Occlusal Variation in the Primary Dentition: A Study of Australian Twins and Singletons

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ABSTRACT

With moves toward early intervention and treatment of developing malocclusions in the late primary and early mixed dentitions, there is a need for more information on the nature and causes of occlusal variation in the primary dentition. Knowledge of the nature and extent of variation in occlusion is important for anthropologists, orthodontists and paediatric dentists.

There are many references in the literature relating to occlusal variation in the permanent dentition, but detailed and thorough descriptions of the primary dentition are rare, so, consequently, there are many avenues to explore and clarify.

It is now widely accepted that the observed phenotypic variation in occlusion is a result of a polygenic or multifactorial mode of inheritance. In human genetic epidemiologic studies, the degree of phenotypic similarity between individuals correlates positively not only with the degree of genetic similarity but also the degree of environmental similarity, both pre- and post-natally. The study of twins compares the similarity of monozygous and dizygous twin pairs and is a most efficient and powerful method for detecting genetic and shared environmental effects on phenotypic variation. Observed phenotypic variation of a trait may be divided into additive and non-additive genetic factors and individual and family and environmental factors. The study of correlations between relatives is most commonly used, in particular, the classical twin method. However, this method alone has limited

usefulness as it gives no insight into the presence or absence of particular factors or their direction of causation.

In this study, a modern approach to estimating heritability involving the structural equation modelling package Mx was carried out on the twin data. The Mx package allows specification of a model (hypothesis) regarding the relative contribution of genetic and environmental influences to the observed phenotypic variation and testing the goodness-of-fit of the model.

Methods and Materials

The present study investigated the extent of variation in different occlusal features in Australian caucasian children, all with complete primary dentitions and with no permanent teeth present in the mouth. The first group of 114 singletons, 58 males and 56 females with a mean age of 4.7 years (standard deviation 0.62 years),were selected from the study models of Victoria Farmer in 1990 for her Master of Dental Surgery research project on "Odontometric and Morphologic Variability in the Deciduous Dentition". Access to a questionnaire completed by parents revealed various developmental factors that may be associated with or influence the development of the dental arches, for example, maternal health during pregnancy.

The second group comprised 83 twin pairs, including 81 males and 79 females with a mean age of 5.4 years (standard deviation 0.57 years),selected from an on-going study of dento-facial morphology being carried out in the Department of Dentistry at the University of Adelaide. The twin group comprised 35 monozygous twin pairs, 34 dizygous twin pairs and 11 opposite sex dizygous twin pairs. Zygosity was confirmed from isolation of DNA obtained from buccal cheek swabs. Information relating to birthweight, birthlength and medical histories were obtained by way of a questionnaire completed by parents.

Various measures of occlusal variability including interdental spacing, overbite, overjet, canine and molar relationships, crossbite relationship, arch breadth and depth and arch shape were obtained directly from stone models or indirectly from photocopies or impressions of the models.

The scoring of a continuous range of interdental spacing required the development of a new method of data collection. Impressions of each cast were obtained with Examix-monophase type hydrophilic polyvinyl siloxane material and then sectioned longitudinally and measurements made. For the remaining variables, methods described by other authors were used for data collection including Moorrees (1959), Foster and Hamilton (1969) and Richards et al. (1990).

Data were analyzed statistically using the software package SPSSX at The University of Adelaide. Descriptive statistics were computed including mean values, standard deviations and coefficients of variation for the continuous variables. Paired and unpaired t-tests were used for comparison between males and females, between left and right-sides and between maxilla and mandible

Estimates of heritability for the various occlusal variables measured were:

overjet- 0.28

overbite- 0.53

interdental spacing- ranged between 0.62 and 0.81

arch dimensions- ranged between 0.69 and 0.89

arch shape- ranged between 0.79 and 0.87

Discussion

Mean total arch spacing was greater in the maxilla than in the mandible. This concurs with the findings of other authors (Kaufman and Koyoumdjisky 1964, Foster et al. 1969, Joshi and Makhija 1984, El-Nofely et al. 1989). Reported arch dimensions from Moorrees' 1959 study compare well with the present study. This study found a significant difference in the means between males and females for each variable except maxillary arch depth and arch breadth at the canine in the mandible. This finding may be related, in part, to the consistently larger crown diameters in boys than girls found by Farmer and Townsend (1993) in the same sample of children as the present study.

The mean overbite and overjet averaged 1.8±1.4mm (mean±SD) and 2.5±1.3mm. No significant difference was found between males and females. However, a significant difference was found in the variance between males and females for both overbite and overjet. In the female sample, 13.1% of individuals had an open bite compared with 0% in the male sample. Similarly, the maximum recorded overjet for the female sample was 8mm compared with 5.5mm for the male sample. Open bite and increased overjet have been associated with sucking habits. However, no records were available to check this hypothesis.

In all cases, fourth-order polynomial equations fitted the data well with all correlations exceeding 0.99. This result is consistent with the finding of Richards et al.(1990). The quadratic and quartic terms reflecting overall arch shape did not differ significantly between males and females. Similarly, the linear and cubic terms representing arch asymmetry did not differ significantly.

A Class I canine relationship was the most frequently occurring category in both males and females, and on the left and right sides of the arch, ranging from 52.8 to 66.1%. A Class III relationship was the least frequent relationship, occurring in 1.9% of the female sample.

A Class I molar or straight terminal plane relationship was the most common molar relationship in both males and females, left and right sides, ranging from 62.5% to 84.0%. A Class III or mesial terminal plane relationship occurred least frequently, ranging from 6.0 to 16.7%.

Most children did not show evidence of a crossbite relationship, frequencies ranging from 87.5% to 91.4% in males and females. Bilateral crossbite occurred least frequently, being present in 1.8% of the female sample. The frequencies of canine, molar and crossbite relationships found in the present study compare well with other published studies (Ravn 1975, Otuyemi et al.. 1997, Tschill et al. 1997).

Previous heritability studies of occlusal variables have all been conducted on the permanent dentition. To the author's knowledge, no other studies on the primary dentition are available for comparison. Heritability values found in this study were generally higher than those reported in earlier studies of the permanent dentition, possibly due to the sensitive nature of the analysis. However, the researcher should keep in mind that heritability estimates are specific to a particular population and so comparisons between populations should be carried out with caution. The pattern of heritability values for the various occlusal traits in this study (that is, highest for arch dimensions and lowest for overjet) were similar to previous studies of the permanent dentition. However, whether both the primary and permanent dentitions are under control of the same set of genes is not yet known.

This study found that, generally, occlusal variation in the primary dentition appears to be under moderate to high genetic control. Important environmental factors are not yet clear; however, subtle environmental influences, for example, consistency of the diet, head posture, pre- and peri-natal factors and peri-oral muscular activity, have been reported as important factors affecting variation in craniofacial morphology. Further research involving a multivariate analysis of the data to determine genetic and environmental influences on co-variation within the primary dentition is required.

Recent developments in craniofacial biology propose a new approach in the management of malocclusion. Preliminary results from Finnish trials of early occlusal and orthopaedic treatment look promising as an alternative to conventional active treatment during adolescence and adulthood. If fruitful, contemporary orthodontic treatment may fundamentally change direction. Indeed, there is clearly a need for continuing research into the nature and causes of occlusal variation in the primary dentition, particularly from the view point of prevention and early clinical intervention.

This study has presented a comprehensive investigation into the occlusal variability in the primary dentition in a group of Australian children. The results are similar to those found in other populations and confirm that a wide range of occlusal variation exists in the primary dentiton. It is intended that a future longitudinal study will provide further insight into the nature and causes of occlusal variation in the primary dentition.

SIGNED STATEMENT

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other 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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Publications produced during the period of canditature

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1. INTRODUCTION

Over the past century, there has been considerable literature published on the developmental changes that occur in the human dentition. However, detailed and thorough descriptions of occlusal variation in the primary dentition are still relatively scarce. Consequently there are still many avenues to explore and clarify.

It is the aim of this thesis to provide insights into the nature and extent of occlusal variation in the primary dentition of Australian singletons and twins and to quantify the relative roles of the genetic and environmental influences to observed variation.

As a basis for discussing occlusal variation in the primary dentition, it is important to understand the nature and sequence of normal development and to appreciate that a vast array of occlusal patterns exist within and between populations. Many factors contribute to dental occlusion, including tooth size and position, arch size and shape, and the relationship of the upper dental arch to the lower arch. It is essential to realise that the presence of a wide variety of occlusal patterns in a population does not necessarily imply that a wide variety of malocclusions exist in that population. Indeed, the definition of what constitutes a malocclusion is very subjective and this, in part, has been due to the lack of a universal system for classifying occlusal traits.

In the literature, there are many references to craniofacial growth and development and their relationship with occlusal variation. Indeed, many different systems, including skeletal-based, soft tissue and tooth-based components, interplay with each other to determine the final occlusal phenotype. It is now widely accepted that observed variation results from a multifactorial inheritance pattern with both genetic and environmental influences playing important roles.

An insight into the complex interactions between the genome and the environment and their effects on occlusal variation may lead to new philosophies in prevention and early treatment of malocclusion in the primary dentition. Indeed, the classical orthodontic thinking of strong and immutable genetic causes of malocclusion has now been abandoned widely and recent research has been directed towards true prevention and early orthopaedic treatment of developing malocclusion. Clearly, this has important implications in clinical dentistry.

2. LITERATURE REVIEW

Primary Dentition

Prevention and treatment of malocclusion requires a thorough knowledge of the normal growth and development of the primary and secondary dentitions. The term "malocclusion" needs qualification, as it is a broad term generally used to describe variations from normal occlusal development. It is suggested that the term "occlusal variation" is more appropriate to describe the continuous range of dental occlusion observed in populations, with the more extreme variations located at the tails of the distribution. Reports in the literature concerning growth and development of the child first appeared at the beginning of the 18th century and, since then, many aspects have been clarified.

Moorrees (1959) gives an account of early studies of dental development conducted in the 18th, 19th and early 20th centuries. There is general agreement on the main changes that take place in the dental arches during the transition from the primary to permanent dentitions including:

- a slight increase in maxillary arch length and a decrease in mandibular arch length
- an increase in arch breadth, being larger in the maxilla and greatest during eruption of the permanent incisors and canines
- an increase in palatal height

However, Moorrees noted a number of deficiencies in these early studies which can be summarised as follows:

- the sex, race and socio-economic status of subjects were not always reported clearly, although this is an important factor when studying absolute dimensions

- statistical evaluation of the data was often inadequate; for example, failure to report standard deviations from the mean
- the choice of landmarks for measuring arch dimensions varied

Normal Development

Tooth formation is the result of three main entities working in harmony with each other: the enamel organ which produces the ameloblasts and enamel; the dental papilla which produces the pulp, odontoblasts and dentine; and the dental follicle which produces cementum, fibroblasts to form the periodontal ligament and osteoblasts to form alveolar bone.

All of the tissues of the tooth (except the enamel) and supporting structures begin as ectomesenchyme derived from neural crest cells that arise from the ectodermal germ layer. The neural crest cells migrate to the oral region and interact in a specific manner with oral ectoderm (Ten Cate 1994). In a four-week-old foetus, areas of ectodermal thickening appear in both the developing maxilla and mandible, representing the sites of the future primary teeth in each dental arch. The permanent tooth germs appear later from the primary tooth bud, close to its attachment to the dental lamina (Hall 1994). Therefore, the primary incisors and canines produce the dental laminae for the permanent incisors and canines, while the first and second primary molars produce the dental laminae for the permanent first and second premolar teeth. The first, second and third permanent molars develop from an extension of the dental lamina, distal to the second primary molar (Ten Cate 1994). The entire primary dentition is initiated between the sixth and eighth weeks of embryonic development, the successional permanent teeth between the 20th week in utero and the 10^{th} month after birth and the permanent molars between the 20th week in utero (first molar) and the fifth year of life (third molar) (Ten Cate 1994).

Common features of the primary dentition

Five features have been described commonly in the complete primary dentition:

- interdental spacing between incisors
- the presence of anthropoid or primate spaces in the maxillary and mandibular dental arches
- a deep overbite which reduces with increasing age
- the presence of one of three possible terminal plane relationships: straight, mesial or distal
- relatively broad dental arches

Each of these features will now be considered in turn:

1. Interdental spacing between incisors

Crowding is not a common feature of the primary dentition (Proffit 1993; Alexander and Prabhu 1998), and young children with crowding or no anterior interdental spacing have a far greater chance of crowding in the permanent dentition. Information regarding the “spaced dentition” is scarce in the literature, particularly in relation to the primary dentition, even though reference was first made to anterior spacing of primary teeth last century by Delbarre (1819).

A few authors have studied the relationship between tooth size, dental arch dimensions and interdental spacing. Clearly, whether there is crowding or spacing in the dental arch depends on the relationship between the size of the dental arch and the dimensions of the individual teeth. For example, Baume (1950) found that arches without spacing were on average 1.5mm narrower than those with spacing and that lack of spacing was not always due to a greater width of the primary anterior teeth. Foster et al. (1969) found a high degree of correlation between mesiodistal tooth diameters and dental arch size in the primary dentition and suggested this may be the reason for the rarity of crowding in the primary dentition. Lundström (1969) reported marked crowding appeared primarily in those arches with large teeth and a small perimeter. El-Nofely et al. (1989) noted that spacing of the primary anterior teeth was related to both mesiodistal crown diameter and intercanine arch width.

When discussing interdental spacing and crowding, it is important to make a distinction between the permanent and primary dentitions, as their basis and functional roles are different (see Primate and Developmental spaces below). Proffit (1986) reports that spacing between incisors is normal in the primary dentition and, in fact, necessary for the alignment of the succedaneous permanent teeth.

2. Presence of anthropoid or primate spaces in the maxillary and mandibular dental arches

Two distinct types of spacing can be classified in the primary dentition:

- Primate or anthropoid spaces. These spaces are thought to be genetically determined and characteristic of our ancestral and modern primate dentitions (El-Nofely et al. 1989). They are located between the lateral incisor and the canine in the maxilla and between the canine and first molar in the mandible (Figure 2.1). In Homo sapiens, they are found in the primary dentition alone; however, most non-human primates have these spaces throughout life, hence the name (Proffit 1993). The presence of primate spaces is an important working phase in the transition from primary to the permanent dentition (Boyko 1968).

- Developmental spaces. These spaces are located elsewhere in the dental arch, most commonly between the anterior teeth and less frequently between the molar teeth. They are usually present from the commencement of the primary dentition.

The incidence of interdental spacing in the primary dentition appears to vary between ethnic groups. Reported frequencies of primate spaces range from 46% (Kaufman and Koyoumdjisky 1967) to 98% (Boyko 1968) in the maxilla and between 45% (Tschill et al. 1997) and 87% (Kisling and Krebs 1976) in the mandible. The absence of anterior interdental spaces has been reported as ranging from 4% (Kaube et al. 1995) to 24% (Tschill et al. 1997) in the maxilla and between 10% (El-Nofely et al. 1989) and 54% (Tschill et al. 1997) in the mandible. In spite of the wide variation in reported frequencies of interdental spacing, one fact that emerges from all these studies is that interdental spacing is perceived to be more prevalent in the maxillary arch than in the mandibular arch.

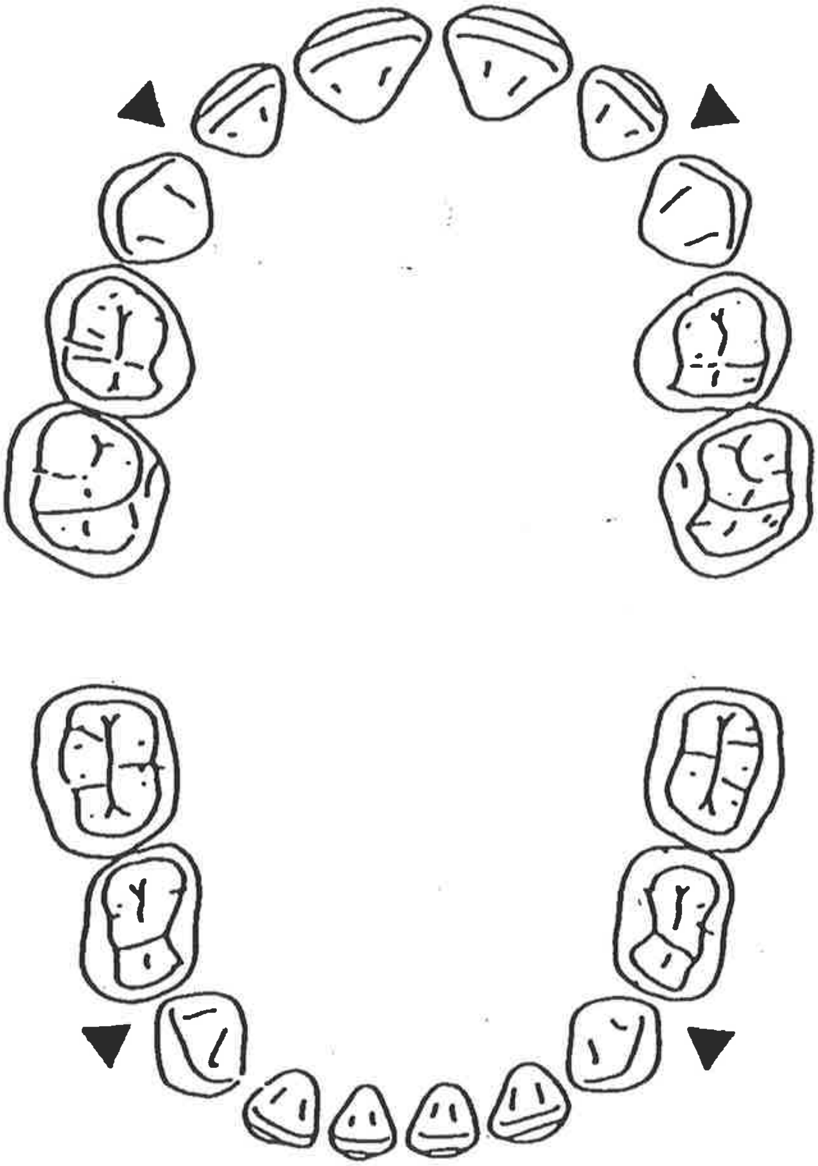


Figure 2.1 : Anthropoid or primate spaces in the maxillary and mandibular arches.

3. A deep incisor overbite which reduces with increasing age

Incisal overbite in the primary dentition has been studied by relatively few authors and, indeed, those who have, present conflicting reports on aetiological factors, as well as the pattern and incidence of this occlusal feature. In addition, what constitutes a deep bite often appears to be based on subjective judgement.

Possible aetiological factors are presented by Baume (1950) and include a lack of vertical height of the mandibular ramus, supra-eruption of the incisors, infra-eruption of posterior teeth and the possible influence of the eruption sequence of the canines and premolars.

Baume (1950) studied a series of 52 plaster casts of children and found, generally, the overbite in the primary dentition did not change except when environmental influences, for example, attrition and habits, were present. During the transition into the mixed dentition, there was a tendency toward the formation of a deeper bite.

However, Moorrees' (1959) study revealed a decrease in overbite during the period of the primary dentition, a finding that was confirmed by Nanda et al. (1973). Nanda and co-authors found a reduction in the magnitude of the overbite in their sample of Indian children aged between two and six years and suggested that this was probably caused by growth of the mandible.

The incidence of deep bite in the primary dentition varies between sample populations, ranging from 1.6% (Tschill et al. 1997) to 31% (Baume 1950). Indeed, comparison between studies is difficult due to differing methods of classification and recording of incisal overbite. Proffit (1993) states that a deep bite may occur in the primary dentition, but that it is usually the result of a skeletal imbalance.

4. The presence of one of three possible terminal plane relationships : straight, mesial or distal

Proffit (1986) reports occlusal relations present in the mixed dentition parallel those in the permanent dentition but that the terminology differs. The terminal plane relationship in the primary dentition may be used to forecast the interocclusal relationship of the erupting permanent molars. A flush terminal relationship is the normal relationship of the primary molars and is defined as the distal surface of the second maxillary and mandibular molars being in the same vertical plane. A distal step corresponds to an Angle Class II relationship in the permanent dentition; that is, the distal surface of the mandibular second molar is posterior to the maxillary second molar. In the same way, a mesial step corresponds to an Angle Class I relationship in the permanent dentition; that is, the distal surface of the mandibular second molar is anterior to the maxillary second molar. Figure 2.2 shows the possible occlusal relationships of the primary and permanent molars. When the permanent molars first erupt, their relationship is determined by that of the primary molars. However, the final relationship will be modified by the forward growth of the mandible and shift of the teeth anteriorly. An asymmetrical molar relationship could be attributed to a difference in the space distribution between teeth on the left and right sides of the arch, or rotation or inclination of a molar on one side only.

