, the upper and lower premolars which were inclined distally tended to then move distally.

- Axial Inclination of the Teeth

Dewell (1949) commented that mesial drift may be related to the angulation of the long axes of the teeth. Examination of the skulls of rodents and primates indicated that for incisors or buccal teeth, where proximal contacts were present, the long axes are inclined to a common centre and this inclination progresses towards the end of the row of teeth (Picton and Moss, 1974). The rat (Sicher and Weinmann, 1944) and the hamster (Kronman, 1971) have distally migrating buccal teeth where the roots are inclined distally and the most anterior of these teeth have the greatest distal inclination. A horizontal force component is said to develop in teeth which are inclined away from the vertical from biting forces and the repetition of such forces may be responsible for migration in the direction of tilt (Picton, 1962). Picton and Moss (1974) hypothesised that the direction and magnitude of approximal drift might exhibit a correlation with the direction and the degree of inclination of the tooth roots. In their study on nine adult monkeys and seventy pairs of “cheek teeth”, the authors were unable to establish a correlation between the angulation of the long axes between tooth pairs and the magnitude or direction of tooth migration. It has been noted that the maxillary molars in humans are inclined distally yet migrate mesially (Moss, 1976). Picton and Moss (1974) believed that the “axial inclination of the teeth may be important in the eruptive movements of a tooth but does not necessarily contribute to the approximal drift.”

- Soft Tissue Pressures

Richardson (1994), in a review of the ætiology of late lower arch crowding, concluded that “the dentoalveolar structures are responsive to soft tissue pressures and adapt to a position of balance between the muscles of the lips, cheeks and tongue.” Huckaba (1952) wrote that forward migration of human teeth is an abnormal process because of a “perverted oral musculature.” A normal oral musculature is said to prevent the forward movement of the labial dentition and mesial migration and the dental arch expands. Moss and Picton (1970) isolated the buccal teeth of primates from buccal and lingual soft tissue forces and did not find a significant reduction in dental drift and surmised that the muscular environment played an insignificant role in the migration of teeth (at least in adult monkeys).

Proffit (1978) believed that a slight imbalance of forces between the tongue on one side and the lips and cheeks on the other is normally present. The teeth “are stabilised against this imbalance by forces produced in the periodontal membrane by active metabolism.” Southard et al (1992), in measuring the interproximal force between teeth, showed the presence of a “continuous periodontal force acting to maintain the proximal contacts in a state of compression.” This, along with other forces, may exacerbate the development of late lower incisor crowding.

- Contraction of Transseptal Fibres

The transseptal fibre system is thought to stabilise teeth against separating forces. It is hypothesised that this fibre system maintains the approximal contacts of adjacent teeth with the long-term result of this force being interproximal contact slippage and arch collapse (Southard et al, 1992). The illustrative sobriquet “driftodontics” (Creekmore, 1982) was used to describe the effects noted in a case report by Miyajima and Nakamura (1994) following the placement of a “passive” lingual arch and the subsequent distal “drift” of the lower second premolar and first molar. The authors postulated that the effect of the pull of the transseptal fibres allowed the spontaneous distal movement of adjacent teeth. No evidence was supplied as to veracity of this assumption.

Picton and Moss (1973) and Moss and Picton (1974) have previously demonstrated on the divided molars of monkeys that trauma to the transseptal fibre system substantially reduced approximal drift for several weeks. Moss and Picton (1982), with the use of a capacitance transducer to measure the changes in distances between pairs of adjacent teeth following the removal of tooth contact in adult monkeys, noted that removal of the tooth contact allowed the transseptal fibre system to contract and produce approximation of the adjacent teeth.

Murphey (1970) stated that a break made in the transseptal fibre system temporarily stops the posterior teeth migrating mesially and this movement only returns when socket repair is complete.

In contrast to the findings of Picton and Moss (1974), van Beek (1979) compared the relative importance of the transseptal fibre contraction and the functional occlusion of adult monkeys. With the use of approximal and selective occlusal grinding, the second molars were found to migrate mesially faster than the first molars. On the side where the approximal contact remained intact between the first and second molars, the first molars tended to migrate faster on that side. This indicated a possible drift potential transferred by approximal contact explained by a horizontal vector of occlusal forces rather than any transseptal fibre contraction.

It would appear that the best current models used for the understanding of approximal drift in humans are from animal models, particularly rats. Rat molars are said to provide a good model for the study of physiological drift because they have a similar histological structure to human teeth and, as with humans, they continually erupt with their investing tissues (Robinson and Schneider, 1992). Robinson and Schneider 1992), demonstrated that supracrestal fibrotomy resulted in a significant decrease in the distal migration rate of rat molars. The authors stated that the transseptal fibres act primarily on the teeth, affecting the rate of drift and secondarily affecting the rate of alveolar bone remodelling in the socket.

Moss (1976) concluded that there appeared little doubt that the transseptal fibre system "is of considerable importance in the causation of approximal drift." Human clinical conditions (such as lower incisor crowding) can be explained on the basis that the transseptal fibre system draws neighbouring teeth together. One can only surmise the effect that transseptal fibres and functional influences (both hard and soft tissues) may have on a first permanent molar (and other adjacent teeth) following extraction of a second permanent molar and the subsequent effects (if any) on the erupting permanent third molars.

5.12 The pattern of human tooth eruption

The description of the process of tooth eruption has been addressed by various authorities over a long period.

Darling and Levers (1975) attempted to rationalise the numerous theories into five interrelated stages of the eruptive process:

- Concentric growth of the tooth follicle;
- Bodily movement of the tooth until it reaches the occlusal plane;
- Equilibrium with no occlusal movement of the tooth;
- Second phase of bodily tooth movement associated with the adolescent growth spurt;
- Further equilibrium achieved at about eighteen years of age and continuing into adulthood.

Steedle and Proffit (1985) further delineated the bodily movement of a tooth toward the occlusal plane to reflect the different rates of eruption before and after emergence into the oral cavity. The authors defined eruptive movements in six phases: three prefunctional and three postfunctional eruption stages. These were:

- Follicular growth;
- Pre-emergent eruptive spurt;
- Post-emergent eruptive spurt;
- Juvenile occlusal equilibrium;
- Circumpubertal occlusal eruptive spurt;
- Adult occlusal equilibrium.

Generally, tooth eruption can be divided into three distinct yet continuous phases: the pre-eruptive phase, the eruptive phase and the intraoral phase.

1. PRE-ERUPTIVE PHASE

During this phase the tooth is in its intraosseous position and there is concentric growth of the tooth within its follicle.

From studies of the alveolar crypts, human teeth can demonstrate axial movement towards the occlusal plane (Darling and Levers, 1976). There is some drifting and tilting of the teeth during this stage. Baume (1953) described distolingual deposition of bone within the crypts of lower permanent incisors in monkeys commensurate with a forward and lateral relocation.

2. ERUPTIVE PHASE

This period involves axial movement of the teeth toward the oral cavity (Steedle and Proffit, 1985). Root formation continues and the tooth moves occlusally. This is a period of increasing rate of eruption as the tooth approaches the surface.

Darling and Levers (1976) noted that the rates of eruption for different teeth were variable, ranging from 3.5mm per year for the lower permanent second premolar to 1.2mm for the permanent lower third molar.

Fletcher (1963) demonstrated that teeth erupt along a path of least resistance producing tilting movements of the erupting dentition.

Di Biase (1976) observed the eruption patterns of upper permanent central incisors following the removal of adjacent supernumerary teeth. He concluded that the eruption pattern was curved if the upper incisor was initially inclined mesially or distally. Do other teeth demonstrate a similar pattern of behaviour; for example, the lower third molars following extraction of an adjacent pre-molar or molar?

3. INTRAORAL PHASE

The rate of eruption is greatest at the time of gingival emergence (Burke, 1963). The rate then slows as the tooth nears the occlusal plane and comes under the influence of masticatory and intraoral forces.

Berkowitz and Bass (1976) quantified the rates of emergence of the upper third molars in a group of 19 years old students. With available space, the maximum rate of eruption was 1mm every 3 months. If crowded, the rate was 1mm every 6 months.

Steedle and Proffit (1985) delineated the intraoral equilibrium of tooth eruption into three phases:

- *Juvenile occlusal equilibrium*

Occlusal movement is reported to stop for several years while the occlusal plane stays at the same distance from the inferior alveolar canal (Darling and Levers, 1976). This is a period of relative "quiescence" which ends at the beginning of puberty;

- *Circumpubertal occlusal eruptive spurt*

Then teeth begin a second phase of active eruption which lasts 2-3 years between 11 and 16 years of age (Darling and Levers, 1975). The facial and masticatory muscles lengthen which lowers the mandible and soft tissues while alveolar growth maintains the freeway space. This phase slows as the face reaches maturity and a "state of equilibrium" is established at about 18 years of age;

- *Adult occlusal equilibrium*

There is evidence of small eruptive movements throughout the life of a tooth (Ainamo and Talari, 1976). Teeth follow a mesio-occlusal eruptive pattern with varying amounts of interproximal wear (Begg, 1954; Murphy, 1959).

In addition to occlusal movements of the teeth, tilting and approximal movements also occur (see section 5.11). The actual rates of drift (primarily mesial) in humans varies according to age, diet, tooth dimensions and the methods of measurement utilised. The rates of "drift" of mandibular teeth are believed greater than the rates for maxillary teeth (Moxham and Berkovitz, 1995).

Lateral drift of the teeth occurs during the development of both dental arches in humans. In modern humans, the final arch width in the canine, premolar and molar regions is completed by 12 to 13 years of age. Relatively small increases in arch dimensions occur after the eruption of the permanent teeth (Sillman, 1964).

5.12.1 The pattern of third molar development and eruption

Little has been written regarding the early stages of development and subsequent axial eruption of both the upper and lower third molars. Certainly, the permanent third molars (apart from their possible role in late lower arch crowding) could be seen as the "poor cousins" of human dental development.

In comparison with the development and eruption of the rest of the permanent dentition, the development of the lower third molars occurs over an extended period.

The third molars are the most commonly agenic teeth in humans (Garn et al, 1962). The age at which the third molar develops, however, is important to the orthodontic practitioner.

Adamson (1962) believed that the third molar crypts do not appear radiographically until 9 or 10 years of age. Garn and Lewis (1962) found that the "critical age" after which third molars would not develop to be 14 years of age. Garn et al (1962) stated that most third molar crypts appear radiographically at 8 years of age.

Gravely (1965) examined the radiographs of 550 children aged 6 to 15 years and noted radiographic evidence of third molar development at 7 years of age. The "peak" formation period was at 9 years of age and third molar formation had "virtually ceased" at 14 years of age.

The lower third molar develops in the ramus of the mandible with its occlusal surface facing upwards and forwards. With the availability of space, the tooth uprights as it begins its eruption process (Richardson, 1970). To gain a "normal" occlusal relationship, the uprighting movement will be of a greater or lesser degree depending on its original angulation to the mandibular plane (Richardson, 1978).

In the early stages of its developmental course, the lower third molar crypt lies on the bone surface, "submerging as it calcifies" (Richardson, 1970). Tait and Williams (1978) believed that the orientation of a lower third molar crypt was determined by the slope of the bone surface where the crypt initially formed. It has also been claimed that "as the bone surface behind the lower permanent second molar curved upwards, the further back the third molar crypt develops the more severely tilted it [the third molar] is likely to be, and vice versa" (Tait, 1982).

The per-eruptive movements of the lower third molar have attracted some investigation.

Broadbent (1943) stated that "important changes in the axial inclination of the mandibular third molar take place between the age of 16 to 18 years when the roots of these teeth move abruptly forward in the bone…"

Silling (1973) believed that third molar uprighting occurred only when the erupting tooth had made "contact" with the adjacent second molar.

Richardson (1978) radiographically examined the angular changes of the developing and erupting lower third molar in 3 groups. The first group was that of 11 third molars which had uprighted and erupted from an initial angle of 45° or more to the mandibular plane. Group 2 had 8 third molars which remained in their original angular position and had become impacted. The third group had 10 third molars which had undergone "reverse" angular changes and become prostrate. These were either severe mesioangular or horizontal impactions. Richardson (1978) found that the mesial and distal root and crown surfaces of lower third molars did not always develop at the same rate. It was postulated that "differential growth was the factor responsible for the changing angulation of the tooth." She also found that:

- The developing lower third molar is continually changing its angular position relative to the mandibular plane and adjacent teeth;
- For normal uprighting and eruption, the mesial root [of the third molar] must dominate;
- Without sufficient space, uprighting movements will lead to mesioangular impaction;
- Continued growth of the mesial root leads to vertical and distoangular impaction;
- Continued growth of the distal root may lead to severe mesioangular or horizontal impaction.

Several authors have attempted to define "predictors" in order to determine at an early stage of development which third molars will become impacted.

Björk (1956) described several factors responsible for a lack of space for the lower third molar including; a reduced rate of growth in mandibular length; vertical condylar growth; a backward direction of the eruption of the dentition and retarded maturation of the dentition.

Richardson (1975b) radiographically compared 2 groups; one with impacted third molars and the other group whose lower third molars had erupted. She found a significantly higher developmental angulation of the third molar to the mandibular plane in the impacted third molar group. The mandible grew significantly more in the erupted third molar group. It was concluded that "a steeply angled developing lower third molar has a greater than average chance of becoming impacted particularly in the absence of extraction."

In a follow-up assessment, Richardson (1977) found that a skeletal Class II dental base relationship with a shorter, narrower, more acutely angled mandible was found in association with impacted third molars at age 18 years. There was also a tendency for the impacted third molars to be slightly larger than those which had erupted. Unfortunately, accurate prediction of third molar impaction from radiographic measurements is not possible at age 10 to 11 years.

Haavikko et al (1978) studied the eruption pattern of third molars from orthopantomographs. The authors could not predict a favourable path of eruption from an assessment of the size of the gonial angle or the angulation of the adjacent lower second molar. The most valuable variable was the initial angulation of the lower third molar. The smaller the initial angulation (to the mandibular plane), the greater the chance the tooth would erupt favourably. It was also found that the chances of a lower third molar erupting were occasionally increased by the extraction of premolars.

Tait (1982) compared 2 groups of children aged 10 to 13 years radiographically, one group having lower second deciduous molars present, the other showing mesial migration of the lower first permanent molars and impaction of the second premolars following early extraction of the lower second deciduous molars. It was found that a majority of children who have early removal of lower second deciduous molars have lower third molars which are less tilted than those children whose deciduous molars are present. This may support the hypothesis that "the early forward movement of posterior teeth improves the position of lower third molars by allowing their crypts to develop further forward and consequently attain a more upright position." One may postulate whether this early extraction may also apply favourably to the early extraction or enucleation of the lower permanent second molars.

Garn et al (1962) investigated a possible genetic basis for the impaction of lower third molars. The authors radiographically investigated the developmental interrelationships between calcification and movement and relationships with measures of physical maturation of the lower third molar tooth. They found an absence of any sexual dimorphism in calcification or movement of the third molar as opposed to all other permanent teeth which tended to form and erupt earlier in females. It was also established that a late calcifying tooth would be similarly late in eruption time. The authors speculated whether the delayed or impacted third molar tooth may be determined genetically and whether the general population tendency towards earlier sexual maturation has had an effect on the eruption of the lower third molar tooth.

Efstratiadis et al (1984) stated that it was unknown whether the inclination of the developing mandibular third molar is mainly under genetic or environmental influences. The authors radiographically measured the anterior and medial inclinations of third molars from 10 to 18 years of age in monozygotic twins. They found that "normal" third molars had mesial and lingual inclinations from which they gradually uprighted during their eruptive movements. This process had a consistent left-right symmetry. The findings demonstrated a close correlation in the development, initial position and uprighting of lower third molars in monozygotic twin pairs. This would "strongly suggest a major genetic impact on the normal course of third molar development and eruption toward its emergence with a minor environmental contribution."

6. Materials & Methods

6.1 Sample

The sample for the present investigation was drawn from the patient records of a specialist orthodontic practitioner in Adelaide, South Australia. The cephalometric and study model records of forty-five patients (nineteen males and twenty-six females) were evaluated. The following criteria were set down for selection of the subjects to be included in the final sample:

1. Complete record documentation of treatment by the operator;
2. Full fixed appliance therapy utilising the TipEdge™ bracket (TP orthodontics) with minimal or no use of inter-maxillary elastic traction;
3. Each member of the sample had all four permanent second molars removed during the course of treatment. The presence of all four permanent third molars was a requirement for selection in the sample;
4. Pre-treatment and end of treatment lateral cephalometric radiographs (see points 5. and 6.) and study models (see points 7. and 8.);
5. Pre-treatment lateral cephalometric radiographs taken within six months of the start of fixed appliance treatment. The average time between the pre-treatment lateral cephalogram and full fixed appliance placement ("lead" time) was 123 days for females and 142 days for males;
6. End of treatment lateral cephalometric radiographs taken within six months of fixed appliance removal. The average time between the end of treatment lateral cephalogram and removal of full fixed appliances ("lag" time) was 38 days for females and 47 days for males;
7. Pre-treatment study models taken before the start of fixed appliance treatment;
8. End of treatment study models taken on the day of fixed appliance removal.

The average age of the female sample at the start of treatment was 13.8 years with a range of 12.1 years to 17.7 years. The average age of the male sample at the start of treatment was 13.9 years with a range of 12.1 years to 15.6 years. The average total treatment time from the placement of fixed appliances to the removal of fixed appliances for females was 1.7 years with a range of 1.0 years to 2.4 years and for males was 1.7 years with a range of 1.1 years to 2.9 years.

Four second permanent molars were normally removed either just prior to fixed appliance treatment or when the state of dental development was deemed appropriate by the operator.

The classification of the malocclusion type was operator dependent and documented by angle classification (Angle, 1907), overbite and overjet. However, the malocclusions were reassessed by statistical retrospective analysis of the cephalograms and study model measurements.

6.2 Radiographic technique

Lateral cephalograms were obtained from the records held at two suburban locations of the specialist orthodontic practitioner, Dr Colin Twelftree. The radiographs were exposed at one of four radiology centres in Adelaide. Complete standardisation of the cephalograms was not feasible but the presence of a metric ruler exposed in the mid-sagittal plane of each radiograph enabled a calculation to be made of the magnification error for each individual radiograph.

The calculation for the magnification error was completed with the use of the following equation:

$$\%\ \text{magnification} = \left(\frac{Lc}{Li} - 1\right) * 100$$

where: Lc = length of metric ruler as measured on lateral cephalogram

Li = inferred original length of metric ruler according to scale

Table 1 Cephalometric radiographic sources

Cephalometric radiographic sources

Radiology centre	Number of cephalograms	% magnification range	% magnification mean
Miller & Moore	32	6.9 – 11.7	8.0
R. MacDonald & Associates	15	8.0 – 9.9	8.9
Benson & Partners	11	10.0 – 15.1	12.4
Jones & Partners	32	6.6 – 9.4	7.6

6.3 Tracing technique

All radiographs were traced under standardised conditions in a darkened room using a viewing light box with opaque sliding screens to reduce peripheral light in the immediate area of interest. Each tracing was completed with the use of acetate sheets (3M™ Unitek Cephalometric Tracing Acetate) using a 0.3mm mechanical pencil.

The landmarks (Fig 8) for each cephalogram were traced in one sitting.

6.4 Cephalometric landmarks

The following describes the cephalometric landmarks used (in order of digitisation):

Table 2 Cephalometric landmarks

Number	Hard tissue landmark name	Abbreviation
1	Sella	S
2	Nasion	N
3	Orbitale	Or
4	Porion	Po
5	A point	A
6	B point	B
7	Anterior nasal spine	ANS
8	Posterior nasal spine	PNS
9	Upper incisal edge	U1E
10	Upper incisal apex	U1A
11	Upper molar distal cusp reference point	UM

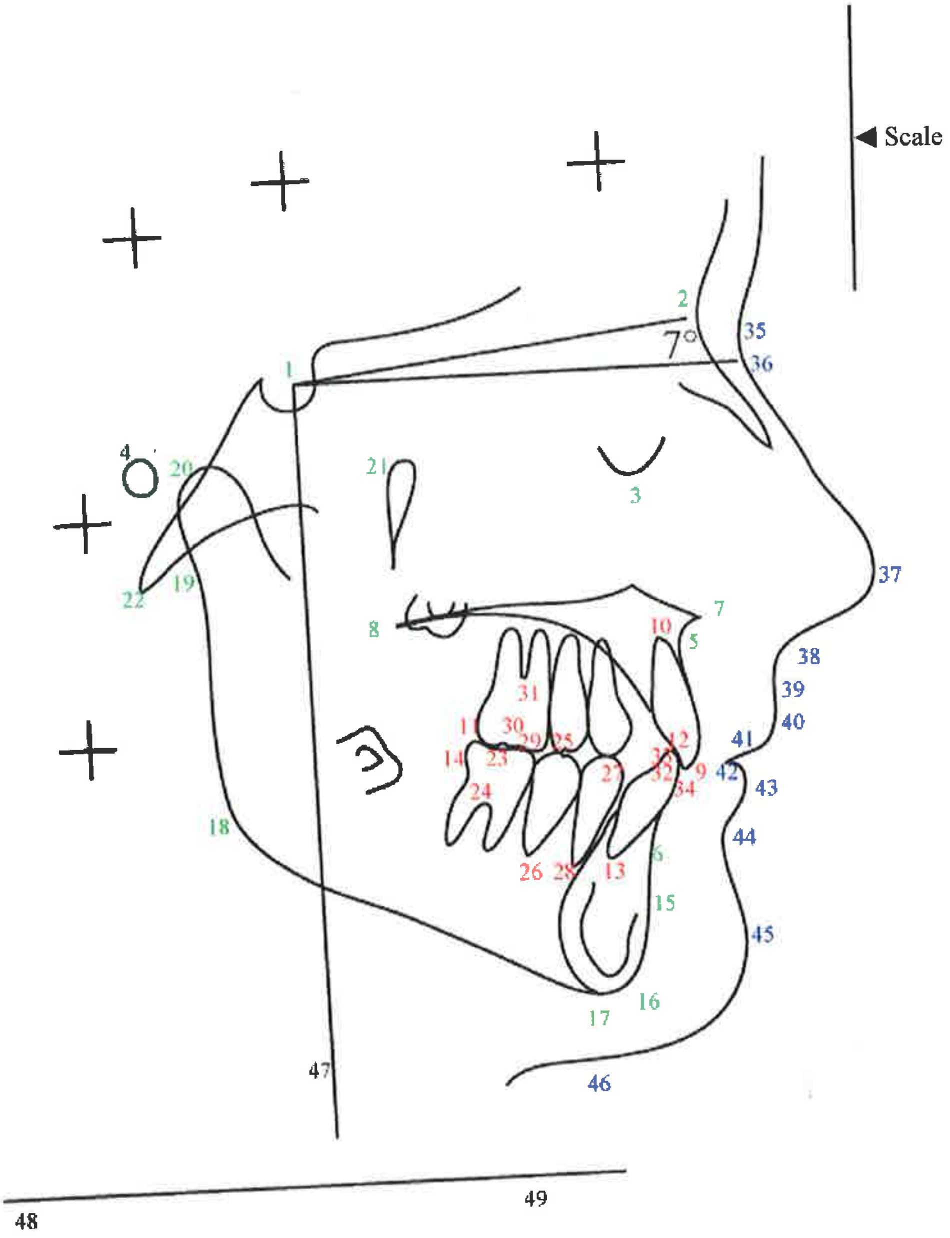
Table 2 (continued)

Cephalometric landmarks

12	Lower incisal edge	L1E
13	Lower incisal apex	L1A
14	Lower molar distal cusp reference point	LM
15	Pogonion	Pog
16	Gnathion	Gn
17	Menton	Me
18	Gonion	Go
19	Articulare	Ar
20	Condylion	Co
21	Pterygo-maxillary fissure	PTM
22	Basion	Ba
23	Lower molar crown centre	LMC
24	Lower molar bifurcation	LMF
25	Lower second premolar cusp tip	L5E
26	Lower second premolar apex	L5A
27	Lower first premolar cusp tip	L4E
28	Lower first premolar apex	L4A
29	Posterior Downs point	PDP
30	Upper molar crown centre	UMC
31	Upper molar trifurcation	UMF
32	Most prominent labial point of lower incisors	L1L
33	Anterior Downs point	ADP
34	Intersection of perpendicular lines through U1E and L1E	L1C
	Soft tissue landmark name	
35	Soft tissue nasion	ST N
36	Point of intersection of SN 7 on soft tissue profile	ST 7
37	Nasal tip	N tip
38	Subnasale	Sn
39	Sulcus superius	Ss
40	Labrale superius	Ls
41	Most inferior point of upper lip	ULL
42	Most superior point of lower lip	LLH
43	Labrale inferius	Li
44	Sulcus inferius	Si
45	Soft tissue pogonion	ST Pog
46	Soft tissue menton	ST Me
47	Point on sella vertical	Y axis
48	X axis origin	X1
49	X axis terminal	X2

Complete cephalometric landmark definitions are contained in Appendix I and the points used to construct both the hard and soft tissue variables are located in Appendix II.