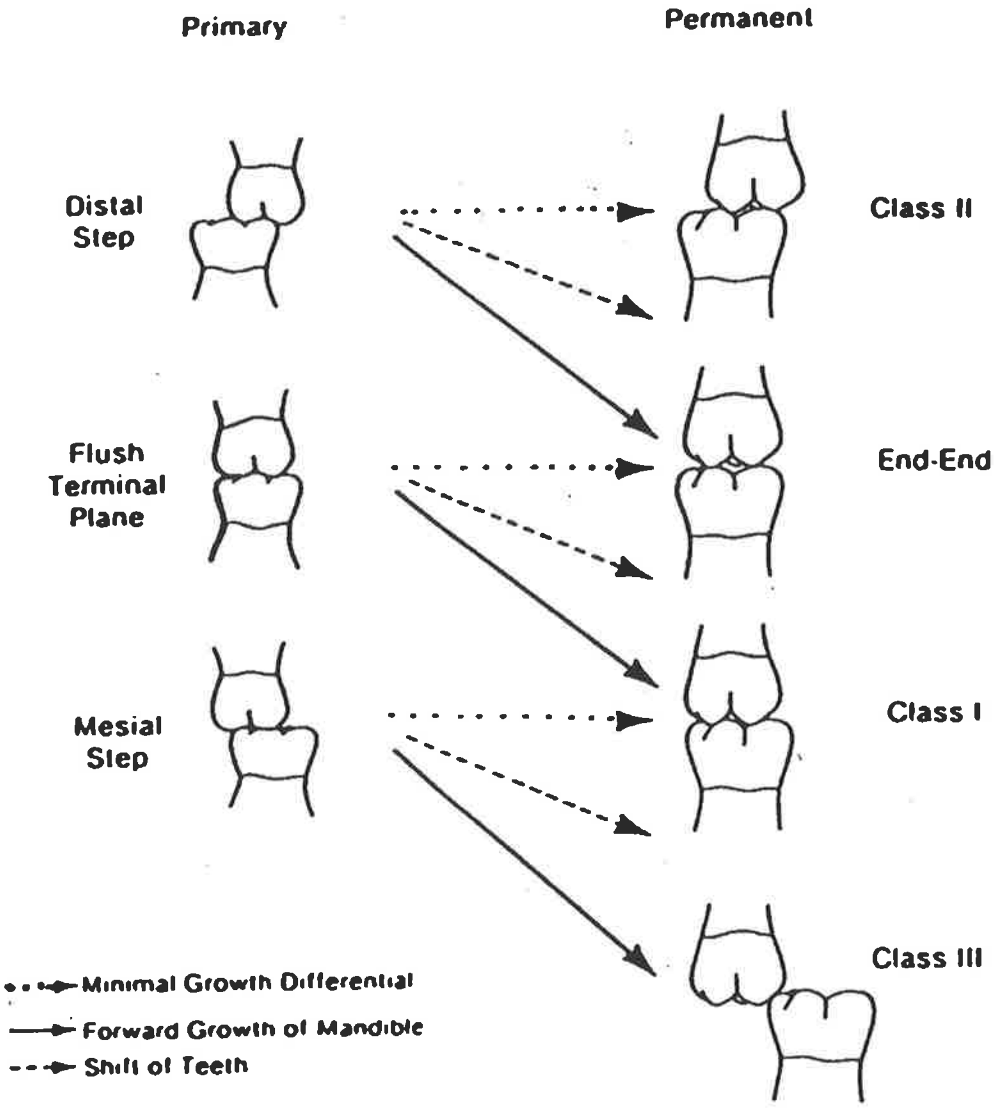


Figure 2.2 : Terminal plane relationships of the primary and permanent molars. The possible terminal plane relationships of the primary molars are shown on the left. When the permanent first molars erupt, their relationship is determined initially by the primary molars. Loss of the second primary molar combined with the adolescent growth spurt results in a shift of the permanent molar relationship, as shown by the arrows. The dotted lines indicate the change if the leeway space is inadequate and there is no differential forward growth of the mandible. If leeway space is available, but forward mandibular growth is limited, the possible change is indicated by the broken lines. With good forward mandibular growth and a shift of the molars, the change that may be expected is shown by the solid line (Proffit 1993).

Due to the fact that the normal growth pattern of the mandible lags behind the maxilla, a mesial terminal plane is rarely seen in the primary dentition. At the time the second primary molars are exfoliating, the first permanent molars drift mesially into the leeway space, averaging 1.5mm and 2.5mm in the maxilla and mandible respectively, contributing to the development of a Class I relationship in the permanent dentition. In addition, at this stage of growth, the mandible is growing faster than the maxilla, allowing a deficient mandible to catch up. However, only a slight adjustment in the molar relationship, approximately half a cusp, can be produced by the combination of mesial migration of the mandibular molar and differential jaw growth.

5. Relatively broad dental arches

The dental arches of the primary dentition have been described as being more rounded (Ingervall 1991). In comparison, the maxillary and mandibular dental arches of the permanent dentition have been described as taking the form of a half-ellipse and a parabola respectively (Krogh-Poulsen 1958).

The size and form of the primary dental arches vary considerably within and between human populations. Indeed, the determinants of arch size and shape are not well understood. A number of factors contribute to the variation observed in arch size and shape and are responsible for modification of the arch form that is determined very early in the foetus. These include :

- normal lip and tongue pressures
- variability in the eruptive path of the teeth
- growth of the jaw bones
- movement of the teeth following eruption due to habits and unbalanced muscle pressures; that is, the teeth are not in a neutral zone where there is a balance between the lip and tongue

<u>Occlusal changes during the complete primary dentition stage</u>

Some authors consider the period of the primary dentition to be static, with no changes in arch dimensions or occlusal relations taking place (Sillman 1948; Baume 1950). Sillman (1948) was one of the first researchers to present a developmental series of the dentition from birth. He found that molar termination patterns during the primary dentition period did not change. Furthermore, following eruption of the primary teeth, the presence or absence of spaces did not change significantly (Sillman 1964). This concurs with the findings of Baume (1950), whose study found that after the primary dentition was formed, the sagittal and transverse dimensions did not change, except when influenced by environmental factors, for example, habits. However, others believe occlusal relations do change with time (Humphreys and Leighton 1950; Moorrees 1959; Nanda et al. 1973; Infante, 1974; Ravn 1980).

Humphrey and Leighton (1950) reported on changes in occlusal relations during the period of the primary dentition and found a small increase in the incidence of Class II molar relations in children between the ages of two and five years. Nanda et al. (1973) and Ravn (1980) similarly reported a change in terminal plane relations in the primary dentition. Both authors found no significant change in the number of children with Class II molar relations but a decrease in the incidence of Class I molar relations and an increase in the frequency of Class III relations. In addition, a significant reduction in overjet and overbite with age was reported. In contrast, Infante (1974) found that the incidence of a Class II molar relation decreased significantly from two and a half to six years of age.

Moorrees' (1959) classical study followed 184 North American white children from the primary to the permanent dentition. His findings can be summarised as follows:

- arch length : maxillary and mandibular arch length decreased from age 3 to 18 years of age. The first decrease occurred mainly between 4 and 6 years and was a result of diminishing interdental space between the primary molars and canines. A second decrease occurred between the ages of 10 and 14 years and was the result of the replacement of the primary molars with the smaller permanent premolars.
- arch breadth : both maxillary and mandibular arch breadths increased from age 5 years to 18 years. The increase in the maxillary arch could be divided into three phases. The first increase occurred between the age of 3 and 4 years at the level of the canines and was probably a result of a growth spurt. The second growth phase began at age 5 to 6 years, and the final phase began just before the emergence of the canines. The change in arch breadth at the molars followed a similar pattern, but the overall magnitude was much less.

  In the mandibular arch, the intercanine distance increased continuously and markedly after 5 years of age until about 10 years when there was a slight decrease as the permanent canines erupted. Between the molars, the arch breadth increased after age 6 years and increased again after the emergence of the premolars.
- crowding and spacing : there was no increase in the average amount of interdental space in the primary dentition after 3 years of age until approximately one year before the emergence of the central incisors, when the development of spacing was evident as a result of alveolar growth. The interdental spaces between the primary molars decreased after 3 years of age and disappeared at age 6 years.
- overbite : there was a decrease in overbite with increasing age during the period of the primary dentition.

This period of the primary dentition should not be confused with the transitional phase between the primary and permanent dentitions when a great deal of growth and remodelling will result in a change in arch dimensions and in the position and size of spacing present in the arch.

Occlusal patterns in the primary dentition.

Reports of occlusal patterns in the primary dentition have concentrated on samples from different populations. Kaufman and Koyoumdjisky (1967) looked at patterns of interdental spacing, overjet and overbite and terminal plane relations in 313 Israeli preschool children. They found a straight or flush terminal plane occurred 2.4 times more often than a mesial terminal plane. A distal terminal relationship was not found. No statistically significant correlation was found between interdental spacing and type of terminal plane. Primate spaces were found more often with a mesial terminal plane in the maxilla and with equal frequency for both mesial and straight terminal patterns in the mandible. This study showed that anterior interdental spaces were more common in the maxilla than in the mandible in both males and females. A review of the literature has revealed similar findings by other authors (Ravn 1975; El-Nofely et al. 1989; Tschill et al. 1997; Otuyemi et al. 1997; Thomas and Townsend 1999). Overbite and overjet tends to show a positive correlation with a straight terminal plane; overbite tends to be deeper and overjet larger in children with a straight terminal plane. Kaufman and Koyoumdjisky (1967) suggest that a reduced degree of overbite and overjet in children with a terminal mesial step relationship may be a result of a more uniform growth rate of the maxilla and mandible, and that the transition to the normal permanent molar relationship may be different in the straight terminal plane pattern.

The incidence of primate spaces in 50 three-year-old Canadian children was reported by Boyko (1968). As in previous studies (Kaufman and Koyoumdjisky 1967; El-Nofely et al. 1989), a high incidence of primate spaces was found, 98%

in the maxilla and 86% in the mandible. Boyko reported a straight terminal plane was present in 64% of cases examined which is similar to the 68% of cases found by Kaufman and Koyoumdjisky (1967). A mesial step was present bilaterally in 14% of cases and a distal step in 12% of children. This agrees closely with Baume (1950) but conflicts with the findings of Infante (1974) and Foster and Hamilton (1969) who found a much lower incidence of Class III relationships. The sample sizes of Boyko and Baume, however, were small, being 50 and 30 children respectively.

Foster and Hamilton (1969) studied the occlusion of 100 children in the age range 2.5 to 3 years, including 56 males and 44 females. They found a wide variety of occlusal conditions and suggested that the concept of an ideal occlusion in the primary dentition was basically a myth. Their results revealed only a small proportion of children had no interdental spacing in the arches, there were roughly equal numbers of Class I (flush terminal plane) and Class II (distal step) arch relationships but very few Class III (mesial step) relationships. A high proportion of children (72%) had an increased incisor overjet (more than 2mm) and another feature noted was that 24% of children had anterior open bites. However, the authors did not suggest any possible reason for the presence of these features.

Foster et al. (1969) reported on the dimensions of the teeth and dental arches of 100 white British children aged between two and a half and three years including 50 males and 50 females. The size of the dental arch has in the past been related to the size of the jaws and the position of the teeth which, in turn, is influenced by the soft tissues of the oral cavity. They found a high degree of correlation between the size of the dental arches and the size of the teeth in both males and females and suggested that this may be why the incidence of crowding in the primary dentition is low.

Nanda et al. (1973) reported on occlusal patterns of 2500 Indian children aged between two and six years and found a straight terminal plane predominated through all ages. They found a significant decrease in the incidence of Class I (straight) molar relations with age and a corresponding increase in Class III (mesial) molar relations. Nanda and colleagues attributed this to mesial migration of the mandibular teeth and a mesial mandibular shift, probably caused by growth. The percentage of children with Class II (distal) molar relations did not change significantly during the study and a similar trend was noted for canine relationship. These results concur with those of Ravn (1980) but conflict with Infante (1974), who found a significant decrease in the incidence of Class II relations in children of a similar age group. Nanda and colleagues found:

- a decrease in the magnitude of overbite and overjet with increasing age
- a very low incidence of open bite (2.75%), the prevalence of which did not change with age.

In addition, this study found the prevalence of Class II molar relations was greater in siblings of children with a disto-occlusion compared with the prevalence in the general population.

Infante (1974) studied primary molar relations in 680 children, aged between two and a half and six years and found a significant reduction in the prevalence of Class II molar relations with advancing age. He suggested a mesial shift of the mandible in some children between the ages of two and six years may have been caused by horizontal mandibular catch-up growth.

Infante also noted a high association between finger sucking and posterior lingual crossbite, a finding which is well-documented (Graber 1966; Popovich 1967; Moyers 1973). He suggested that following cessation of the habit, even before age six years, the crossbite might not resolve spontaneously, a belief that is contrary to other authors (Myllarniemi 1973; Otuyemi et al. 1997).

Transverse discrepancies in the primary dentition are most commonly the result of a constricted maxillary arch, particularly in the region of the canines and are often associated with a sucking habit. A sucking habit is perhaps the most common type of occlusal parafunction in children and prolonged sucking results in changes in the form of the jaws and dental arches. The maxillary arch fails to develop in width because of an alteration in the muscle balance between tongue and cheek pressures (Proffit 1993) and may result in an increased overjet, an anterior open bite, crossbite and distal occlusion (Figure 2.3). Myllarniemi (1973) and Nanda et al. (1972) found thumb sucking children had greater overjet and a significantly higher percentage of openbite. Nanda et al. (1972) and Popovich and Thompson (1973) found a significant difference existed in the incidence of Class II canine and molar relationships between children with and without oral habits.

An increase in the overjet that accompanies many digit sucking habits can make normal swallowing a difficult procedure. The required anterior lip seal may not be formed due to the protrusion of the incisors and so the tongue may be placed in this area to seal off the gap for successful swallowing and speech. Alternatively, the lower lip may create a seal by cushioning the lingual surface of the maxillary incisors, pushing them further anteriorly.

Mouth breathing is known to influence the development of the dentition. Habitual mouth breathing is often due to an obstruction in the nose or nasopharynx and, in order to breath through the mouth, the child may need to extend the head and lower the mandible and the position of the tongue. This changes the normal balance of the muscles surrounding the dentition, often resulting in a crossbite of the posterior teeth and less labial inclination of the incisors (Linder-Aronson 1970).

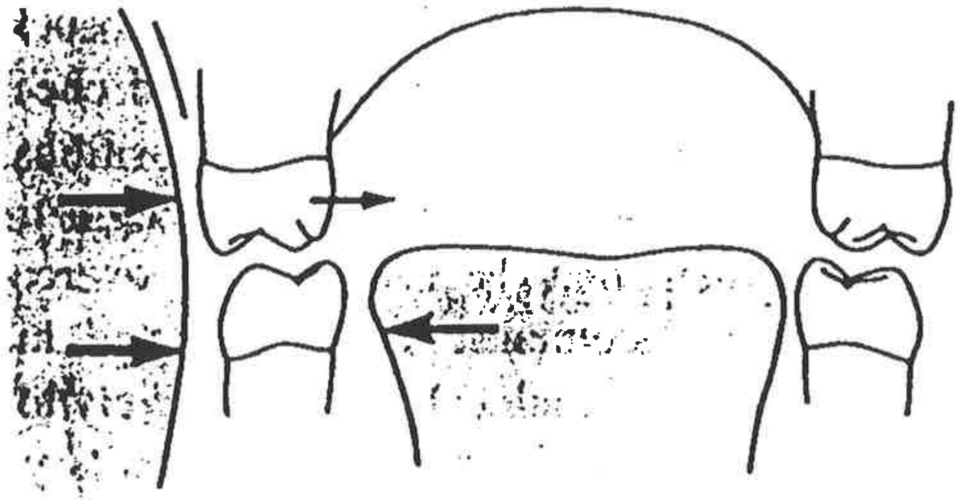


Figure 2.3 : Diagrammatic representation of soft tissue pressures operating in the molar region during sucking. The maxillary teeth are displaced palatally when the tongue is lowered and the cheeks contract during sucking (Proffit 1993).

Ravn (1975) studied 310 Danish children aged three years and noted that 68% had a flush or a mesial terminal plane relationship; however, only 31.2% had a mesial terminal plane relationship bilaterally and 14.8% had a bilateral distal terminal relationship. In addition, the canine relationship was recorded and classified as Class I, II or III. Ravn found that 90% of cases with Class I canine relationship also had a straight terminal plane relationship. In contrast, only 58% with a distal canine occlusion had a distal terminal plane relationship and 32.7% had a straight terminal plane. He suggested that sucking habits may have a role to play in this discrepancy. Incisor overjet was measured in millimetres using a Boley gauge, 57% of subjects displaying an overjet between 2-4 mm and 34% with an anterior open bite. About 3.5% of children had no interdental spacing which is consistent with many other studies.

Kisling and Krebs (1976) reported on patterns of occlusion and spacing in 1,624 three-year-old Danish children. They found a wide variety of occlusal patterns between children, as did Foster and Hamilton (1969), but found uniformity of occlusal characters within specific occlusal patterns. Their study found that in children with normal transverse relations, just over 50% had a mesial terminal plane relationship in the second primary molar and canine regions, in contrast to Ravn (1975) who recorded a 90% incidence. Kisling and Krebs, however, used the mesial surface of the second primary molar to determine the terminal plane relationship because they reported that:

- the relationship of the distal surfaces could not be decided safely in the early primary dentition
- the mesial relationship reflected the sagittal jaw relationship, while the terminal relationship of the arches also depended on the mesiodistal widths of the second primary molars.

In both the studies of Kisling and Krebs (1976) and Ravn (1975), a strong correlation between incisor maxillary overjet and open bite was demonstrated, and a statistically significant association was found between sucking habits and crossbites. This concurs with the findings of Infante (1974). Kisling and Krebs classified spacing conditions into four groups: overlapping of teeth; contact; no contact; and space > 2mm. The authors reported crowding was present in very few cases examined and that primate spaces were observed in the majority of children.

A longitudinal study of occlusion in the primary dentition in three to seven year-old Danish children by Ravn (1980) revealed that a distal terminal plane in the primary dentition was most stable, and that this occlusion was always transferred unchanged to the permanent dentition. This study found an increase in the number of Class I mesial terminal plane relationships and a reduction in the number with a straight terminal plane with increasing age, a phenomenon frequently reported in the literature. Ravn found the canine relationship to be a very unstable entity during the period of the study and suggested that, in view of the many factors influencing occlusal development, for example, premature extraction of a primary molar tooth, sucking habits, caries or a combination of these, it is difficult to arrive at any general conclusion in relation to the changes noted. The author found that patients with distal terminal relationships, on the whole, possessed a narrower maxilla and suggested this could be interpreted as indicating growth of the mandible in a distal direction, thus presenting the possibility of a change in occlusion by an expansion of the maxilla prior to the eruption of the permanent dentition.

Joshi and Makhija (1984) studied the plaster casts of 100 Indian children, aged three-six years, noting the magnitude and frequency of interdental spacing. The authors reported 87.5% of subjects had a spaced type arch and the remainder (12.5%) were closed type or "no space" type arches. Anthropoid or primate spaces were more common in the maxillary arch (42.5%) than in the mandibular arch (21.0%), and more common in males than females. The total amount of spacing in the maxillary and mandibular arches was greater in males than females.

In his textbook, Contemporary Orthodontics, Proffit (1993) discusses changes that may occur during the primary and subsequent mixed dentition phases of dental development. He reports that :

- spacing between the incisors is normal in the primary dentition and, in fact, necessary for alignment of the succedaneous permanent teeth
- incisor displacement resulting from a sucking habit will usually spontaneously correct if the habit stops before eruption of the permanent teeth
- sucking habits tend to produce a transverse discrepancy in the arch, particularly in the canine region
- a flush terminal plane (dictated by the distal surface of the second primary molars) is normal, whereas a mesial terminal plane, corresponding to a Class I molar relation in the permanent dentition, is cause for concern as it may

indicate excessive mandibular development. A distal terminal plane correlates with a skeletal Class II jaw relationship and, in most children, can be diagnosed by the age of three years

- both deep bite and open bite malocclusios occur in the primary dentition. A deep bite is usually the result of a skeletal imbalance. An open bite, on the other hand, is often seen in children with a sucking habit but good skeletal proportions.