Figure 8 Cephalometric landmarks



Skeletal landmarks
Dental landmarks
Soft tissue landmarks
Superimposition landmarks

The following describes the hard tissue cephalometric variables and abbreviations:

Table 3 Cephalometric landmarks and abbreviations (hard tissues)

Number	Hard tissue variable	Abbreviation
1	Sella-nasion to Frankfort horizontal	SN-FH (°)
2	SNA angle	SNA (°)
3	Maxillary plane to sella-nasion	MaxPl-SN (°)
4	Maxillary length	Co-A (mm)
5	Upper incisor to sella-nasion	U1-SN (°)
6	Upper incisor to NA angle	U1-NA (°)
7	Upper incisor to NA distance	U1-NA (mm)
8	Upper incisor to maxillary plane angle	U1-MaxPl (°)
9	Inter-incisal angle	U1-L1 (°)
10	Overjet	OJ (mm)
11	Overbite	OB (mm)
12	ANB angle	ANB (°)
13	Lower incisor to NB angle	L1-NB (°)
14	Lower incisor to NB distance	L1-NB (mm)
15	Lower incisor to mandibular plane angle	IMPA (°)
16	Lower incisor apex to mandibular plane distance	L1-MP (mm)
17	SNB angle	SNB (°)
18	True mandibular length	Co-Gn (mm)
19	Mandibular length	Ar-Gn (mm)
20	True ramus height	Co-Go (mm)
21	Ramus height	Ar-Go (mm)

Table 3 (continued)

Cephalometric variables and abbreviations (hard tissues)

22	Upper anterior face height	UFH (mm)
23	Lower anterior face height	LFH (mm)
24	Anterior face height ratio	UFH:LFH
25	Total anterior face height	N-Me (mm)
26	Posterior face height	S-Go (mm)
27	Posterior to anterior face height ratio	PFH:AFH
28	Frankfort horizontal to mandibular plane angle	FMA (°)
29	A point to sella vertical	A-S vert (mm)
30	B point to sella vertical	B-S vert (mm)
31	Pogonion to sella vertical	Pog-S vert (mm)
32	Lower molar to sella vertical	LM-S vert (mm)
33	Upper molar to sella vertical	UM-S vert (mm)
34	Lower molar to mandibular plane angle	LM-MP (°)
35	Lower second premolar to mandibular plane angle	L5-MP (°)
36	Lower first premolar to mandibular plane angle	L4-MP (°)
37	Upper molar to palatal plane angle	UM-PP (°)
38	Sella-nasion to Downs occlusal plane angle	SN-OP (°)
39	Mandibular plane to Downs occlusal plane angle	MP-OP (°)

The following describes the soft tissue cephalometric variables and abbreviations:

Table 4 Cephalometric variables and abbreviations (soft tissues)

Number	Soft tissue variable	Abbreviation
40	Facial convexity	F. conv.(°)
41	Nasolabial angle	N-L ang. (°)
42	Labiomental angle	L-M angle (°)
43	Holdaway's harmony angle	H angle (°)
44	Upper lip thickness	Ls-A (mm)
45	Lower lip thickness	Li-B (mm)
46	Soft tissue total face height	ST TFH (mm)
47	Soft tissue upper face height	ST UFH (mm)
48	Soft tissue lower face height	ST LFH (mm)
49	Soft tissue lower face percentage	ST LFH %
50	Upper lip (Ls) to E line	Ls-E line (mm)
51	Lower lip (Li) to E line	Li-E line (mm)
52	Upper lip length	ULL (mm)
53	Lower lip length	LLL (mm)
54	Soft tissue anterior face height	STPog-STN (mm)
55	Subnasale to sella vertical	Sn-S vert
56	Sulcus superius to sella vertical	Ss-S vert
57	Labrale superius to sella vertical	Ls-S vert
58	Labrale inferius to sella vertical	Li-S vert
59	Sulcus inferius to sella vertical	Si-S vert
60	Soft tissue pogonion to sella vertical	STPog-S vert

6.5 Superimposition technique

The method of superimposition for the pre-treatment and post-treatment lateral cephalograms was based on the structural superimposition technique employed and described by Björk (1968) and Björk and Skieller (1983). This was applied to the cranial base and mandibular superimpositions.

This method was chosen as the structural method since it was based on a long-term, longitudinal investigation of patients with fixed metallic implants and serial radiography. The technique is based on the observations of De Coster (1952) questioning "the immutability of the basicranial line." The superimposition of tracings on the pituitary fossa and the cribriform plate was described by Keith and Campion (1922).

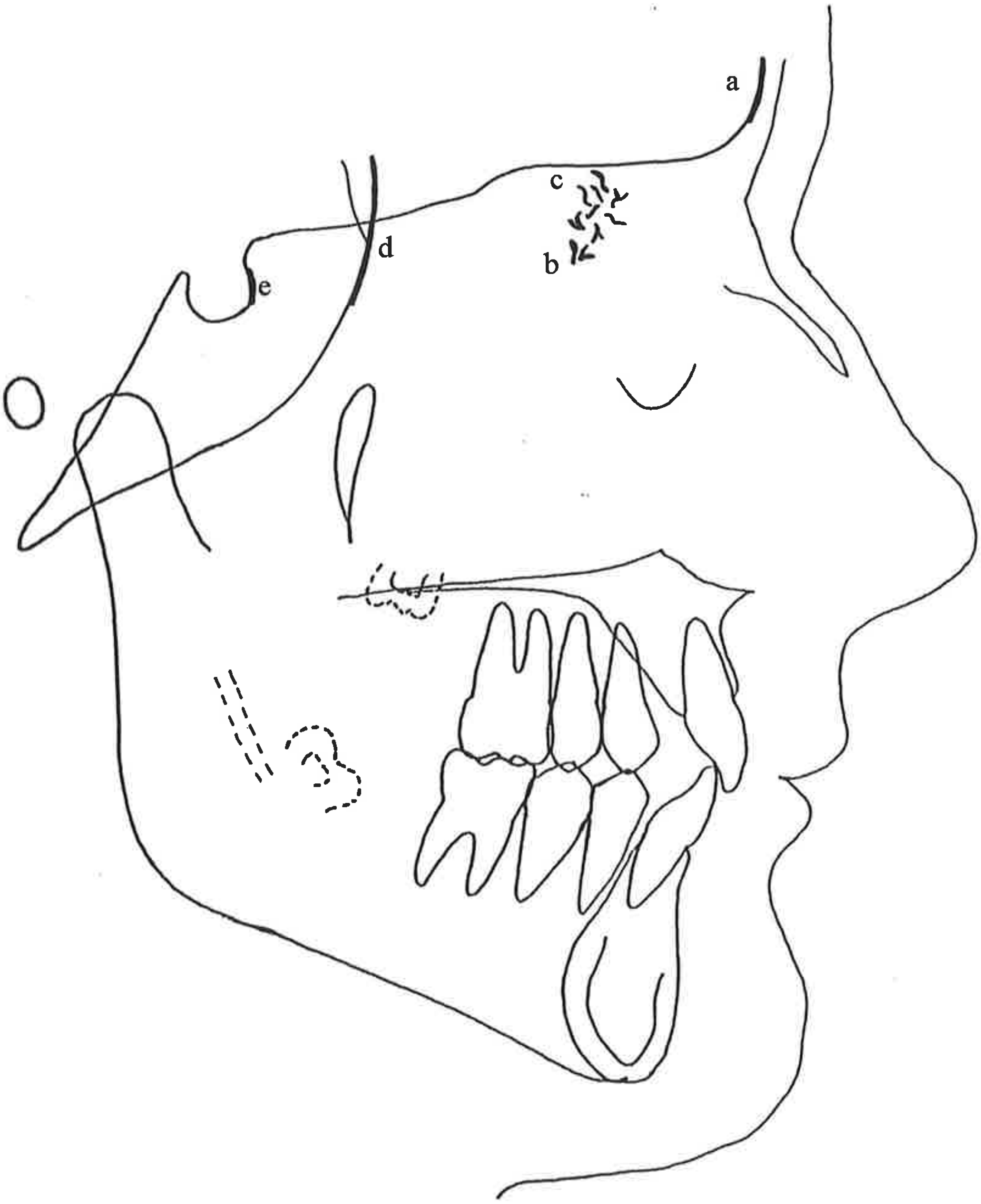
The cranial base superimpositions (Fig 9) were based on natural reference structures:

1. *Sagittally*
    - Contour of the anterior wall of the sella turcica;
    - Anterior contours of the middle cranial fossa.
2. *Vertically*
    - The mean intersection point of the lower contours of the anterior clinoid processes and the contour of the anterior wall of the sella;
    - The coincidences of the cribriform plates;
    - Trabeculations of the ethmoid bone & anterior cranial base.

The mandibular superimpositions (Fig 10) were based on the following natural reference structures:

- The anterior contour of the chin.
- The inner contour of the cortical plate at the lower border of the symphysis;
- Trabeculations in the symphysis;
- The contour of the mandibular canal;
- The lower contour of a molar tooth germ *before root development begins.*

Figure 9 Cranial base superimposition reference structures



a. anterior, inner surface of the frontal bone

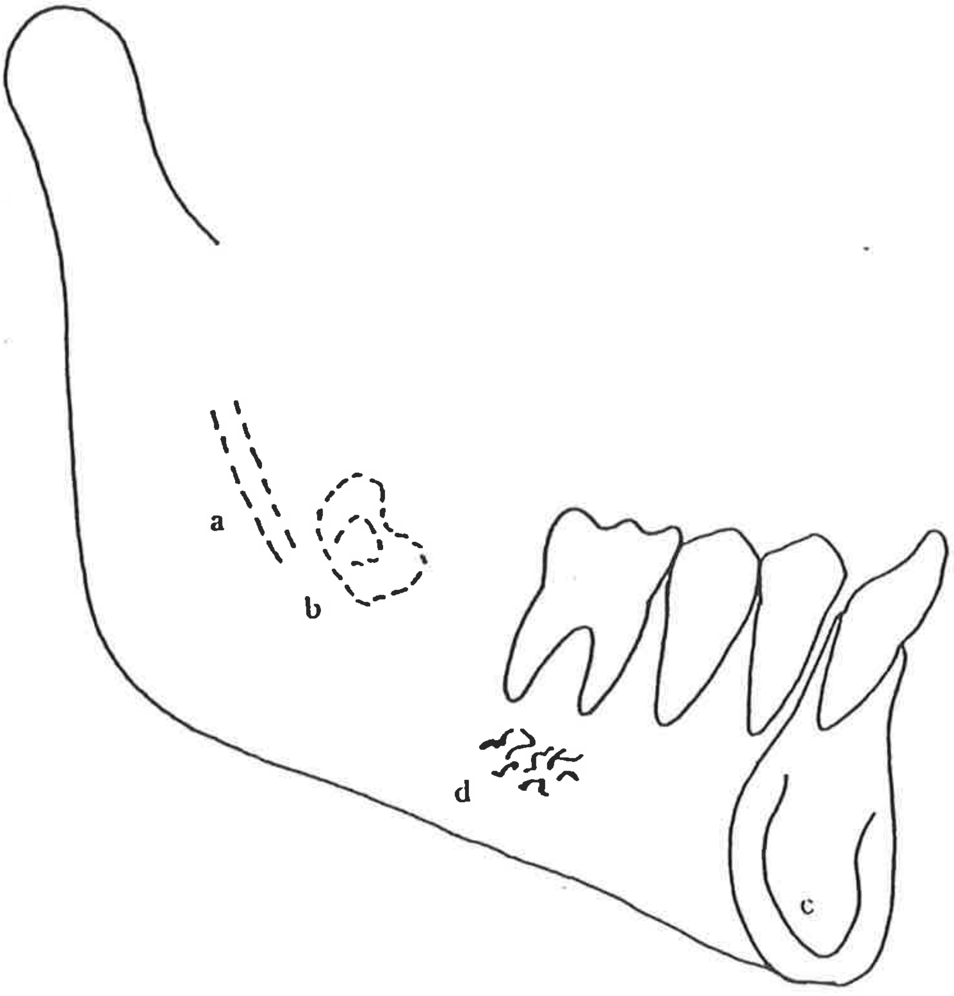
b. trabeculations of the ethmoid bone

c. coincidences of the cribriform plate

d. greater wing of the sphenoid bone

e. anterior surface of sella turcica (adapted from Björk and Skieller, 1983)

Figure 10 Mandibular superimposition references structures



a. the contour of the mandibular canal

b. the lower contour of unerupted third molar crypts

c. trabeculations in the symphysis

d. bony trabeculations (adapted from Björk and Skieller, 1983)

Björk and Skieller (1983) described in some detail the preferred method of superimposition technique. A line was drawn through nasion-sella and a vertical line constructed through sella point directly on the initial radiograph. The subsequent radiographs were superimposed according to the structures on the first radiograph, as described above. The sella point and the constructed crosslines were then transferred from the first to the subsequent radiographs. So when nasion (for instance) is displaced vertically during growth it is projected onto the transferred nasion-sella line.

The current investigation used the same premise of transfer between pre-treatment and post-treatment lateral radiographs and utilised fiducial markers as the preferred method of structural transfer, described below:

For each radiograph, five (or more) "+" symbols were placed on the radiograph in a widely distributed pattern (e.g three in the cranial vault, one adjacent the first and second cervical vertebrae) and transferred to the tracing medium.

The following tracing protocol was observed:

1. The pre-treatment lateral cephalogram was placed on the viewing lightbox and firmly secured with clear cellotape;
2. An acetate sheet was placed and secured on the radiograph, the cephalometric tracing completed (as described) and the five fiducial landmarks (T1) transferred to the acetate;
3. The post-treatment lateral cephalogram was placed on the viewing lightbox in the same manner as 1., traced and fiducial landmarks transferred to the acetate (T2);
4. The pre-treatment radiograph was replaced on the viewing box and secured as described. The post-treatment radiograph was then overlaid on the pre-treatment radiograph according to the anatomical structural method of Björk (1968);
5. The post-treatment acetate tracing was then secured with cellotape over the post-treatment radiograph adjacent the original fiducial landmarks on the post-treatment radiograph and the T1 fiducial markings transferred to the T2 acetate overlay;
6. The fiducial markings were clearly labelled to prevent any confusion regarding their origin (that is, T1 or T2).

The identical protocol was observed for each cranial base and mandibular superimposition.

6.6 Digitisation technique

All tracings were digitised on a Hewlett Packard 9874A digitiser (Fig 11) utilising an Apple IIGS computer and a computerised cephalometrics software programme (author: Professor Tasman Brown, The University of Adelaide, South Australia).

Digitisation of landmarks was completed with use of a Cartesian coordinate system. Coordinate values enabled fast and efficient retrieval of the data and subsequent analysis and processing. The use of coordinate values instead of conventional manual measurement eliminated one potential source of error (Baumrind and Frantz, 1971a,b). The determination of a horizontal reference plane has attracted much debate in cephalometrics. Natural head posture (Solow and Tallgren, 1971; Ferrario et al, 1993) has been suggested as the reference plane of choice owing to its reproducibility if impeccable techniques are employed. In the current retrospective investigation, it was decided to employ sella-nasion minus seven degrees (SN-7°) as the best approximation of the horizontal reference plane (Burstone et al, 1978; Marcotte, 1981). This was considered to be more reproducible and accurate than Frankfort horizontal based on the difficulty in locating the images of anatomical porion and orbitale (Baumrind and Frantz, 1971a).

The following digitising procedure was employed:

1. Iso-propyl alcohol used to clean the digitiser screen;
2. The pre-treatment tracing was affixed to the digitising tablet with cellotape. The patient's details (name and age) were recorded to the Apple programme;
3. The origin and X-axis points were defined on the digitiser at a distance not less than 100mm apart;
4. Endpoints on the millimetre rule image on the original radiograph were digitised which accounted for radiographic magnification variation;
5. All hard and soft tissue landmarks were digitised in a specific order by aligning the cursor cross-hairs over the landmark and gently pressing the button on the cursor which recorded the X and Y coordinates of the selected landmark;

Figure 11 Photograph of Hewlett Packard 9874A digitiser (a)

6. A plot was of the digitised tracing was printed by the plotter and checked with the original tracing to inspect for inaccuracies and, if required, redigitised;
7. The post-treatment tracing was superimposed on the pre-treatment tracing with the use of fiducial markers. The origin and X-axis were redefined using SN-7 from the pre-treatment tracing and then the pre-treatment tracing was removed;
8. Repeated steps 4. 5. and 6.

6.7 Model analysis

Photographs were taken of all the pre- and post-treatment study casts in order to assess model measurements. Other forms of model measurement include direct measurement from the three-dimensional models (Hunter and Priest, 1960) or photocopies of the models (Champagne, 1992).

Yen (1991) believed that the direct measurement of a three-dimensional object had a high potential for error and that a two-dimensional "copy" would be easier to assess and provide the same results.

Champagne (1992) thought that photocopies were unreliable for arch length measurement and space analysis but were useful for comparing pre- and post-treatment archforms. Schirmer and Wiltshire (1997) confirmed that "accurate space analyses and arch length measurements cannot be made from photocopies." They list several reasons for the inaccuracy of a two-dimensional photocopy of a three-dimensional object including the convexity of the teeth, the curve of Spee, differences in tooth inclinations, deviations of teeth axes from the perpendicular and dental crowding. The authors also felt that the manual measurement of teeth with an accurate calibrated gauge provided the "most accurate, reliable and reproducible results."

Fraser (1993) completed a comparison of measurements from photocopies, photographs and directly from the models. The measure of lower arch length discrepancy was compared. Ten subjects had repeated measurements taken utilising the three different modes of analysis. The results indicated a better coefficient of reliability for both the photographs and the photocopies compared to the direct measurement from the models. Both the Dahlberg (1940) variance scores and the reliability coefficients were better for the two-dimensional methods.

The photographs were taken according to the method described by Telfer (1978) and Fraser (1993):

- The dental models were securely placed in a stand with a universal joint (Fig 12);
- Utilising a levelling tripod and spirit level (Fig 13), the dental casts were levelled with respect to the central incisors and the first molars (Figs 14, 15);
- The levelled models were placed in a height adjustment apparatus incorporated in the photographic unit (Fig 16) at a predetermined focal length;
- A millimetre scale and the patients' details were placed between the upper and lower casts during the photographic process to allow the negatives to be enlarged to a 1:1 scale (Fig 17).

The photographs were then measured with electronic callipers (resolution to 0.01mm).

The following measurements were determined for both upper and lower arches from photographs:

1. **Inter-canine width** (ICW): distances between the canines defined at the constructed centroids (Fig 18).
2. **Inter-premolar width** (IPMW): distances between the second premolars defined at the constructed centroids(Fig 18).
3. **Inter-molar width** (IMW): distances between the first permanent molars defined at the constructed centroids (Fig 18).
4. **Arch depth** (AD): distances measured from the midpoints of the most labial points of the central incisors to a line joining the distal midpoints of the second premolars (Fig 18).
5. **Arch length** (AL): distances measured from the midpoints of the most labial points of the central incisors to the distal midpoints of the second premolars (Fig 19).
6. **Irregularity index** (Little, 1975): the sum total of the deviations of the contact points labio-lingually from the mesial contact point of left canine to the mesial contact point of right canine (Fig 19).

Figure 12 Study model placed in stand

Figure 13 Leveling tripod with spirit level

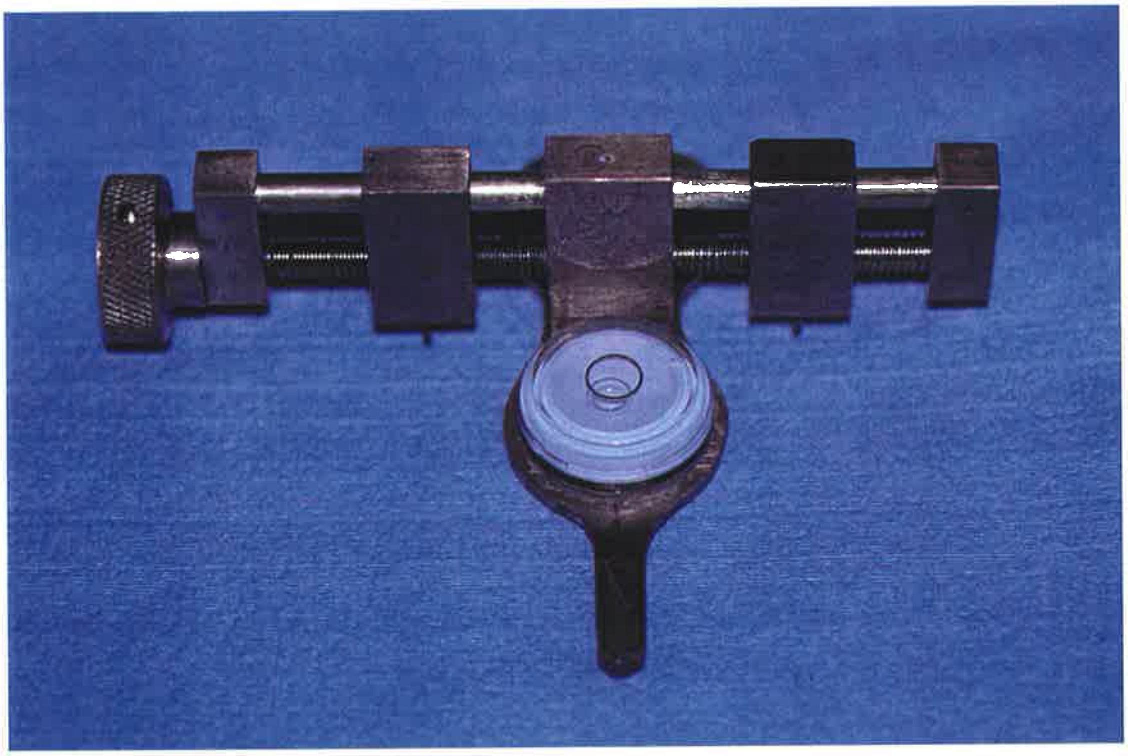


Figure 14 Leveling tripod in position (side view)

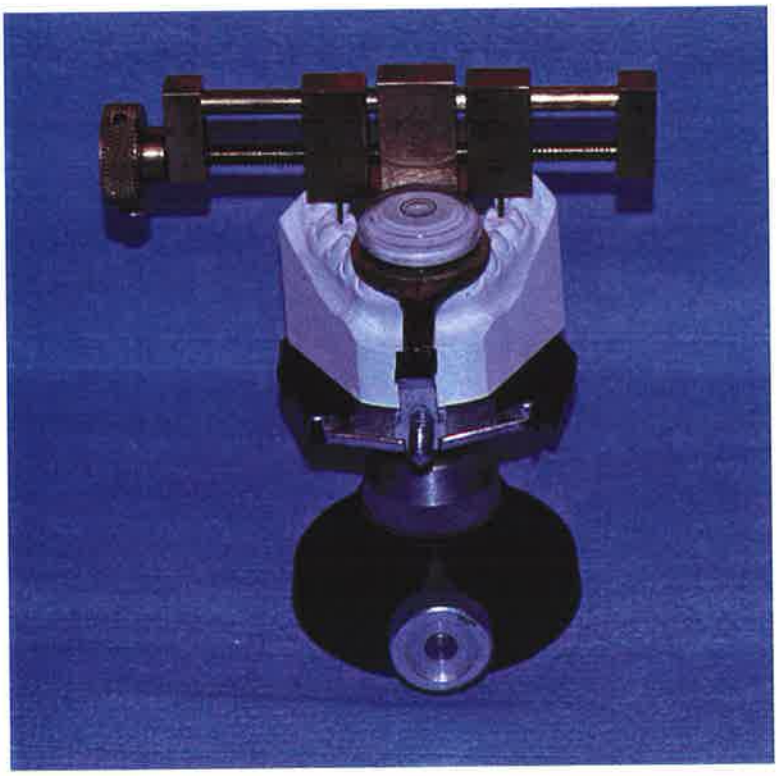
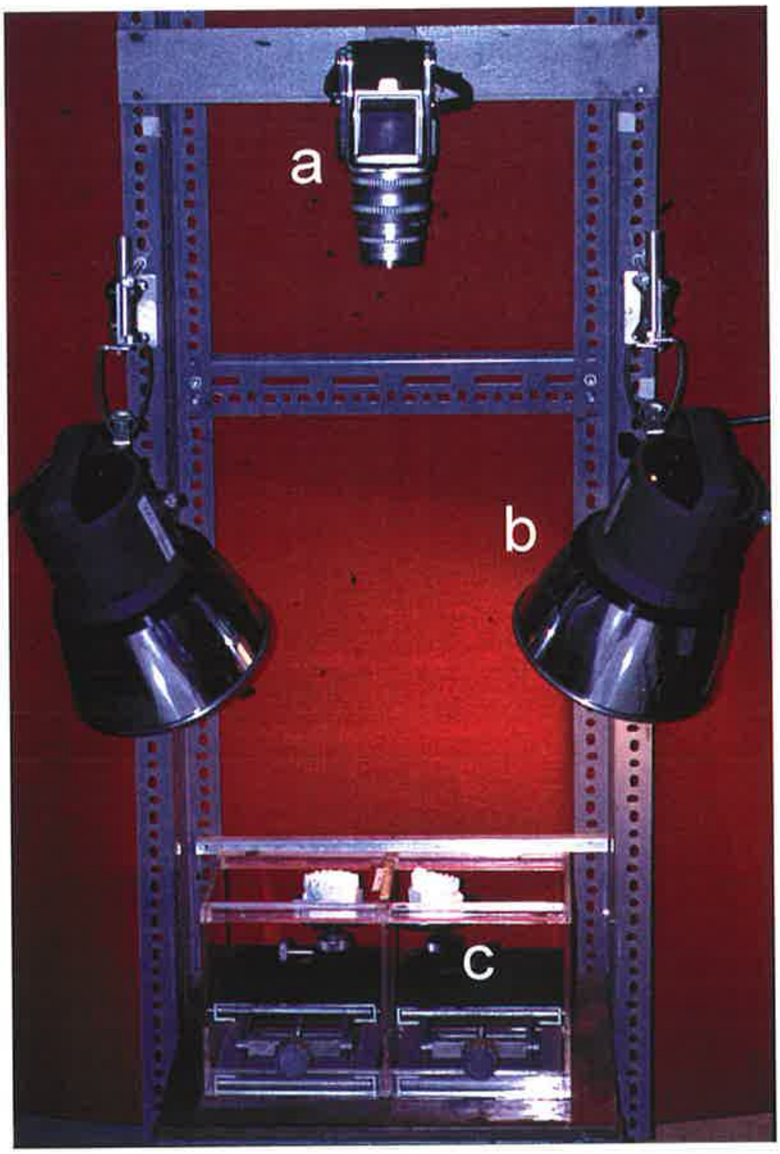