El-Nofely et al. (1989) studied dental casts of 243 Egyptian preschool children aged between 2.5 and 5.5 years. All children had complete primary dentitions, free from dental malocclusion and proximal caries and with no permanent teeth erupted. Each arch was classified as: Type I - where no spaces were present; Type II - where primate spaces were absent but other spaces between anterior teeth were present; Type III - where only primate space were present ; Type IV - where both primate and other spaces were present. In addition, tooth crown dimensions were measured and intercanine and intermolar dimensions were recorded. The most convex lateral point of the tooth in question was taken as the reference point. Arch length was measured from the middle of the distal surface of one second deciduous molar all around the teeth buccally to the corresponding point on the other side of the arch.

El-Nofely and colleagues reported a highly significant difference in the relationship between the sum of the mesiodistal crown diameters of the six anterior teeth, intercanine width and type of spacing in the dental arch. Simply, the narrowest anterior teeth and the widest dental arches were associated with very spaced arches. There was a significant association between the mesiodistal crown diameters of the four molar teeth and the type of spacing in the dental arch, indicating that the molars were significantly wider mesiodistally in the dental arches with no interdental spacing. Arch length, however, was not significantly related to the spacing in the dental arches. El-Nofely and colleagues concluded that interdental spacing in the primary dentition is fundamentally related to the need to compensate for the discrepancies in anterior tooth size between the primary and succedaneous dentitions and that space is rarely used in molar adjustment. Other factors are involved in molar adjustment including greater forward growth of the mandible than in the maxilla, occlusal attrition of the primary teeth and favourable peri-oral muscle function. In addition, a greater leeway space in the mandibular arch may be important.

Ohno et al. (1990) studied a number of occlusal variables in a sample of 55 Indian children aged between five and seven years. All children were free of dental malformations, extractions or caries and some children had erupted first permanent molars. The authors reported :

- maxillary primate spaces were considerably more frequent than mandibular primate spaces
- a bilateral straight terminal plane relationship was found in about 50% of subjects at ages 5 to 6 years, in both males and females
- the mesiodistal crown diameters (MDCD) of all primary teeth were greater in males than in females
- the sum of the MDCD in the closed dental arches (those with no interdental spaces) was larger than in the spaced arches
- the dental arch increased in width slightly, but decreased a little in length, with changes in age during the primary dentition period

Generally, their results indicated that spacing in the primary arches was significantly related to the MDCD, to intercanine and intermolar arch widths. These results concur with the findings of El-Nofely et al. (1989).

Kharbanda et al. (1994) conducted a study among 1608 Indian children aged five to seven years to estimate the prevalence of malocclusion and to study its possible aetiological factors. Malocclusion (which was not defined) was found in 18.4 per cent of children aged five to seven years, which is very low when compared with most studies, for example, Kaube (1995) who reported a 50% incidence. However, Kharbanda and collegues used the presence of spacing and attrition in the dentition as indicators of normal occlusion, but said no scientifically analysed data were available to support this presumption. The rate of malocclusion was found to be highest in children without interdental spacing (32%), and lowest in children with greater than 4mm of spacing in the dental arch (2%). The authors concluded that development of the occlusion is predominantly under morphogenetic influence, the most significant factor being interdental spacing. Attrition was reported as having a minor, but significant, contribution to malocclusion and deleterious oral habits also influenced normal development. These three factors explained only about 20 per cent of the total variation observed in the sample and the authors concluded that this indicated a significant genetic contribution in the development of occlusion.

Kaube et al. (1995) studied the incidence of malocclusion in the primary dentition of 221 African children aged between three and six years. They found 50% of the children had some form of malocclusion, including 13% with a deep bite and 12% with an anterior open bite, a finding not dissimilar to that of Foster and Hamilton (1969). In addition, 5% of children had an anterior crossbite, 1% had a posterior crossbite and 13% had a maxillary overjet. Kaube and colleagues noted this to be "the most striking feature of the occlusion" in the sample studied, but offered no explanation for their finding. A mesial terminal plane recorded from the second primary molars was found in 43% of cases, similar to that found by Ravn (1975), and a straight terminal plane was found in 53% of children, a finding similar to Nanda et al. (1973) in British school children. A distal step was recorded in only 1% of the sample. Anthropoid or primate spaces were observed in 85% of children, while maxillary incisor spacing was found in 69% of children and mandibular spacing in 62%.

Otuyemi et al. (1997) reported on occlusal relationships and spacing and crowding of teeth in 525 Nigerian children aged three-to four-years. They found a bilateral straight terminal plane and a Class I canine relationship were the most common features, 74.5% and 73.3% respectively. Overjet was measured in centric occlusion as the greatest distance between the incisal edges of the maxillary and mandibular primary incisors in the occlusal plane using a millimetre gauge and classified as ideal, increased or reversed. The majority of children (68.6%) recorded an ideal overjet of 2mm or less and 76.6% of children had an ideal overbite, which was recorded when the incisal edges of the lower incisors were touching the lingual surface of the upper incisors in centric occlusion. Open bite was revealed in 5.3% of children, a similar finding to Nanda et al. (1973), but contrasting with Ravn's (1975) finding of 34%. Anthropoid or primate spaces occurred in 60.9% of cases in the maxilla and in 58.8% of cases in the mandible. Contact or crowding in the anterior segments was found in 24.4% and 26.3% of children in the maxilla and mandible respectively.

Alexander and Prabhu (1998) studied 1026 Indian children with complete primary dentitions and assessed profiles, occlusal plane relationships and spacing of the teeth. The authors reported a flush terminal plane was the most common, followed by a mesial step. They also found that a convex profile was significantly correlated with these terminal plane relationships. They suggested that these children were at a higher risk of developing a malocclusion and should be monitored closely. The majority of subjects (75%) had interdental spacing in the maxilla and mandible and only 3% had no interdental spaces. The authors concluded that planning, execution and evaluation of interceptive treatment is complicated by the host of individual patient characteristics and numerous treatment modalities available.

Direct comparison between published studies is difficult because of the great variation in methods of classifying occlusal variation, of definitions used and of variations in sample size, age and sample population. In addition, there are many aspects of occlusion to consider including spacing and crowding, canine and terminal plane relationship, overbite and overjet, all with complex inter-relationships that are not yet completely understood.

The primary dentition is completed usually between the ages of two and a half and three years and from the occlusal pattern present at this time, a relatively accurate prediction of any occlusal disharmonies that may present in the permanent dentition can be made (Proffit 1993). Early recognition should allow interceptive orthodontic treatment to begin at an young age, possibly ameliorating the disharmony as growth continues.

Functional changes in occlusion during growth and development

The primary physiological functions of the oral cavity include respiration, swallowing, speech and mastication and each of these activities influences tooth and jaw position.

The newborn infant is an obligatory nasal breather, but mouth breathing becomes physiologically possible later. To establish an open airway, the mandible must be positioned downward and the tongue downward and forward away from the posterior wall of the pharynx. Hence, respiratory needs are a primary determinant of posture of the mandible and tongue.
To sustain life, the newborn must obtain milk and swallow. This process may be divided into two phases as growth and development continue. During the first year of life, the infant obtains milk through suckling, not sucking. Suckling consists of small nibbling movements of the lips which is a reflex action in infants.

Once the milk is in the mouth, the infantile swallow is characterised by contraction of the lip musculature with the tongue tip positioned forward to contact the lower lip. As the infant matures, it is necessary to use the tongue in a more complex manner and food must be positioned in the middle of the tongue and transported posteriorly. The elevator muscles of the mandible become more active and the typical chewing pattern of the child involves moving the mandible laterally upon opening and then moving back to the midline before closing the teeth together. This pattern is generally well established by the time the primary molars erupt. The chewing pattern of the adult differs from that of the child in that the adult usually opens straight down, moves the mandible laterally and then occludes the teeth onto the bolus of food. The development of the adult chewing pattern appears to coincide with the eruption of the permanent canines (Proffit 1993).

Maturation of oral function generally follows a pattern from the anterior to the posterior region of the oral cavity. In the newborn, the lip muscles are relatively mature and suckle well. In comparison, the posterior structures are not so well developed. Posterior parts of the tongue and the pharyngeal structures mature with time and achieve more complex manoeuvres. The maturation of speech follows this pattern. The first sounds, for example, /m/, /p/ and /b/ are formed by the lips, whereas later acquired sounds, for example, /r/ which requires precise positioning of the tongue tip, are mastered by about the age of four or five years.

At the beginning of the second year of life, the bottle or breast is replaced with drinking from a cup and, with cessation in suckling activity, the adult swallowing pattern is acquired. In the adult swallowing pattern, the lips are relaxed, the tongue tip is placed against the alveolar process behind the upper incisor teeth and then the posterior teeth occlude. However, as long as any sucking habits are present, for example digit sucking, there will not be a complete transition to the adult swallowing pattern (Proffit 1993).

A continuing search for environmental and soft tissue influences on the developing occlusion shows the clinicians desire to prevent or mollify the development of a malocclusion in their patients.

Transition from Primary to Permanent Dentition

This is a period of dynamic change in the dento-alveolar structures, and clinicians and researchers alike have an interest in predicting the potential for a malocclusion to develop during transition from primary to permanent dentition. However, reports on this transition to the very young permanent dentition are relatively few.

A number of aspects of occlusion must be considered including the possibility of crowding or excess spacing in the arch, that is, a tooth size-arch length discrepancy (TSALD) as well as the development of an acceptable buccal segment relationship, ideally an Angle Class I relationship, in their growing patients, to name just two. Accurate predictions could allow early interceptive orthodontics to proceed.

Establishment of the buccal segment relationship

The establishment of an acceptable buccal segment relationship is a complex process involving many variables in the dental arches and dentofacial structures. The initial occlusion of the first permanent molars is not independent of the primary terminal plane relationship (Alexander and Prabhu 1998). Although a study by Arya et al. (1973) revealed a direct association of considerable degree between the initial occlusion of the first permanent molars and the primary terminal plane relationship, the former was considered to be not entirely determined by the latter. The first permanent molars may erupt into a cusp-to -

cusp occlusion initially and proceed to an Angle Class I relationship as a result of two factors: greater mandibular anterior growth and greater leeway space in the mandibular arch. This results in greater mesial migration of the mandibular permanent molars.

Bishara et al. (1958), in a longitudinal study of changes in the molar relationship between the primary and permanent dentitions, found that slightly more than half of the cases studied had a flush terminal plane relationship in the primary dentition that progressed to a normal Angle Class I molar relationship in the permanent dentition, while 44% changed to a Class II molar relation. For cases where a mesial terminal plane existed in the primary dentition, they observed that there was a greater possibility for development of a Class I occlusion.

Baccetti et al. (1997) conducted a longitudinal study of dentofacial features of Class II malocclusion from the primary to the mixed dentition. The authors reported that, where Class II occlusal and craniofacial patterns had already been established in the primary dentition, self-correction did not occur during the transition to the mixed dentition.

Development of crowding in the dental arch

Many theories of dental crowding have been put forward involving evolutionary, heredity and environmental components. Howe et al. (1983) summarised these succinctly:

- an evolutionary trend toward a reduced facial skeleton size without corresponding reduction in tooth size
- interbreeding between ethnic groups
- environmental factors including the refined diet of western man implicated in reducing muscle stimulation, abnormal muscle forces and loss of arch length through dental caries.

Other studies have reported dental crowding to be the result of large teeth (Lundström 1969), small arch size (McKeown 1981) or a combination of both. The selected treatment approach depends upon causative factors and may involve extraction of permanent teeth, palatal expansion or the use of functional appliances. Implicit in the treatment regimen chosen is sound knowledge of the relationship between the disparity in tooth size, jaw size and environmental factors.

Moorrees and Chadha (1965) studied available space for the incisors during dental development based on a total of 184 serial dental casts obtained from white American children between the ages of 3 and 16 to 18 years. The children were chosen on the basis of excellent tooth alignment. The amount of interdental space at the point where approximal contact usually occurs was obtained by probing wires of known diameters. The amount of crowding was obtained by subtracting space available for a tooth in the arch from its mesiodistal crown diameter.

This study found a sudden decrease in available space in the incisor segment during the emergence of the permanent central and lateral incisors. In the mandible, there remained a lack of space for the permanent incisors for about two years after their eruption, that is, a small amount of crowding was normal at that stage of dental development. In the maxilla, however, there was either a small excess or lack of space after the permanent incisors had erupted. An increase in intercanine width and arch length during the eruption of the lateral incisors resulted in adequate space for the permanent teeth in the maxilla, but crowding was present in both males and females in the mandible as there is no increase in arch length in the mandible. This finding correlates well with Sillman (1964). Moorrees and Chadha concluded that, generally, incisor crowding present after eruption of the lateral incisors will not reduce spontaneously.

Lundström (1969) reported on changes in crowding and spacing of teeth with age. His study was based on 100 pairs of twins aged between 9 and 19 years and a subsequent examination 13 years later when 41 pairs of twins could be re-examined. Lundström reported a reduction in spacing with age and attributed this mainly to a reduction in arch length. However, this study noted a large variation in the tendency towards a reduction in spacing and suggested other explanations for this, including the presence of third molars.

Sampson and Richards (1985) studied the predicability of mandibular incisor and canine crowding in a sample of 47 Aboriginal children during the mixed dentition and subsequent early permanent dentition stages. This study reported that changes in dental arch width and depth were neither predictable nor predictive of anterior crowding development. Consistent with other studies, molar and canine arch widths generally increased, while arch depth decreased almost exclusively. They found crowding appeared to be directly related to tooth size and inversely related to molar arch width, canine arch width and arch depth. Changes in arch depth and molar arch width were more important in relation to the changes in crowding than was a change in the canine arch width. The authors concluded that it is wise to monitor a mild to moderately crowded mixed dentition and not to intervene unless over-whelming social and functional factors are present.

Proffit (1986) reports anterior spacing between the primary teeth is essential for proper alignment of the permanent incisors. In the maxilla, all available space is taken up by the permanent incisors but, in the mandibular arch, there is generally inadequate space available to accommodate the four permanent incisors in perfect alignment. However, continued development of the arches improves the crowding situation. Proffit suggests the extra space for alignment comes from three sources:

- a slight increase in the intercanine width which is greater in the maxilla than the mandible and more in boys than girls
- the permanent incisors assume a more labial position in the arch relative to their primary predecessors
- repositioning of the canine in the mandibular arch by labial and distal drift into the primate space.

Space gained from these three sources will, on average, alleviate mild crowding, but severe crowding is likely to persist into the permanent dentition.

Dimensional changes in the dental arches

Major growth changes occur in the molar region which increases in length, and there is some anterior adjustment during eruption of the permanent incisors. However, arch width changes during the mixed dentition stage are minimal and in a consistent direction, but individual variations may occur (Knott 1961; Sillman 1964; Moorrees and Chadha 1965; DeKock 1972). Some authors believe prediction of adult arch width may be made at an early age, but other authors report difficulty in predicting eventual tooth size-arch length discrepancy in the permanent dentition from dental arch measurement in the primary dentition.

However, predicting TSALD in the mixed dentition can be performed with much greater accuracy (Bishara et al. 1995).

Sillman (1964) studied dimensional changes in the dental arches in 65 white American Caucasians from birth to 25 years of age. He included subjects with "good" and "poor" occlusions, children who had been treated and thumb suckers. Correlations between different arch lengths and widths from birth to age 25 years revealed the least variable dimensions to be:

- arch length from a point between the central incisors to a line connecting the distal surfaces of the primary molars
- arch width between the primary second molar in both maxillary and mandibular arches

The highest correlations were found in total arch length and posterior arch width as most postnatal growth takes place in the posterior segments of the arch.

A composite mean pattern of the dental arches from birth to age 25 years was described and it was found that changes in the canine length (from a point located between the upper central incisor teeth to the canine tooth) were significantly greater between birth to four years in the maxilla than for any other age group studied. In the mandible, the change in canine length differed in that the change from 8 to 12 years was greater than the previous period (four to eight years). The greatest increase in the canine width in the maxilla and mandible was observed from birth to four years. From 12 years of age, no significant change was reported.

Molar width increased in the maxilla from four to eight years and from 8 to 12 years by approximately the same amount. Between 12 to 16 years, the change was significantly less than the preceding period and from 16 to 20 years there was no evidence of significant change. The mandible, however, showed a significant difference in the change in molar width between 8 to 12 years compared with 12 to 16 years.

Permanent Dentition

A wide variety of occlusal variation may be present in the permanent dentition and the variation may be grouped into three main categories:

- dentitional anomalies of individual teeth, including alteration in eruption, morphology and alignment
- occlusal anomalies of the antero-posterior, transverse and vertical intermaxillary relations
- space anomalies which refer to spacing or crowding in the dental arches

The frequency of occlusal variation is high in most populations, but the proportions of the three categories may vary (Bjork and Helm 1969).

During the period of the permanent dentition, there are continual changes occurring in the dentofacial complex. The occlusion alters with time through the processes of attrition, mesial migration and uprighting of the incisor teeth. In addition, the research work of Behrents (1985) has revealed that the facial skeleton continually remodels throughout life. Studies of the permanent dentition are numerous, but discussion is limited in this thesis as they are not the primary topic of concern.

DeKock (1972) studied the change in dental arch depth and width in 26 Caucasian subjects with acceptable occlusion from the age of 12 years to adulthood. They found a decrease in arch depth with age in both the maxillary and mandibular arches. For female subjects, arch width revealed no significant changes during the period of observation. In males, there was a small statistically significant increase in arch width from 12 to 15 years of age. No mention was made of the causative factors involved in the changes in arch dimensions.

De Kock proposed that a decrease in arch depth may account for post-retention mandibular incisor crowding seen in some patients.

McKeown (1981) reported on tooth size and arch width in a group of 33 subjects aged between 18 and 25 years. None of the subjects had a history of orthodontic treatment. Dimensionally accurate photographs were obtained to analyse arch form. This study found a strong association between arch width and crowding. Subjects with a difference between first molar arch width and anterior tooth width greater than 4mm in the maxilla, or 10mm in the mandible, rarely had crowding. McKeown concluded that, as arch width changes minimally after age 7 years, measurements of arch width and permanent anterior tooth width following eruption may allow identification of individuals at high risk of future crowding.

Howe et al. (1983) investigated the relationship between dental crowding and tooth size and arch dimension in 104 subjects aged between 9 and 44 years with no history of orthodontic treatment. This study reported that crowded dental arches were the result of smaller arch dimensions and not larger mesiodistal tooth dimensions. Non-crowded arches tended to be wider and more broadly contoured than did the crowded arches. Howe concluded that these findings have clinical relevance in determining the treatment approach chosen in a crowded dental arch. This concurs with the findings of McKeown (1981).

Steigman (1985) studied the prevalence of spaced dentitions in 1269 subjects aged between 12 and 18 years and found a frequency of 51.8 per cent in the males and 45.5 per cent in the females and a decreasing prevalence with age. The most common sites and the largest space widths were located between the canine and lateral incisors in the maxilla and between the canine and the first premolar in the mandible, that is,. the primate spaces.

Tooth Size in the Primary and Permanent Dentitions

There are many reports in the literature on permanent tooth size variability in human populations and the relationship with arch dimensions, but few studies have been published in relation to the primary dentition. Comparisons of odontometric data and arch dimensions, both within and between populations, may provide an insight into possible causes of variation in terms of genetic and environmental factors and the relationship between the two variables. Correlations between tooth size, arch size and interdental spacing will be presented in this thesis and the results compared with similar studies in the literature.

The dentition provides a record of developmental events that occur both pre-, peri- and post-natally. The initiation of tooth germ formation begins around 4 weeks in utero and follows a well-defined pattern of soft tissue proliferation and calcification. Research into the association between primary and permanent tooth size in individuals, between maxillary and mandibular teeth and between left and right sides provides information on the nature of developmental influences operating during odontogenesis.

Genetic Influences of Tooth Size

Variation in tooth size appears to be under a polygenic or multifactorial mode of inheritance; that is, the observed phenotypic variability is a result of both genetic and environmental factors operating during odontogenesis (Krogman 1967). The phenotypic variability in tooth size or, indeed, any trait under consideration may be described in terms of heritability, symbolised by h^2. Heritability is a statistic that describes the ratio of genetic to phenotypic variance, the value obtained depending on the population being measured and the amount of environmental variability present at the time of measurement. Heritability is a population phenomenon and applies to groups, not to individuals. In general, if the heritability is 100%, the environment has no effect and all variation seen is due to genetic factors.