Figure 15 Leveling tripod in position (frontal view)

Figure 16 Photographic apparatus incorporating height adjustable stand platforms



a. Hasselblad camera

b. tungsten lights

c. adjustable platforms

Figure 17 Photographic image (1:1) of study models with patient identification label and millimetric scale

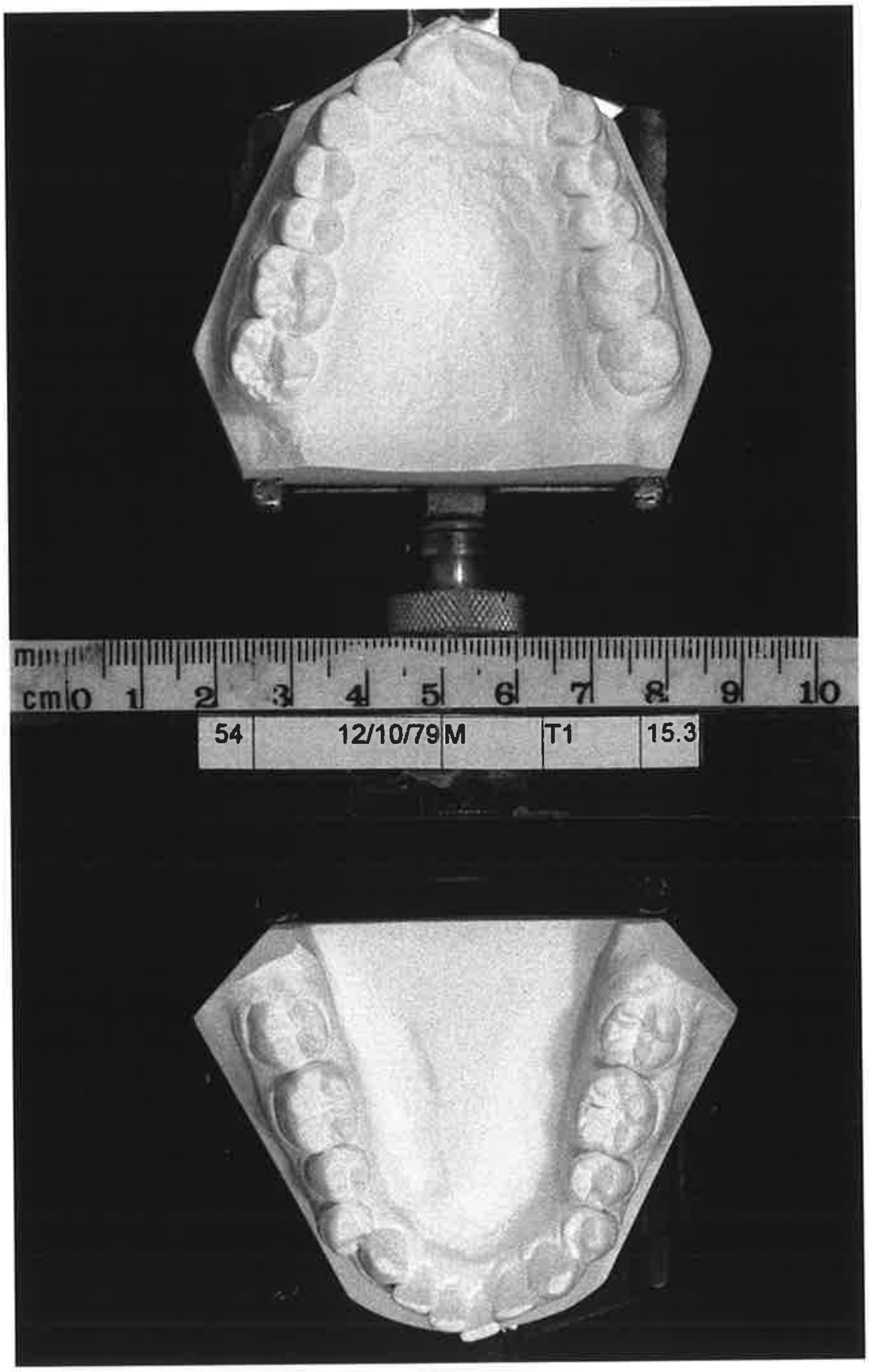
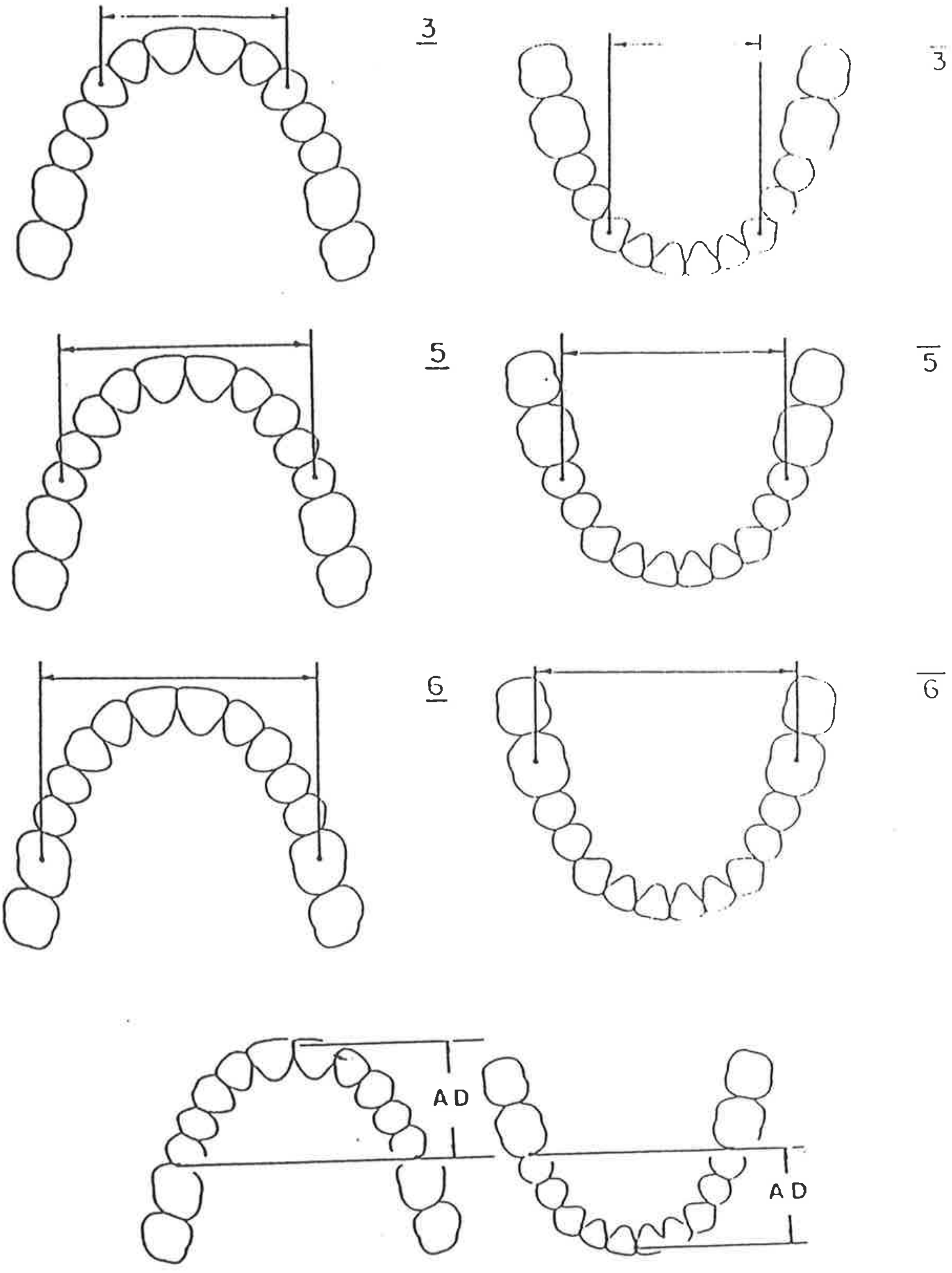
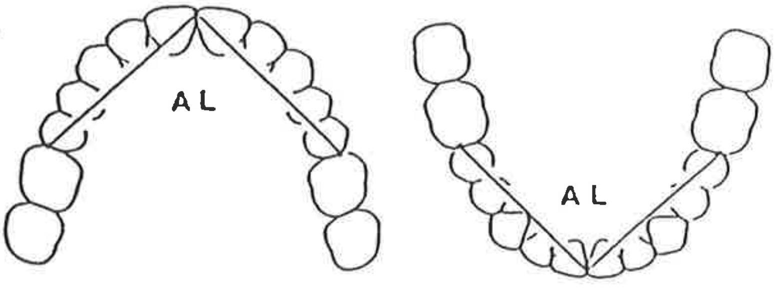


Figure 18 The linear measurements from standardised photographs of dental arch widths and arch depths

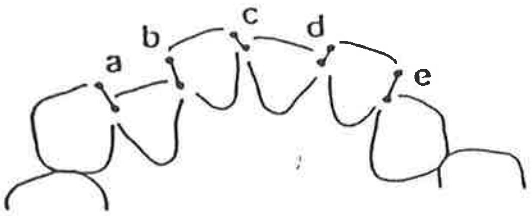


from Moyers et al, 1976

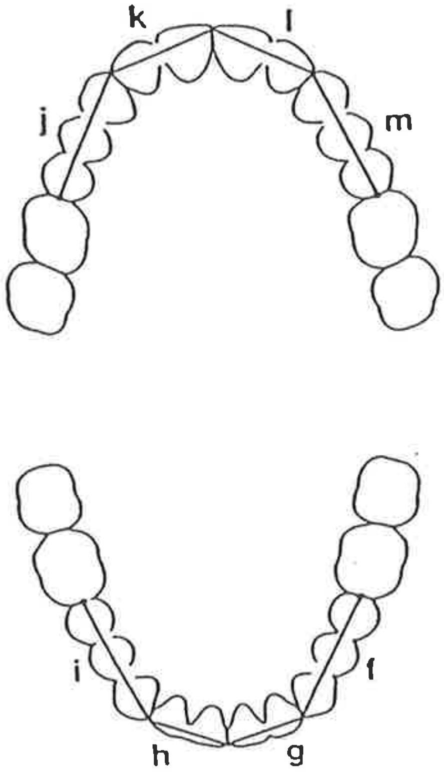
Figure 19 The linear measurements from photographs of dental arch lengths, incisor irregularity index and tooth size-arch length discrepancy



from Sinclair and Little, 1983

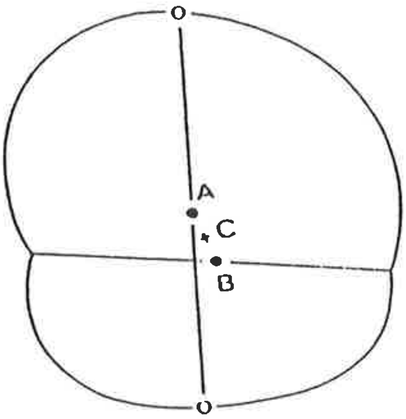


From Little, 1975



from Lundström, 1954

Figure 20 Schematic illustration of centroid determination of the teeth



A. midpoint between the approximal midpoints

B. point halfway between the buccal and lingual points

C. the centroid: halfway between A. and B.

from Moyers et al, 1976

7. **Tooth size arch length discrepancies** (Lundström, 1954): the sum of the mesio-distal tooth widths measured from the distal midpoints of the second premolars minus the total available arch length (Fig 19).

The arch width measurements were taken from constructed centroids (Fig 20) of the teeth as described by Moyers et al (1976). All widths are the shortest distance between the centroids of the respective antimeres. The authors felt that this method of measurement would be less affected by attritional changes of the dentition. The "real" position of the crown could then be determined independent of the number and location of cusps and crown "tipping." The centroid is determined by using four points located on the circumference of the dental crown.

6.8 Statistical analyses

Basic descriptive statistics were applied to the data. These included terms and formulae as follows:

n	sample size
mean	average of a series of values
sd	standard deviation of a sample
SE mean	standard error of the mean where SE mean = $\frac{sd}{\sqrt{n}}$
F ratio	to assess the difference in variances between the two groups.

Calculated as:

$$F = \frac{sd_1^2}{sd_2^2}$$ where sd is the standard deviation of a particular group.

Student's t-test was used to assess the significance of the differences between values for both paired and unpaired data.

6.9 Error of the method

Errors associated with the present investigation could arise from several sources including:

- Cephalometric projection (Houston, 1983);

- Landmark identification (Baumrind and Frantz, 1971a,b);
- Tracing (Houston, 1983);
- Digitisation (Baumrind and Frantz, 1971a,b);
- Automated measurement by the equipment;
- Superimposition errors: primary or secondary (Baumrind et al, 1976);
- Model casting and measurement errors.

Houston (1983) categorised cephalometric errors as both *random* and *systematic.*

Random error, as the term implies, is introduced to the data in a random fashion, typically in cephalometric landmark location.

Systematic error refers to a consistent injection into the data, in a conscious or subconscious fashion, incorrect values which may over- or under-estimate the "true" values.

To determine the presence and extent of errors for the cephalometric investigation, twenty radiographs were re-traced and re-digitised not less than three months after the original tracings. The cranial base superimpositions were performed for each set of radiographs.

To quantify the error in the model measurements, twenty sets of study models were selected at random and remeasured not less than three months after the original recordings.

Statistical analyses were then applied to compare the results with the original data and determinations made for the means, standard deviations, reliability of determination coefficients, systematic and random errors. The calculations included:

diff	difference between values for first and second determinations
mean diff	mean of differences between paired values from the two determinations
$\Sigma diff^2$	sum of squared differences of paired values between the two determinations
sd diff	standard deviation of paired differences between the two determinations

SE mean diff	standard error of the mean difference
Se	Dahlberg (1940) statistic (as a measure of random error; see calculation following)

The Dahlberg statistic is calculated as:

$$Se = \sqrt{\frac{\sum diff^2}{2n}}$$

where n = number of double determinations

The Dahlberg error variance indicates that for any single measurement made, the "actual" value will lie within three standard deviations 99% of the time.

Student's "t-test" values and coefficients of reliability were calculated to determine both *systematic* and *random* error.

Systematic error was calculated as follows:

t	value of "t" as derived from Student's "t-test"

The "t" value was calculated as:

$$t = \frac{meandiff}{SEmeandiff}$$

using the SE mean diff between double determinations.

The "t" value differences were calculated at three levels of significance: $p<0.05$, $p<0.01$, and $p<0.001$.

Random error was calculated as follows:

Percentage error variance was calculated as:

$$E(\text{var}) = \frac{Se^2}{sd^2}$$

and overall reliability as:

(1-*E* var)* 100 (%).

Buschang, Tanguay and Demirjian (1987) stated that reliability coefficients greater than 90% are acceptable while values less than 80% render the measure doubtful.

7. Results

7.1 Error of the method

7.1.1 Cephalometric measurements

Error coefficients were calculated for repeated measurements of both angular and linear cephalometric variables.

For the hard tissue angular variables, eight revealed Dahlberg standard errors greater than 1.0 degree. These were U1-SN° (Se = 1.23), U1-NA° (Se = 1.39), U1-Max° (Se = 1.14), U1-L1° (Se = 1.73), L1-NB° (Se = 1.13), IMPA° (Se = 1.10), LM-MP° (Se = 1.84) and UM-PP° (Se = 1.61). Noteworthy is the presence of the upper or lower incisor in six of these measures. This may be explained by the difficulty in precisely relocating the apices of these teeth in repeated tracings. For the hard tissue linear variables, only UFH:LFH ratio (Se = 0.56) had a standard error greater than 0.5mm. Clearly, the possibility of error compounds with the addition of several landmarks in the calculation of a variable.

The variables N-L ang° (Se = 1.06) and L-M angle° (Se = 1.69) were the only soft tissue measurements to exhibit standard errors greater than 1.0 degree. No soft tissue linear measures had Dahlberg scores greater than 0.5mm.

As an indication of systematic error, t-tests were applied to the differences between the double-determinations and tested for significance at $p<0.05$*, $p<0.01$** and $p<0.001$***. For the hard tissue variables, L1-MP mm ($p<0.05$) and LM-S vert mm ($p<0.05$) displayed significant mean differences between determinations. Both variables are defined by landmarks associated with Dahlberg standard errors greater than 0.50mm and possibly suggests a consistent difficulty in relocating L1A and LM points.

The soft tissue measurements exhibiting significant t-values were Ls-A mm ($p<0.05$), ST UFH mm ($p<0.01$), Li-E line mm ($p<0.05$), STPog-STN mm ($p<0.05$), Ss-S vert mm ($p<0.05$) and Si-S vert mm ($p<0.05$). No angular soft tissue variables revealed significant mean differences. A relatively higher proportion of soft tissue systematic errors may be a consequence of the quality of the radiographic soft tissue images. These results must also be evaluated in the light of the absolute values of the mean differences and standard error of the mean differences (Table 5). For each of the significant soft tissue t-values a small standard error of the mean difference was accompanied by a small but relatively larger numerical mean difference value. This resulted in larger t-values than may have been expected from the initial inspection of the data.

Reliability coefficients were calculated by comparing the variance due to measurement error (Dahlberg standard error) for the error sample with the observed variance for the entire sample group, expressed as a percentage. Most cephalometric variables had reliability values greater than 95%. Four variables were below this level including OB mm (94.1%), L1-NB mm (94.7%), LM angle° (91.3%) and UM-PP° (93.1%). Of these, high random error was associated with the variables LM angle° and UM-PP°. Low levels of reliability have been associated with operator inexperience particularly with landmark location and may help explain these results (Cohen, 1984).

7.1.2 Study model measurements

Standard error results for repeated measures were all below 0.30mm for both upper and lower arches. The lower arch tended to have higher Dahlberg scores with the variables overall mesio-distal tooth width (Se = 0.26) and tooth size arch length discrepancy (Se = 0.27) having the highest standard error values. This trend was reflected in the upper arch but to a lesser numerical extent.

Systematic error was determined by Student's t-tests. In the lower arch, ICW ($p<0.05$), IPMW ($p<0.05$) and IMW ($p<0.05$) returned significant mean differences between determinations. As with the cephalometric variables (*7.1.1*), relatively small standard errors of the mean differences resulted in significant t-values. For the upper arch, AL ($p<0.001$) exhibited a highly significant mean difference between recordings. This revealed a consistent tendency for an over-estimation of the repeat measurement. Arch perimeter ($p = 0.06$) approached significance at the 5% level of significance and reflects the error involved in repeat measurements for calculating a single variable.

Observer error was also quantified in the calculation of reliability coefficients for the study cast variables. For both upper and lower arches, variable coefficients were above 99% except for the lower arch measures irregularity index (98.9%) and tooth size arch length discrepancy (98.8%). Both variables rely on repeated measurements for their calculation.

Table 5 Error study: results of cephalometric double determinations

VARIABLE	mean diff	sd diff	SE mean diff	Se	E (var) (%)	Reliability (%)	t- value
SN-FH	-0.01	0.33	0.11	0.22	0.55	99.45	0.02
SNA	-0.03	0.48	0.15	0.32	0.90	99.10	0.19
MaxPl-SN	0.10	0.46	0.15	0.32	1.63	98.37	0.65
Co-A	0.09	0.35	0.11	0.25	0.32	99.68	0.82
U1-SN	-0.10	1.83	0.58	1.23	3.31	96.69	0.17
U1-NA (°)	-0.07	2.07	0.66	1.39	4.46	95.54	0.11
U1-NA (mm)	-0.10	0.79	0.25	0.54	4.80	95.20	0.41
U1-MaxPl (°)	-0.01	1.70	0.54	1.14	2.95	97.05	0.01
U1-L1	-0.44	2.54	0.80	1.73	4.35	95.65	0.55
OJ	-0.14	0.46	0.14	0.32	4.51	95.49	0.95
OB	-0.08	0.52	0.16	0.35	5.94	94.06	0.48
ANB	-0.05	0.41	0.13	0.28	2.09	97.91	0.35
L1-NB	0.56	1.58	0.50	1.13	4.81	95.19	1.12
L1-NB (mm)	0.00	0.57	0.18	0.38	5.27	94.73	0.00
IMPA	0.38	1.58	0.50	1.10	2.71	97.29	0.76
L1-MP (mm)	0.38	0.47	0.15	0.41	2.01	97.99	**2.54** *
SNB	0.02	0.22	0.07	0.15	0.30	99.70	0.23
Co-Gn	-0.04	0.41	0.13	0.28	0.26	99.74	0.32
Ar-Gn	0.06	0.50	0.16	0.34	0.46	99.54	0.39
Co-Go	0.01	0.30	0.10	0.20	0.28	99.72	0.08
Ar-Go	-0.02	0.40	0.13	0.27	0.46	99.54	0.13
UFH	0.05	0.35	0.11	0.24	0.51	99.49	0.47
LFH	0.27	0.46	0.14	0.36	0.51	99.49	1.87
UFH:LFH (%)	-0.24	0.80	0.25	0.56	0.55	99.45	0.95

Table 5 (continued)

Error study: results of cephalometric double determinations

VARIABLE	Mean diff	Sd diff	SE mean diff	Se	E (var) (%)	Reliability (%)	t-value
N-Me	0.27	0.51	0.16	0.39	0.38	99.62	1.70
S-Go	0.05	0.59	0.19	0.39	0.60	99.40	0.29
PFH:AFH (%)	-0.12	0.55	0.17	0.38	0.81	99.19	0.69
FMA	0.18	0.36	0.11	0.27	0.28	99.72	1.56
A-S vert	0.09	0.43	0.13	0.29	0.52	99.48	0.65
B-S vert	0.12	0.26	0.08	0.19	0.13	99.87	1.51
Pog-Svert	-0.04	0.31	0.10	0.21	0.13	99.87	0.44
LM-S vert	0.28	0.39	0.12	0.33	0.60	99.40	2.25 (*)
UM-S vert	0.26	0.44	0.14	0.35	0.77	99.23	1.88
LM-MP (°)	-0.17	2.74	0.87	1.84	8.69	91.31	0.19
L5-MP (°)	0.17	0.90	0.28	0.61	1.62	98.38	0.58
L4-MP (°)	-0.27	1.10	0.35	0.76	2.05	97.95	0.76
UM-PP (°)	-0.91	2.20	0.70	1.61	6.89	93.11	1.31
SN-OP	-0.06	1.25	0.39	0.84	3.22	96.78	0.14
MP-OP	0.22	1.07	0.34	0.73	2.34	97.66	0.65
F conv	-0.08	0.45	0.14	0.30	0.49	99.51	0.53
N-L ang	0.25	1.55	0.49	1.06	2.32	97.68	0.51
L-M angle	0.63	2.43	0.77	1.69	4.03	95.97	0.82
H angle	0.13	0.53	0.17	0.37	0.68	99.32	0.78
Ls-A	0.16	0.19	0.06	0.17	0.50	99.50	**2.65** *
Li-B	-0.16	0.26	0.08	0.21	0.51	99.49	1.92
ST TFH (mm)	0.17	0.30	0.10	0.24	0.13	99.87	1.75
ST UFH	0.17	0.15	0.05	0.15	0.15	99.85	**3.59** **
ST LFH	0.05	0.31	0.10	0.21	0.17	99.83	0.49
ST LFH (%)	-0.05	0.17	0.05	0.12	0.24	99.76	0.87
Ls-E line	-0.06	0.20	0.06	0.14	0.46	99.54	0.88

Table 5 (continued)

Error study: results of cephalometric double determinations

VARIABLE	Mean diff	Sd diff	SE mean diff	Se	E (var) (%)	Reliability (%)	t-value
Li-E line	-0.20	0.25	0.08	0.22	1.05	98.95	**2.49** *
ULL	0.07	0.31	0.10	0.22	0.89	99.11	0.69
LLL	-0.11	0.24	0.08	0.18	0.22	99.78	1.46
STPog-STN (mm)	0.27	0.33	0.10	0.29	0.34	99.66	**2.58** *
Sn-S vert	0.16	0.33	0.10	0.25	0.33	99.67	1.56
Ss-S vert	0.17	0.18	0.06	0.17	0.15	99.85	**2.98** *
Ls-S vert	0.11	0.15	0.05	0.13	0.08	99.92	2.18 (*)
Li-S vert	0.02	0.29	0.09	0.20	0.17	99.83	0.24
Si-S vert	0.15	0.16	0.05	0.15	0.09	99.91	**2.95** *
STPog-S vert	0.16	0.29	0.09	0.22	0.14	99.86	1.72

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***; (*)=approaching significance

Table 6 Error study: results of study models double determinations

VARIABLE	mean diff	Sd diff	SE mean diff	Se	E (var) (%)	Reliability (%)	t- value
LOWER ARCH							
ICW	0.10	0.11	0.02	0.07	0.23	99.77	**2.65** *
IPMW	0.12	0.12	0.03	0.08	0.10	99.90	**2.69** *
IMW	0.07	0.09	0.02	0.06	0.03	99.97	**2.28** *
AD	0.04	0.19	0.04	0.09	0.46	99.54	0.69
AL	-0.04	0.25	0.06	0.12	0.18	99.82	0.56
IRREG INDEX	0.05	0.39	0.09	0.19	1.13	98.87	0.41
ARCH PERIM.	0.04	0.30	0.07	0.14	0.19	99.81	0.40
TOOTH SIZE	0.28	0.42	0.09	0.24	0.90	99.10	1.96
TSALD	-0.24	0.51	0.11	0.27	1.18	98.82	1.41

Table 6 (continued)

Error study: results of study models double determinations

VARIABLE	mean diff	Sd diff	SE mean diff	Se	E (var) (%)	Reliability (%)	t- value
UPPER ARCH							
ICW	0.00	0.08	0.02	0.04	0.04	99.96	0.17
IPMW	0.00	0.09	0.02	0.04	0.03	99.97	0.14
IMW	0.00	0.09	0.02	0.04	0.03	99.97	0.01
AD	0.04	0.14	0.03	0.07	0.16	99.84	0.89
AL	-0.29	0.18	0.04	0.17	0.24	99.76	**4.13 *****
ARCH PERIM.	0.18	0.27	0.06	0.16	0.20	99.80	2.04 (*)
TOOTH SIZE	0.16	0.25	0.06	0.15	0.22	99.78	1.92
TSALD	0.02	0.29	0.07	0.14	0.30	99.70	0.21

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***; (*)=approaching significance

7.2 Cephalometric descriptive statistics

Standard descriptive statistical analyses were applied to the variables to evaluate any differences between males and females for the following:

1. Pre-treatment variables;
2. Post-treatment variables;
3. Treatment changes.

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests. Where F-prob was <0.05, heteroscedastic t-tests for unequal variances were applied.

For all tables, statistically significant differences are in bold type.

7.2.1 Pre-treatment variables

Table 7 Pre-treatment mean cephalometric variables

	Males n = 19			**Females** n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
SN-FH	9.21	2.83	0.65	9.72	2.68	0.53	0.79	0.62
SNA	78.98	3.37	0.77	81.15	3.21	0.63	0.81	**2.19 ***
MaxPl-SN	5.63	3.09	0.71	6.78	1.90	0.37	0.03	1.42
Co-A	87.15	4.17	0.96	85.21	4.32	0.85	0.89	1.51
U1-SN	101.98	7.27	1.67	99.36	7.89	1.55	0.73	1.13
U1-NA	23.00	6.89	1.58	18.22	7.06	1.38	0.93	**2.27 ***
U1-NA	4.72	2.45	0.56	3.39	2.47	0.48	0.99	1.78
U1-Max	107.61	6.70	1.54	106.14	7.26	1.42	0.74	0.69
U1-L1	134.83	7.15	1.64	139.26	10.36	2.03	0.11	1.60
OJ	4.45	2.42	0.55	3.51	1.62	0.32	0.06	1.56
OB	4.24	2.10	0.48	4.27	1.47	0.29	0.10	0.06
ANB	2.85	2.16	0.50	3.04	1.90	0.37	0.54	0.31
L1-NB	19.32	3.71	0.85	19.49	5.46	1.07	0.09	0.12
L1-NB	3.27	1.29	0.30	2.98	1.80	0.35	0.15	0.58
IMPA	87.59	4.37	1.00	86.45	6.63	1.30	0.07	0.65
L1-MP	18.34	3.03	0.70	17.41	2.17	0.43	0.12	1.20
SNB	76.13	2.13	0.49	78.11	2.83	0.55	0.21	**2.56 ***
Co-Gn	110.36	5.49	1.26	108.69	4.61	0.90	0.41	1.10
Ar-Gn	102.50	5.89	1.35	101.50	3.80	0.75	0.04	0.65
Co-Go	51.18	3.66	0.84	49.97	3.86	0.76	0.83	1.06
Ar-Go	41.75	4.06	0.93	41.47	3.83	0.75	0.77	0.24
UFH	49.48	3.57	0.82	48.96	3.05	0.60	0.47	0.52
LFH	64.59	5.59	1.28	61.80	3.46	0.68	0.03	1.89
UFH:LFH	77.15	8.39	1.92	79.50	7.15	1.40	0.45	1.01

Table 7 (continued)

Pre-treatment mean variables

	Males n = 19			Females n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
N-Me	112.91	7.10	1.63	109.40	4.40	0.86	0.03	1.88
S-Go	71.07	5.08	1.17	68.75	4.79	0.94	0.77	1.56
PFH:AFH	63.03	3.85	0.88	62.89	4.41	0.86	0.56	0.11
FMA	26.39	5.22	1.20	25.20	4.42	0.87	0.43	0.83
A-S vert	64.70	3.22	0.74	64.27	4.39	0.86	0.18	0.36
B-S vert	57.27	4.21	0.96	58.44	5.36	1.05	0.29	0.79
Pog-S vert	58.28	4.99	1.14	59.22	6.03	1.18	0.41	0.55
LM-S vert	28.54	3.08	0.71	29.92	4.52	0.89	0.10	1.15
UM-S vert	29.08	3.37	0.77	30.15	4.16	0.81	0.36	0.92
LM-MP	77.87	6.60	1.51	75.81	5.75	1.13	0.52	1.11
L5-MP	75.68	4.50	1.03	76.03	5.12	1.00	0.58	0.24
L4-MP	73.98	6.57	1.51	73.93	4.90	0.96	0.17	0.03
UM-PP	74.80	5.89	1.35	80.15	4.82	0.94	0.35	**3.34** **
SN-OP	15.57	5.24	1.20	16.35	4.43	0.87	0.43	0.54
MP-OP	20.03	4.30	0.99	18.57	5.09	1.00	0.46	1.01
F conv	127.42	4.02	0.92	129.08	4.46	0.87	0.65	1.28
N-L angle	133.28	6.83	1.57	129.40	5.85	1.15	0.47	**2.05** *
L-M angle	129.23	7.48	1.72	128.14	7.69	1.51	0.92	0.48
H angle	156.43	5.11	1.17	158.29	4.65	0.91	0.65	1.27
Ls-A	21.54	2.62	0.60	20.34	1.88	0.37	0.13	1.78
Li-B	23.26	2.56	0.59	21.38	2.61	0.51	0.95	**2.41** *
ST TFH	116.81	7.56	1.73	114.65	4.80	0.94	0.04	1.08
ST UFH	50.00	3.87	0.89	50.22	4.11	0.81	0.80	0.19
ST LFH	71.85	5.79	1.33	69.27	3.45	0.68	0.02	1.71
ST LFH%	61.49	2.37	0.54	60.44	2.54	0.50	0.77	1.41
Ls-E line	-3.10	2.46	0.57	-3.79	1.98	0.39	0.31	1.03

Table 7 (continued)

Pre-treatment mean variables

	Males n = 19			Females n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
Li-E line	-1.96	2.26	0.52	-2.68	2.37	0.46	0.86	1.03
ULL	22.72	2.12	0.49	21.05	1.91	0.37	0.62	**2.76** **
LLL	48.40	4.41	1.01	48.08	3.04	0.60	0.08	0.29
STPog-STN	98.16	5.10	1.17	97.44	4.28	0.84	0.41	0.51
Sn-S vert	81.72	3.48	0.80	79.98	3.87	0.76	0.64	1.55
Ss-S vert	79.05	3.60	0.82	78.12	4.30	0.84	0.44	0.77
Ls-S vert	80.93	4.28	0.98	80.36	4.39	0.86	0.92	0.43
Li-S vert	76.91	3.77	0.87	76.81	5.00	0.98	0.22	0.07
Si-S vert	68.45	4.05	0.93	69.14	5.16	1.01	0.29	0.48
STPog-S vert	70.28	4.91	1.13	71.85	5.94	1.17	0.41	0.94

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

Six hard tissue and three soft tissue variables evaluated, exhibited significant differences between genders pre-treatment.

The mean angular variable SNA was significantly reduced in males compared with females at $p<0.05$. This may have reflected, on average, greater maxillary retrognathia for the male sample. This trend was not reflected in U1-NA° which showed a greater mean upper incisor proclination in males compared to females at $p<0.05$. Although not statistically significant, U1-NA mm tended to mimic the angular incisal position. It is possible that the generally retrusive position of the upper incisor (and hence A point) has contributed to the smaller mean SNA value in males.

A similar skeletal pattern was found for mandibular position with males exhibiting greater retrognathia for angular measure SNB at $p<0.05$. However, a general pattern of a skeletal Class I sample was apparent with a mean ANB for males of 2.85° and females 3.04° based on the assumption that a Class I skeletal pattern lies between 2° and 4° (Proffit, 1993).

Two hard tissue facial height measures tended to be greater in males than females, specifically LFH and N-Me at $p<0.05$. This sexual dimorphism is not unexpected based purely on the absolute size discrepancy that exists between the sexes following childhood.

UM-PP angle exhibited a mean increased distal axial inclination in males at $p<0.01$.

For the soft tissue variables, N-L angle was significantly greater in males at $p<0.05$. Li-B was, on average, significantly greater in males, possibly as a result of an increase in lower lip procumbence compared to the female group. ULL, at $p<0.01$, was greater in males. This mean difference may be as a consequence of an absolute size difference between the genders.

7.2.2 Post-treatment variables

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests.

Table 8 Post-treatment mean cephalometric variables

	Males n = 19			**Females** n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
SN-FH	8.23	2.75	0.63	9.07	2.51	0.49	0.67	1.06
SNA	78.50	3.33	0.76	80.74	3.04	0.60	0.66	**2.35** *
MaxPl-SN	5.88	3.25	0.75	6.79	1.56	0.31	0.00	1.12
Co-A	88.51	4.42	1.01	85.15	3.79	0.74	0.47	**2.74** **
U1-SN	99.63	5.38	1.23	99.09	6.24	1.22	0.52	0.31
U1-NA	21.13	5.26	1.21	18.34	6.10	1.20	0.52	1.60
U1-NA	4.21	2.30	0.53	3.06	2.33	0.46	0.96	1.64
U1-Max	105.51	5.86	1.34	105.88	6.73	1.32	0.55	0.19
U1-L1	136.15	8.00	1.84	136.56	6.88	1.35	0.47	0.19
OJ	2.22	1.06	0.24	2.09	0.97	0.19	0.66	0.44
OB	2.35	1.25	0.29	2.51	1.12	0.22	0.60	0.46

Table 8 (continued)

Post-treatment mean variables

	Males n = 19			**Females** n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
ANB	1.96	1.75	0.40	2.90	1.84	0.36	0.85	1.72
L1-NB	20.76	6.07	1.39	22.19	5.20	1.02	0.47	0.85
L1-NB	3.78	1.91	0.44	4.11	1.56	0.31	0.34	0.63
IMPA	87.62	7.64	1.75	88.22	7.68	1.50	1.00	0.26
L1-MP	20.14	4.00	0.92	18.53	2.39	0.47	0.02	1.55
SNB	76.54	2.71	0.62	77.84	2.75	0.54	0.96	1.58
Co-Gn	115.82	6.53	1.50	110.73	4.23	0.83	0.04	**2.89** **
Ar-Gn	107.53	5.76	1.32	102.70	3.62	0.71	0.03	**3.11** **
Co-Go	53.68	4.27	0.98	51.54	3.51	0.69	0.36	1.84
Ar-Go	43.86	4.41	1.01	42.29	3.61	0.71	0.35	1.31
UFH	51.73	3.98	0.91	49.55	2.46	0.48	0.03	**2.08** *
LFH	68.98	6.26	1.44	64.61	4.16	0.82	0.06	**2.59** **
UFH:LFH	75.57	8.79	2.02	77.00	6.53	1.28	0.17	0.63
N-Me	119.64	7.66	1.76	112.57	4.53	0.89	0.02	**3.44** ***
S-Go	75.06	5.00	1.15	70.26	4.47	0.88	0.59	**3.38** **
PFH:AFH	62.86	4.04	0.93	62.50	4.51	0.88	0.64	0.27
FMA	28.37	5.80	1.33	27.06	5.30	1.04	0.66	0.79
A-S vert	64.13	3.60	0.83	63.06	4.66	0.91	0.26	0.83
B-S vert	56.81	5.05	1.16	56.42	6.27	1.23	0.35	0.22
Pog-S vert	57.64	5.87	1.35	57.11	6.77	1.33	0.54	0.27
LM-S vert	28.16	3.82	0.88	28.59	4.89	0.96	0.28	0.31
UM-S vert	27.23	3.35	0.77	27.78	4.65	0.91	0.16	0.44
LM-MP	70.81	7.20	1.65	71.22	5.83	1.14	0.33	0.21
L5-MP	68.99	5.26	1.21	70.99	4.41	0.87	0.41	1.38
L4-MP	69.60	5.33	1.22	71.29	4.84	0.95	0.64	1.11
UM-PP	76.29	5.33	1.22	79.20	6.91	1.35	0.26	1.53

Table 8 (continued)

Post-treatment mean variables

	Males n = 19			**Females** n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
SN-OP	18.38	3.88	0.89	18.28	5.12	1.00	0.23	0.07
MP-OP	18.23	5.65	1.30	17.85	4.20	0.82	0.17	0.26
F conv	125.34	3.85	0.88	129.35	3.96	0.78	0.91	**3.39** **
N-L angle	135.00	8.20	1.88	130.37	6.17	1.21	0.19	**2.16** *
L-M angle	131.11	9.13	2.09	128.65	9.48	1.86	0.88	0.87
H angle	157.74	4.11	0.94	159.81	4.00	0.79	0.88	1.70
Ls-A	22.45	2.43	0.56	19.76	1.66	0.33	0.08	**4.40** ***
Li-B	24.61	2.97	0.68	22.90	3.01	0.59	0.97	1.90
ST TFH	124.24	7.89	1.81	118.35	4.83	0.95	0.02	**2.80** **
ST UFH	53.42	3.67	0.84	51.53	3.85	0.75	0.85	1.66
ST LFH	76.25	6.27	1.44	71.51	4.15	0.81	0.06	**3.05** **
ST LFH%	61.34	2.15	0.49	60.42	2.52	0.49	0.50	1.27
Ls-E line	-4.63	2.00	0.46	-4.58	1.92	0.38	0.83	0.09
Li-E line	-2.25	2.02	0.46	-2.01	1.97	0.39	0.88	0.40
ULL	23.52	2.05	0.47	20.93	2.09	0.41	0.96	**4.14** ***
LLL	52.24	4.77	1.09	50.39	3.13	0.61	0.05	1.57
STPog-STN	104.16	5.48	1.26	100.01	4.38	0.86	0.30	**2.83** **
Sn-S vert	83.26	4.13	0.95	79.05	4.47	0.88	0.74	**3.22** **
Ss-S vert	79.42	3.63	0.83	76.70	4.81	0.94	0.22	**2.07** *
Ls-S vert	81.23	3.79	0.87	78.76	4.97	0.97	0.24	1.81
Li-S vert	77.71	4.42	1.01	76.22	5.58	1.09	0.31	0.96
Si-S vert	68.54	5.18	1.19	67.63	5.97	1.17	0.54	0.53
STPog-S vert	70.09	5.95	1.36	69.81	7.03	1.38	0.47	0.14

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

A discrepancy in maxillary skeletal position sagittally was maintained post-treatment with SNA significantly different between genders at $p<0.05$. Co-A, Co-Gn and Ar-Gn were also significantly different at $p<0.01$ perhaps reflecting greater change at condylion in the male sample for the treatment period. This was reflected in overall greater mean linear dimensions for the mandibular measurements. Males also exhibited mandibular "catch-up" with a mean increase in SNB angle, negating any pre-treatment significant difference with the female group.

Skeletal facial height variables exhibited sexual dimorphism post-treatment, particularly for LFH ($p<0.01$) and N-Me ($p<0.001$). Large mean increases were noted especially in the male sample. This would be a reflection of any overall mean growth increases (compared with females) or an increase in the vertical dimension as a consequence of the treatment mechanics.

The proclination of the upper incisors remained greater in males post-treatment but not at significant levels for the angle U1-NA. There was a small, mean decrease for this variable in males whereas there was little change in the female group.

For the soft tissue variables, N-L angle remained greater in males post-treatment ($p<0.05$). Variable F conv was significantly greater for females post-treatment possibly reflecting a differential in nasal tip projection between the genders. Ls-A ($p<0.001$) and ULL ($p<0.001$) remained larger in males, complementing the difference in position of the upper incisors post-treatment. The variables ST TFH ($p<0.01$), ST LFH ($p<0.01$) and ST Pog-STN ($p<0.01$) all reflected the underlying hard tissue differences between the genders for facial height.

The upper lip variables Sn-S vert ($p<0.01$) and Ss-S vert ($p<0.05$) exhibited dimorphism between the genders. For the male sample, there was a mean increase in the value for both variables post-treatment whereas for the female group there was a small mean decrease. It would appear that the soft tissue growth changes for the males may have negated any effect the retraction of the upper incisors may have had on these upper lip variables.

7.2.3 Treatment changes

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests.

Table 9 Treatment changes mean cephalometric variables

	Males n = 19			**Females** n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
SN-FH	-0.98	0.87	0.20	-0.65	0.87	0.17	0.17	1.01
SNA	-0.48	1.08	0.25	-0.41	1.06	0.21	0.01	0.15
MaxPl-SN	0.25	1.23	0.28	0.02	1.35	0.27	0.23	0.51
Co-A	1.37	2.79	0.64	-0.06	2.85	0.56	0.36	1.79
U1-SN	-2.35	5.59	1.28	-0.28	8.19	1.61	0.60	0.88
U1-NA	-1.87	5.68	1.30	0.13	8.05	1.58	0.45	0.88
U1-NA	-0.51	2.09	0.48	-0.33	2.60	0.51	0.24	0.25
U1-MaxPl	-2.10	5.93	1.36	-0.26	7.84	1.54	0.70	0.80
U1-L1	1.31	9.28	2.13	-2.70	10.80	2.12	0.14	1.38
OJ	-2.23	1.79	0.41	-1.43	1.78	0.35	0.30	1.34
OB	-1.89	1.44	0.33	-1.76	1.61	0.32	0.11	0.23
ANB	-0.89	1.21	0.28	-0.14	1.20	0.24	0.14	1.77
L1-NB	1.44	4.74	1.09	2.70	4.80	0.94	0.45	0.81
L1-NB	0.52	1.28	0.29	1.13	1.42	0.28	0.71	1.37
IMPA	0.02	5.02	1.15	1.77	4.91	0.96	0.64	1.13
L1-MP	1.81	1.46	0.34	1.12	1.30	0.26	0.05	1.40
SNB	0.41	0.69	0.16	-0.27	1.07	0.21	0.40	1.95 (*)
Co-Gn	5.46	3.20	0.73	2.04	3.29	0.65	0.38	**3.71** ***
Ar-Gn	5.02	2.10	0.48	1.21	2.13	0.42	0.45	**5.51** ***
Co-Go	2.50	2.31	0.53	1.57	3.26	0.64	0.30	1.03
Ar-Go	2.11	1.34	0.31	0.82	2.02	0.40	0.27	1.88

Table 9 (continued)

Treatment changes mean variables

	Males n = 19			Females n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
UFH	2.25	1.37	0.31	0.58	1.36	0.27	0.11	**3.41** ***
LFH	4.39	1.62	0.37	2.81	1.73	0.34	0.51	**2.83** **
UFH:LFH	-1.58	2.47	0.57	-2.50	2.62	0.51	0.53	1.10
N-Me	6.73	2.32	0.53	3.17	2.33	0.46	0.13	**4.29** ***
S-Go	3.99	1.68	0.38	1.51	1.95	0.38	0.58	**4.43** ***
PFH:AFH	-0.17	1.21	0.28	-0.39	1.84	0.36	0.32	0.44
FMA	1.98	1.93	0.44	1.86	2.29	0.45	0.13	0.20
A-S vert	-0.57	1.53	0.35	-1.20	1.47	0.29	0.03	1.02
B-S vert	-0.46	2.52	0.58	-2.02	2.50	0.49	0.87	**2.10** *
Pog-S vert	-0.65	2.74	0.63	-2.11	2.83	0.55	0.57	1.80
LM-S vert	-0.38	2.20	0.50	-1.34	2.23	0.44	0.55	1.35
UM-S vert	-1.86	1.91	0.44	-2.36	1.86	0.36	0.57	0.95
LM-MP	-7.06	5.94	1.36	-4.60	5.60	1.10	0.22	1.28
L5-MP	-6.69	4.26	0.98	-5.04	5.10	1.00	0.16	1.20
L4-MP	-4.38	4.60	1.05	-2.64	4.85	0.95	0.71	1.15
UM-PP	1.49	5.62	1.29	-0.95	5.18	1.02	0.32	1.41
SN-OP	2.81	4.03	0.93	1.93	5.43	1.07	0.85	0.54
MP-OP	-1.80	3.88	0.89	-0.72	4.29	0.84	0.40	0.77
F conv	-2.08	2.25	0.52	0.28	2.33	0.46	0.82	**3.29** **
N-L angle	1.72	5.72	1.31	0.97	6.08	1.19	0.58	0.39
L-M angle	1.88	7.79	1.79	0.51	8.14	1.60	0.87	0.55
H angle	1.31	3.12	0.72	1.52	3.20	0.63	0.66	0.21
Ls-A	0.91	1.03	0.24	-0.58	0.95	0.19	0.00	**3.11** **
Li-B	1.35	2.39	0.55	1.52	2.16	0.42	0.13	0.23
ST TFH	7.43	3.32	0.76	3.70	3.53	0.69	0.71	**3.38** **
ST UFH	3.43	2.98	0.68	1.31	3.09	0.61	0.10	**2.57** **

Table 9 (continued)

Treatment changes mean variables

	Males n = 19			Females n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
ST LFH	4.40	1.87	0.43	2.24	2.09	0.41	0.19	**2.97** **
ST LFH%	-0.16	1.62	0.37	-0.02	1.82	0.36	0.01	0.33
Ls-E line	-1.53	1.22	0.28	-0.79	1.16	0.23	0.07	1.73
Li-E line	-0.29	1.25	0.29	0.68	1.21	0.24	0.33	**2.40** *
ULL	0.80	1.19	0.27	-0.12	1.17	0.23	0.20	**2.28** *
LLL	3.84	1.82	0.42	2.31	1.94	0.38	0.04	1.90
STPog-STN	6.00	3.27	0.75	2.56	3.51	0.69	0.39	**2.98** **
Sn-S vert	1.54	1.67	0.38	-0.93	1.66	0.32	0.29	**4.43** ***
Ss-S vert	0.37	1.58	0.36	-1.42	1.53	0.30	0.18	**3.36** **
Ls-S vert	0.30	1.95	0.45	-1.60	2.01	0.39	0.49	**2.93** **
Li-S vert	0.80	2.45	0.56	-0.59	2.35	0.46	0.89	1.93
Si-S vert	0.08	2.15	0.49	-1.51	2.11	0.41	0.54	**2.36** *
STPog-S-vert	-0.19	2.70	0.62	-2.03	2.71	0.53	0.82	**2.21** *

t-values significant at: p<0.05*; p<0.01**; p<0.001***; (*)=approaching significance

Interestingly, only linear skeletal variables revealed significant treatment changes between males and females. An absolute growth increment differential could account for this.

Of the inter-regional skeletal variables (SNA, SNB, ANB), only SNB *approached* significant mean change between the genders (p<0.05). SNB showed a mean increase in males and a mean decrease in females. This may reflect growth changes in the males and a down and back mandibular rotation in the female sample. SNA decreased in both sexes to similar degrees as did ANB (greater in males). The variable S-Go also expressed a significantly greater mean increase in the male group (p<0.001).

For the mandibular skeletal variables, Co-Gn (p<0.001) and Ar-Gn (p<0.001) both revealed greater mean increases in males. B-S vert had a significantly larger mean decrease in females (p<0.05) perhaps as a result of a mandibular downward rotational change at B point. FMA increased nearly two degrees in both sexes.

The skeletal facial height variables UFH, N-Me (both $p<0.001$) and LFH ($p<0.01$) all exhibited greater mean linear dimensional increases in males. This is not unexpected based on the probability of a growth differential between the genders.

The upper incisors were retroclined more in males than females for all mean upper incisor variables but the treatment changes were not significantly different between the sexes. The lower incisors were minimally proclined in both groups (figs 21, 22).

Of the mean soft tissue variable changes, fourteen expressed significant differences between the groups. F conv had a greater mean change (decrease) in males reflecting any gross nasal dimensional increases. ULL ($p<0.05$) measured larger dimensional change sagittally in males. For the soft tissue variables to S vert, all (except Si-S vert) were significantly different between pre- and post-treatment. All of these dimensions had a mean decrease in females whereas there was a trend for a mean increase in males. An overall growth differential as well as a greater downward rotation in the female sample may in some way explain these mean differences.

The vertical soft tissue variables reflected the underlying skeletal changes with ST TFH, ST UFH, ST Pog-STN and ST LFH (all $p<0.01$) showing significantly greater mean increases in males.