Recent studies reveal that previous heritability estimates of permanent tooth size were likely to be exaggerated (Townsend 1992). Heritability estimates of primary and permanent tooth size in Australian Aborigines indicate that approximately 60% of the variation observed was due to additive genetic effects (Townsend and Brown 1978; Townsend 1980). Potter et al. (1983) studied tooth size variability in Pima Indians and found genetic factors accounted for 52% and 35% of molar and lateral incisor size variability respectively. Similarly, Dempsey (1999) reported that heritability estimates for tooth crown size were moderate to high, with shared environmental influences and unique environmental influences contributing up to 27% and 29% respectively.

DiSalvo et al. (1972) studied mesiodistal tooth widths of primary anterior teeth in 62 sets of twins and found the intrapair differences were significantly greater in dizygous twin pairs than in monozygous twin pairs for the upper right and both lower primary canines, but not for the remaining teeth. The authors concluded that the upper right and both lower canines had a higher degree of genetic variability, and the fact that the upper left canine demonstrated a lower degree of genetic variability when compared with the other canines was probably due to experimental error.

Sirianni and Swindler (1973) reported on the inheritance of primary tooth size in 135 pairs of Macaques. Their aim was to determine whether primary tooth size in non-human primates was similar to that in human permanent teeth. They found an average correlation coefficient between full-siblings of 0.38 and combining the maternal-half and paternal-half siblings resulted in a mean correlation coefficient of 0.20. Tooth size correlations for unrelated monkeys were consistently close to zero. The value obtained for full-siblings was similar to the mean correlation coefficients reported by Garn et al. (1965) for permanent teeth. Sirrianni and Swindler's data suggested that the X chromosome may not be involved in determining primary tooth size in Macaques, but raised the possibility that the Y chromosome was involved.

Townsend (1980) studied a group of Australian Aboriginals living at Yuendumu in the Northern Territory of Australia and found about 58% of primary tooth-size variability was due to additive genetic variance and about 15% to common environmental variance. The relatively large contribution of common environment to total observed variability emphasised the importance of the intra-uterine environment. In comparison, the respective figures for the permanent dentition were 64% and 6%, indicating that additive genetic variance of tooth size was similar in the primary and permanent dentitions, but that the environmental component differed.

Hughes et al. (1999) studied the relative contributions of genetic and environmental factors to deciduous tooth crown size in 221 pairs of South

Australian twins, including 99 monozygous and 122 dizygous pairs. Genetic analysis using the structural equation modelling package, Mx, revealed that, within each sex, both additive genetic and unique environmental components were required to adequately describe the data. A significant improvement in the fit did not result when non-additive genetic variation was included and there was little evidence of shared environmental influence. Estimates of heritability for primary tooth crown size varied from 80% to 90%. The authors concluded that their study indicated a strong genetic component influenced deciduous crown size, similar to that reported in recent studies of the permanent dentition, but further study was required to determine whether the genetic components were the same for both deciduous and permanent teeth.

Variability within and between populations

By comparing the tooth size of individuals within a given population, important information may be gained about the roles of genetic and environmental factors. For example, tooth size tends to be greater in males than in females; however, this sexual dimorphism varies between teeth and is of greater magnitude in the permanent dentition when compared with the primary dentition (Garn et al. 1967).

Reports on tooth size in the primary dentition are limited. The data from comparative studies of the primary dentition show phenotypic variability of tooth-size across populations and provide an insight into possible genetic and environmental influences operating during odontogenesis. Townsend (1992) presents data on primary crown diameters of males in several human populations, noting that Australian Aboriginals had the largest primary teeth of all the populations compared. Similarly, a longitudinal investigation of Australian Aboriginals by Margetts and Brown (1978) found that the primary teeth of

Australian Aboriginals were larger mesiodistally than Japanese, Pima, Caucasian and American Negro populations.

The study of crown-size variability in the primary dentition of South Australian children by Farmer and Townsend (1993) found that the magnitude and pattern of tooth size was similar to other published data for Caucasian populations. In addition, the authors reported that anterior teeth were generally more variable in size than posterior teeth, the second primary molar being particularly stable. The relative length of the developmental period that tooth crowns spent in the soft tissue stage, prior to calcification, was proposed to be a possible reason, being longer for anterior than posterior teeth.

Correlation in tooth size between the primary and permanent dentitions

The relationships between tooth size of the primary and permanent dentitions have been described by a number of authors (Moorrees 1959; Ono 1960; Clinch 1963; Garn et al. 1979; Brown et al. 1980). Moorrees (1959) presents the mesiodistal crown diameters of the deciduous teeth expressed as percentages of their permanent successors. In humans, correlations between primary and permanent crown dimensions are of moderate magnitude. There is some variation in the size relationships between different populations, although the significance is not clear (Brown et al. 1980). Garn et al. (1979) have reported that the dimensional correspondences between the primary and permanent teeth are surprisingly high and suggested that common control mechanisms operating from pre-natal time through the pre-school years may be responsible for this finding.

Nance (1947) discussed the clinical significance of the size difference between the primary canine, first and second molars and their permanent successors and used the phrase “leeway space” to describe the size excess of the three primary teeth.

Nance pointed out that the leeway space allowed for some molar adjustment following the eruption of the permanent premolars, allowing some anterior movement of the first permanent molar and establishment of a normal molar relation.

Brown et al. (1980) compared the leeway space of various population groups including Australian Aborigines and found that it was amongst the highest for the populations compared (Table 2.1). Although there was considerable difference in the leeway space between populations, a general trend emerged. For example, the magnitude of the leeway space was greater in the mandible than in the maxilla in all groups and it was consistently greater in females in the mandible. The authors concluded that the large leeway space observed in Australian Aborigines compared with other populations was "significant in the establishment of optimal occlusal relationships in the Aboriginals".

Group	Maxilla		Mandible	
	Males	Females	Males	Females
Australian Aborigines	1.42	1.28	2.82	3.25
NorthAmerican Caucasoids	1.20	1.46	2.16	2.59
British Caucasoids	0.77	0.74	1.94	2.11
Swedes	1.04	1.28	2.18	2.51
Tristanites	0.95	0.82	1.73	1.51
North American Negroes	0.42	1.14	1.59	2.33
Japanese	0.73	1.01	2.77	2.89
Pima Indians	0.29	0.84	1.82	2.72

Table 2.1 : A comparison of leeway space (in mm) in different populations (Brown et al. 1980, pp33).

Correlation between tooth size and arch dimensions

Whether there is crowding or spacing in the arch depends on the relationship between tooth size and arch dimensions. Numerous studies have shown:

- anterior primary teeth, as a whole, are smaller than their permanent successors
- dimensional changes in the dental arches follow a general pattern; namely, an increase in breadth and a decrease in depth (Moorrees 1959)

However, individual variation in the timing and magnitude of these changes are great, highlighting the complex nature of the developmental process.

Foster et al. (1969) studied the relationship between primary dentition tooth size and arch size and found that the coefficient of correlations between total arch length and dentition size were high for both maxillary and mandibular arches, being 0.95 and 0.98 respectively The authors suggested that large teeth were associated with large dental arches and small teeth with small dental arches. They proposed that this may be because the primary dentition preserves more characteristics of our ancestral primate dentition (for example, presence of anthropoid or primate spaces) than does the permanent dentition.

El-Nofely et al. (1989) found the presence of interdental spaces was significantly dependent on mesiodistal crown diameters and intercanine arch width. These authors suggested that interdental spacing in the primary dentition was fundamentally related to the discrepancy in anterior tooth size between the primary and permanent dentitions.

Bishara et al. (1995) conducted a longitudinal study on tooth-size arch length relationships of 62 children from age four to thirteen years. This longitudinal study followed children from the complete eruption of the primary dentition to the time of eruption of the second molar. Each subject had a clinically acceptable occlusion. Correlation coefficients were calculated between the primary and corresponding permanent teeth and also for arch length and width parameters and tooth size-arch length discrepancy relationships in both dentitions. Accuracy was much improved using measurements obtained during the mixed dentition period as dental arch dimensions are established by the time the mandibular incisors have erupted.

The authors found:

- with the exception of the maxillary second molars, all primary mesiodistal tooth dimensions were significantly correlated with their permanent successors
- all arch length segments (left, right, anterior and posterior) were significantly correlated in the primary and secondary dentitions except the mandibular right and left anterior segments
- all correlations between tooth-size arch length discrepancies in the primary and secondary dentitions were significant; that is, if there was a discrepancy between tooth size and arch length in the primary dentition, then the discrepancy would be mirrored in the permanent dentition.

Bishara and colleagues concluded that, in view of the significant but relatively low correlations between the variables studied, an accurate prediction of the tooth-size arch-length discrepancy in the permanent dentition could not be made from measurements of the primary dentition. Indeed, changes in the dentofacial structures during this period are complex and multifactorial and their relationship is not yet completely understood or predictable.

Dental Arch Form

Dental arch form is determined by the position of the maxillary and mandibular teeth which, in turn, is influenced by supporting bone, circum-oral musculature and intraoral forces. Arch form varies greatly between individuals and human populations. The qualitative and quantitative description of arch form has interested anthropologists and clinicians for many decades, and most studies have revolved around fitting geometric curves to the dental arch using mathematical analysis. The publication of Angle's classification of malocclusion in the 1890s (Angle 1900) resulted in the first clear definition of normal occlusion in the natural dentition. Angle's postulate was that the line of occlusion was a smooth, caternary curve, passing through the central fossae of the maxillary molar teeth and across the cingulum of the canine and incisor teeth. In the mandible, the line ran along the buccal cusps of the molar teeth and incisal edges of the anterior teeth. The size and form of the dental arches shows considerable variability within and between human populations; however, the factors influencing arch size and shape are not well understood (Cassidy et al. 1998).

Classification and methodology for determining arch shape

Several approaches are available to evaluate differences in form between biological structures, the choice depending on the nature of the structure under investigation and on the hypothesis being tested. While macroscopic differences may be detected with the naked eye, subjective evaluation is difficult to quantify. The form of any structure may be described in terms of size and shape and, in most cases, size can be quantified, but quantification of shape is more challenging (Ferrario et al. 1993).

Two of the earliest investigations of arch form, by Bonwill in 1885 and Hawley in 1905, dominated orthodontic thinking for many years. They described arch form as the arc of a circle (from canine to canine) joined to straight buccal segments posteriorly. Since then, other authors have described arch form in terms of an semi-ellipse (Black 1894), an ellipse (Izard 1927), and a caternary curve (McConnail and Scher 1949)

In addition to metric approaches involving measurement of linear distances, angles and ratios, two main categories of procedures have been developed to date: homologous-point representation and boundary representation (Lestrel 1989). Boundary representations involve computing the outline of the object. A curve fitting procedure is used to derive a mathematical function which will describe the objects profile and compare different objects; for example, fourth-order polynomials (Lu 1966; Richards et al. 1990) and the beta-mathematical functions (Braun et al. 1998). Homologous-point representations involve defining a set of homologous landmarks on the forms to be compared and then analysing how the relationships between the points change; for example, Euclidian-distance matrix analysis (Ferrario et al. 1993). Euclidian distance matrix analysis (EDMA) compares the form of two objects as defined by homologous landmarks. All possible Euclidian distances between the selected landmarks on a simple object are computed and then the analysis compares the two objects by determining a matrix of ratios of corresponding linear distances measured on each object. EDMA results in an objective measurement of shape differences and, in addition, localises the sites of major variations.

Lu (1966) described dental arch form by way of a polynomial equation of the fourth degree, an approach applied more recently in twins by Richards et al. (1990). This approach has the advantage that each coefficient has a biological interpretation. Lu's fourth-order polynomial, which takes the form of

$y = b_0 + b_1 x + b_2 x^2 + b_3 x^3 + b_4 x^4$, fits the human arch form quite well. The quadratic (b_2) and quartic (b_4) terms in the equation are measures of arch shape. The quadratic term reflects how tapered an arch is, and the quartic term reflects squareness. The linear (b_1) and cubic (b_3) terms reflect two aspects of asymmetry, lopsidedness and tiltedness respectively. This method allows a quantitative assessment of dental arch form.

Braun et al. (1998) studied 40 sets of pre-treatment orthodontic models of patients with fully developed adult dentitions and found the human dental arch form was accurately represented by the beta-mathematical function (an analytical equation of dental arch shape describing the relationship between arch width and depth), more so than any previously reported model. The average correlation coefficient between measured arch shape and the mathematical arch shape, expressed as the beta function, was found to be 0.98 with a standard deviation of 0.02.

Genetic and environmental factors

It is now generally believed that occlusion and arch form are the result of an interplay between genetic and environmental factors, the magnitudes and directions of which are still to be clarified. Proffit (1978) and Moss (1980) report that the final position of the teeth in the arch is primarily the result of resting pressures from the lips, tongue and cheeks which are, in turn, influenced by secondary factors, for example, the postural position of the jaws and head.

Harris and Smith (1982) studied 761 Melanesian individuals from 112 families leading to estimates of heritability for 17 attributes including ten features of arch size and shape and seven variables related to occlusion. The authors found that the heritability estimate for overall arch size from their sib-sib analysis was 0.76.

The estimate from the mother-offspring and father-offspring analysis was found to be 0.56 indicating that, of all the variables measured, this was least affected by the elimination of shared environmental influences. In other words, arch size was under stronger genetic control than the measured occlusal variables. In contrast, the authors found arch shape to have the lowest heritability estimate of 0.35 from the sib-sib analysis suggesting it was much more susceptible to non-genetic factors. Low correlations among individual occlusal variables suggested that many factors contributed to occlusal variation. The authors concluded that their results indicated there are no simple solutions or easy answers to the question of the causes of occlusal variability and that, most importantly, the researcher should distinguish clinical significance from statistical significance.

This finding of a significant genetic component to arch size was confirmed by Boraas et al. (1988) in their study of 44 monozygous (MZ) and dizygous (DZ) twin pairs reared apart. Common environment is one potential source of bias when studying twins reared together, so Boraas and co-workers suggested that, by studying twins reared apart, the bias of trait-relevant environmental factors would be removed and intraclass correlation between MZ twins would be a direct measurement of heritability. The authors found intercanine and intermolar arch width showed significant resemblance within both MZ and DZ pairs, despite separation early in life and being subjected to different environmental factors including diet.

Corruccini and Potter (1980) calculated genetic variance and heritability for a series of arch and occlusal traits in 60 American twin pairs. In relation to arch size variables, the authors found arch length generally more heritable than arch breadth. The average heritability for arch size measurements equalled 0.27; that is, about 27% of the variance was genetic and 73% environmental.

Sharma and Corruccini (1986) studied occlusal variation in Indian twins and found significant genetic variance for dental arch and palate dimensions. However, environmental factors seemed to play a more important role in the variation of occlusal traits.

Corruccini et al. (1990) studied variation in dental occlusion between older, originally nomadic Australian Aboriginals and younger, settled and rationed Australian Aboriginals. The authors noted significant differences in measurable occlusal characteristics including overbite, overjet and arch breadth and suggested this was related to altered diet and food habits commensurate with a change from a traditional hunting and gathering existence to a modern, settled western style existence. In conclusion, Corruccini and colleagues reported that complex interactions between genetic and environmental influences are important in determining occlusal variation in man.

Hu et al. (1991) studied 360 dental casts selected from 102 Japanese families, each including both parents and one of their offspring. Most of the subjects had well aligned permanent dentitions. Their results showed that genetic variation played a role in determining phenotypic variation, in both arch form and tooth position, about 55-60% and 39-77% respectively. An analysis of variance suggested the existence of both autosomal and sex-linked additive genetic effects.

Richards et al. (1990) studied dental arch morphology in 29 monozygous and 19 dizygous Caucasian twin pairs and in 45 unrelated individuals to estimate the transmissible component of variation. The results provided some evidence of a genetic contribution to the variation in maxillary arch shape and, to a lesser extent, mandibular arch shape. However, environmental factors were found to play a significant role in dental arch asymmetry. The authors suggested that additional information on the mechanism by which genetic and environmental factors influence arch form should be sought by studying the occlusion of a larger sample of twins.

Ferrario et al. (1993) reported on human dental arch shape as evaluated by Euclidian distance matrix analysis (EDMA) in 95 subjects aged between 20 and 27 years. This study showed that the dental arch form difference between males and females was a size difference and not a shape difference, female arches being smaller than male arches. The analysis revealed some gender-specific variations in arch form, located in different areas in the maxillary and mandibular arches, which could not be considered sex-linked differences but rather areas of higher gender variability. The authors concluded that both genetic and environmental influences could shape the form of the dental arches.

Cassidy et al. (1998) studied arch size and shape in a group of 320 adolescents from 155 sibships. They found that arch dimensions had heritability estimates significantly different from zero, the highest estimates being for arch width which averaged about 60%. The authors concluded that, in spite of this significant genetic component of arch size, environmental factors still had a significant influence over the phenotypic variation in arch size and shape.

In conclusion, factors influencing arch size and shape are complex and need clarification as they are important clinically in the management of any variation from "normal". If environmental factors are predominant, then interceptive measures may play a greater role in ameliorating or removing causes of the malocclusion. However, the researcher and clinician should be aware that genetic and environmental factors are not independent of each other. Genetic-environmental interaction and genetic-environmental association are important and complex factors that, in part, determine the phenotypic expression of a trait

In addition, one must use caution when extrapolating the findings from a sample population to the general population.

Craniofacial growth and development

Although a considerable body of data exists regarding craniofacial growth and development, in many areas we have only theories and hypotheses. Occlusal variation reflects an interplay between many factors including the size and relationship of the maxilla to the mandible, the number, size and relationship of the teeth and also the soft tissues of the lips, cheeks and tongue. Recent reports have revealed that a large proportion of occlusal variation is environmentally determined (Corruccini and Potter 1980; Townsend et al. 1988; Harris and Johnson 1991) and, therefore, the clinician may be in a position to influence this portion of variation through preventive or early orthopaedic treatment procedures. With so many factors involved, it is no wonder that the wide range of variation observed reflects multifactorial inheritance with both genetic and environmental influences contributing.

Horowitz and Osborne (1971) report that much of the variability in the craniofacial complex appears to have a detectable genetic component, but few characteristics appear to be due to single gene effects.

Smith and Bailit (1977) conclude that malocclusions have a polygenic mode of inheritance based on the following observations:

- no simple pattern of segregating genes can be established in studies of family pedigrees
- craniofacial variation is continuous
- the correlation amongst relatives for craniofacial variables within occlusal categories conforms to the expectations of polygenic inheritance

In addition, the role of epistatic factors, that is, the interaction between genes at different loci, may play a more important role than previously thought.

Environmental factors

Anthropological studies have shown a rapid rise in occlusal variation in non-industrialised nations during the last few hundred years (Corruccini 1984; Varrela and Alanen 1995). The rapidity with which this has occurred has caused researchers to look for reasons other than genetic factors. The role of environmental factors in this change has been questioned by many authors (Niswander 1967; Lombardi and Bailit 1972) and a variety of hypotheses have been put forward (Beecher and Corruccini 1981; Varrela and Alanen 1995).

The masticatory hypotheses suggest that a change in the energy content and texture of the modern diet has led to reduced muscle activity and subsequently reduced jaw growth. Allergies and other factors affecting the size of the nasopharyngeal space may affect the growth of the jaws by interfering with normal breathing leading to, for example, mouth breathing. In addition, the activity of the facial musculature and tongue may affect the growth of the jaws and also occlusal development, for example, abnormal sucking habits. Current knowledge is inadequate to make a scientific judgement of these three hypotheses and further study is needed.

Proffit (1986) discusses aetiologic possibilities for specific types of malocclusion summarised as follows:

- crowding of the teeth is related in part to the continuing reduction in jaw and tooth size in human evolutionary development

- class I (non-skeletal) problems, for example, crossbites, seem to result from a combination of the initial position of the tooth germ and pressures from the lips, tongue, cheeks, fingers or other digits
- major skeletal problems may arise from a number of causes including inherited patterns, defects in embryologic development, trauma and functional (environmental) influences can contribute
- class III problems are probably related to inherited jaw proportions but functional factors are important, for example, jaw posturing because of respiratory needs or tongue size.

Begg and Kesling (1977) studied Australian Aborigines and found a smaller prevalence of malocclusion amongst these people consistent with the notion that modernisation has led to an increase in malocclusion. This is also supported by the findings in Etruscan cranial material of good occlusions with less crowding by Corruccini and Pacciani (1989).

Historically, the type of orthodontic treatment offered has been influenced to a surprising degree by the prevailing views about the genetic causes of malocclusion. Indeed, most orthodontic textbooks consider the possibility of early intervention and treatment to be very limited indeed (Graber and Swain 1985; Moyers 1988; Proffit 1993).

Early twin studies by Detlefson (1928), Macklin and Moore (1935) and Lundström (1948) showed that monozygous twin similarity exceeded that shown by dizygous twins in dental arch size, shape and occlusion. Other studies involving the similarity between other kinds of relatives, for example, among offspring or among offspring and their parents, found that the chance of malocclusion occurring in relatives of those with a malocclusion was higher when compared with the general population (Stein et al. 1956; Chung and Niswander

1975). However, the more recent analyses of heritability of occlusal characteristics by Corruccini and Potter (1980) and Harris and Smith (1980) differ from previous studies in that they apply newer methods of statistical analyses to data from twins (to be discussed in a later section of twin studies) and, in addition, their samples were carefully selected to avoid biases as a result of prior dental treatment, including orthodontic treatment. These authors have concluded that the view of genetic causes of malocclusion were premature as recent research has shown the matter to be much more complex.

Genetic Factors

It has often been speculated that genetic factors, for example, racial outcrossing, inbreeding and matching of discrepant parts may explain the rapid rise in the incidence of malocclusion in relatively recent populations even when it occurs between successive generations. However, this viewpoint is probably related to the belief in genetic causes of malocclusion as discussed in the previous section. Chung et al. (1971) provide convincing arguments against this explanation and have refuted genetic mechanisms as significant epidemiologic factors. This rapid transition is an important area of research and plays a significant role in the search for aetiologic factors in malocclusion. Indeed, variation in dentofacial structures depend on a number of factors which are summarised succinctly by Townsend (1994) and include:

- intrinsic polygenic factors, including additive, dominance and epistatic effects
- epigenetic factors, both local and general, that regulate gene expression
- maternal factors
- environmental factors, both local and general

Knowledge of the causes of variation are relevant not only to the clinician but also to basic biologic research.

Corruccini and Potter (1980) studied arch and occlusal traits in 60 twin pairs and found no significant heritability estimates for overbite, overjet, buccal segment relationship, total tooth displacement and occlusal discrepancies in arch shape. A significant genetic variance, averaging about 36% of the total variance, was found for arch size, individual tooth displacement scores and crossbite. The authors concluded that orthodontic researchers may wish to give more consideration to the importance of environmental factors in the future.

Potter et al. (1981) examined occlusal traits in 164 pairs of twins and concluded that, in the twin model, the assumptions of environmental equality between zygosity groups was biased for many occlusal triats studied. Therefore, genetic variance and heritability estimates based on within twin pair data were not valid. They found that environmental factors accounted for the major portion of twin variance in most of the traits studied, including overjet, crossbite, buccal segment relationship, malalignment and the treatment priority index scores. On the other hand, overbite and spacing were found to have a greater genetic than environmental influence. The authors suggested that future research should be directed towards isolating specific environmental factors contributing to occlusal variation. This concurs with the findings of Sharma et al (1985) whose study was a cross-cultural comparison of twin variances between Indian and American twins. The authors found widespread total variance heterogeneity among monozygous (MZ) and dizygous (DZ) twins in occlusal traits, with environmental factors responsible for invalidation of the high within-pair genetic variance ratios found.

Townsend et al. (1988) studied several occlusal traits in 82 pairs of MZ and DZ Australian twins. Their study found a significant genetic variance for some occlusal traits including overbite, overjet, sagittal molar relationship and also rotations and displacement of anterior teeth. However, heritability estimates were about 30% indicating the importance of environmental factors on occlusal traits.

This is similar to the results obtained by Harris and Smith (1980), Lundström (1984) and Chung and Niswander (1985).

Harris and Johnson (1991) reported that few studies have distinguished between the causes of malocclusion, that is, whether it is a skeletally-based problem or a tooth-based one. The authors found craniometric (skeletal) variables to have high heritabilities ranging from 0.6 at age 4 years to 0.9 at age 20 years, compared with arch and occlusal variables, ranging from 0.5 at age 4 years to 0.1 at 20 years. They concluded that further exploration of the range of underlying maternal, co-habitational or other environmental causes of occlusal variation should be sought.

Although studies aimed at understanding the relative magnitude of genetic and environmental influences to human morphological variation generally require large sample sizes, a great deal of information can be gained by observation of individual twin pairs. Indeed, there are many reports in the literature where authors have compared occlusal variation in twin pairs (Harris and Smith 1980; Boraas et al. 1988; Townsend et al. 1988, Leighton 1992; Richards et al. 1990).

Monozygous (MZ) twins who theoretically share all of their genes may show remarkable similarity in their occlusion and craniofacial development. There are, however, MZ twins who show dental differences as a result of environmental factors. Willmot (1984) presents a case report of a set of MZ twins, aged 14 years, one of whom sucked her thumb and one who did not. Examination of the teeth revealed remarkably similar tooth shape and position in the arch; however, the thumb sucker had a bilateral molar crossbite and an 8mm overjet whereas the non-thumb sucker had a unilateral molar crossbite and an overjet of 5mm. Cephalometric measurements were very similar, except for the measurements relating to the upper labial (anterior) segment. The author concluded that the difference in the labial segment was probably the result of remodelling of the

Genetic and Environmental Contribution to Occlusal Variation

The objective of a genetic study may be to partition the genetic and environmental causes of variation of a particular trait. However, one problem in human genetics is that the degree of phenotypic similarity between individuals correlates positively not only with the degree of genetic similarity, but also with the degree of environmental similarity. For example, siblings on average share one half of their genetic material but also share a very similar environment, both during pre-natal development (that is, in the same uterus, although at a different time) and post-natally (that is, a common home environment). First cousins, on average, share one-eighth of their genetic material but will, in general, be exposed to environmental influences of a similar socio-economic background.

Contemporary research has refuted the simplistic idea that malocclusion is a result of independent inheritance of dental and skeletal characteristics; however, the precise role of genetic and environmental factors in the aetiology of malocclusion has not been clarified. There is much evidence that genetic factors influencing craniofacial growth and morphology are inherited as continuous traits or so-called quantitative characters; that is, they do not show distinct discontinuities in their phenotypic expression.

Environmental subtleties and different mechanisms of gene action call for more sophisticated methods of data analysis and hypothesis testing than were envisaged fifty or a hundred years ago. Today, a model-fitting strategy allows the researcher to work through all kinds of data and to test systematically for correlation between theory and observation. New genetic modelling methods have resulted in the ability to fit models to data, to test for goodness-of-fit of each model, to separate common environment from genetic factors and to separate additive from non-additive genetic effects.

Analysis of multifactorial traits

It was RA Fisher's paper in 1918 on the correlations between relatives and the relationship with Mendelian inheritance that sparked rigorous statistical analysis of multifactorial traits. Until recently, most genetic studies in human populations were conducted by partitioning observed variation into genetic and environmental components based on comparison between relatives, for example, twins, siblings, parent and offspring. There are several problems relating to the study of occlusal variation in human populations:

- there is difficulty in obtaining large sample sizes of related individuals to provide sufficient statistical power for genetic analysis
- a wide range of phenotypic variation of the trait under consideration needs to be included in the study to avoid introducing bias
- longitudinal studies provide more information than cross-sectional approaches but at considerably greater cost

The variability in phenotype of a particular trait (V_P) is the sum of the genetic variance (V_G) and the environmental variance (V_E). Assuming there is no interaction between genotypic and environmental values, $V_P = V_G + V_E$. The genotype is the collection of all genes of an individual and is composed of an additive component V_A which is the sum of the separate effects of all genes influencing the trait, a dominance component V_D which is the result of dominance interactions among alleles at a locus by one allele masking the effect of another and an epistatic component V_I, the interaction of genes at different loci. Mathematically, this can be written, $V_G = V_A + V_D + V_I$. So, too, environmental variance can be partitioned into a common environmental component, V_{EC}, which is shared by family members and potentiates phenotypic similarity and a specific environmental component V_{EW}. Little is known about the effect of specific environmental factors on craniofacial growth; for example, nutrition, trauma and childhood illness will all influence the phenotype, but a large proportion of the phenotypic variance still remains unexplained.

The additive component of the genetic variance, V_A, is the principal determinant of the resemblance between related individuals. The proportion of phenotypic variance attributable to V_A is known as the narrow-sense heritability, h^2; that is, $h^2 = V_A / V_P$ and ranges in value from 0 (no heritable variation) to 100% (all observed variation is due to genetic factors). Broad-sense heritability estimates, H^2, represents the proportion of phenotypic variance that is due to total genotypic variance, that is, $H^2 = V_G / V_P$. However, it must be remembered that heritability estimates are specific to the population under study and are a function of the gene frequencies and environmental influences within the population at that particular time.

Family method

In its traditional form, the family method in genetic studies involves a pedigree analysis. This method has application when the trait in question is dependent on simple genetic mechanisms, following simple Mendelian patterns. Consequently, family methods are the most efficient in linkage studies and in any studies requiring detection of a carrier state. This efficiency is derived from the fact that, with knowledge of parental data, siblings can be analysed on the basis of known phenotypic mating types. However, in relation to dental traits, family pedigrees have generally not provided any evidence of single gene transmission and researchers have looked towards other methods of analysis.

Twin method

The classical twin study compares the similarity of monozygous (MZ) and dizygous (DZ) twins. Because MZ twins share all their genes and DZ twins share on average only half, a comparison of phenotypic variation allows partitioning of the variability of a trait into genetic and environmental factors. Important qualifications and assumptions (to be discussed later in this section) behind the classical twin study must be kept in mind when using this model, otherwise dubious and often erroneous inferences may be made. Martin et al. (1997) suggest that twin studies are far from becoming irrelevant today and may play an important role in unravelling developmental genetic mechanisms in the future. The authors state that "nature has provided a near-perfect design" in the genetic study of complex traits (Martin et al. 1997, pp 387).

However, the fact that a trait "runs in the family" does not mean it is genetically determined, as families have similar predisposing environments as well as genes. Strictly speaking, genetic studies involving dizygous (DZ) twins offer no advantage over ordinary sibling pairs as, on average, they both share one half of their segregating genes. However, DZ twins match as closely as possible MZ twins in the pre- and post-natal circumstances of gestation and rearing and there are no confounding factors with age differences in the expression of the trait due to either environment or age-related gene expression.

The incidence of twin births varies between populations and this phenomenon is, even at its highest frequencies, a rare event. Dizygous twins (DZ) stem from multiple ovulation in the same cycle with subsequent fertilisation by two different spermatozoa. Each oocyte develops within its own chorionic sac and forms an individual placenta. Such twins bear no more genetic resemblance than do other children of the same parents and may obviously be the same or the opposite sex.

It is thought there is a familial tendency toward DZ twinning and that the rate increases with maternal age and parity (Lauweryns et al. 1993). Monozygous (MZ) twins develop from a single egg and are therefore the same sex and genetically identical. The fertilised egg cleaves at an early stage of embryological development (sometime during the first 10 days post-conception), the timing of cleavage determining the type of MZ twins formed. The embryo is surrounded by two membranes which are contiguous with the placenta, the inner amnion and outer chorion. If the zygote cleaves between day one and five post-conception, then the placenta, chorion and amnion will be doubled. Between 20-30% of MZ twins fall into this category and are called dichorionic. The majority of MZ twins are monochorionic, that is, they have one placenta, one chorion and a double amnion. However, in a small percentage (about 3%) the placenta, chorion and amnion are all single as a result of a late clevage at about day nine or ten post-conception.

In the study of genetic-environmental interactions, the twin method is the most efficient method available and is valuable in dealing with complex genetic traits. However, it is necessary to take into account the positive correlation between the genetic relationship and environmental similarities, both pre- and post-natally of the twin pair. For example, monozygous twin pairs are genetically identical but usually will have shared an extremely similar environment. It is the aim of the researcher to establish to what extent the similarity in a particular trait is a result of their genetic make up and to what extent a result of their common environment.

The co-twin control method provides a most efficient method of studying the effect of a specific environmental factor on a trait. That is, one member of the twin pair is used as a control for the other. In addition, studies of single born siblings, parent-child pairs and parental pairs provide insights into the relative contribution of the environment and genetic factors on a particular trait.

Twin studies

The study of twins has a long history and it is from the work of Francis Galton in the latter half of the 19th Century that today's researchers owe the first systematic studies of individual differences and family resemblance and the recognition that the differences between monozygous (MZ) and dizygous (DZ) twins can provide an insight into the relative contribution of genes and environment. Phenotypic differences between MZ pairs reflect environmental factors as, theoretically, MZ twin pairs share all of their genes, while differences between DZ pairs reflect both genetic and environmental factors, the twins, on average, sharing only half of their genes.

The classical twin study, in which monozygous twins and dizygous twins are reared together in the same home, is one of the most powerful designs for detecting genetic and shared environmental effects. However, the traditional twin analysis method, based on correlations, is limited as it is not able to detect, estimate or correct for the effects of genetic-environmental correlation or genetic-environmental interaction.

Most early twin studies (for example, Macklin and Moore 1935 and Lundström 1948) and intra-familial comparisons (for example, Stein et al. 1956 and Jago 1974) over-estimated the importance of genetic factors primarily because of the inability to separate the effects of common environment and gene-environment interactions from purely genetic interaction. Several sources of error were present, most of which increased the similarity of MZ twins. These included:

- genetic-environmental interaction; that is, the effect of the environment on the phenotype differs according to the genotype, therefore increasing the variance in DZ twins but not in MZ twins

- frequent sharing of embryonic membranes between MZ twins results in more similar intrauterine environment
- greater similarity in the treatment of MZ twins by parents, teachers and peers resulting in decreased environmental variance in MZ twins (Hartl 1992).

In addition, previous studies have assumed genetic and environmental factors to be independent for the purposes of analysis, but clinically this is not likely to be the case. Other factors that need to be considered are:

- assortive mating, that is; matings in which the partners are non-random with respect to the trait under investigation
- genotype-environment correlation; that is, genotypes do not occur at random in all possible environments

Twins share a common environment from conception to birth and over the period of the time they are reared together. Therefore, the within pair variance is only a small part of the total environmental variance. Until recently, it had been assumed that MZ and DZ twin pairs shared a common environment to approximately the same extent. In addition, the majority of twin studies have assumed no dominance or epistatic effects and that genetic-environmental covariances are not present or are the same in both twin types. Researchers have documented and questioned previously hidden assumptions of the traditional twin model due to the importance of environmental variance and covariance (Christian et al. 1974; Kang et al. 1977). The following assumptions should hold before a meaningful genetic analysis can be conducted:

- twin zygosity must not be associated with the mean of the trait. Differences in the mean of the trait between MZ and DZ twins would reflect inherent biologic differences associated with the twinning process
- the standard twin model partitions total variance into within twin pair mean squares to contrast DZ and MZ twins. Christian et al. (1974) has shown that

the total within twin mean squares (WMS) plus among twin pair mean squares (AMS) must be equal between MZ and DZ twins for the model to hold

- genetic variance estimates will also be biased by inequality of environmental covariances of MZ and DZ twins.

Christian (1979) reports that twin studies provide a "most effective and cost-efficient" method of quantitative genetic analysis provided a number of guidelines are followed (Christian 1979, pp36). Firstly, when collecting the sample population, biases of ascertainment must be prevented. Secondly, all testable assumptions of the twin model should be tested before proceeding with the genetic analysis if meaningful results are to be obtained. Thirdly, the most efficient methods of analysis available should be used, and any hypotheses formulated from twin studies should be tested on singletons.

There have been several advancements in the use of twins over the past two decades including a refinement in the technique of analysis, through partitioning genetic variance estimates into additive and dominance variances and evaluating the effect of dominance variance and environmental covariance on heritability estimates obtained (Christian et al. 1974; Christian1979; Christian 1981; Kang et al. 1977; Kang et al. 1974). The development of structural equation modelling, for example, LISREL (Boomsma et al. 1989) and Mx (Neale 1991) has been a major advance.

Genetic modelling in twin studies

Advances in genetic analyses have been significant over the past few decades and the reader is directed to the text by Neale and Cardon (1992) for a detailed account of the methodology for genetic studies of twins and families. The authors summarise the main streams of the intellectual tradition which converge to yield modern mathematical genetic methodology in a flow diagram (Figure 2.5). Integration of the Birmingham School's method of biometrical genetics with the method of path analysis was a crucial step in advancing genetic analysis and, since then, the approach of path analysis has been accepted as a first strategy for analysing family resemblance.

Important developments in human quantitative genetics have been in the area of multivariate analysis in which maximum-likelihood factor analysis and the concepts of biometrical genetics have been combined to shed light on the genetic basis of co-variation between traits (Martin and Eaves 1977). The structural equation modelling package LISREL developed by Boomsma, Martin and Neale (1989) employed this blend of genetic analyses, and recently Neale (1991) has written his own structural equation modelling program, Mx, which accommodates complex data structures and models into its structural modelling techniques in a powerful and versatile fashion. The aim of this technique is to determine the combination of genes that pleiotropically influence the trait under consideration and to what extent there are genetic effects specific to each trait.

In this thesis, simple genetic models will be fitted to the data using the Mx software package.

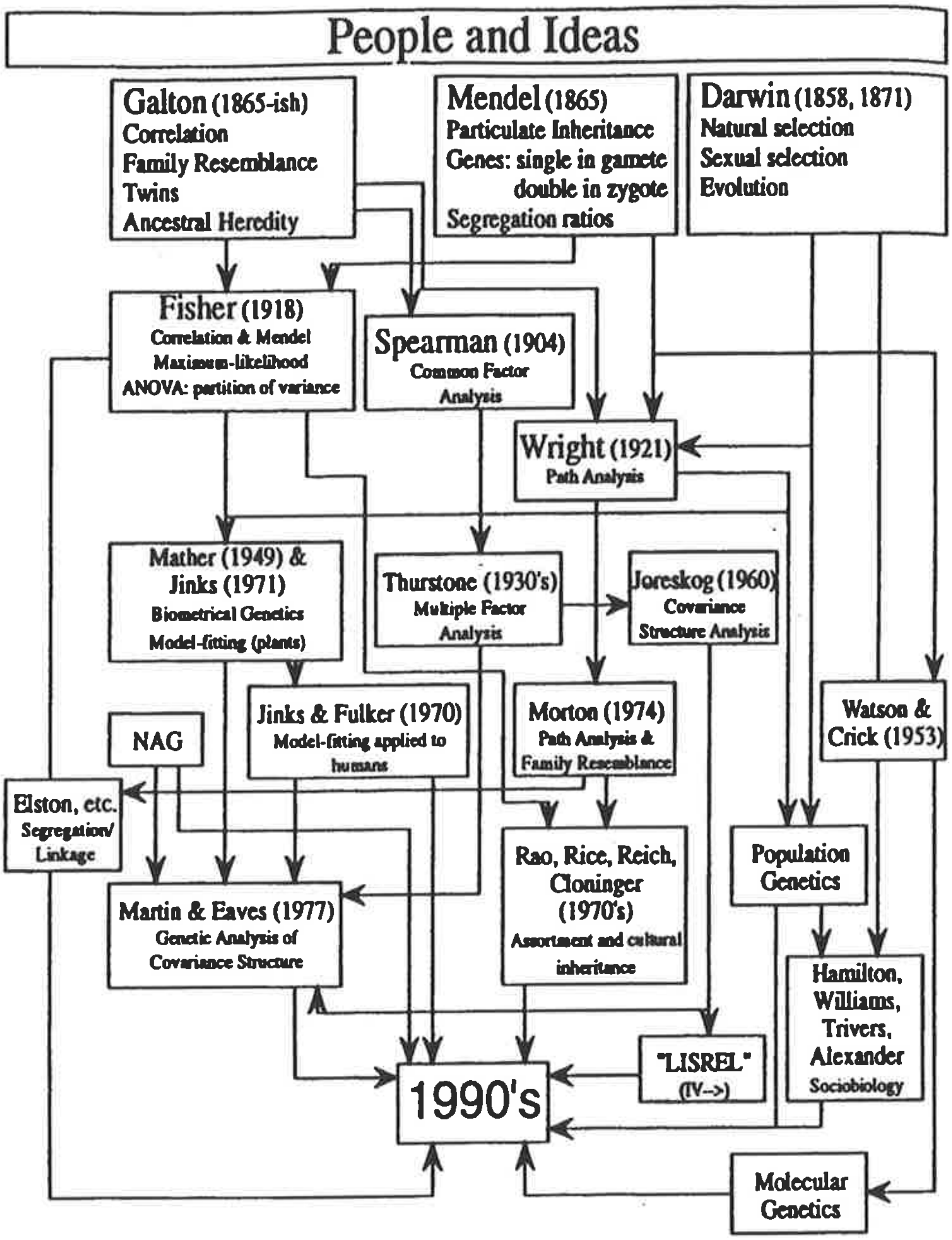


Figure 2.5 : Diagram of the intellectual traditions leading to modern mathematical genetic methodology (Neale and Cardon 1992).