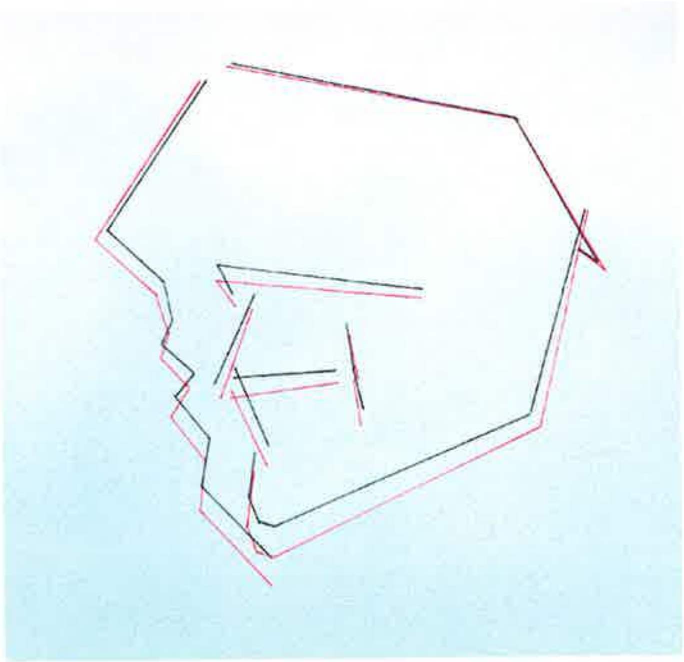
7.2.4 Sample age and treatment time

The chronological ages of the sample were used to define the developmental status for both the male and female sub-groups. Based on the available records, skeletal or maturational development would have proven difficult to determine. Males and females were therefore compared with respect to overall treatment start and finish ages (fixed appliance therapy duration) and "actual" treatment start and finish ages (interval between pre- and post-treatment cephalometric radiographs):

Table 10 Treatment ages

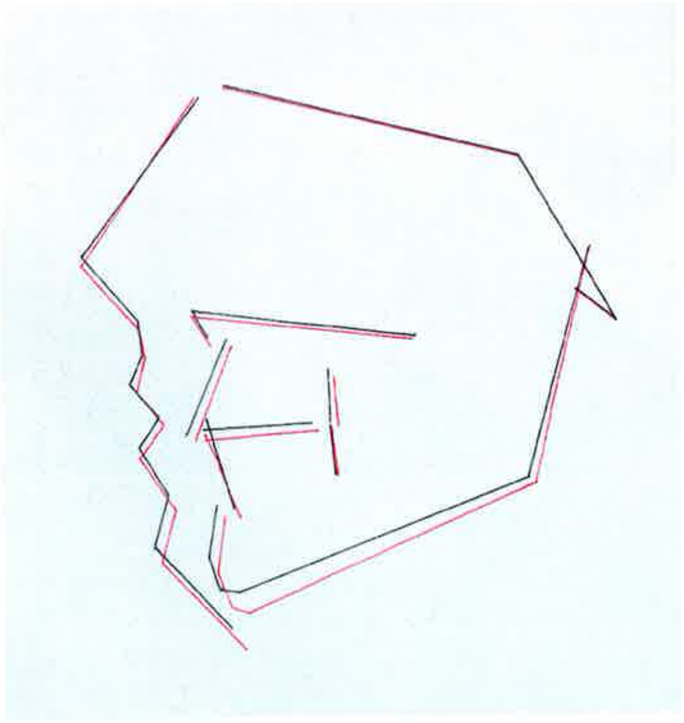
	Bands on age		**Pre-ceph age**		**Bands off age**		**Post-ceph age**	
	mean (years)	sd	mean (years)	sd	mean (years)	sd	mean (years)	sd
Females	14.09	1.37	13.75	1.38	15.81	1.20	15.71	1.38
Males	14.32	1.10	13.94	1.10	15.98	1.16	15.86	1.12

Figure 21 Pre- and post-treatment composite tracings superimposed on anatomical cranial base structures – males



________ pre-treatment
________ post-treatment

Figure 22 Pre- and post-treatment composite tracings superimposed on anatomical cranial base structures – females



________ pre-treatment
________ post-treatment

Differences were noted between the time pre-treatment radiographic records were obtained and the start of fixed appliance therapy ("lead time") and similarly for the post-treatment radiographic cephalogram and fixed appliance removal ("lag time"). "Effective" treatment time was calculated on the time interval between cephalometric exposures and these values were used for any treatment interval data for both males and females:

Table 11 Treatment times

	Lead time		**Lag time**		**Treatment time**		**Effective time**	
	mean (days)	sd	mean (days)	sd	mean (days)	sd	mean (days)	sd
females	123	110	-38	20	628	119	718	179
males	142	95	-47	38	607	152	702	165

A comparison was made between males and females to test for any significant differences for the "effective" treatment age and time values in Tables 10 and 11 with Student's t-tests:

Table 12 Treatment times and sample age: t-values

	Lead time (years)	**Lag time** (years)	**Actual time** (years)	**Pre-ceph age** (years)	**Post-ceph age** (years)
t-value	0.61	0.94	0.31	0.5	0.39

The t-tests revealed no significant mean difference between males and females for "lead" and "lag" time, "effective" time or the ages at which the pre- and post-treatment cephalometric radiographs were taken. "Effective" treatment durations varied broadly with the females ranging from 1.10 years to 3.30 years and males 1.39 years to 3.01 years. Fixed appliance intervals were similar with females ranging from 1.04 years to 2.42 years and males 1.11 years to 2.92 years.

The following summarises the cephalometric male and female sample comparisons:

- For the pre-treatment variables, males revealed a reduced SNA angle but a greater proclination of the upper incisors (U1-NA angle). Generally, both groups exhibited a mean Class I skeletal pattern (ANB angle). Both hard and soft tissue vertical variables were greater in males in absolute terms presumably as a result of gender dimorphism;

- For the post-treatment variables, males exhibited mandibular "catch-up" negating any pre-treatment difference for SNB angle. The upper incisors remained further proclined in males compared to females although this was not significant. Large increases were noted in males for absolute sagittal linear variables probably as a result of normal growth and development;
- Pre- and post-treatment chronological ages were broadly similar for both groups. Intervals between cephalometric radiographs served to provide the data for the calculations of "effective" treatment times. This allowed direct comparison with the variable data derived from the radiographs. No significant differences were noted between males and females for "lead" and "lag" times, "effective" times and ages.

7.2.5 Sample comparison with longitudinal standards

The sample results for both pre- and post-treatment cephalometric variables were compared with the data from two longitudinal growth studies collated by Bhatia and Leighton (1993) and Riolo et al (1974), the latter described as the "*Michigan*" group.

Both longitudinal groups were drawn from populations comprising a selection of malocclusion types, mainly Class II. Of the 121 caucasian subjects in the Bhatia and Leighton (1993) sample, 65 had "normal" or Class I malocclusion and 42 Class II division I malocclusion based on the incisor relationships. The "Michigan" data (Riolo et al, 1974) is drawn from the records of 83 individuals.

Chronological ages were matched for both the male and female groups from an assessment of pre- and post-treatment times (Table 10). Pre-treatment age was compared at 14 years and post-treatment age at 16 years, for both sexes.

Not all variables were available for direct comparison. The data from the Bhatia and Leighton (1993) sample had been adjusted for radiographic magnification (7.76%). The "Michigan" sample data was published with magnification set at 12.7% and this was adjusted for in the tabulated results.

Standard descriptive statistics were applied to the comparisons which included sample means, standard deviations and Student's t-tests to test for statistically significant differences between the male groups:

Table 13 Male comparisons with longitudinal growth studies

		Present study n = 19		Bhatia & Leighton n = 58 (pretreatment) n = 58 (posttreatment)			Michigan n = 40 (pretreatment) n = 23 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
SN-FH	pretreat	9.21	2.83	10.6	2.6	**1.98** *	4.70	4.1	**4.92** ***
	posttreat	8.23	2.75	10.70	2.30	**3.87** ***	3.10	3.6	**5.1** ***
	change	-0.98	0.87						
SNA	pretreat	78.98	3.37	80.7	4.1	1.65	80.70	3.4	1.82
	posttreat	78.50	3.33	80.90	4.10	**2.31** *	81.40	4.4	**2.37** *
	change	-0.48	1.08						
MaxPl-SN	pretreat	5.63	3.09	6.9	3	1.59	7.30	3.5	1.78
	posttreat	5.88	3.25	6.90	2.90	1.29	7.00	3	0.29
	change	0.25	1.23						
Co-A	pretreat	87.15	4.17	84.3	4.3	**2.53** *			
	posttreat	88.51	4.42	86.50	4.30	1.76			
	change	1.37	2.79						
U1-SN	pretreat	101.98	7.27	102.3	7.7	0.16	102.60	6	0.35
	posttreat	99.63	5.38	103.00	8.10	**2.07** *	105.20	6.4	**3.01** **
	change	-2.35	5.59						
U1-NA	pretreat	23.00	6.89	21.6	8	0.68	21.90	5.6	0.65
	posttreat	21.13	5.26	22.10	8.10	0.60	23.80	6.1	1.5
	change	-1.87	5.68						
U1-NA	pretreat	4.72	2.45	3.7	2.4	1.6	3.75	2.8	1.29
	posttreat	4.21	2.30	4.00	2.50	0.32	4.80	2.7	0.75
	change	-0.51	2.09						

Table 13 (continued)

Male comparisons with longitudinal growth studies

		Present study n = 19		**Bhatia & Leighton** n = 58 (pretreatment) n = 58 (posttreatment)			**Michigan** n = 40 (pretreatment) n = 23 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
SNB	pretreat	76.13	2.13	77.6	3.9	**2.08 ***	77.30	3.1	1.69
	posttreat	76.54	2.71	78.30	3.90	**2.19 ***	78.20	3.9	1.57
	change	0.41	0.69						
Co-Gn	pretreat	110.36	5.49	110.7	5.1	0.25	110.43	5.7	0.04
	posttreat	115.82	6.53	115.80	4.90	0.01	116.63	5.4	0.44
	change	5.46	3.20						
Ar-Gn	pretreat	102.50	5.89	104.3	4.9	1.32	103.71	5.2	0.8
	posttreat	107.53	5.76	109.70	4.80	1.63	109.91	4.8	1.46
	change	5.02	2.10						
Co-Go	pretreat	51.18	3.66	53.2	4	1.95	53.78	4.4	**2.23 ***
	posttreat	53.68	4.27	57.00	4.30	**2.93 ****	57.71	4.1	**3.11 ****
	change	2.50	2.31						
Ar-Go	pretreat	41.75	4.06	43.1	4.2	1.23	43.48	4.6	1.4
	posttreat	43.86	4.41	46.70	4.60	**2.36 ***	47.40	4.1	**2.69 ***
	change	2.11	1.34						
UFH	pretreat	49.48	3.57	51.5	2.5	**2.29 ***	50.81	4.1	1.21
	posttreat	51.73	3.98	53.40	2.60	1.71	52.12	3.9	0.32
	change	2.25	1.37						
LFH	pretreat	64.59	5.59	63.3	5.1	0.93	64.86	5.8	0.17
	posttreat	68.98	6.26	65.90	5.50	**2.05 ***	69.40	6.2	0.22
	change	4.39	1.62						
N-Me	pretreat	112.91	7.10	113.6	6.4	0.4	113.75	7.9	0.39
	posttreat	119.64	7.66	118.20	6.80	0.78	119.43	7.9	0.09
	change	6.73	2.32						

Table 13 (continued)

Male comparisons with longitudinal growth studies

		Present study n = 19		**Bhatia & Leighton** n = 58 (pretreatment) n = 58 (posttreatment)			**Michigan** n = 40 (pretreatment) n = 23 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
S-Go	pretreat	71.07	5.08	72.3	4.7	0.97	72.37	5.6	0.86
	posttreat	75.06	5.00	76.80	4.80	1.36	77.00	5.9	1.14
	change	3.99	1.68						
FMA	pretreat	26.39	5.22	24.3	4.6	1.66	27.70	5.8	0.84
	posttreat	28.37	5.80	23.00	5.10	**3.85** ***	28.70	5.2	0.19
	change	1.98	1.93						
SN-OP	pretreat	15.57	5.24	18.7	4.2	**2.65** **	15.4	3.9	0.14
	posttreat	18.38	3.88	16.50	4.20	1.72	12.90	4.1	**4.42** ***
	change	2.81	4.03						
MP-OP	pretreat	20.03	4.30	16.2	4.3	**3.37** **			
	posttreat	18.23	5.65	17.20	4.60	0.80			
	change	-1.80	3.88						
F conv	pretreat	127.42	4.02	131.1	4.9	**2.96** **			
	posttreat	125.34	3.85	129.60	5.20	**3.28** **			
	change	-2.08	2.25						
Ls-E line	pretreat	-3.10	2.46	-3.1	1.8	0			
	posttreat	-4.63	2.00	-4.10	2.00	1.00			
	change	-1.53	1.22						
Li-E line	pretreat	-1.96	2.26	-2.4	1.7	0.9			
	posttreat	-2.25	2.02	-3.10	2.00	1.60			
	change	-0.29	1.25						

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

For the inter-regional skeletal variables, SNA and SNB exhibited significant differences between the samples. SNA remained smaller in males post-treatment compared to both comparison samples ($p<0.05$). This trend was also present in the pre-treatment measures as reflected by Co-A which was significantly smaller than the Bhatia and Leighton (1993) group. SNB was also smaller than the Bhatia and Leighton (1993) sample. ANB, however, was similar between the groups at both ages, all within Class I skeletal "norms". SN-FH was significantly greater in the treated group than the "Michigan" sample perhaps reflecting a more divergent facial pattern in the treated group. These results may also explain the significantly smaller SNA values in the current study group compared to the "Michigan" sample.

Ramal height (Co-Go and Ar-Go) was smaller in the study sample compared to both comparison groups for post-treatment values but mean mandibular length (Co-Gn) was not significantly different at either age.

Lower face height (LFH) increased in all three groups but was significantly greater post-treatment in the study sample than the Bhatia and Leighton (1993) male group. N-Me length provided no significant differences perhaps indicating that any increase in the vertical dimension in the treated sample was mainly a growth effect. The smaller LFH in the Bhatia and Leighton (1993) was also reflected in a decreased FMA at 16 years of age. This longitudinal growth study sample appeared to have slightly shorter vertical skeletal facial dimensions than both the study and "Michigan" groups.

U1-SN and U1-MaxPl angles were significantly less in the treated sample post-treatment than in either comparison group. This would reflect the reduction in upper incisor proclination as part of the orthodontic correction in the treated group. The lower incisors were significantly less proclined in the treated sample at both pre- and post-treatment intervals as measured by variables L1-NB angle and IMPA. This may indicate the "mild" nature of the presenting malocclusions in the treated sample. OJ was larger in the treated sample pre-treatment but significantly smaller post-treatment than the Bhatia and Leighton (1993) group at $p<0.01$. This trend was also evident for OB pre-treatment and also in the treated group post-treatment.

Change in Downs occlusal plane were revealed for the treated group. SN-OP was significantly smaller pre-treatment but significantly greater than the "Michigan" sample post-treatment ($p<0.001$). This would not be unexpected as part of an orthodontic correction.

One soft tissue variable exhibited a significant difference compared with the Bhatia and Leighton (1993) sample at both pre- and post-treatment periods. F conv ($p<0.01$) was smaller in the treated sample at both time intervals perhaps indicative of a more convex profile in the treated group. Li-E line tended to be smaller in the present study group compared to the Bhatia and Leighton (1993) sample. The lower lip in the present sample may be slightly more procumbent at both treatment intervals than the controls.

Standard descriptive statistics were applied to the comparisons which included sample means, standard deviations and Student's t-tests to test for statistically significant differences between the female groups:

Table 14 Female comparisons with longitudinal growth studies

		Present study n = 26		**Bhatia & Leighton** n = 63 (pretreatment) n = 62 (posttreatment)			**Michigan** n = 25 (pretreatment) n = 9 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
SN-FH	pretreat	9.72	2.68	10.9	2.3	**2.1** *	5.3	3.4	**5.17** ***
	posttreat	9.07	2.51	11.1	2.5	**3.47** **	4.80	2.9	**4.23** ***
	change	-0.65	0.87						
SNA	pretreat	81.15	3.21	80	3.8	1.36	81.3	3.5	0.16
	posttreat	80.74	3.04	80	3.9	0.86	81.80	3.7	0.85
	change	-0.41	1.06						
MaxPl-SN	pretreat	6.78	1.90	8	4	1.95	8.1	1.8	**2.54** *
	posttreat	6.79	1.56	8	4	**2.04** *	8.00	2.2	1.8
	change	0.02	1.35						
Co-A	pretreat	85.21	4.32	81.5	2.9	**4.02** ***			
	posttreat	85.15	3.79	82.1	3	**4.03** ***			
	change	-0.06	2.85						
U1-SN	pretreat	99.36	7.89	101.3	7.3	1.11	104	6.2	**2.33** *
	posttreat	99.09	6.24	101.3	7.4	1.34	103.10	6.5	1.64
	change	-0.28	8.19						

Table 14 (continued)

Female comparisons with longitudinal growth studies

		Present study n = 26		**Bhatia & Leighton** n = 63 (pretreatment) n = 62 (posttreatment)			**Michigan** n = 25 (pretreatment) n = 9 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
U1-NA	pretreat	18.22	7.06	21.3	6.3	**2.02 ***	22.7	5.4	**2.54 ***
	posttreat	18.34	6.10	21.2	6.1	**2.01 ***	21.40	6.9	1.26
	change	0.13	8.05						
U1-NA	pretreat	3.39	2.47	3.6	2	0.42	3.58	2.5	0.27
	posttrea	3.06	2.33	3.7	2	1.3	3.32	2.7	0.28
	change	-0.33	2.60						
U1-Max	pretreat	106.14	7.26	109.5	6.9	**2.06 ***	112.1	6.1	**3.17 ****
	posttreat	105.88	6.73	109.4	6.9	**2.2 ***	111.10	6.2	**2.04 ***
	change	-0.26	7.84						
U1-L1	pretreat	139.26	10.36	134.7	10	1.94	128	9.5	**4.04 *****
	posttreat	136.56	6.88	135.6	9.9	0.52	133.60	13	0.65
	change	-2.70	10.80						
OJ	pretreat	3.51	1.62	3.4	1.1	0.32			
	posttreat	2.09	0.97	3.3	1.1	**4.87 *****			
	change	-1.43	1.78						
OB	pretreat	4.27	1.47	3.1	1.7	**3.07 ****			
	posttreat	2.51	1.12	3	1.9	1.5			
	change	-1.76	1.61						
ANB	pretreat	3.04	1.90	2.3	2.5	1.35	3.4	2.5	0.58
	posttreat	2.90	1.84	2	2.6	1.84	2.60	2.4	0.39
	change	-0.14	1.20						
L1-NB	pretreat	19.49	5.46	22.4	7	1.89	25.9	7.1	**3.62 *****
	posttreat	22.19	5.20	21.8	7.2	0.28	22.40	9.6	0.06
	change	2.70	4.80						

Table 14 (continued)

Female comparisons with longitudinal growth studies

		Present study n = 26		**Bhatia & Leighton** n = 63 (pretreatment) n = 62 (posttreatment)			**Michigan** n = 25 (pretreatment) n = 9 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
L1-NB	pretreat	2.98	1.80	3.1	2.3	0.24	4.10	2.6	1.78
	posttreat	4.11	1.56	3	2.4	**2.57** *	2.97	3.6	0.92
	change	1.13	1.42						
IMPA	pretreat	86.45	6.63	89.7	6.8	**2.07** *	94.5	6.9	**4.25** ***
	posttreat	88.22	7.68	89.4	6.9	0.71	92.00	9.4	1.2
	change	1.77	4.91						
SNB	pretreat	78.11	2.83	77.9	3.8	0.25	77.9	3.8	0.22
	posttreat	77.84	2.75	78.2	3.9	0.49	79.20	2.3	1.33
	change	-0.27	1.07						
Co-Gn	pretreat	108.69	4.61	107.7	4.1	1	104.67	4	**3.32** **
	posttreat	110.73	4.23	109.4	4	1.4	107.90	4	1.75
	change	2.04	3.29						
Ar-Gn	pretreat	101.50	3.80	101.3	4	0.22	98.91	5.3	**2.01** *
	posttreat	102.70	3.62	103	4.3	0.31	102.14	5	0.36
	change	1.21	2.13						
Co-Go	pretreat	49.97	3.86	52.3	3.2	**2.94** **	49.59	3.5	0.37
	posttreat	51.54	3.51	53.8	3.9	**2.55** *	52.82	2.4	1.01
	change	1.57	3.26						
Ar-Go	pretreat	41.47	3.83	42.3	3.4	1.01	40.51	4.6	0.81
	posttreat	42.29	3.61	43.80	4	1.66	43.30	3.9	0.71
	change	0.82	2.02						
UFH	pretreat	48.96	3.05	49.7	2.8	1.1	48.28	2.7	0.84
	posttreat	49.55	2.46	50.00	2.6	0.75	48.63	2.1	1
	change	0.58	1.36						

Table 14 (continued)

Female comparisons with longitudinal growth studies

		Present study n = 26		**Bhatia & Leighton** n = 63 (pretreatment) n = 62 (posttreatment)			**Michigan** n = 25 (pretreatment) n = 9 (posttreatment)		
VARIABLE		**mean**	**sd**	**mean**	**sd**	**t- value**	**mean**	**sd**	**t- value**
LFH	pretreat	61.80	3.46	60.9	5	0.97	60.32	5	1.22
	posttreat	64.61	4.16	61.80	5.3	**2.4** *	60.50	5.2	**2.4** *
	change	2.81	1.73						
N-Me	pretreat	109.40	4.40	109.5	5.8	0.08	106.77	5.9	1.81
	posttreat	112.57	4.53	110.80	6	1.35	107.55	5.1	**2.78** **
	change	3.17	2.33						
S-Go	pretreat	68.75	4.79	69.9	4.2	1.13	66.87	5.5	1.3
	posttreat	70.26	4.47	71.40	4.6	1.07	69.05	4.3	0.71
	change	1.51	1.95						
FMA	pretreat	25.20	4.42	23.8	5.5	1.15	24.8	5.8	1.36
	posttreat	27.06	5.30	23.10	5.7	**3.03** **	25.80	3	0.87
	change	1.86	2.29						
SN-OP	pretreat	16.35	4.43	18.7	4.7	**2.18** *	15.7	4	0.55
	posttreat	18.28	5.12	18.10	4.8	0.16	14.40	2.5	**3.46** **
	change	1.93	5.43						
MP-OP	pretreat	18.57	5.09	16	3.6	**2.34** *			
	posttreat	17.85	4.20	16.10	4.1	1.81			
	change	-0.72	4.29						
F conv	pretreat	129.08	4.46	132.5	4.6	**3.22** **			
	posttreat	129.35	3.96	132.20	4.6	**2.76** **			
	change	0.28	2.33						
Ls-E line	pretreat	-3.79	1.98	-4.5	2.6	1.25			
	posttreat	-4.58	1.92	-4.90	2.50	0.58			
	change	-0.79	1.16						

Table 14 (continued)

Female comparisons with longitudinal growth studies

VARIABLE		Present study n = 26 mean	sd	Bhatia & Leighton n = 63 (pretreatment) n = 62 (posttreatment) mean	sd	t- value	Michigan n = 25 (pretreatment) n = 9 (posttreatment) mean	sd	t- value
Li-E line	pretreat	-2.68	2.37	-3.3	2.2	1.18			
	posttreat	-2.01	1.97	-3.40	2.10	**2.88** **			
	change	0.68	1.21						

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

In slight contrast to the male comparisons, the female inter-regional variables SNA, SNB and ANB were broadly similar between the groups at both pre- and post-treatment ages. All groups were within the mean range for Class I skeletal "norms". As with the male sample, Co-A linear variable was significantly greater in the present study group at both time intervals. The difficulty in the reproducibility of *condylion* must be recalled when interpreting these results. The "Michigan" sample again provided a surprisingly low SN-FH angle compared to the other two groups.

Mandibular length variable Ar-Gn was larger in the pre-treatment sample compared to the "Michigan" group. This difference was not evident post-treatment. Co-Go, in the present study, was significantly smaller at both time periods compared to the Bhatia and Leighton (1993) sample but not for the "Michigan" group. For mandibular length, Co-Gn was larger pre-treatment in the present study compared to the "Michigan" females. However, at the second time period, all three groups exhibited mean equivalence for this variable.

Vertical skeletal variable LFH was significantly larger in the post-treatment present study group compared to both longitudinal growth studies. This may be indicative of the extrusive effects of fixed orthodontic mechanics. This was reflected by N-Me being larger in the present study group compared to the "Michigan" group at the second time period. FMA revealed a mean increase in the treated group which was significantly greater than the Bhatia and Leighton (1993) sample ($p<0.01$).

The upper incisor position, as with the male sample, was significantly more retroclined than either comparison group at both time periods ($p<0.05$). Variables U1-NA angle and U1-Max Pl were both significantly smaller in the present study group compared to the controls. There was little mean change in sagittal incisor position for the treated group, with a mean change for U1-MaxPl of –0.26 degrees. A similar trend was noted form the pre-treatment lower incisor variables, L1-NB angle and IMPA. Both were significantly smaller in the present study group pre-treatment. No significant difference was exhibited post-treatment. OJ was similar between the groups at the initial time period but was significantly smaller in the treated group post-treatment ($p<0.001$). OB was significantly larger in the pre-treatment study group compared to the female Bhatia and Leighton (1993) sample ($p<0.01$) but no difference was evident post-treatment.

Occlusal plane angulation changes were revealed in the present study group with significant differences exhibited between both control groups. SN-OP was significantly smaller pre-treatment in the present study group compare to the Bhatia and Leighton (1993) sample. With an increase for this variable during treatment, no significant difference was noted post-treatment between these groups but SN-OP was significantly larger than the "Michigan" sample ($p<0.01$).

For the soft tissue variables, F conv was significantly smaller in the present study females (as for males) for both pre- and post-treatment data ($p<0.01$). Li-E line was significantly smaller in the treatment group post-treatment compared to the Bhatia and Leighton (1993) sample. This may be indicative of a slightly more procumbent lower lip in the present study sample.

The following summarises the comparisons of the present study sample with the longitudinal growth study samples:

- The present sample exhibited a mean Class I skeletal pattern based on the variables SNA, SNB and ANB. The male study group tended to have a smaller SNA value than the controls;
- Ramal height (Co-Go) was smaller in both study groups but mean mandibular lengths were broadly similar for both groups compared to both control groups;
- Skeletal facial height increases were noted post-treatment for the study group presumably as a result of extrusive fixed appliance mechanics;

- Both upper and lower incisors tended to be more retroclined in the study group for both sexes, pre- and post-treatment;
- Significant OB and OJ reduction was exhibited for both males and females in the study group compared to the controls. An increase in Downs occlusal plane in both sample study groups is indicative of an orthodontic correction;
- The present study group revealed significantly more soft tissue facial convexity than the corresponding controls. The lower lip relative to E-line in both sexes of the study group was significantly more procumbent than the controls.

7.2.6 Mandibular regional superimpositions

Mandibular regional superimpostions were undertaken as previously described (Section 6.5) after the anatomical method of Björk and Skieller (1983). The mean changes of four hard tissue variables were analysed for both male and female samples.

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests:

Table 15 Pre-treatment mean cephalometric variables

	Males n = 19			Females n = 26				
VARIABLE	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
LI angle	87.46	4.57	1.05	86.63	6.85	1.34	0.08	0.45
LM angle	78.82	6.95	1.59	76.89	5.87	1.15	0.43	1.01
L5 angle	76.08	4.42	1.01	75.99	4.69	0.92	0.81	0.07
L4 angle	74.38	5.64	1.29	73.82	4.76	0.93	0.42	0.36

No significant differences were noted between the sexes for the angular pre-treatment variables. LM angle exhibited a tendency to be larger in the male group.