Deficiencies in studies to date

Many investigators have endeavoured to measure occlusion for epidemiologic purposes. There is, however, no generally acceptable method. Variations in terminology, concepts and methodology can be given as the main reasons for the lack of a universal system and, as a result, a meaningful comparison of the data between studies is difficult. In addition, studies of the complete primary dentition are few in number. This may be a result of a lack of interest in the primary or "deciduous" dentition to date, a statement which is reflected in the writings of Brash et al. (1956) who wrote "it was generally believed that malocclusion did not occur in the primary dentition, and if it did, it was inconsequential". Alternatively, a paucity of fossil material of children, the relatively small size of primary teeth or the fact that the primary teeth are shed at an early age may all be contributing factors.

Inappropriate methods of classification of malocclusion have led to serious deficiencies in most genetic studies of occlusal variation. Due to the complex multifactorial aetiology and continuous distribution of occlusal variation, it is not surprising that analyses of occlusion based on Angle's classification, as Smith and Bailit (1977) noted has been done in most studies, has hampered progress in this area of research. In recent times, reports in the literature have questioned the practice of combining skeletal (bony) and tooth-based variables under a common heading of malocclusion. Harris and Johnson (1991) show a schematic representation of the inter-relationship between bone and tooth-based sources of malocclusion (See Figure 2.6) and suggest that, in some individuals, malocclusion is predominantly related to one or the other source but, more commonly, it is a combination of both, a tooth and bony based disharmony. Consequently, the researcher should look towards assessing the role of heredity individually in the phenotypic expression of these two variables.

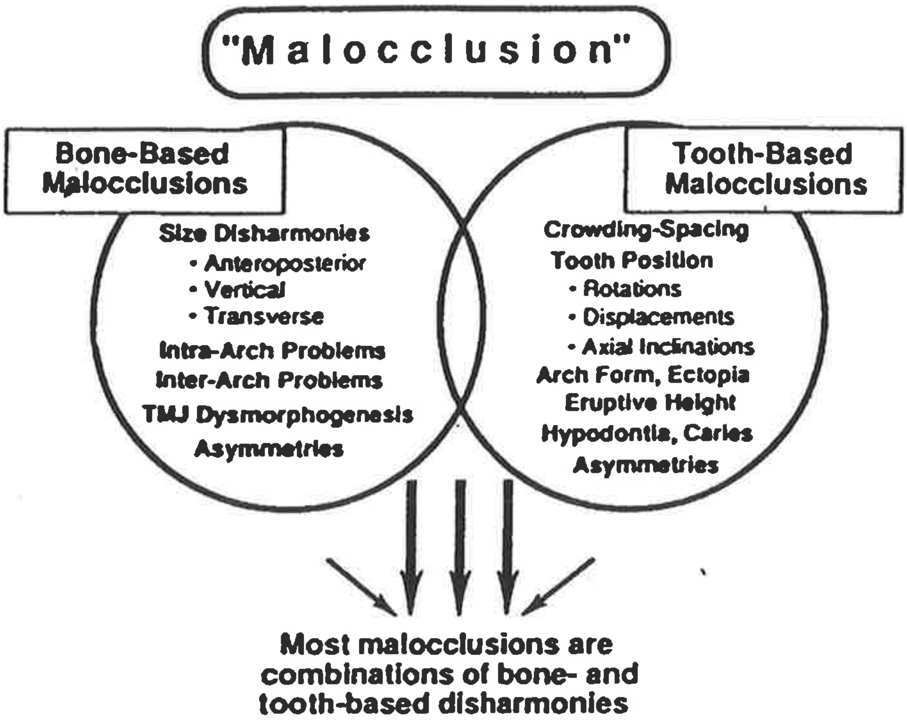


Figure 2.6 : The cause of a malocclusion may be predominantly a tooth-based or a bone-based problem. More commonly, malocclusion is a combination of both a tooth-based and bone-based disharmony (for example, a skeletal Class II with blocked out canines and incisor crowding). In these cases, co-occurrence should not imply a single or even similar cause of the malocclusion (Harris and Johnson 1991).

Another problem in human studies of occlusal variability relates to sampling. Firstly, to provide sufficient statistical power for genetic analysis sample sizes should be large; however, these are often difficult to obtain. Secondly, the researcher must avoid introducing bias into the study by including a wide range of phenotypic variation of the trait; for example, studies of occlusal variation should include a broad range of individuals. Thirdly, longitudinal studies provide more information than cross-sectional studies but at a much greater cost.

Indeed, many early studies had limitations such as using methods unsuitable for estimating heritability or other components of variation and numerous factors were assumed to be absent, for example, common environment, assortive mating and GxE interactions. Other drawbacks included small sample sizes and having inaccurate methods of zygosity determination (Dempsey 1999).

A major reason for a lack of data in a genetic context on occlusal traits is the difficulty in obtaining valid observations between parent-offspring pairs due to tooth loss and previous restorative or orthodontic treatment of the parent generation, hence pre-treatment occlusal conditions are difficult to ascertain. Studies often are restricted to analysing similarities between brothers and sisters, rather than parents and offspring. Indeed, this places limitations on the interpretation of data as statistical associations between different types of relatives are due to different factors; that is, siblings may be phenotypically similar because of genetic material inherited in common from parents as well as due to a similar home environment. It is known that full-sib correlations generally over estimate the additive genetic component because they include a dominance effect as well as a shared environment effect.

Recent research has been directed towards separating previously unrecognised genetic and environmental heterogeneities and attempting to elucidate the complex interactions between the genome and the environment through the application of new statistical modelling approaches to twin and family data.

The philosophy of early treatment

The timing of orthodontic treatment is a topic of continuous debate. Cost-effectiveness, functional, psychosocial benefit and patient cooperation must be considered.

As a result of classical orthodontic thinking concerning the genetic aetiology of malocclusion, very little research work has been directed towards true prevention of malocclusion, for example, posterior crossbite or distal occlusion.
There are numerous reports in the literature suggesting early treatment of some malocclusions, for example, anterior and posterior crossbites, but controversy exists as to the best timing for the correction of other malocclusions, for example, Class II malocclusions, crowding and deep bite malocclusions (Proffit 1993, Viazis 1995, Gianelly 1995, Varrela and Alanen 1995, Tschill et al. 1997, Kirjavainen et al. 1997).

Those studies proposing treatment in the late-mixed dentition or early permanent dentition are based on clinical practice rather than on carefully controlled studies. Indeed, recent developments in the area of craniofacial biology and clinical orthodontics have prompted a review in the field of preventive and interceptive orthodontics (Varrela and Alanen 1995). Clinical trials are being conducted in Finland to determine the effectiveness of early orthopaedic treatment. The aim of these trials is to diagnose malocclusions and to initiate treatment in children at age five or six years and thereby guide the growth of the maxilla and mandible with orthopaedic appliances. The researchers are aiming to harness growth at a time when the facial skeleton is very "plastic", correcting occlusal problems, for example, lack of space or a deep bite in the early mixed dentition. Early findings have shown good treatment results may be achieved with a favourable cost-effectiveness ratio (Varrela and Alanen 1995). However, to date there are few published papers addressing early orthopaedic treatment in children.

Kirjavainen et al. (1997) used orthopaedic cervical headgear to correct Class II malocclusions in children in the mixed dentition and found an increase in maxillary arch width which was significantly greater than normal growth in control subjects. Spontaneous widening of the mandibular arch followed the maxillary expansion. The authors reported the best time for treatment may be in the early mixed dentition "because at that time the skeletal system is dynamic and is easy to remodel" (Kirjavainen et al 1997, pp59).

It has become evident through recent research that the development of malocclusion seems to be strongly related to the influences of various oro-facial functions, for example, tongue and cheek pressures especially in the early post-natal phase of growth. This is an exciting area for the clinician because, if the malocclusions are to a large extent, environmentally induced, then, theoretically, they are preventable. Consequently, prevention may be a potential alternative for active treatment.

Aims of the present study

The overall aim of this study is to provide a better understanding of the nature of occlusal variation in the primary dentition of Australian singletons and twins and to contribute to knowledge by quantifying the relative contributions of genetic and environmental influences to that variation.

Specific aims include:

- documenting the range of occlusal variation found in the primary dentition, for example, interdental spacing, arch dimensions and interarch relationships
- documenting the relationship between occlusal variables, for example, tooth size, arch dimensions and interdental spacing
- exploring the genetic and environmental contributions to occlusal variation in the primary dentition, including correlations within and between twin pairs.

Hypotheses to be addressed include that :

- crowding is present in very few individuals in the primary dentition
- there is more interdental spacing in the maxillary arch than mandibular arch
- total interdental spacing does not differ significantly between males and females
- maxillary primate spaces occur more frequently than mandibular primate spaces
- there is a significant difference in arch dimensions between males and females
- arch shape can be described adequately in terms of fourth-order polynomial equations
- spacing in the dental arches is related to mesiodistal tooth diameter, intercanine and intermolar arch widths
- there is a significant correlation between tooth size and arch size
- a Class I canine relationship occurs more frequently than a Class II or Class III relationship
- a straight terminal plane relationship occurs more frequently than mesial or distal relationship
- crossbite is infrequent in the primary dentition and bilateral crossbite occurs less frequently than unilateral crossbite

- individuals with a Class I canine relationship tend to have a straight terminal plane relationship
- the pattern of variability in occlusal features does not differ significantly between singletons and twins
- there is a significant genetic contribution to variation in primate and developmental spaces in the dentition
- there is a significant genetic contribution to variation in arch size
- there is a significant genetic contribution to variation in overbite and overjet
- there is a significant genetic contribution to variation in arch shape but not to arch asymmetry

In Summary

Dorland's Medical dictionary defines malocclusion as "Improper relations of opposing teeth when the jaws are in contact" (Dorland's Medical Dictionary 1995, pp474). It is not surprising, then, that there is considerable disagreement among researchers and clinicians alike about how much deviation from the ideal should be accepted as normal. It is suggested that "occlusal variation" is a more appropriate term to use rather than malocclusion when discussing the wide variety of occlusal patterns which exist in the complete primary dentition. It was Sheffer et al (1950) who suggested that the concept of an ideal occlusion was "a figment of the imagination". Indeed, it is clear from a review of the literature that this is the case, as there is much occlusal variation both within and between populations.

During the past decade, reports in the literature suggest that regulation of craniofacial growth is, to a large extent, under environmental control and less strict genetic control (Varrela and Alanen 1995). It seems that the development of the occlusion is under the influence of various orofacial functions, especially early in the post-natal phase of growth, and that disturbances in the functional balance between oral and facial musculature may be important.

Recent developments in craniofacial biology propose a new approach in the management of malocclusion. Preliminary results from Finnish trials of early occlusal and orthopaedic treatment look promising as an alternative to conventional active treatment during adolescence and adulthood. If fruitful, contemporary orthodontic treatment may fundamentally change direction.

There is clearly a need for continuing research into the roles of genetic and environmental influences on human craniofacial and occlusal development, particularly from the viewpoint of prevention and early clinical intervention.

3. STUDY POPULATION AND METHODS

Material

Morphometric dental variation in the primary dentition was studied in two groups of Australian Caucasian preschool and primary school children: a group of singletons and a group of twins.

The first group of 114 singletons, 56 females and 58 males, aged between three and six years (Table 3.1), was selected from the study models collected by Victoria Farmer in 1990, as part of her Master of Dental Surgery research project titled "Odontometric and Morphologic Variability in the Deciduous Dentition". Most of the children were examined by Dr Farmer in kindergartens, primary schools and day-care centres or at the Adelaide Dental Hospital. Some of the casts were supplied by private practitioners. Impressions of the upper and lower dental arches were obtained of each child using alginate impression material. The impressions were washed free of saliva and poured immediately in yellowstone plaster.

The children were primarily from middle class socio-economic backgrounds and were selected on the basis of being apparently healthy with complete primary dentitions. For this thesis, casts were selected on the basis of the presence of a complete primary dentition, with no permanent teeth present in the mouth. Access to a questionnaire completed by parents revealed various developmental factors that may be associated with, or influence, the development of the dental arches;

for example, maternal health during pregnancy, birth weight, birth length, complications at birth, post-natal illness and oral habits (Appendix I).

The twin sample of 80 twin pairs was selected from an on-going study of dento-facial development being carried out in the Dental School at The University of Adelaide (Table 3.2). To date, over 600 pairs of twins are enrolled in this study. A range of observations and records is obtained from subjects, including direct examinations, dental impressions from which stone models are constructed, colour photographs of the face and cheek cell samples for the determination of zygosities.

Zygosity was determined from isolation of DNA obtained from buccal cheek swabs which involved wiping the inside of the cheek with a sterile cotton tip applicator. Four highly variable genetic loci, D17S30, D1S80, HVR-Ig and APOB-HVR,. were used to determine zygosity. Those twin pairs who shared the same alleles at all four loci were considered to be monozygotic. The chances of the twin pair being dizygotic while sharing all four loci was less than 1%.

Information relating to birth weight, birth length and medical histories was obtained by way of a questionnaire completed by parents at the initial appointment (Appendix II). The twins, aged between four and seven years (Table 3.3), were from a broad socio-economic cross-section of the community and were selected on the basis of having a full complement of primary teeth, with no permanent teeth erupting into the mouth. Descriptive statistics of age of each group are shown in Table 3.4.

The ethical guidelines issued by the National Health and Medical Research Council of Australia were followed and informed consent of all participants was obtained. The project was approved by The University of Adelaide Human Ethics Committee, Project Number H/07/84A.

Table 3.1 Age distribution of singletons

	Age (years)				
	3-3.99	4-4.99	5-5.99	6-6.99	Total
Male	4	26	12	1	43
Female	4	33	9	1	47
Total	8	59	21	2	90

Age of 24 children unavailable

Table 3.2. Zygosity distribution of twins

Zygosity	**Male**	**Female**	**Total**
MZ[a]	44	26	70
SS-DZ[b]	26	42	68
OS-DZ[c]	11	11	22
Total	81	79	160

[a] Monozygous
[b] Same sex dizygous
[c] Opposite sex dizygous

Table 3.3. Age distribution of twin sample

Zygosity	Age(years)				
	4	5	6	7	Total
MZ	20	40	8	2	70
SS-DZ	6	58	4	0	68
OS-DZ	6	10	6	0	22
Total	32	108	18	2	160

Table 3.4. Descriptive statistics for age of study groups (years)

Zygosity	$\bar{x}$	SD	Range
MZ	5.3	0.68	4.0-7.0
SS-DZ	5.4	0.36	4.7-6.1
OS-DZ	5.5	0.74	4.1-6.5
Singletons	4.7	0.62	3.0-6.8

2. Elastomeric impressions of each cast including

Interdental spacing and crowding

From group II, measurements of arch shape, arch breadth and arch depth were obtained from a photocopy of each cast placed in a standard position with the occlusal plane parallel to the photographic plate of the photocopying machine. Repeat measurements revealed no significant distortion or magnification of the photocopied image. This will be discussed later in the section entitled Double Determinations.

Measurements of interdental spacing and crowding were obtained from impressions of the casts taken with Examix-monophase type hydrophilic polyvinyl siloxane material and then sectioned longitudinally. Mandikos (1998) reports that this type of impression material produces highly accurate impressions as they have excellent elastic recovery and exceptional stability. The width of the interdental spacing was measured with Mitutoyo digital vernier calipers to the nearest 0.1mm under two times magnification. The smallest measurement that could be made was 0.3mm.

A data sheet was designed for recording all observations of the study. This sheet is illustrated in Appendix III. The data recorded on the sheet represented the measurements made from each dental cast and these were subsequently transferred to computer for analysis.

Measurement Methods

There are numerous methods of characterising, classifying and measuring occlusal variation in the permanent and primary dentitions. Variation in terminology, concepts and methodology can be cited as the major reasons for the lack of a universally acceptable index of occlusion. In this study, the methods of measurement were taken from previous studies of Moorrees (1959), Foster and Hamilton (1969) and Richards et al. (1990), allowing valid comparisons to be made with other studies.

Overbite

The amount of vertical overlap of the maxillary incisors on the mandibular incisors was marked with a sharp pencil on the labial surface of the mandibular incisor (Figure 3.1). The distance from the incisal edge of the mandibular incisor to the line was measured with a graduated probe to the nearest 0.5mm. Open bite was recorded as a negative measurement (Moorrees 1959).

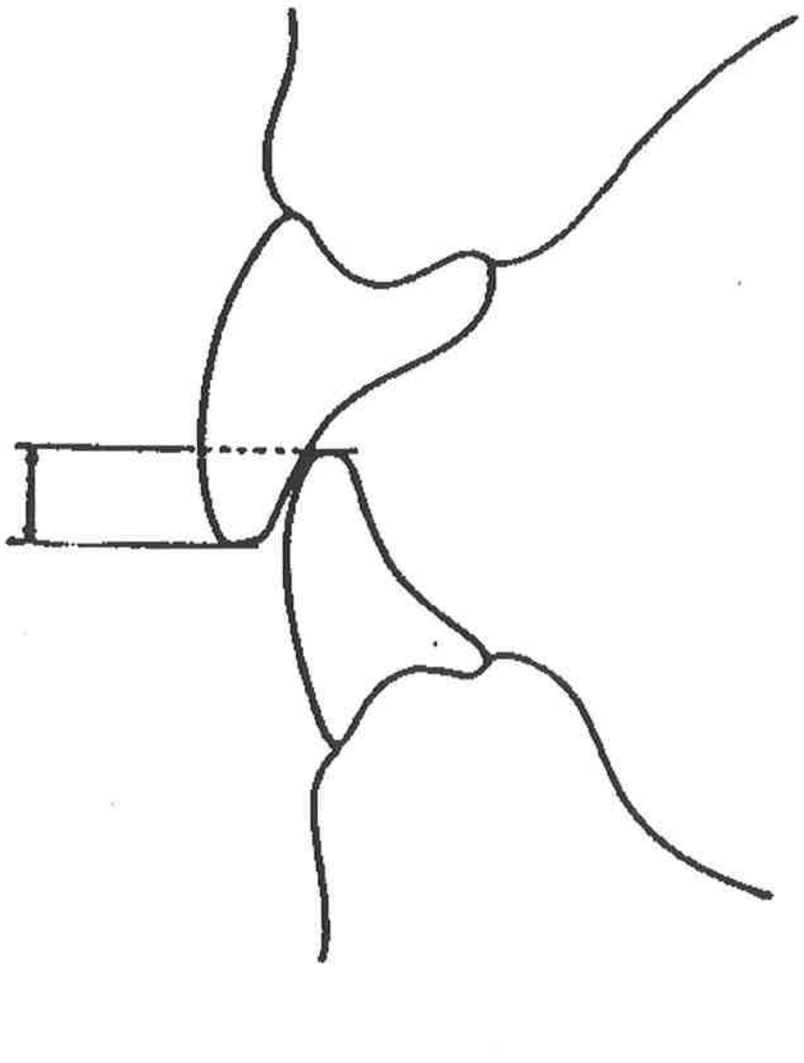


Figure 3.1 : Diagrammatic representation of overbite

Overjet

Overjet was defined as the amount of horizontal overlap between the labial surface of the maxillary incisors and the labial surface of the mandibular incisors (Figure 3.2). The distance was measured with a graduated probe to the nearest 0.5mm (Moorrees 1959).

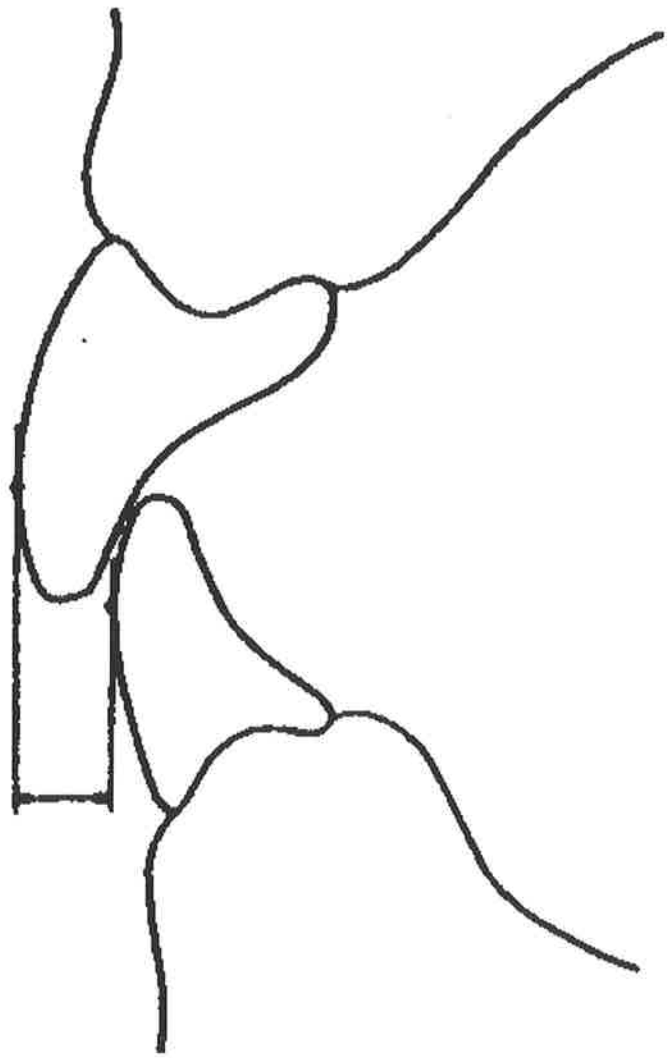


Figure 3.2 : Diagrammatic representation of overjet

Sagittal relationship

(1) Molar relationship (terminal plane) was defined by the relationship of the second molars when the maxillary and mandibular casts were articulated and was recorded as straight when their distal surfaces were in the same vertical plane and distal when the mandibular second molar was in a posterior relationship to the maxillary molar. If the distal surface of the mandibular molar was anterior to the maxillary molar, it was considered mesial (Figure 3.3) (Foster and Hamilton 1969).

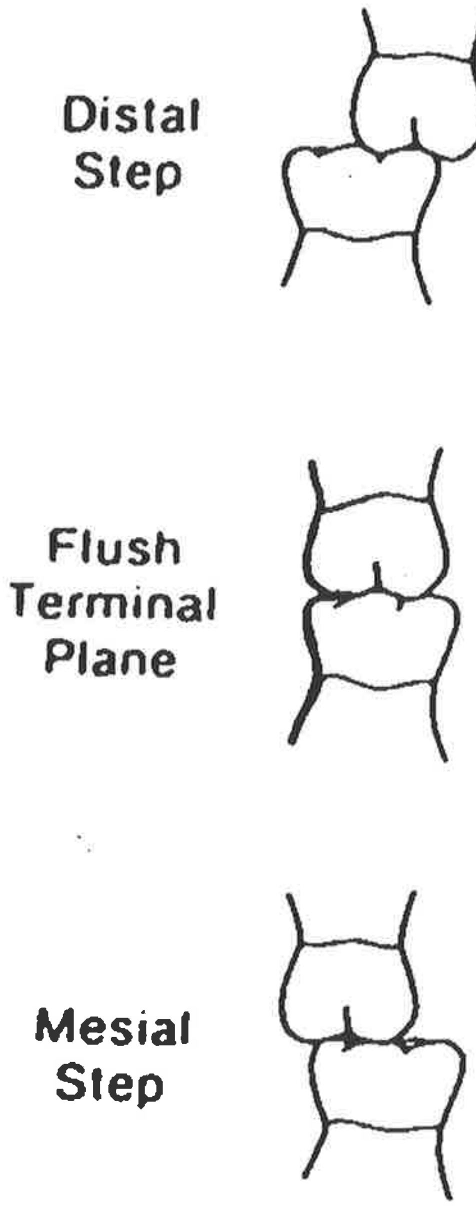


Figure 3.3 : Diagrammatic representation of terminal plane or molar relationship

(2) Canine relationship was defined by the relationship of the maxillary and mandibular canine teeth and was considered as Class I when the cusp tip of the maxillary canine was in the same vertical plane as the distal surface of the mandibular canine +/- 1mm, Class II if the cusp tip of the maxillary canine was anterior to the distal surface of the mandibular canine and Class III when the cusp tip of the maxillary canine was posterior to the distal surface of the mandibular canine (Figure 3.4) (Foster and Hamilton 1969).

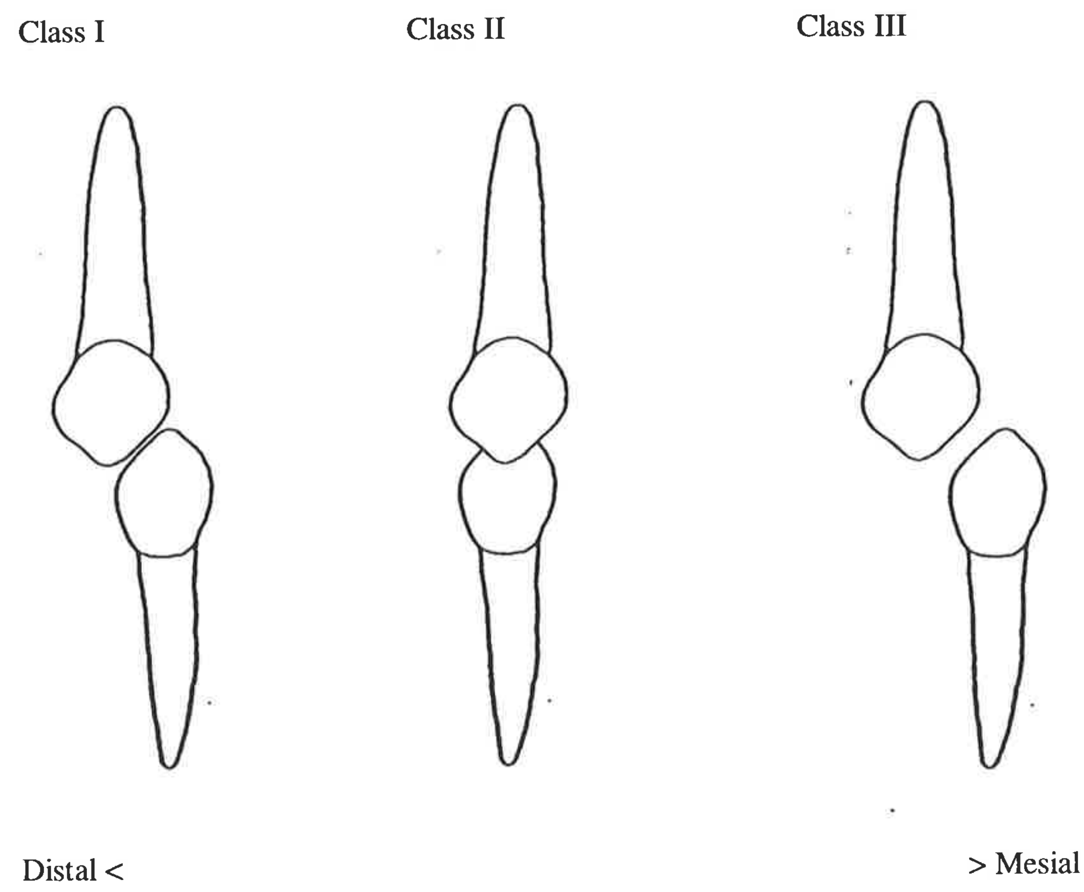


Figure 3.4 : Diagrammatic representation of canine relationship

Posterior crossbite

A normal relation is defined when a buccal cusp of a mandibular tooth lies between the maximum heights of the buccal and lingual cusps of an opposing maxillary tooth (Figure 3.5). A buccal (B) crossbite exists when a buccal cusp of a mandibular tooth lies lingual to the maximum height of a lingual cusp of an opposing maxillary tooth. A lingual (L) crossbite exists when a buccal cusp of a mandibular tooth lies buccal to the maximum height of a buccal cusp of an opposing maxillary tooth (Foster and Hamilton 1969).

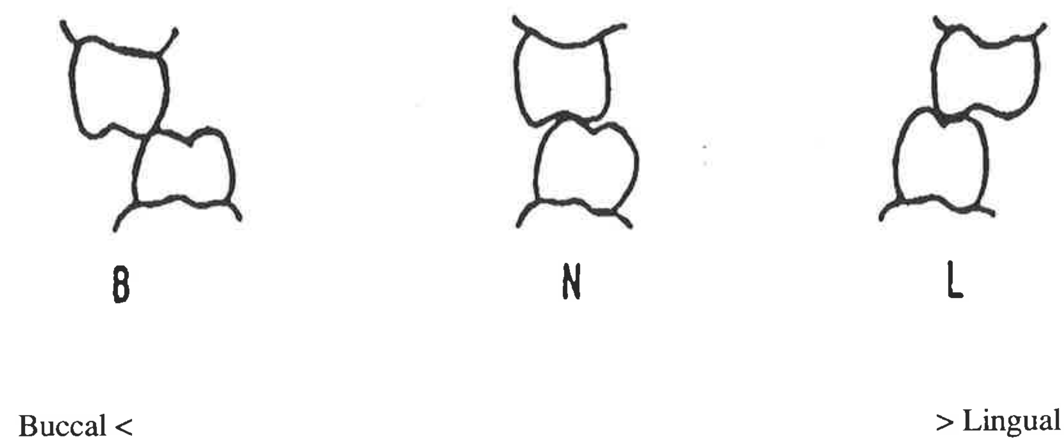


Figure 3.5 : Diagrammatic representation of posterior crossbite

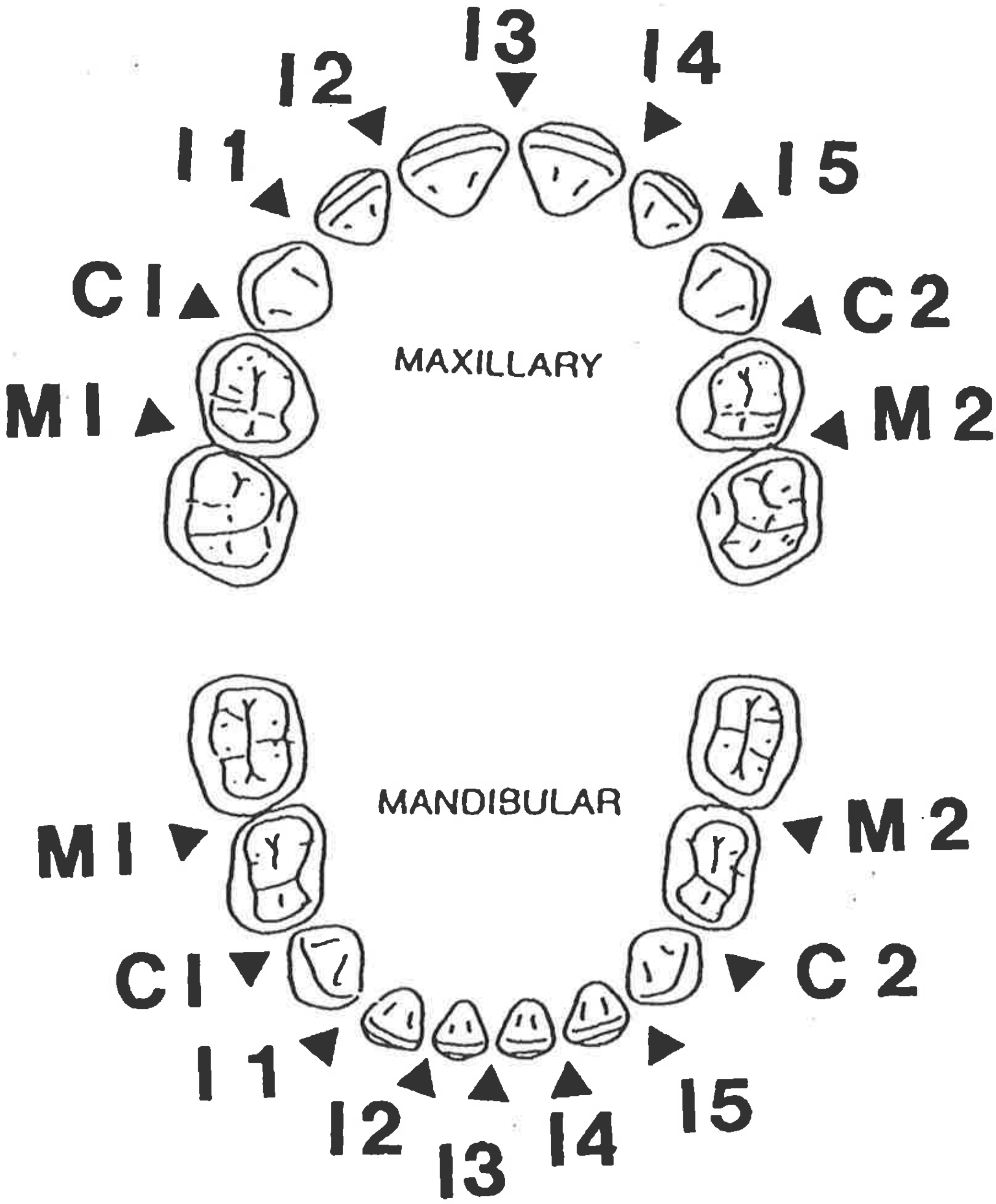


Figure 3.6 : Notation for interdental spacing

Crowding

Crowding was measured as a lack of space for a tooth in the dental arch. The measurement was obtained by subtracting the space available for the crowded tooth in the arch from its mesiodistal crown diameter (Moorrees 1959). When two adjacent teeth were crowded, the lack of space was computed by subtracting the available space in the arch from the combined mesiodistal crown diameters of the teeth involved. When crowding involved more than two adjacent teeth, the available space was obtained by making one or two sectional measurements (Figure 3.7). The measurements were made using Mitutoyo digital calipers under two times magnification

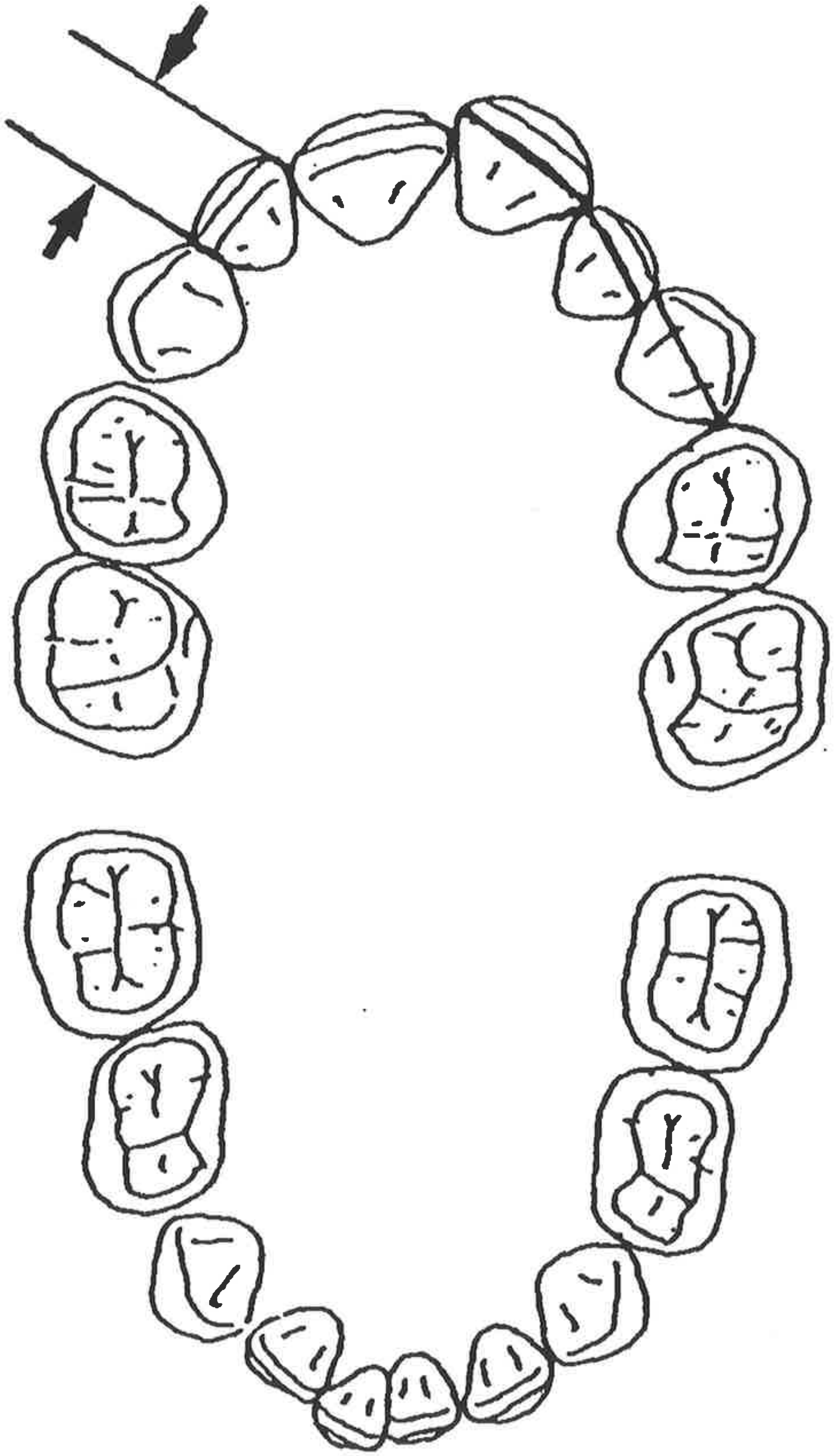


Figure 3.7 : Diagrammatic representation of arch crowding

Arch breadth

Arch breadth was defined as the distance between corresponding teeth, on the left and right sides of the dental arch, in both maxilla and mandible (Figure 3.8). The cusp tips of the canines and the mesiolingual cusp tips of the second molars were used as landmarks. If the cusp tips were worn, the centres of the resulting facets were used as landmarks (Moorrees 1959). Arch breadth measurements were not made if the teeth showed excessive wear and the associated landmarks could not be identified accurately.

The various dimensions were abbreviated as follows :

arch breadth in the maxilla at the canine - ABMaxC

arch breadth in the maxilla at the molar - ABMaxM

arch breadth in the mandible at the canine - ABManC

arch breadth in the mandible at the molar - ABManM

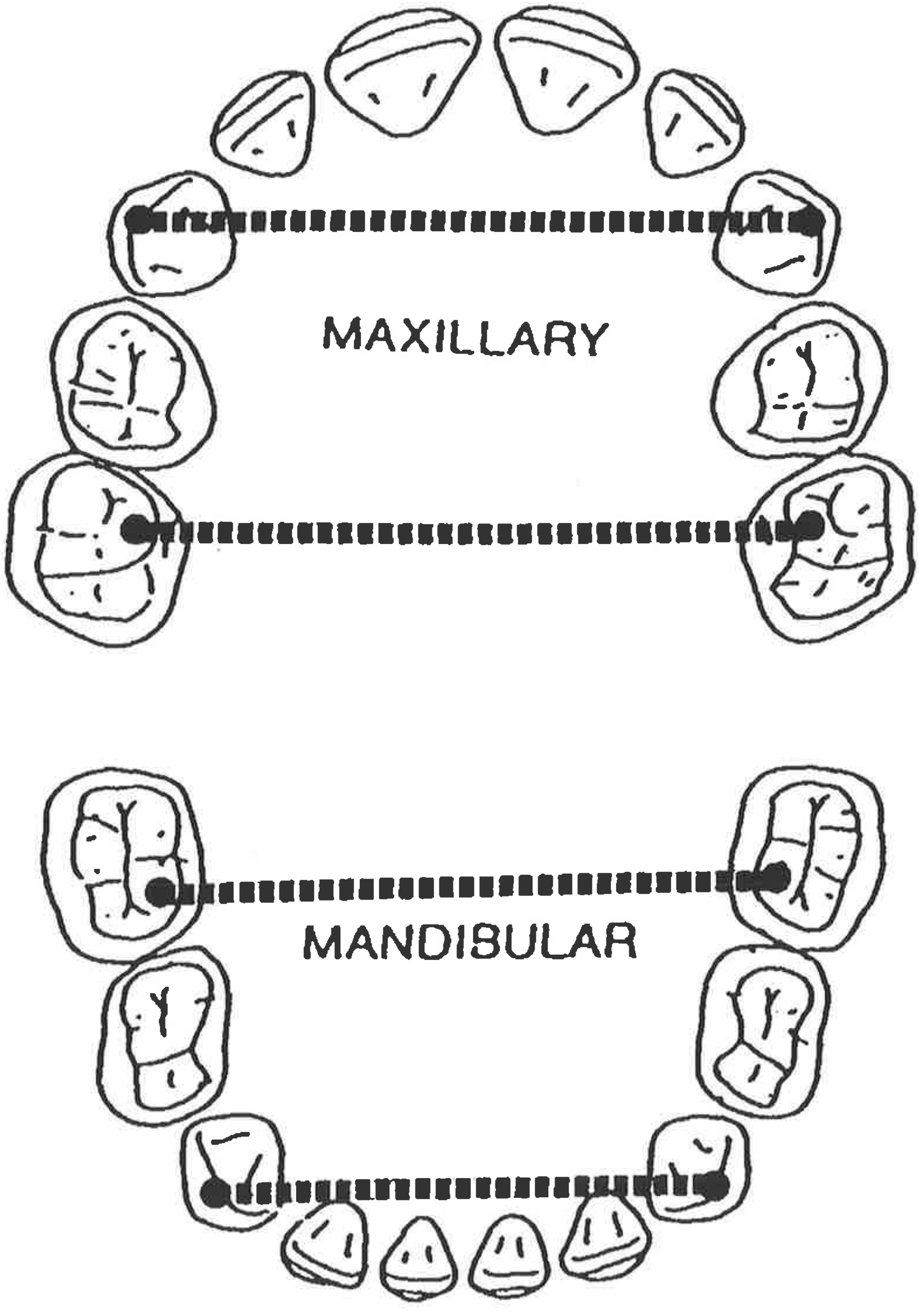


Figure 3.8 : Diagrammatic representation of arch breadth

Arch depth

Arch depth was defined as the distance between a tangent from the incisal edge of the central incisors and a line connecting the most distal surface of the second molars in both maxillary and mandibular arches (Figure 3.9) (adapted from Moorrees 1959).