Table 16 Post-treatment mean cephalometric variables

	Males n = 19			Females n = 26				
VARIABLE	mean	sd	SE	mean	sd	SE	F-prob	t- value
LI angle	87.32	7.42	1.70	88.31	7.62	1.49	0.93	0.44
LM angle	70.51	6.86	1.57	71.87	6.53	1.28	0.80	0.67
L5 angle	69.12	5.16	1.18	71.26	4.56	0.89	0.56	1.47
L4 angle	69.67	5.16	1.18	71.44	4.69	0.92	0.64	1.20

There were no statistically significant differences for the post-treatment variables between the genders. L5 and L4 angles tended to be larger in females.

Table 17 Treatment changes mean cephalometric variables

	Males n = 19			Females n = 26				
VARIABLE	mean	sd	SE	mean	sd	SE	F-prob	t-value
LI angle	-0.14	5.36	1.23	1.68	5.13	1.01	0.82	0.61
LM angle	-8.31	6.82	1.56	-5.03	6.87	1.35	0.99	1.96 (*)
L5 angle	-6.96	3.48	0.80	-4.73	4.71	0.92	0.19	1.96 (*)
L4 angle	-4.71	4.65	1.07	-2.38	4.46	0.87	0.83	1.25

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***; (*)=approaching significance

For treatment changes, no variables exhibited statistically significant differences between males and females. LM and L5 angles approached significance at $p<0.05$. For the male sample, all the dental angular variables revealed a mean decrease post-treatment. The same mean tendency was exhibited by the female group except for LI angle which increased slightly. Overall, the lower buccal segment exhibited mean distal uprighting (note minimal or no use of intermaxillary elastic force) whereas the lower labial segment remained relatively stable in the sagittal plane.

In summary, for the mandibular superimpositions (figs 23, 24):

- There were no statistically significant differences between the groups for both pre- and post-treatment variables;

Figure 23 Pre- and post-treatment composite tracings based on mandibular structural superimpositions - males

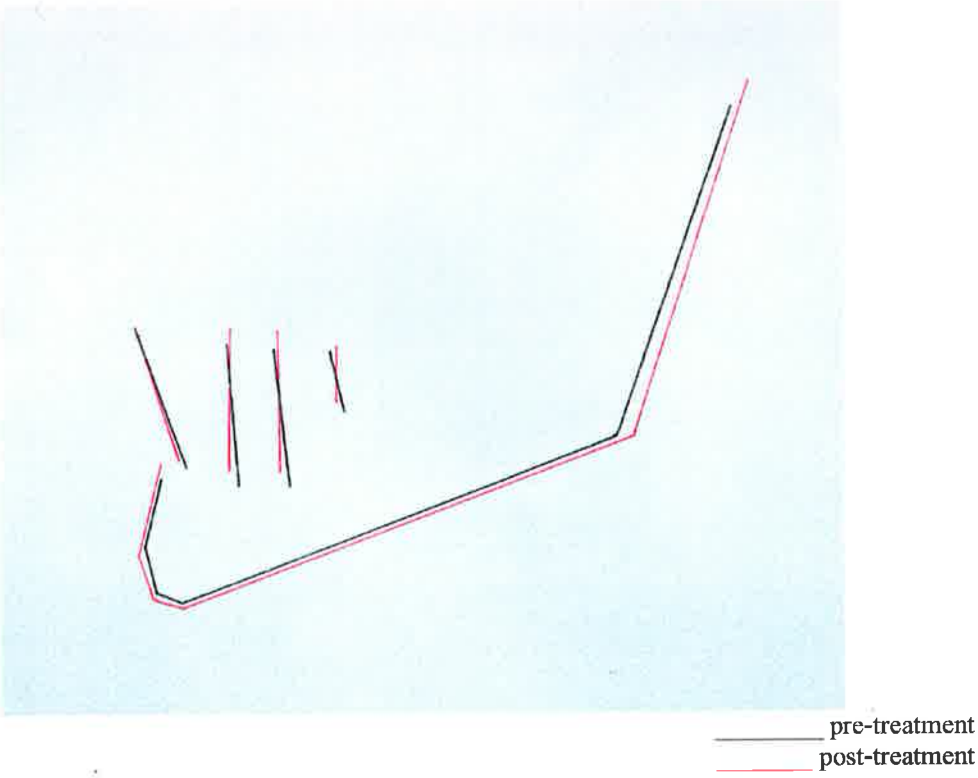
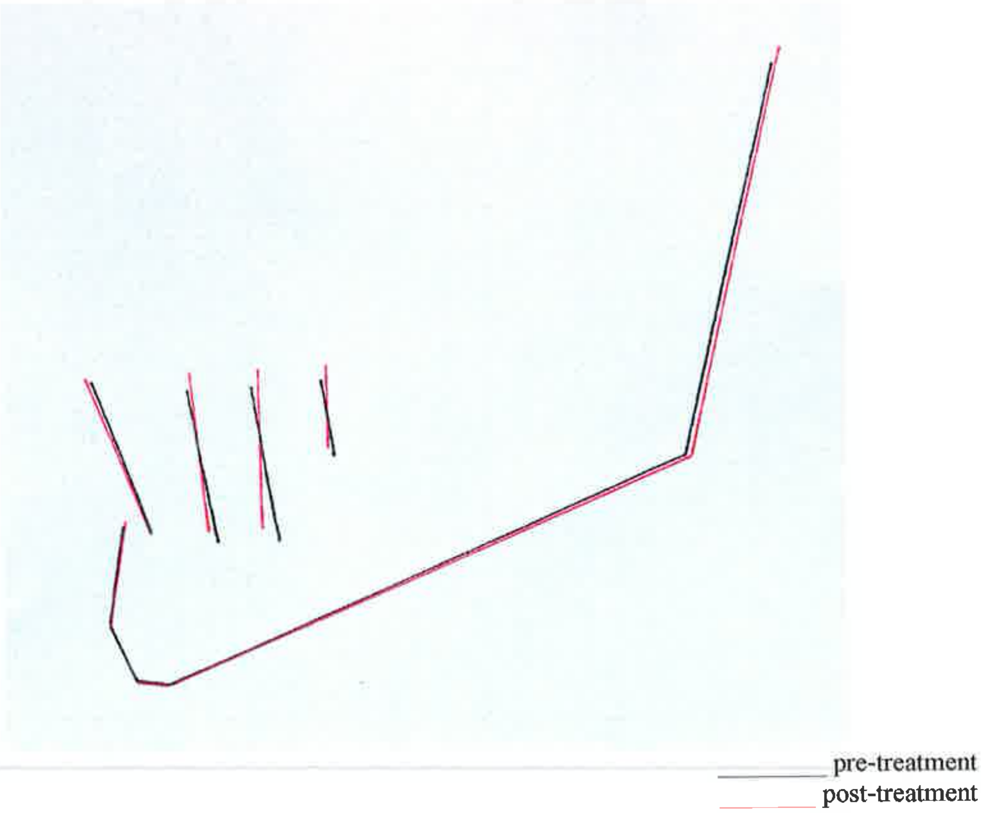


Figure 24 Pre- and post-treatment composite tracings based on mandibular structural superimpositions - females



- For the mandibular mean changes, both genders revealed an overall distal uprighting of the lower buccal segments and little change in the lower labial segment.

7.3 Study model descriptive statistics

Standard descriptive statistical analyses were applied to the variables to evaluate any differences between males and females for the following:

1. Pre-treatment variables;
2. Post-treatment variables;
3. Treatment changes.

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests.

For all tables, statistically significant differences are in bold type.

7.3.1 Pre-treatment variables

Table 18 Pre-treatment mean study model variables

	Males n = 19			**Females** n = 26				
VARIABLE (mm)	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
LOWER ARCH-T1								
ICW	24.94	1.83	0.42	23.73	1.50	0.29	0.35	**2.43** *
IPMW	35.50	2.29	0.52	33.91	2.84	0.56	0.35	**2.01** *
IMW	41.24	2.92	0.67	39.00	3.27	0.64	0.63	**2.38** *
AD	23.61	1.32	0.30	22.60	1.35	0.27	0.92	**2.51** *
AL	61.11	2.57	0.59	58.32	2.90	0.57	0.60	**3.33** **
IRREG INDEX	5.00	1.81	0.41	4.33	1.73	0.34	0.82	1.26
ARCH PERIMETER	64.48	3.26	0.75	62.99	3.14	0.62	0.85	1.55
TOOTH SIZE	67.95	2.61	0.60	65.89	2.18	0.43	0.40	**2.87** **
TSALD	-3.47	2.64	0.61	-2.90	2.41	0.47	0.65	0.75

Table 18 (continued)

Pre-treatment mean variables

	Males n = 19			Females n = 26				
VARIABLE (mm)	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
UPPER ARCH- T1								
ICW	31.02	2.22	0.51	30.53	1.99	0.39	0.60	0.78
IPMW	39.66	2.42	0.55	38.40	2.46	0.48	0.95	1.70
IMW	45.90	2.55	0.58	44.24	2.58	0.51	0.96	**2.14** *
AD	28.98	1.96	0.45	27.03	1.74	0.34	0.56	**3.52** **
AL	71.32	3.55	0.82	67.54	3.07	0.60	0.49	**3.80** ***
IRREG INDEX	6.59	2.12	0.49	6.34	2.10	0.41	0.94	0.39
ARCH PERIMETER	74.91	3.57	0.82	72.79	3.22	0.63	0.62	**2.09** *
TOOTH SIZE	75.82	3.66	0.84	73.74	2.26	0.44	0.03	**2.15** *
TSALD	-0.91	2.55	0.58	-0.95	2.53	0.50	0.96	0.05

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

For the lower arch pre-treatment, all the transverse dental arch variables (ICW, IPMW and IMW) were significantly larger in males than females ($p<0.05$). An absolute size discrepancy between genders could explain this. In the sagittal plane, both AD ($p<0.05$) and AL ($p<0.01$) were significantly greater in males. This correlates with the significant discrepancy for overall mesio-distal tooth size, being smaller in the female group ($p<0.01$). There appeared to be no significant difference between the groups for lower incisor irregularity (Little, 1975) or overall tooth-size arch length discrepancy (space available – space required).

A similar pattern was exhibited in the upper arch pre-treatment. Mean values for ICW and IPMW tended to be larger in the male sample with IMW significantly larger ($p<0.05$). AD and AL were significantly larger in males. Overall arch perimeter and tooth size were smaller in the female sample reflecting sexual dimorphism. As with the mandibular arch, maxillary incisor irregularity and tooth-size arch length discrepancy variables were not significantly different between sexes.

7.3.2 Post-treatment variables

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests.

Table 19 Post-treatment mean study model variables

	Males n = 19			**Females** n = 26				
VARIABLE (mm)	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
LOWER ARCH- T2								
ICW	26.04	1.31	0.30	25.02	1.07	0.21	0.34	**2.86 ****
IPMW	36.45	2.41	0.55	34.15	2.00	0.39	0.38	**3.49 ****
IMW	41.32	2.55	0.59	39.33	2.53	0.50	0.95	**2.60 ***
AD	24.64	1.33	0.30	23.91	1.14	0.22	0.48	2.00 (*)
AL	63.15	2.32	0.53	60.48	2.13	0.42	0.68	**3.98 *****
UPPER ARCH- T2								
ICW	32.35	1.79	0.41	31.74	1.40	0.27	0.24	1.27
IPMW	41.88	1.92	0.44	40.49	2.06	0.40	0.76	**2.29 ***
IMW	46.59	2.29	0.53	45.03	2.30	0.45	1.00	**2.25 ***
AD	28.67	1.42	0.33	27.65	1.33	0.26	0.74	**2.48 ***
AL	71.77	3.09	0.71	69.24	2.57	0.50	0.38	**2.99 ****

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***; (*)=approaching significance

Following an evaluation of the post-treatment dental casts, the determination of the post-treatment study model variables "irregularity index" and "tooth size-arch length discrepancy" were both deemed to be zero.

All post-treatment lower arch variables were or approached significant differences between males and females, reflecting the pre-treatment results. The transverse variables ICW, IPMW and IMW were all significantly larger in males. AL ($p<0.001$) was larger in the male sample to a highly significant degree. Mean AD variable approached significance ($p<0.05$) with female dimensions smaller than males.

A similar scenario was exhibited in the upper arch. In contrast to the pre-treatment result, ICW was not significantly different between the genders although the mean value tended to be larger in males. IPMW and IMW remained significantly larger in the male group ($p<0.05$). AD and AL reflected the pre-treatment results.

7.3.3 Treatment changes

Sample means, standard deviations and standard error of the means were calculated for each variable and the gender comparisons made with the application of Student's t-tests.

Table 20 Treatment changes mean study model variables

	Males n = 19			**Females** n = 26				
VARIABLE (mm)	**mean**	**sd**	**SE**	**mean**	**sd**	**SE**	**F-prob**	**t-value**
LOWER ARCH- T1								
ICW	1.10	1.20	0.27	1.30	1.02	0.20	0.47	0.58
IPMW	0.95	1.40	0.32	0.24	1.43	0.28	0.95	1.67
IMW	0.08	2.11	0.48	0.33	1.59	0.31	0.19	0.45
AD	1.03	1.05	0.24	1.31	1.41	0.28	0.19	0.72
AL	2.04	2.14	0.49	2.16	2.75	0.54	0.28	0.15
UPPER ARCH- T1								
ICW	1.33	1.81	0.42	1.22	1.68	0.33	0.72	0.21
IPMW	2.22	1.67	0.38	2.09	1.89	0.37	0.59	0.24
IMW	0.69	2.03	0.47	0.79	1.40	0.28	0.09	0.19
AD	-0.31	1.17	0.27	0.61	1.56	0.31	0.21	**2.16 ***
AL	0.45	2.29	0.53	1.70	2.58	0.51	0.61	1.68

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

There was no statistically significant difference between males and females in the lower arch for all the study model variables. There was a small mean increase in all variables for both sexes.

Similar changes were revealed in the upper arch. There was a general mean increase in the upper arch variables for both sexes. There were no statistically significant differences between males and females for treatment changes except for AD ($p<0.05$). AD exhibited a mean decrease in males but a mean increase in females. This result reflects the cephalometric treatment changes (Table 9). UM-PP angle in males increased indicating a possible decrease in arch depth posteriorly while U1-NA angle also decreased resulting in a mean loss of arch depth overall.

In summary, analysis of the study model variables revealed:

- Pre-treatment, larger mean values for most variables in the male sample for both transverse (ICW, IPMW, IMW) and sagittal (AD, AL) measures;
- A mean similarity for the irregularity indices and tooth-size arch length discrepancy in both upper and lower arches in both genders pre-treatment;
- Post-treatment, a mean increase in the pre-treatment absolute values for both sexes in both arches. The values were significantly larger in males for all variables except for ICW in the upper arch;
- For mean treatment changes, there were no significant differences for the mean changes between males and females except for AD which revealed a mean decrease in males and increased in females. Generally, there was an increase in the values for the variables analysed between pre- and post-treatment.

7.3.4 Sample comparison with longitudinal standards

The study cast results from the present study group were compared with the longitudinal sample results published by Moyers et al, 1976. This is from the "*Michigan*" group whose cephalometric standards have also been reported (Riolo et al, 1974). The data from the "Michigan" group was drawn mainly from individuals of North European origin with untreated occlusions. This led to a general reduction in the number of subjects with serial records available from three to eighteen years of age as many received orthodontic treatment during the term of the growth study.

As with the cephalometric analysis, chronological ages from the present sample were matched with those of the "Michigan" group for both pre- and post-treatment times.

Standard descriptive statistics were applied to the comparisons which included sample means, standard deviations and Student's t-tests to test for statistically significant differences between the male groups:

Table 21 Male comparisons with "Michigan" growth study

VARIABLE (mm)			**Present study** n = 19		**Michigan**		
LOWER ARCH	**Michigan**		**mean**	**sd**	**mean**	**sd**	**t- value**
ICW	n = 48	pretreat	24.94	1.83	24.73	1.45	0.5
	n = 44	posttreat	26.04	1.31	24.66	1.68	**3.18 ****
		change	1.10	1.20			
IPMW	n = 37	pretreat	35.50	2.29	37.19	2.2	**2.68 ****
	n = 46	posttreat	36.45	2.41	37.26	2.33	1.26
		change	0.95	1.40			
IMW	n = 52	pretreat	41.24	2.92	42.13	2.27	1.35
	n = 45	posttreat	41.32	2.55	42.77	2.62	**2.05 ***
		change	0.08	2.11			
AD	n = 37	pretreat	23.61	1.32	23.93	1.35	0.85
	n = 44	posttreat	24.64	1.33	23.42	1.68	**2.8 ****
		change	1.03	1.05			

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

For the lower arch comparisons, ICW was significantly larger in the present study sample post-treatment ($p<0.01$). This may reflect the orthodontic correction in this group. IPMW was significantly smaller pre-treatment but this difference was not evident at the second time period, however, IPMW remained less than the mean "Michigan" sample. Mean IMW remained smaller in the present study group at both pre- and post-treatment intervals. This was significant at the post-treatment assessment ($p<0.05$).

Arch depth was similar between the male groups pre-treatment but was significantly larger in the present study group post-treatment ($p<0.01$).

General increases in most variables for the treated group was not an unexpected finding.

Table 22 Male comparisons with "Michigan" growth study

			Present study n = 19		Michigan		
VARIABLE (mm)			**mean**	**sd**	**mean**	**sd**	**t- value**
UPPER ARCH	**Michigan**						
ICW	n = 42	pretreat	31.02	2.22	32.45	1.55	**2.54 ***
	n = 45	posttreat	32.35	1.79	32.25	1.84	0.2
		change	1.33	1.81			
IPMW	n = 36	pretreat	39.66	2.42	41.11	2.02	**2.36 ***
	n = 44	posttreat	41.88	1.92	41.22	2.61	0.99
		change	2.22	1.67			
IMW	n = 54	pretreat	45.90	2.55	45.86	2.53	0.06
	n = 46	posttreat	46.59	2.29	46.63	2.87	0.05
		change	0.69	2.03			
AD	n = 34	pretreat	28.98	1.96	29.19	1.86	0.39
	n = 43	posttreat	28.67	1.42	28.38	2.36	0.6
		change	-0.31	1.17			

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

For the upper arch comparisons, two variables displayed significant differences between the male samples. ICW was significantly smaller pre-treatment in the present study group ($p<0.05$). There was a mean increase in the ICW for the treated group but this was not significantly different from the "Michigan" sample. Similarly, IPMW was significantly smaller in the pre-treatment study group ($p<0.05$) but a mean increase in IPMW during treatment resulted in a non-significant difference between the groups post-treatment.

Table 23 Female comparisons with "Michigan" growth study

			Present study n = 26		Michigan		
VARIABLE (mm)			**mean**	**sd**	**mean**	**sd**	**t- value**
LOWER ARCH	**Michigan**						
ICW	n = 31	pretreat	23.73	1.50	24.39	1.14	1.89
	n = 23	posttreat	25.02	1.07	23.90	1.76	**2.65 ***
		change	1.30	1.02			
IPMW	n = 21	pretreat	33.91	2.84	36.23	2.06	**3.13 ****
	n = 21	posttreat	34.15	2.00	36.10	1.8	**3.47 ****
		change	0.24	1.43			
IMW	n = 38	pretreat	39.00	3.27	41.11	2.58	**2.88 ****
	n = 25	posttreat	39.33	2.53	41.46	2.11	**3.26 ****
		change	0.33	1.59			
AD	n = 20	pretreat	22.60	1.35	22.92	1.89	0.67
	n = 20	posttreat	23.91	1.14	21.87	1.68	**4.67 *****
		change	1.31	1.41			

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

The female study model comparisons followed a similar pattern to the male group. ICW was significantly larger post-treatment in the present study group ($p<0.01$). IPMW was significantly smaller in the treated group pre-treatment but a mean increase was exhibited at post-treatment. IMW revealed a mean increase for the "Michigan" group ($p<0.05$) with little mean change noted in the female treated group. As with the male sample, AD increased significantly post-treatment ($p<0.01$).

Overall, all measured parameters for the female study group revealed mean increases over the observation period.

Table 24 Female comparisons with "Michigan" growth study

			Present study n = 26		Michigan		
VARIABLE (mm)			**mean**	**sd**	**mean**	**sd**	**t- value**
UPPER ARCH	**Michigan**						
ICW	n = 31	pretreat	30.53	1.99	31.3	1.36	1.67
	n = 24	posttreat	31.74	1.40	31.43	1.62	0.73
		change	1.22	1.68			
IPMW	n = 22	pretreat	38.40	2.46	39.37	2.78	1.28
	n = 23	posttreat	40.49	2.06	39.99	2.74	0.73
		change	2.09	1.89			
IMW	n = 37	pretreat	44.24	2.58	44.32	2.47	0.12
	n = 25	posttreat	45.03	2.30	45.01	2.65	0.03
		change	0.79	1.40			
AD	n = 21	pretreat	27.03	1.74	28.07	1.59	**2.12** *
	n = 20	posttreat	27.65	1.33	27.4	1.36	0.63
		change	0.61	1.56			

t-values significant at: $p<0.05$*; $p<0.01$**; $p<0.001$***

Remarkable similarities were noted between the female treated group and the "Michigan" group for most upper arch variables. No statistically significant differences were noted post-treatment for ICW, IPMW IMW or AD. AD was significantly smaller in the present study group pre-treatment ($p<0.05$).

A general trend was noted for a mean increase in all variables post-treatment in the present study group.

In summary, comparisons made with longitudinal "norms" for the study model variables revealed:

- For the lower arch in the male group, statistically significant differences for ICW, IMW and AD post-treatment. IPMW was smaller than the mean "Michigan" sample;
- The male sample upper arch revealed smaller pre-treatment values for ICW and IPMW ($p<0.05$). No variables were significantly different post-treatment;

- ICW and AD were significantly larger in the lower arch for the female present study group post-treatment. IPMW and IMW were smaller in the treated sample at both pre- and post-treatment comparisons ($p<0.01$);
- Broad similarities were exhibited in the upper arch for the female samples. Only AD was significantly smaller in the present study group pre-treatment ($p<0.05$);
- Overall, all mean inter-dental variables measured from the study casts tended to increase in both sexes of the present study group.

8. Discussion

8.1 Error determination

8.1.1 Radiographic error

Pre- and post-treatment cephalometric radiographs were available for the current study sample. Generally, the radiographs were of a high standard with landmark identification reproducible. Allowance was made for the magnification of each radiograph by marking the length of the slide rule exposure onto the acetate tracing medium prior to digitisation. As far as possible, this allowed standardisation of magnification between successive cephalograms. Several radiographs were without a slide rule exposure and the magnification values for these were calculated based on the "average" magnification for the institution where the patient attended.

Cephalometric measurement error may be attributable to:

- Projection errors;
- Measuring system errors; and
- Landmark identification error.

An attempt has been made in the current study to limit magnification error as previously described. Distortion also occurs due to some landmarks not lying in the mid-sagittal plane and in differing depths of field. Broadbent (1931) proposed the use of both frontal and lateral projections to limit this. The midpoints of the images of bilateral structures were traced in the current study to limit any distortion effect. However, this technique does not allow for skeletal asymmetry (Grayson et al, 1984). Further distortion can be caused by tilting of the cephalostat, the film or its holder or the angulation of the subject's head. This distorts both linear and angular measurements (Baumrind and Frantz, 1971 b). This could not be controlled in the present study but was likely to manifest in a random manner.

Measuring system errors are minimised by the use of computerised equipment for data collection (Macri and Athanasiou, 1995). According to Eriksen and Solow (1991), the precision of the recording system is determined by the locating device (cross-hairs) and the inherent resolution of the digitiser. Houston (1979) believed an accuracy to 0.1mm was acceptable. The current study utilised manually traced radiographs which were subsequently electronically digitised. Several authors have stated that direct digitisation off the cephalogram is more accurate than hand-tracing facial landmarks and outlines. The differences are small, however, and only plays a small part in overall landmark reproducibility (Richardson, 1981; Cohen, 1984).

The major source of cephalometric error is landmark identification error. As previously described (Chapter 6.9), there are broadly three contributory factors including the quality of the exposed image, the reproducibility of cephalometric landmark locations and the experience of the observer. Baumrind and Frantz (1971a) noted that some landmarks are more reliably located in a certain facial plane and each landmark produced a unique "envelope of error". Training and "alertness" of the observer also play a role in the accuracy of landmark determinations (Houston, 1983). This can lead to the dual difficulties of both "systematic" and "random" error.(see chapter 6.9).

8.1.2 Superimposition error

The choice of reference structures for repeated superimpositions is critical to the accuracy of the results. Ideally, those skeletal landmarks which undergo minimal remodelling between serial radiographs should be used as reference markers. Björk (1968) utilised metallic implants as references. The current study, in the absence of implants, superimposed on "stable" cranial base and mandibular anatomical structures (Björk and Skieller, 1983). Unfortunately, the reproducibility of the superimposition on these reference planes has been found to be less than reliable (Baumrind et al, 1976). Several methods have been used in an attempt to improve the overall accuracy of repeated superimpositions including "best fit" and the use of a "blink comparator" (Houston and Lee, 1985). However, no individual method has been found to be more reliable than another and indeed poor attention to detail may lead to erroneous assumptions about facial growth (Houston and Lee, 1985). As previously described, cranial base and mandibular anatomical structures were used for superimpositions in the current study (chapter 6.5).

8.1.3 Radiographic error results

Radiographs for the error study were drawn at random from the main sample and measured under the same conditions as recommended by Houston (1983). This assisted in controlling for systematic error.

Eight hard tissue angular variables had random error scores greater than 1.0 degree. Of these, six involved the location of the apex of the upper or lower incisor. This result is perhaps not surprising in light of the work of Miethke (1989) who claimed that landmarks which lie in the confines of the skull are likely to be confounded by "noise" from adjacent or superimposed structures. Three of the eight angular variables also involved the recognition of landmarks from the cusps of posterior teeth or those that define the mandibular plane, all of which are associated with poor reproducibility (Baumrind and Frantz, 1971a,b). It was not unexpected that nearly all the variables with a significant random error were angular and not linear as "both the absolute values of errors and the variability among replicated estimates tend to be greater for angular than linear measures" (Baumrind and Frantz, 1971b).

Two soft tissue variables exhibited standard errors greater than 1.0 degree, specifically nasolabial and labiomental angles. It has been reported in a comparative study that the errors of landmark location between hard and soft tissues are generally the same (Wisth and Boe, 1975).

Significant differences were noted between determinations for hard tissue variables lower incisor to mandibular plane (mm) and lower molar to sella vertical (mm), both $p<0.05$. Both measures tended to have been "over-estimated" in repeat determinations. Six soft tissue variables revealed significant mean t-values from repeat measurements. Note that for each of these variables a small standard error of the mean difference was associated with a relatively larger mean difference value which resulted in larger t-values overall.

8.1.4 Study cast measurement error

Pre- and post-treatment study models were available for analysis in the current study. All the pre-treatment models had the four permanent second molars intact while the post-treatment casts were missing all four permanent second molars. Standardised photographs reproduced at 1:1 magnification were exposed and later checked for accuracy by measuring a 100 mm scale incorporated into the film. A "correction factor" was calculated if the digital measuring caliper and photographic scale measure were not equal.

For the current study, the transverse inter-dental variables ICW, IPMW and IMW all exhibited low random error values. It would appear that, following the precise determination of "centroids" (Moyers et al, 1976), the inter-dental variable measurements are highly reproducible. The least reliable variables from the "double-determinations" were total mesio-distal tooth width and tooth size arch length discrepancy where the addition of multiple variables would compound any error repetition. The variables ICW, IPMW, IMW all exhibited significant mean differences between determinations from student's t-tests. A relatively small standard error of the mean difference resulted in significant t-values for these parameters. The variability coefficients were small compared to the overall sample variability with all coefficients above 98% for all repeated measures.

These error results compare favourably with Sinclair and Little (1983) who reported standard deviation differences for their measured variables between 0.06 mm and 0.18 mm. Their coefficients of variability were also small in relation to the variability of their entire sample. Moyers et al (1976) stated that the smallest values for the standard deviation differences in their longitudinal sample were associated with measurements derived from two points on a single tooth and larger values for measures derived from two points on different teeth in the same arch. These results corroborate the findings of the current study in that higher errors were revealed for those variables which relied upon the analysis of multiple dental units.

8.2 Sample characteristics

8.2.1 Sample size

The current study sample comprised the complete cephalometric and study model records of 45 patients, 26 females and 19 males. A larger sample would have been desirable but the unavailability of full records precluded this. The group size was also predicated by the limited time that the orthodontic practitioner supplying the records had been routinely extracting four second permanent molars as part of fixed appliance therapy. The sample size, however, allowed for standard statistical analyses of the data and the extrapolation of valid conclusions. The ratio of males to females in the sample reflected the general attendance patterns of the population presenting for orthodontic treatment (Shaw et al, 1991).

The current study sample size compares favourably with similar published research. Staggers (1990) and Cavanaugh (1985) examined the radiographic data only of a total sample of 25 second molar extraction cases. Cryer (1967) examined the complete records of 66 cases as did Huggins and McBride (1978) on 27 cases. In a five-year follow-up study, Lawlor (1978) recalled 60 patients in an assessment of both lateral oblique radiographs and study casts. Richardson (1996) examined the study models only of a group of 30 patients (8 males) as part of a ten-year follow-up examination.

Based on the mean age of the current sample, it would be anticipated that a complete radiographic and study cast examination of the eruption status of the third molars would be possible in the medium term.

8.2.2 Sample age

The sample was drawn from a mixed population in suburban Adelaide, South Australia. The sample was of caucasian origin. The ages of the current sample individuals bear similarities between genders. Chronologically, the average age of the pre-treatment females was 13.8 years compared to the male group of 13.9 years. It may have been expected that the discrepancy between ages would have been larger based on the average growth and development of the sexes in the general population. For both males and females, the youngest pre-treatment age was 12.1 years. The oldest male pre-treatment was 15.6 years and, somewhat surprisingly, the oldest female 17.7 years. Based on the limited available literature regarding "ideal" timing of permanent second molar extractions and the uneventful and successful eruption of permanent third molars (Bishara and Burkey, 1986), it would be interesting to follow-up these "outliers" and assess their occlusal status in the medium to long-term. It may be that the delayed treatment of these patients will lead to a more stable occlusal result (Pancherz, 1997) in preference to the final positioning of the third molars. The average developmental status of the lower second permanent molar results in completed root development at 14 to 15 years of age (Wheeler, 1974). Several investigators recommend the extraction of the second molars before there is any radiographic evidence of root development (Huggins and McBride, 1978; Lehman, 1979) at around 12 to 14 years of age. It is anticipated that several of the individuals in the current study will require some form of simple orthodontic mechanic to later align the third molars (particularly the lower third molars) into the line of occlusion (Twelftree, 1999).

8.2.3 Treatment time

For the calculation of treatment times and effects, the exposure dates of the patients' cephalograms represented "pre-treatment" and "post-treatment". This was desirable as it provided the most accurate available means to directly relate treatment changes observed to "actual" changes as revealed by the study model and cephalometric data. The duration of fixed appliance therapy was also calculated from the data presented in the patients' records.

The average treatment time for both males and females was 1.7 years. The range varied broadly with females 1.0 to 2.4 years and males 1.1 to 2.9 years. Several authors have advocated the extraction of permanent second molars in order to decrease treatment times compared to pre-molar or "mid-arch" extraction cases. Unfortunately, these authors failed to report the actual amounts of decreased time intervals they had observed (Quinn, 1985; Marceau and Trottier, 1983). Staggers (1990) compared the treatment times of a group of pre-molar extraction cases with a sample of permanent second molar extraction cases. She found no significant difference in treatment times between the groups with the second molar extraction group experiencing slightly *longer* mean treatment times of 3.2 years compared to 3.1 years for the pre-molar group. These results indicated comparatively shortened treatment times for the current study group by a factor of two. Others have indicated that the "overall" treatment time must be calculated considering the possibility of "follow-up" mechanics to align the third molars (Magness, 1986). Whitney and Sinclair (1987) reported on the changes in 30 individuals following permanent second molar extraction. "Combination therapy" involving 12.5 months of sagittal appliances, 14.0 months of Bionator therapy and 13.0 months of fixed appliances resulted in overall treatment times far greater than the current study group.

8.3 Cephalometric differences between genders

8.3.1 Pre-treatment

Males were significantly more maxillary retrusive than females ($p<0.05$) based on the Steiner (1960) classification for sagittal skeletal discrepancy, SNA. Males (SNA, 79°) were outside the "norm" of 82° ± 2 for white caucasians. This could be partly explained by the angle SN-FH for males which was slightly increased at 9.2° thereby potentially decreasing the SNA angle. UFH was also increased in males compared to females (not significant) which has a similar effect on SNA angle (Proffit, 1993). A similar discrepancy was noted for SNB angle which was significantly larger in females ($p<0.05$). SNB for both sexes was within the Steiner (1960) normal range (78° ± 2). The resultant angle ANB was not significantly different between genders. Steiner (1960) believed that the ANB "norm" was the angle to which orthodontic treatment should be aimed. Males had an ANB of 2.9° and females 3.0°. Based on the Steiner (1960) values, both sexes were within the skeletal Class I range (2° - 4°) pre-treatment.

The differences of two vertical skeletal parameters approached significance between the groups. LFH (mm) and N-Me (mm) were larger in males pre-treatment. These differences are most likely as a result of the normal absolute size discrepancies between males and females. Inouye (1957) and Sinclair and Little (1985) also found, cephalometrically, larger facial structures and greater linear measurements in boys compared with girls. It may also have indicated that the male group generally were longer-faced individuals although this was not reflected by the mandibular plane angle or the ratio PFH:AFH which were similar between the groups.

Several dental variables were significantly different between the genders. U1-NA angle was larger in males ($p<0.05$). Other variables reflected the increased protrusion of the upper incisors including U1-SN angle, OJ mm and U1-L1 angle, all larger (although not significantly) in males. The same differences were not revealed for the lower incisor variables between sexes. Indeed, these parameters exhibited a tendency for the lower incisors to be in a more retroclined position compared to "norms"

(Steiner, 1960). This may be indicative of a selection bias on the part of the orthodontic operator.

The soft tissue variables N-L angle ($p<0.05$), Li-B ($p<0.05$) and ULL ($p<0.01$) were significantly larger in the male group. Generally, all the soft tissue variables analysed reflected a size discrepancy between genders and their underlying skeletal patterns.

In summary, the pre-treatment groups revealed a mean Class I skeletal pattern, moderately increased overjet, vertical parameters and upper incisor protrusion in the male group and slightly retroclined lower incisors in both males and females.

8.3.2 Post-treatment

A significant mean difference between sexes for SNA angle was repeated post-treatment ($p<0.05$). Generally, the angle tended to decrease in both groups reflecting a decrease in the proclination of the upper incisors in both groups having an effect on the position of landmark "A" point. SNB angle increased in males and decreased in females. The increase in males can be explained by the growth changes in the mandible for this group exhibited by increases in Co-Gn mm and Ar-Gn mm ($p<0.01$). The small decrease in females for SNB may have been as a result of a backward rotation of the mandible during orthodontic treatment. The large mandibular length increases witnessed in the male group were not repeated in the female sample. As a result, ANB angle remained largely unchanged in females (2.9°). For the male group, ANB angle decreased and entered the range for a mild Class III skeletal "norm" (2.0°).

UFH mm ($p<0.05$), LFH mm ($p<0.01$) and N-Me mm ($p<0.001$) were all significantly larger in males post-treatment. The relative increases for these parameters were also greater for males from the pre-treatment values. This reflected the later growth and development generally observed in males compared with females. PFH:AFH ratio remained largely unchanged for both genders post-treatment.

No cephalometric dental variables were significantly different between genders post-treatment. There was a general decrease in the proclination of the upper incisors in males whereas in females the upper incisors remained largely unchanged. The lower incisors proclined in both groups. Overbite and overjet decreased in both males and females.

Nine soft tissue variables were significantly different between the groups post-treatment, all larger in the male sample. Facial convexity angle ($p<0.01$) revealed an overall "straightening" of the male soft tissue profile reflecting the underlying skeletal change particularly in the mandible. Nasolabial angle ($p< 0.05$) remained significantly larger in males and increased in both groups probably as a result of the decrease in upper incisor angulation with treatment and an overall increase in the size of the nose sagittally. Ls-A mm ($p<0.001$), ULL mm ($p<0.001$) and Ss-S vert mm ($p<0.05$) all revealed greater upper lip proportions in the male sample. ST TFH mm ($p<0.01$) and ST LFH mm ($p<0.01$) reflected the underlying vertical skeletal increases in males compared to females.

In summary, remarkable similarities were exhibited for the cephalometric variables post-treatment between the genders. Both groups were Class I or mild Class III (males) skeletal patterns with an increased vertical component in the male group. Inter-dentally, the groups were largely the same. The soft tissues reflected the skeletal proportions with males having larger upper lip patterns and vertical parameters.

8.3.3 Treatment changes

Sagittally, significant increases were noted for the skeletal variables SNB ($p<0.05$), Co-Gn ($p<0.001$), Ar-Gn ($p<0.001$) and S-Go ($p<0.001$) for males compared to females. This clearly demonstrated the mandibular developmental changes experienced by the male sample between the mean ages of 13.9 years and 15.9 years. Björk (1951) noted a similar response with his male sample becoming less convex between the ages of 12 years to 21 years mainly as a result of a proportionately greater increase in mandibular prognathism.

Significant differences for treatment changes were also noted for UFH mm ($p<0.001$), LFH mm ($p<0.01$) and N-Me mm ($p<0.001$) with mean increases for these variables in both groups, males greater than females. Both growth and fixed appliance orthodontic treatment effects could be responsible for these changes. Conversely, Lande (1952), in an untreated sample, found a decrease in the mandibular plane angle in males from 7 years to 17 years of age. Sinclair and Little (1985) noted similar increases in vertical skeletal variables namely UFH mm and LFH mm. Between the ages 9 years to 13 years, the male sample showed significantly greater increases than females for UFH and LFH in their untreated sample.

The majority of the soft tissue variables analysed in the current study revealed significant differences for treatment changes between genders. Ls-A mm ($p<0.01$), ULL mm ($p<0.05$), Sn-S vert mm ($p<0.001$), Ls-S vert ($p<0.01$) and Ss-S vert mm ($p<0.01$) were all exhibited significantly greater change in males than females. Generally, these variables *increased* in the male sample but *decreased* for the female sample. This could reflect the far larger decrease in upper incisor proclination in males compared with females and a sexual dimorphism for overall soft tissue size increases over the treatment period. Nanda et al (1990) stated that lip position is affected by the position of the incisors. In a longitudinal study, Nanda et al (1990) found that the average increase in upper and lower lip length in males was more than twice that of males. The authors also revealed that the male sample had an average lip length increase of seven millimetres and was therefore more able to accommodate greater incisor protrusion compared with the female untreated group. Nanda et al (1990) also found that most of the soft tissue growth changes at the nose, lips and chin were suggestive of sexual dimorphism with males having a greater increase in these soft tissue parameters over a longer time period than females. In the vertical plane, ST TFH mm ($p<0.01$), ST UFH mm ($p<0.01$), ST LFH mm ($p<0.01$) and ST Pog-STN mm ($p<0.01$) were significantly different between the groups, with generally larger changes in the male group. This accurately reflected the skeletal change observed in the current study sample. Genecov et al (1990) analysed the vertical soft tissue changes in an untreated group from the Bolton study. From the ages of 7 years to 13 years, both sexes revealed five to seven millimetre increases in ST UFH mm, reflecting the underlying skeletal change. However, from 13 years to 17 years the male group continued to show soft tissue increases (six millimetres) while the female untreated group grew only slightly (one millimetre). Genecov et al (1990) revealed similar increases for ST LFH mm with males greater than females particularly from growth increases from 13 years to 17 years.

In summary, sexual dimorphism was revealed for the changes between the sexes from pre- to post-treatment. Skeletally, the male group exhibited mandibular "catch-up" compared to the female sample. The increased skeletal vertical component in the male sample was reflected in the vertical soft tissue parameters. Remarkable similarity was noted for all dental variable changes.

8.3.4 Comparisons with longitudinal growth studies - males

The current study data were compared to two sets of longitudinal growth study records drawn from diverse populations. The "Michigan" sample consisted of 83 individuals, 47 males and 36 females (Riolo et al, 1974) with continuous attendance for complete records from their sixth to their sixteenth birthdays. None had received any orthodontic treatment. The Bhatia and Leighton (1993) group was drawn from the records of 121 caucasian subjects, 58 males and 63 females. This control group also provided data for several soft tissue variables. It was considered that the choice of samples (North American and United Kingdom) would provide a fair comparison for the current study.

SN-FH angle was smaller in the current study data than the "United Kingdom" group but very significantly larger than the "Michigan" sample ($p<0.001$). The large discrepancy with the "Michigan" group may have revealed the difference in definition of *porion*, anatomic porion in the current study and "machine" porion in the "Michigan" group.

SNA angle revealed a retrusive maxilla in the current sample compared to both control groups post-treatment ($p<0.05$). The "Michigan" result should be interpreted with some caution based on the calculation of the aforementioned anterior cranial base angle. Co-A mm was, however, larger in the current study group than the "United Kingdom" group pre-treatment ($p<0.05$). SNB angle was significantly smaller in the current sample than the "United Kingdom" group ($p<0.05$) at both pre- and post-treatment intervals. There was no significant difference in mandibular length measurements (Co-Gn and Ar-Gn) between the groups. ANB angle was also broadly similar for the current study sample and the controls with all groups lying within the Class I or mild Class III skeletal range.

The vertical skeletal parameters exhibited more similarities than differences. LFH ($p<0.05$) was larger post-treatment in the current sample than the "United Kingdom" group. This could be as a result of the extrusive effects of fixed appliance therapy in the current study group (Schudy, 1992). FMA angle was similarly affected ($p<0.001$).

For the dental variables, U1-SN angle and U1-MaxPl angle were significantly larger in the controls post-treatment. This is indicative of the upper incisors being retroclined in the treated group as is the significantly smaller overjet ($p<0.01$) in the current study group post-treatment compared to the "United Kingdom" controls. Compared to both control groups, the interincisal angle in the treated sample was larger both pre- and post-treatment. Dentally, the current study group would appear to have been more "bimaxillary retrusive" than the comparison samples. Overall, the lower incisors were further retroclined than the comparable controls both pre- and post-treatment further emphasising the "upright" nature of the incisors in the current sample compared to the controls.

Facial convexity angle ($p<0.01$) was significantly smaller in the current sample than the "United Kingdom" group. This is possibly indicative of a relatively more convex profile in the treated group.

In summary, the overall skeletal patterns between the groups were similar (Class I or mild Class III) with the treated group slightly more maxillary retrusive. The treated group exhibited an increased vertical component particularly post-treatment. Both the upper and lower incisors were more retroclined in the current study group compared to the controls giving the overall impression of "bimaxillary retrusion" in the treated group compared to the controls. Greater soft tissue facial convexity was exhibited by the current study group.

8.3.5 Comparisons with longitudinal growth studies – females

As with the males, SN-FH angle was significantly larger in the treated group than the "Michigan" group ($p<0.001$). SNA angle was not significantly different between the groups although Co-A (mm) was significantly larger in the current study group than the "United Kingdom" sample ($p<0.001$). This result should be interpreted with some caution considering the difficulty in the reproducibility of landmark *condylion.* ANB angle revealed Class I skeletal patterns for all three groups both pre- and post-treatment. Similar to the male study group, LFH mm was significantly larger in the treated group post-treatment than either control sample ($p<0.05$). N-Me mm was larger in the current study group than the "Michigan" sample post-treatment ($p<0.01$). FMA angle, similarly, was larger compared to the "United Kingdom" group post-treatment ($p<0.01$).

As an indication of transverse changes, inter-canine, inter-second premolar and inter-molar widths were measured between centroids with an electronic caliper accurate to 0.01mm. Others have calculated these variables as part of longitudinal surveys (Sinclair and Little, 1983; Bishara et al, 1989). Various authors have measured dental arch widths from cusp tips or points on the lingual cervical margins of teeth. However, cusp tips can wear off and vary in number or location over the period of observation. The lingual cervical margin is affected by the bucco-lingual width of the tooth and the level of its eruption (Moyers et al, 1976).

Arch depths (Moyers et al, 1976) and arch lengths (Sinclair and Little, 1983; Haruki and Little, 1998) were calculated for both pre- and post-treatment casts. Both measurements give no indication of left-right asymmetry or as to whether the changes noted are as a result of anterior or posterior (or both) dental movement.

The irregularity index (Little, 1975) was used to give an indication, pre-treatment, of the extent of displacement of the contact points of the upper and lower incisors. It is important to recognise that the index is not an arch length assessment but “a guide to quantifying anterior crowding” (Little, 1975). This method has a tendency to assign an unusually high score where there is severe labio-lingual displacement of one or more anterior teeth (Harris et al, 1987) and good arch length where treatment could be relatively simple. Anterior spacing without rotation and or labio-lingual displacement would receive no score and should be differentiated from a case revealing spacing plus irregularity. The index ignores the individual’s cephalometric pattern, age, facial aesthetics and tooth morphology (Little, 1975).

To gain an indication of overall crowding pre-treatment, a determination was made for the tooth size-arch length relationship in both the maxillary and mandibular arches. This was manually completed by the segmental arch length technique (Lundström, 1954; Bishara et al, 1989). The “best” method to determine crowding has attracted much attention in the orthodontic literature (Little, 1975; Rudge et al, 1983; Battagel, 1996). Many manual methods have been used to record arch perimeter including brass wire (Huckaba, 1964), straight-line arch segments (Lundstöm, 1954), the catenometer (Musich and Ackerman, 1973) and individual tooth widths including callipers (Norderval et al, 1975), the travelling microscope (Bhatia and Harrison, 1987) and reflex metrograph (Richmond, 1987). Computerisation has allowed others to develop programmes from which dental cast measurements have been determined

(Moyers et al, 1976). Johal and Battagel (1997) compared three methods of crowding assessment including visual estimation, brass wire/callipers and the "reflex microscope". The authors concluded that the reflex microscope provided a "valid and reproducible measure of dental crowding" whereas the visual method over-estimated the degree of crowding and the brass wire technique under-estimated crowding. The current study did not have access to the "reflex microscope" but this may be considered for any future dental cast analyses.

8.4.2 Pre-treatment

For the lower arch, the variables inter-canine width (ICW), inter-premolar width (IPMW), inter-molar width (IMW), arch depth (AD) and arch length (AL) were all significantly larger in the male group pre-treatment. This equated with the results of Sinclair and Little (1983).

The irregularity index was similar for both groups, tending to be more severe in males (5.0) than females (4.3). Conversely, Sinclair and Little (1983) reported untreated females had statistically greater lower incisor irregularity than their male sample. Whitney and Sinclair (1987) reported their pooled sample required a pre-treatment score of 3.5 or greater to be included in their study but the exact scores are not provided. There was a significant sexual dimorphism for total mesio-distal tooth widths for the current study ($p<0.01$) with males exhibiting larger values than females. Tooth size-arch length discrepancies (TSALD) were essentially similar between genders being –3.5 mm for the current male sample and –2.9 mm for the current female group.

For the upper arch pre-treatment, IMW ($p<0.05$), AD ($p<0.01$) and AL ($p<0.001$) were all significantly greater in males. Moyers et al (1976) revealed a similar gender dimorphism. There was a tendency for ICW and IPMW to also be larger in males. There was no significant difference for the irregularity index between sexes in the upper arch. The absolute values were larger than those for the lower arch. Tooth size-arch length discrepancy was virtually identical between the groups and less than for the lower arch. A paucity of data for the maxillary incisor irregularity index did not allow any meaningful comparisons to be made with the current study group (Bishara et al, 1989). Vaden et al (1997), in a pooled treated sample, reported an average maxillary irregularity index of 7.9 mm pre-treatment compared with 6.6 mm for males and 6.3 mm for females in the current sample).

In summary, there was sexual dimorphism for the inter-arch variables with males generally larger than females in both arches. This was also true for AD and AL. The amount of incisor irregularity was similar between genders, the absolute values larger in the upper arch. TSALD was also similar with less apparent space available in the lower arch for both sexes.

8.4.3 Post-treatment

Remarkable, but not unexpected, similarities were revealed for the lower arch post-treatment. ICW ($p<0.01$), IPMW ($p<0.01$), IMW ($p<0.05$) and AL ($p<0.001$) were all significantly larger for the male sample. AD approached significance ($p<0.05$) with the mean AD greater in males.

The upper arch post-treatment was a reflection of the pre-treatment upper arch, except for IPMW ($p<0.05$) which was significantly greater in males than females.

Overall, the post-treatment study cast parameters reflected the pre-treatment variables for significant differences between males and females.

8.4.4 Treatment changes

For the lower arch, no variables revealed significant differences between the sexes from pre- to post-treatment. All mean parameters increased in absolute terms post-treatment. This change varied from a 0.1 mm increase in IMW for males to a 2.2 mm increase in AL in females.

For the upper arch, only AD exhibited a mean significant difference between genders for treatment changes ($p<0.05$). In fact AD in males *decreased*, the only parameter to do so, and AD in females *increased.* Broadly, however, the variables analysed tended to increase from pre- to post-treatment.

An overall impression was gleaned from the study model variable changes as to the method of resolution of crowding and irregularity (see Tables 18, 19). For the lower arch, an increase in arch length for both genders appeared to dominate the orthodontic correction. This was complemented, to a slightly lesser degree, by an increase in arch depth. Transversely, inter-canine width increased to a far greater degree than inter-premolar width and also inter-molar width, which remained virtually unchanged. For the upper arch, the dental variable changes were far less, generally, than for the lower arch. An increase in inter-premolar width, for both genders, appeared to potentially provide the change required for the resolution of crowding. Inter-canine width also increased but to a far lesser degree than that observed in the lower arch and inter-molar width again appeared immutable. In contrast to the lower arch findings, arch depth and arch length in the upper arch revealed little alteration except for arch length in the female sample which increased a mean 1.7 mm.

8.4.5 Comparisons with standards of occlusal development – males

The current study model data was compared to the longitudinal data of the "Michigan" group which boasts an impressive collation of cephalometric and study cast parameters. Moyers et al (1976) describe the significance of their research thus:

- A large serial sample of both dental cast and cephalometric data;
- Collated by a team of researchers experienced in handling longitudinal craniofacial and dental data, and;
- Extensive computer programmes and computer graphic facilities.

The authors point out that the data presented is limited to the records of a restricted North American white population.

Four dental variables were available from the current study for direct comparison with the records of the "Michigan" sample.

For the lower arch in males, IPMW ($p<0.01$) was the only variable which was significantly different (smaller) in the current study group compared to the "Michigan" sample. A mean 1.0 mm increase post-treatment in the study group for this variable resulted in similar values for both groups. An increase in ICW in the treated males (1.1 mm) led to a significant difference in size compared to the control group ($p<0.01$) whose mean ICW decreased over the observation term. IMW, however, increased slightly in the male study sample (0.1 mm) but increased to a larger extent in the control comparisons to a significant degree ($p<0.05$). Arch depth also produced an interesting disparity. This variable increased in the current study group (mean 1.0 mm) but decreased slightly for the untreated controls ($p<0.01$).

Far fewer differences were revealed for the upper arch. All upper arch variables increased post-treatment in the current study group except for arch depth which decreased slightly (0.3 mm). ICW and IPMW were significantly smaller pre-treatment in the treated females but increased during treatment to a point of no significant difference with the controls post-treatment ($p<0.05$). Vaden et al (1997) reported an increase in upper and lower inter-canine widths only in their pre-molar extraction sample. Arch depth decreased but to a greater extent compared to the current sample.

In summary, all the comparative variables in the male current study group exhibited mean increases post-treatment. IPMW and IMW increased in the controls but to a far lesser degree. ICW and AD revealed a mean decrease from the early to late permanent dentition in the male control sample.

8.4.6 Comparisons with standards of occlusal development – females

For the lower arch, mean increases for all the tested variables were exhibited by the current study group post-treatment. This varied from a mean increase in IPMW of 0.2 mm to an ICW change of 1.3 mm. ICW and AD values were broadly similar between the controls and the current study group pre-treatment. Significant differences were noted at pre- and post-treatment periods for all other variables. ICW ($p<0.05$) and AD ($p<0.001$) were significantly larger in the current study group post-treatment. IPMW and IMW (both $p<0.01$) were significantly smaller than the controls post-treatment.

In the upper arch for females, broad similarities were revealed between both groups, both pre- and post-treatment. Mean increases were noted for all the variables in the current study group post-treatment, particularly IPMW which increased a mean 2.1 mm. The only significant difference between the groups was arch depth ($p<0.05$) which was significantly smaller pre-treatment in the current study sample.

In summary, both males and females in the current study sample exhibited mean increases post-treatment for the variables compared. Generally, relatively large increases were exhibited for IPMW for both males and females in the upper arch for the treated group compared to small increases in the controls. IMW in males increased minimally in the lower arch in the male treated sample compared to a relatively large increase in the "Michigan" group. AD, in the same sample, decreased minimally in the upper arch as for the controls.

8.4.7 General study model variable comparisons

Sinclair and Little (1983) reported on the changes, measured from mandibular dental casts, for 65 untreated "normal" occlusions as part of the Burlington growth study. The authors reported significant mean decreases in arch length, and inter-canine width from the early permanent dentition (13 years) to early adulthood (19 years) in their pooled sample. For the current study sample, arch length increased for both sexes in the lower arch. The medium to long-term effect without retention of this change on "late" lower incisor crowding is yet to be fully analysed in the current sample. Shapiro (1974) reported that treated cases usually exhibit a decrease in arch length post-treatment. Sinclair and Little (1983) believed that the rate of decrease in arch length in their untreated sample was similar to that seen in the treated cases of Shapiro (1974) and implied that similar maturational processes were involved. Some interesting arch length comparisons were also made for the current study group and the Whitney and Sinclair (1987) "combination" therapy, second molar extraction sample. Pre-treatment upper and lower arch lengths were greater in the "combination" group than the current study group. Post-treatment, the "combination" group mandibular arch length increased 1.3 mm compared to the current study sample increase of 2.0 mm (males) and 2.3 mm (females). Maxillary arch length in the "combination" group increased 3.5 mm compared to 0.5 mm (males) and 1.7 mm (females) in the current study group.

Inter-canine width decreased in both sexes in the Burlington sample as it did for the "Michigan" group. Bishara et al (1989) exhibited small decreases in inter-canine width in their untreated sample from 13 years to 26 years. Overall increases in ICW were revealed for both sexes in the current study sample post-treatment. This accounted for part of the relief of incisor irregularity without any accompanying increase in incisor proclination in the current group. Several authors have addressed the vexed issue of post-treatment orthodontic stability (or otherwise) where there has been an increase in inter-canine width (Strang, 1949; Little et al, 1981). Little et al (1981) analysed the records, 10 years post-retention, of a group of class I, first-premolar extraction cases. Inter-canine width decreased significantly more in the treated cases than the "norms" (Sinclair and Little, 1983). The changes in the second molar extraction group in the current study are yet to be compared "long-term". The "combination" therapy sample (Whitney and Sinclair, 1987), revealed significant increases in maxillary inter-canine width (3.7 mm) in their pooled sample. Increases in maxillary inter-canine width were far less in the current sample at 1.33 mm for males and 1.22 mm for females.

Inter-molar width decreased in untreated "norms" (13 years to 26 years) except for the maxillary arch in males (increased) according to Bishara et al, 1989. The "Michigan" controls (14 years to 16 years) exhibited a mean increase for both males and females in both arches. The "Burlington" sample revealed insignificant increases of inter-molar mandibular width in males and small but significant decreases in females from 13 years to 20 years (Sinclair and Little, 1983). The current study revealed mean increases in inter-molar width post-treatment of less than 1.0 mm for both upper and lower arches in both genders. This result is in contrast to the pre-molar extraction group reported by Shapiro (1974) where inter-molar width decreased during treatment and following retention. A non-extraction group in the same study revealed a maintenance or slight increase in inter-molar width. It would appear that the current study sample more closely approximated the "non-extraction" group, possibly as a result of the "posterior arch" extractions as opposed to "mid-arch" extraction therapy. Whitney and Sinclair (1987) reported pooled maxillary inter-molar width mean increases of 4.7 mm and 3.1 mm in the lower arch. These changes far exceed the current study changes. The authors suggested that changes of the magnitude revealed in their study may be stable as they were incorporated at an early age and "the arches can develop and accommodate their new dimensions." No "follow-up" data were available.

8.4.8 Comparisons with "untreated" second molar extraction samples

The question of what changes could be expected if permanent second molars were extracted with no or limited adjunctive orthodontic therapy has been addressed by several authors (Richardson, 1996; Battagel and Ryan, 1998). Comparisons with the current study data could provide further insight into the selection of appropriate individuals for second molar extraction orthodontic treatment and place the changes observed in the current treated sample in perspective.

Richardson (1996) reported on the ten-year results of a group of 8 males and 22 females who had four second permanent molars extracted. The average age at extraction was 13.9 years. All were class I or mild class II malocclusions with "well-aligned, or slightly crowded lower arches". There was no mechanical treatment in the lower arch but the majority of her sample had simple fixed appliances or removable appliance therapy in the upper arch. The "space condition" was analysed with the use of a vernier microscope and the degree of crowding assessed. The data were pooled as no significant differences were apparent between genders. Pre-treatment the lower arch was crowded on average –1.3 mm. There was a significant average decrease in crowding after 5 years of –0.6 mm and an insignificant crowding *increase* of 0.1 mm at the 10 year interval. Although not directly comparable, the current study group was assessed pre-treatment for lower arch tooth size-arch length discrepancies (TSALD). Males in the current group had a pre-treatment TSALD of –3.5 mm and females –2.9 mm. From these findings, it would appear that "crowding" in the lower arch in the current group was more significant than for the Richardson (1996) untreated sample. Richardson (1996) believed that the extraction of second molars in the teenage years is effective in preventing "late" lower arch crowding and that the alignment may be maintained into the third decade. Whether this would apply to the unretained current sample is yet to be analysed. Any effect of upper arch therapy on the lower arch has not been elucidated.

Battagel and Ryan (1998) assessed the lower arch changes on study casts in a sample of 5 males and 13 females following lower second molar extractions. Buccal segment retraction was completed in the upper arch only. The results were as follows:

Table 25 Comparisons with Battagel and Ryan (1998)*

		Present study				**Battagel and Ryan**	
		males n = 19		females n = 26		pooled n = 18	
VARIABLE		**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
ICW	pretreat	24.9	1.8	23.7	1.5	25.9	2.1
	posttreat	26	1.3	25	1.1	26.1	1.8
IMW	pretreat	41.2	2.9	39	3.3	43.6	2.8
	posttreat	41.3	2.6	39.3	2.5	45	2.7

*Lower arch measurements only (in millimetres)

9. Principal Findings

1. Forty-five individuals were assessed following the removal of four second permanent molars and full fixed appliance orthodontic treatment. Pre- and post-treatment study models and cephalograms were analysed. Ideally, a larger sample would have been desirable. No records were available to assess the medium to long-term eruption positions of the third molars.

2. Error determinations were undertaken and it was found that:

   - Eight hard tissue and two soft tissue cephalometric variables had standard errors greater than one degree;
   - These were primarily due to "noise" (Baumrind and Frantz, 1971a) affecting landmark identification particularly for the cusps of the posterior teeth and the apices of the lower incisors;
   - Standardised photographs were used to determine the study model variables. It was revealed that all the inter-dental variables had low random error values. Reliability decreased as the number of individual calculations increased in order to determine a single variable, for example, tooth size-arch length discrepancy. These error values compared well with published data (Sinclair and Little, 1983).

3. 19 males and 26 females were compared for cephalometric variables pre- and post-treatment and it was revealed that:

   - Pre-treatment, both groups exhibited a mean class I skeletal pattern with increased overjet and vertical parameters (LFH and N-Me) in the males and retroclined lower incisors in both genders;
   - Post-treatment, general similarities existed between the sexes with sexual dimorphism for overall linear variables, indicating males were usually larger;
   - The male sample exhibited mandibular "catch-up" growth over the observation period.

4. Males and females were compared for study cast changes and it was found that:

- Irregularity and tooth size-arch length discrepancies were similar between the groups pre-treatment;
- Most dental variables analysed remained significantly larger in males post-treatment.

5. Regional mandibular superimpositions revealed:

- No significant difference between genders for any of the parameters analysed;
- Post-treatment, both sexes exhibited minimal "distalising" of the buccal segments, greater in males than females. The lower incisors remained virtually in their pre-treatment positions.

6. Comparisons with longitudinal growth studies for both cephalometric and study model data showed:

- General similarities between the controls and current study group for both males and females;
- All groups exhibited a mean class I skeletal pattern;
- An increased vertical component post-treatment in the current study group;
- Both upper and lower incisors began and finished retroclined in the current study group compared to the controls over the observation period;
- Post-treatment, relatively greater increases in inter-premolar widths in the upper arch for the current study group compared to the controls (both sexes).

7. The resolution of crowding and incisor irregularity was achieved by:

- For the lower arch, an increase in arch length for both genders and a smaller mean increase in arch depth. Transversely, an increase in intercanine widths and a lesser increase in inter-premolar widths for both sexes in the lower arch;
- For the upper arch, inter-premolar width increases appeared to dominate the orthodontic correction in both males and females. Inter-canine width increases were also observed but to a far lesser degree than that observed for

the lower arch. Changes in arch depth and arch length for the upper arch revealed little change in both genders.

8. The null hypothesis that the extraction of four second permanent molars does not increase the proclination of the lower incisors to a significant degree was accepted.

9. This current sample should be re-examined in the medium and long –term in order to assess the pre- and post-eruption patterns of the third molars in both upper and lower arches and monitor the dental arch stability.

10. From the data contained in the current retrospective study, the extraction of four second permanent molars may be contemplated under the following circumstances:

- An individual aged (chronologically) about 14 years of age;
- A Class I skeletal pattern with minimal to moderate overbite (4 mm) and overjet (4 mm), meso- or slightly brachyfacial with an "average" mandibular plane angle (FMA = 26°);
- Bimaxillary retrusive dental pattern with a mean irregularity index of 4 mm to 5 mm in the lower arch and 6.5 mm in the upper arch. The tooth size-arch length discrepancy should average 3.0 mm to 3.5 mm in the lower and 1.0 mm in the upper arch;
- Further analysis of the eruption patterns of the third molars may allow limited recommendations for the extraction timing and pattern of the permanent second molars.

10. Appendices

10.1 Appendix I The cephalometric landmarks (in order of digitisation):

1. **Sella turcica (S):** the centre of the pituitary fossa of the sphenoid bone;
2. **Nasion (N):** the junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose (Riolo et al, 1974);
3. **Orbitale (Or):** the lowest point on the average of the right and left borders of the bony orbit (Riolo et al, 1974);
4. **Porion (Po):** the upper border of the external auditory meatus (anatomic);
5. **A point (A):** the most posterior point on the curve of the maxilla between the anterior nasal spine and supradentale (Riolo et al, 1974);
6. **B point (B):** the point most posterior to a line from infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible; it should lie within the apical third of the incisor roots (Riolo et al, 1974);
7. **Anterior nasal spine (ANS):** the tip of the median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening (Riolo et al, 1974);
8. **Posterior nasal spine (PNS):** the most posterior point at the sagittal plane on the bony hard palate (Riolo et al, 1974);
9. **Upper incisal edge (U1E):** the incisal tip of the maxillary central incisor (Riolo et al, 1974);
10. **Upper incisal apex (U1A):** the root tip of the maxillary central incisor (Riolo et al, 1974);
11. **Upper molar distal cusp reference point (UM):** the most postero-inferior point on the distal border of the crown of the upper first permanent molar;
12. **Lower incisal edge (L1E):** the incisal tip of the mandibular central incisor (Riolo et al, 1974);
13. **Lower incisal apex (L1A):** the root tip of the mandibular central incisor (Riolo et al, 1974);

14. **Lower molar distal cusp reference point (LM):** the most postero-superior point on the distal border of the crown of the lower first permanent molar;

15. **Pogonion (Pog):** the most anterior point on the contour of the bony chin. Determined by a tangent through nasion (Riolo et al, 1974);

16. **Gnathion (Gn):** the most anterior-inferior point on the contour of the bony chin symphysis. Determined by bisecting the angle formed by the mandibular plane and a line through pogonion and nasion (Riolo et al, 1974);

17. **Menton (Me):** the most inferior point on the symphyseal outline (Riolo et al, 1974);

18. **Gonion (Go):** the midpoint of the angle of the mandible. Found by bisecting the angle formed by the mandibular plane and a plane through articulare posterior and along the portion of the mandibular ramus inferior to it (Riolo et al, 1974);

19. **Articulare (Ar):** the point of intersection of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles (Riolo et al, 1974);

20. **Condylion (Co):** the most posterior-superior point on the curvature of the average of the right and left outlines of the condylar head. Determined as the point of tangency to a perpendicular construction line to the anterior and posterior borders of the condylar head (Riolo et al, 1974);

21. **Pterygo-maxillary fissure (PTM):** the most postero-superior point on the border of the pterygo-maxillary fissure. Where the overlap between the cranial base (f. rotundum) and pterygo-maxillary fissure was visible, the midpoint of the intersecting outlines was taken as the correct landmark;

22. **Basion (Ba):** the most inferior-posterior point on the anterior margin of foramen magnum (Riolo et al, 1974);

23. **Lower molar centre (LMC):** the measured midpoint of the mandibular first molar crown;

24. **Lower molar furcation (LMF):** the most occlusal point in the bifurcation of the roots of the mandibular first molar;

25. **Lower second premolar cusp tip (L5E):** the cusp tip of the mandibular second premolar;

26. **Lower second premolar apex (L5A):** the root tip of the mandibular second premolar;

27. **Lower first premolar cusp tip (L4E):** the cusp tip of the mandibular first premolar;

28. **Lower first premolar apex (L4A):** the root tip of the mandibular first premolar;

29. **Posterior Downs point (PDP):** the midpoint of a line connecting the mesial cusp tip of the mandibular first molar and the mesial cusp tip of the maxillary first molar. This represents the posterior point through which Downs occlusal plane passes (Riolo et al, 1974);

30. **Upper molar centre (UMC):** the measured midpoint of the maxillary first molar crown;

31. **Upper molar furcation (UMF):** the most occlusal point in the trifurcation of the roots of the maxillary first molar;

32. **Labial lower incisor (L1L):** the most labial point on the labial surface of the most proclined lower incisor;

33. **Anterior Downs point (ADP):** the midpoint of a line connecting landmarks 9. and 12. (**U1E** and **L1E**). This represents the anterior point through which Downs occlusal plane passes (Riolo et al, 1974);

34. **Lower incisor centre (L1C):**a constructed point representing the intersection of a line perpendicular to SN-7° passing through landmark 12. (**L1E**) and a line parallel to SN-7° passing through landmark 9. (**U1E**);

35. **Soft tissue nasion (ST N):** the point of greatest concavity in the midline between forehead and nose (Krogman and Sassouni, 1957);

36. **Soft tissue seven (ST 7):** the point representing the intersection of the cephalometric plane SN – 7° with the soft tissue profile;

37. **Nasal tip (N tip):** or pronasale, the most prominent point on the contour of the nose (DeLaat, 1974);

38. **Subnasale (Sn):** the point at which the nasal septum merges with the upper cutaneous lip in the mid-sagittal plane (Legan and Burstone, 1980);

39. **Sulcus superius (Ss):** the point of greatest concavity in the midline of the upper lip between subnasale and labrale superius (Holdaway, 1983);

40. **Labrale superius (Ls):** a point indicating the mucocutaneous border of the upper lip (Legan and Burstone, 1980);

41. **Upper lip lowest point (ULL):** or stomion superius, the lowermost point of the vermilion border of the upper lip (Legan and Burstone, 1980);

42. **Lower lip highest point (LLH):** or stomion inferius, the uppermost point of the vermilion border of the lower lip (Legan and Burstone, 1980);

43. **Labrale inferius (Li):** a point indicating the mucocutaneous border of the lower lip (Legan and Burstone, 1980);

44. **Sulcus inferius (Si):** the point of greatest concavity in the midline between the lower lip and chin (Legan and Burstone, 1980);

45. **Soft tissue pogonion (ST Pog):** the most anterior point on the soft tissue chin (Legan and Burstone, 1980);

46. **Soft tissue menton (ST Me):** the lowest point on the contour of the soft tissue chin; found by dropping a perpendicular from the horizontal reference plane through menton (Legan and Burstone, 1980).

The following describes the points used to define the X any Y cartesian axes:

47. **Y:** a point on the line perpendicular to SN-7° passing through landmark 1. (S);

48. **X1:** the origin point on the X axis which is parallel to SN-7°;

49. **X2:** the terminal point on the X axis which is parallel to SN-7°.

10.2 Appendix II Definitions of the angular and linear variables

1. **Sella-nasion to Frankfort horizontal (SN-FH, [°]):** the angle formed between sella-nasion and porion-orbitale;
2. **SNA (°):** the angle formed between sella-nasion line and a line drawn through nasion and Downs A point;
3. **Maxillary plane to sella-nasion (MaxPl-SN, [°]):** the angle formed between sella-nasion line and the line joining anterior nasal spine (ANS) and posterior nasal spine (PNS);
4. **Maxillary length (Co-A point, [mm]):** the linear distance from condylion to A point;
5. **Upper incisor to sella-nasion (U1-SN, [°]):** the angle formed between a line drawn through sella-nasion and a line drawn through the long axis of the most prominent upper central incisor;
6. **Upper incisor to NA (U1-NA, [°]):** the angle formed between a line drawn through the long axis of the most prominent upper central incisor and a line drawn through nasion and Down's A point;
7. **Upper incisor to NA (U1-NA, [mm]):** the linear distance measured parallel to SN-7° from the most prominent upper central incisor crown tip to a line drawn through nasion and Down's A point;
8. **Upper incisor to maxillary plane (U1-MaxPl [°]):** the angle formed between the long axis of the most prominent upper central incisor and a line formed joining anterior nasal spine (ANS) and posterior nasal spine (PNS);
9. **Interincisal angle (U1-L1, [°]):** the angle formed between the lines drawn through the long axes of the most prominent upper and lower central incisors;
10. **Overjet (OJ, [mm]):** the linear distance measured parallel to SN-7° between the cusp tip of the most prominent upper central incisor and the labial surface of the most prominent lower central incisor;
11. **Overbite (OB, [mm]):** the linear measure of vertical overlap between the cusp tip of the most prominent upper central incisor and the cusp tip of the most prominent lower central incisor;

12. **ANB (°):** the angular difference between the angles sella-nasion and Down's A point and sella-nasion B point;

13. **Lower incisor to NB (L1-NB, [°]):** the angle formed between a line drawn through the long axis of the most prominent lower central incisor and a line drawn through nasion and B point;

14. **Lower incisor to NB (L1-NB, [mm]):** the linear distance measured parallel to SN-7° from the most prominent lower central incisor and a line drawn through nasion and B point;

15. **Lower incisor to mandibular plane (IMPA, [°]):** the angle formed between a line drawn through gonion and gnathion and a line drawn through the long axis of the most prominent lower central incisor;

16. **Lower incisor to mandibular plane (L1-MP, [mm]):** the linear distance between a line drawn through gonion and gnathion and the apex of the most prominent lower central incisor;

17. **SNB (°):** the angle formed between a line drawn through sella-nasion and nasion B point;

18. **True mandibular length (Co-Gn, [mm]):** the linear distance of the line joining condylion and gnathion;

19. **Mandibular length (Ar-Gn, [mm]):** the linear distance of the line joining articulare and gnathion;

20. **True ramus height (Co-Go, [mm]):** the linear distance of the line joining condylion and gonion;

21. **Ramus height (Ar-Go, [mm]):** the linear distance of the line joining articulare and gonion;

22. **Upper anterior face height (UFH, [mm]):** the linear distance of the line joining nasion and anterior nasal spine measured perpendicular to SN-7°;

23. **Lower anterior face height (LFH, [mm]):** the linear distance of the line joining anterior nasal spine and menton measured perpendicular to SN-7°;

24. **Anterior face height ratio (UFH:LFH):** the proportion of the upper anterior face height to the lower anterior face height expressed as a ratio;

25. **Total anterior face height (Na-Me, [mm]):** the linear distance of the line joining nasion and menton measured perpendicular to SN-7°;

26. **Posterior face height (S-Go, [mm]):** the linear distance of the line joining sella and gonion;

27. **Posterior to anterior face height ratio (PFH:AFH):** the proportion of the posterior face height to the anterior face height expressed as a ratio;

28. **Frankfort horizontal to mandibular plane (FMA, [°]):** the angle formed between the lines joining orbital and porion and gonion-gnathion;

29. **A-S vert [mm]:** the linear perpendicular distance from A point to a vertical Y axis through sella;

30. **B-S vert [mm]:** the linear perpendicular distance from B point to a vertical Y axis through sella;

31. **Pog-S vert [mm]:** the linear perpendicular distance from pogonion to a vertical Y axis through sella;

32. **Lower molar to sella vertical (LM-S vert, [mm]):** the linear perpendicular distance from lower molar distal cusp reference point to a vertical Y axis through sella;

33. **Upper molar to sella vertical (UM-S vert, [mm]):** the linear perpendicular distance from upper molar distal cusp reference point to a vertical Y axis through sella;

34. **Lower molar angle (LM angle, [°]):** the posterior angle between the lines formed by the centre of the crown and the bifurcation of the mandibular molar and gonion-gnathion;

35. **Lower second premolar angle (L5 angle, [°]):** the posterior angle between the lines formed by the apex and cusp tip of the mandibular second premolar and gonion-gnathion;

36. **Lower first premolar angle (L4 angle, [°]):** the posterior angle between the lines formed by the apex and cusp tip of the mandibular first premolar and gonion-gnathion;

37. **Upper molar to palatal plane (UM-PP, [°]):** the posterior angle between the lines formed by the centre of the crown and trifurcation of the maxillary first molar and ANS-PNS;

38. **Sella-nasion to Downs occlusal plane (SN-OP, [°]):** the angle between the lines formed by sella-nasion and ADP-PDP;

39. **Mandibular plane to Downs occlusal plane (MP-OP, [°]):** the angle between the lines formed by gonion-gnathion and ADP-PDP;

40. **Facial convexity (F. conv., [°]):** the angle formed between the points soft tissue nasion, nasal tip and soft tissue pogonion;

41. **Nasolabial angle (N-L ang., [°]):** the angle formed between the points nasal tip, subnasale and labrale superius;

42. **Labiomental fold (L-M fold, [°]):** the angle formed between the points labrale inferius, sulcus inferius and soft tissue pogonion;

43. **Holdaway's harmony angle ("H" angle, [°]):** the angle formed between the soft tissue nasion, labrale superius and soft tissue pogonion;

44. **Upper lip thickness (Ls-A, [mm]):** the linear distance between A point and labrale superius;

45. **Lower lip thickness (Li-B, [mm]):** the linear distance between B point and labrale inferius;

46. **Soft tissue total face height (ST TFH, [mm]):** the linear distance between soft tissue nasion and soft tissue menton measured perpendicular to SN-7°;

47. **Soft tissue upper face height (ST UFH, [mm]):** the linear distance between soft tissue nasion and subnasale measured perpendicular to SN-7°;

48. **Soft tissue lower face height (ST LFH, [mm]):** the linear distance between subnasale and soft tissue menton measured perpendicular to SN-7°;

49. **Soft tissue lower face percentage (ST LFH%):** the ratio between the linear distance between subnasale and soft tissue menton and soft tissue nasion and soft tissue menton expressed as a percentage;

50. **Upper lip to E line (Ls-E line, [mm]):** the linear distance between a line drawn through nasal tip and soft tissue pogonion and labrale superius;

51. **Lower lip to E line (Li-E line, [mm]):** the linear distance between a line drawn through nasal tip and soft tissue pogonion and labrale inferius;

52. **Upper lip length (ULL, [mm]):** the linear distance from subnasale to the most inferior point of the upper lip;

53. **Lower lip length (LLL, [mm]):** the linear distance from the most superior point of the lower lip to soft tissue menton;

54. **Soft tissue total face height (STPog-STN, [mm]):**

55. **Sn-S vert (mm):** the linear perpendicular distance from subnasale to a vertical Y axis through sella;

56. **Ss-S vert (mm):** the linear perpendicular distance from sulcus superius to a vertical Y axis through sella. A measure of upper lip position;

57. **Ls-S vert (mm):** the linear perpendicular distance from labrale superius to a vertical Y axis through sella. A measure of upper lip position;

58. **Li-S vert (mm):** the linear perpendicular distance from labrale inferius to a vertical Y axis through sella. A measure of lower lip position;

59. **Si-S vert (mm):** the linear perpendicular distance from sulcus inferius to a vertical Y axis through sella. A measure of lower lip position;

60. **STPog-S vert (mm):** the linear perpendicular distance from soft tissue pogonion to a vertical Y axis through sella. A measure of soft tissue chin position.

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