The measurements were abbreviated as follows :

maxillary arch depth - Max depth

mandibular arch depth - Man depth

All of the above indirect measurements were made with vernier digital calipers to the nearest 0.1mm.

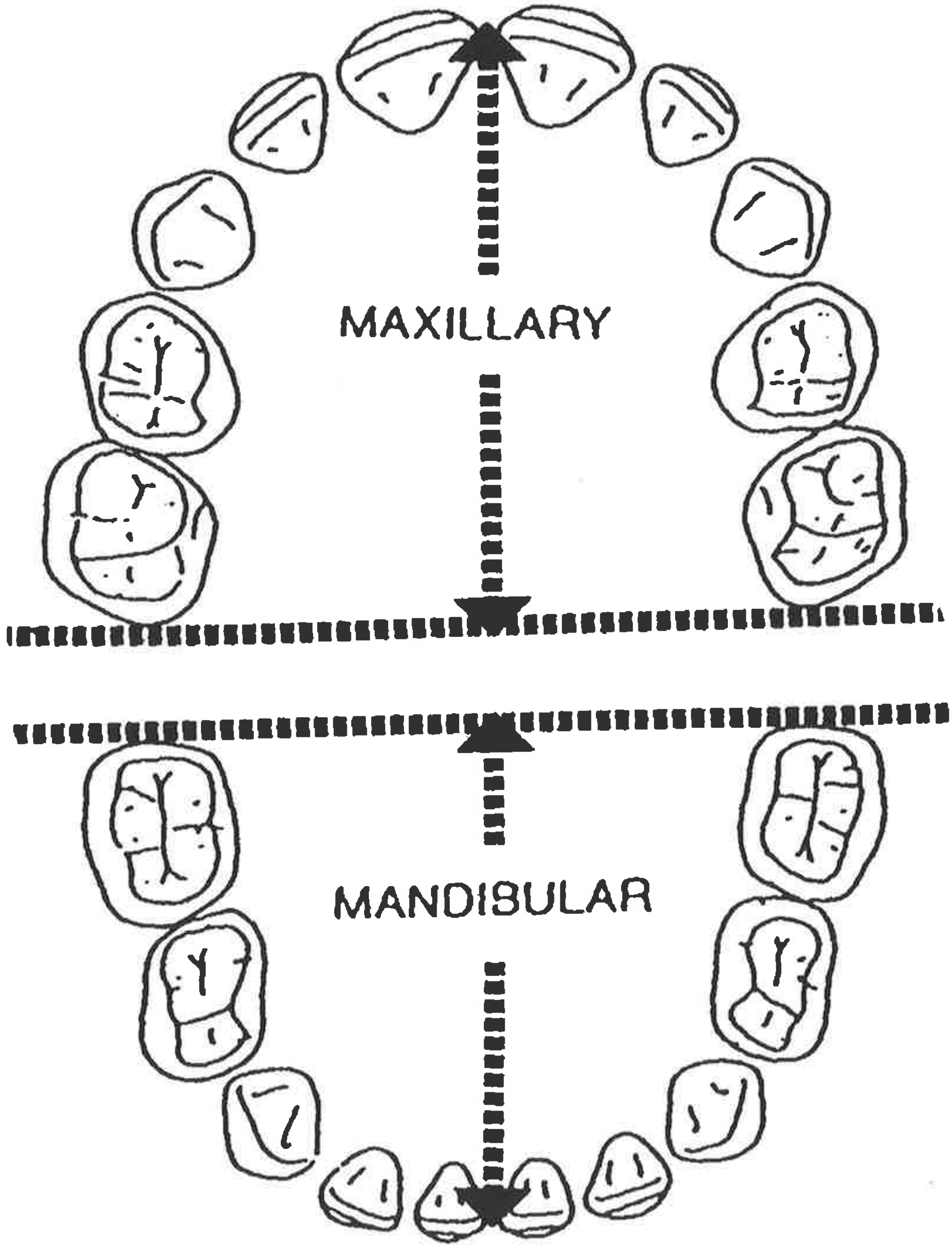


Figure 3.9 : Diagrammatic representation of arch depth

Arch shape

The mid-points of the incisal edges of the anterior teeth and the buccal cusp tips of the posterior teeth in both, maxillary and mandibular arches were defined on the photocopy of the cast (Figure 3.10). In addition, the most distal point of the second molar was identified to facilitate orientation of the photocopy. The Cartesian co-ordinates of these points were obtained using a Hewlett-Packard 9874A digitizer, then transferred to a main frame computer (Richards et al. 1990).

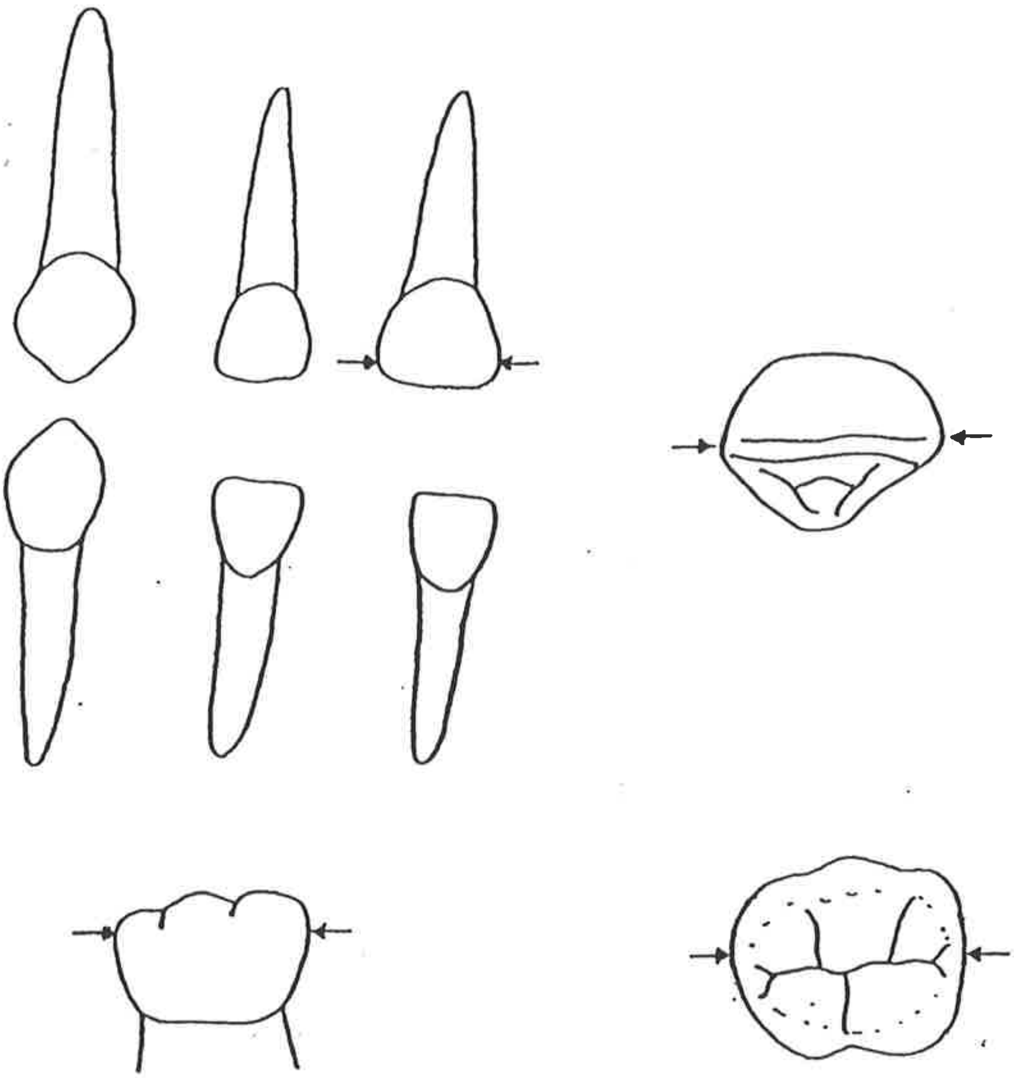


Figure 3.11 : Diagrammatic representation of mesiodistal tooth size

Statistical Analysis

Initially, the singletons and twins were divided into males and females for analysis. Descriptive statistics were computed, including means ($\bar{x}$), standard deviations (SD), and coefficients of variation (CV) for the continuous variables and frequencies of occurrence were computed for the discrete variables.

Statistical analysis of the singleton and twin data included chi-squared tests, Student's t-tests and correlation analyses of selected variables. A simple genetic analysis, using the Mx package, was conducted on the twin data.

<u>Chi-square tests</u>

The chi-square test is often applied to discrete data that are qualitative in nature to compare observed and expected frequencies. The null hypothesis when comparing the observed and expected distribution is that there is no difference between what was observed and what was expected. The frequencies of occurrence of the different occlusal variables were determined for males and females within the singleton and twin groups. Chi-square analysis was performed to test for associations between occlusal variables and different groups. The groups included male vs female, singleton vs twins, monozygous vs dizygous twins and left side vs right side.

The null hypothesis in each instance was that there was no association between the variables being tested. The level of significance was set at $p < 0.05$.

normal. When only two categories are used to describe variation, a tetrachoric correlation results.

Within the twin group, polychoric correlations were calculated between MZ and DZ twin pairs for the following discrete variables:

- canine relationship
- molar relationship

Because the sample sizes were relatively small, it was not possible to apply genetic modelling approaches to the discrete data as was done for the quantitative variables. The use of categorical data is associated with a decrease in statistical power which, therefore, means larger sample sizes are required to enable effective genetic modelling to be applied.

In an attempt to overcome some of the problems associated with the use of categorical data, polychoric correlations were computed assuming an underlying normal distribution to the observed variation. The assumption of normality could not be tested for those variables where only two categories were recorded, for example, crossbite relationship. For the other variables, polychoric correlation values were computed and tested to determine whether they differed significantly from zero.

Concordance

For the categorical data, percentage concordances between selected variables was determined for the singletons and twins including canine relationship and molar relationship. In addition, percentage concordance between MZ and DZ pairs were calculated. Under the assumption of a polygenic mode of inheritance, maximum percentage concordance for MZ twins would be 100% and for DZ twins 50%. Chi-square analyses were also performed to test whether associations between members of the twin pairs were statistically significant.

Heritability

The heritability of a trait, symbolised by h^2, is a statistic that describes the ratio of genetic to phenotypic variance. The value obtained depends on the population being measured and the amount of environmental variability present at the time of measurement. Heritability is a population phenomenon and applies to groups, not to individuals. In general, if the heritability is 100%, the environment has no effect and all variation seen is due to genetic factors. Heritability values were calculated for birth weight and each occlusal variable.

Structural Equation Modelling

Structural equation modelling (SEM) is a method of statistical analysis used to partition the underlying causes of phenotypic variation of a trait where observed variables are explained in terms of unobserved (latent) variables and their intercorrelations. SEM may be divided into five stages: specification of the model (hypothesis), gathering of data and statistics, estimation of parameters, testing the goodness-of-fit of the model and respecification of the model.

Using twin data, a SEM procedure allows testing for and, in the majority of cases, estimation of the relative influences of additive genetic factors (A), non-additive genetic factors (D), common or shared environmental factors (C) and unique environmental factors (E) to variation in the phenotype. This is carried out by comparing MZ twin variances and covariances with those of DZ twins. Figure 3.12 shows how each of the sources of variation in a pair of twins (A, D, E and E) contribute to variances and covariances for a trait. The genetic correlations, r_A and r_D, that is, the correlation for additive and non-additive genetic factors respectively, between MZ twins are 1.0 as these twins are assumed to share all of their genes in common. As DZ twins share on average half their genes, the value of $r_A = 0.5$ for additive genetic effects and $r_D = 0.25$ for non-additive genetic effects because one quarter of all full-sib pairs receive the same genotype from their parents and therefore the same dominance deviation. Assuming that the common or shared environment is the same for MZ and DZ twins, then the shared environmental correlation $R_C = 1.00$ for both twin types. Unique environmental effects are obviously not correlated between twins.

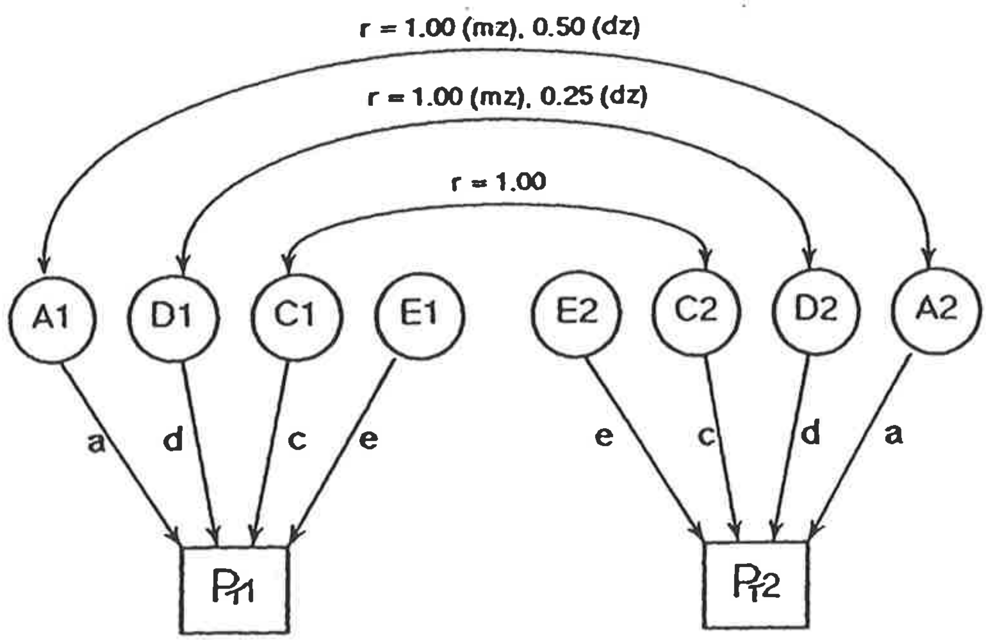


Figure 3.12 : Path diagram for a single variable showing the main sources of variance and covariance. PT1 = phenotype of twin 1, PT2 = phenotype of twin 2, r = correlation between latent factors.

From the path model, the variance for a twin is expected to be Var = $a^2 + c^2 + d^2 + e^2$, while the covariance between co-twins will be $Covar_{12} = a^2 + c^2 + d^2$ for MZ twins reared together and $0.5a^2 + c^2 + 0.25d^2$ for DZ twins reared together.

Models of varying combinations of the four latent variables, A, C, D and E were applied to variance-covariance matrices for MZ and DZ same-sex twins and OS twins. A maximum of three parameters can be modelled at one time because there are only three equations to solve: twin variance, MZ twin covariance and DZ twin covariance. Further details about the model fitting process are given by Neale and Cardon (1992).

In this thesis, genetic modelling procedures were carried out using Mx (Neale 1991), enabling estimates for the parameters a, e, and c or d, as well as a chi-square values for goodness-of-fit of the model to the data.

The simplest model which would explain the data was sought. Chi-square tests allowed comparison of full models, for example ACE, with simpler models, for example AE, to establish whether the more complex model provided a significantly better fit. The level of significance was set at 0.05 for rejection of the null hypothesis. The usual assumptions of the twin method were implied in this model fitting procedure including random mating, that there was no GxE interaction or gene-environment covariation and that trait-related shared environmental influences on MZ and DZ twins were equal (Jinks and Fulker 1970).

Errors of the Methods

Research projects should be planned and conducted with statistical analysis in mind. It is important to establish the degree of accuracy of the methods employed in data collection. One must accept there will always be errors of observation arising from limitations in technique and instruments. However, if these errors are small in comparison with the variability of the measurements, then the methods may be deemed acceptable.

Two basic terms should be distinguished before discussing error measurement : validity and reproducibility.

Validity

Validity is the extent to which, in the absence of measurement error, the value obtained represents the object being measured. This is influenced by what is being measured and also the method of measurement.

Reproducibility

Reproducibility or reliability is defined as the closeness of successive measurements of the same object and this may vary depending on the care taken by the observer, the conditions under which measurements were made and the quality of the records.

Reliability studies indicate the magnitude of errors and the degree to which they affect results. Errors of measurement may be systematic or random.

Systematic errors

Systematic errors or bias arise from limitations in the material or methods employed, leading to consistent under- or over-estimation of a measurement.

Random errors

Random errors are accidental and may result from difficulty in locating landmarks or imprecision of definitions. Both types of errors may be minimised by standardising equipment and procedure during data collection (Houston 1983).

In this study, measurement errors were assessed by a reliability procedure in which double determinations were performed on 10% of the sample, randomly selected from the twin and singleton groups. Errors were minimised by the use of 2.5 times magnification under good lighting during data collection. Recording of a variable was not made if measurement criteria could not be fulfilled.

Double Determinations.

To determine whether any significant distortion occurred upon photocopying of the dental models, 5mm grid graph paper was photocopied and measurements of selected grids on the original and photocopied image were performed with Mitutoyo digital vernier calipers under two times magnification and good lighting. The two measurements differed by a maximum of 0.02mm indicating that no significant distortion occurred between the original and photocopied image.

For arch breadth and depth, each cast was photocopied, landmarks were plotted and measurements made on two separate occasions. Similarly, for arch shape, each cast was photocopied and the landmarks plotted. The Cartesian co-ordinates of these points were obtained using a Hewlett-Packard 9874A digitizer on two separate occasions. The co-ordinates were then transferred to a main frame computer for analysis. The mean difference and associated standard deviation between the first and second determinations of each landmark was 0.50 ± 0.35mm.

For interdental spacing, elastomeric impressions were made of each cast which was then sectioned longitudinally. The interdental space was measured on two separate occasions with digital vernier calipers under two times magnification and good lighting.

The upper and lower dental casts of each individual were hand articulated and overbite, overjet, canine and molar relationships and crossbite were then recorded on two separate occasions.

Methods for Assessing Measurement Error

"Cleaning the data."

Cleaning the data allows detection of frank errors in measurement and can be performed before assessing the magnitude of measurement error. One method of identifying frank errors is through calculation of Z-scores which is the number of units of standard deviation that a score lies away from the mean. Values outside the range +/- 3 may be checked. Z-scores were calculated according to the formula $Z = (x - \bar{x}) / SD$ where x is the measured value, $\bar{x}$ is the sample mean and SD is the standard deviation of the sample.

Statistical Tests

1. Student's t-test.

The paired t-test was used to detect systematic errors by analysing the differences between the first and second determination on a paired comparison basis, according to the following formula:

$$t = \frac{\bar{d}}{SE\bar{d}}$$

where $\bar{d}$ = mean difference between repeated measurements

SE $\bar{d}$ = standard error of the mean difference between repeated measurements

with n-1 degrees of freedom, where n = the number of pairs.

This essentially tests whether the mean difference is significantly different from zero and results are presented in Table 3.5.

2. Dahlberg Statistic

Random errors add to the natural variability of the measurements and may therefore obscure real differences between groups. In this study, Dahlberg's statistic, S_e, or the technical error of measurement (Cameron 1984), was used to determine the magnitude of error of the measurement according to the following formula:

$$Se = \sqrt{\Sigma d^2 / 2n}$$

where d = the difference between repeated measurements

n = the number of double determinations

Results are presented in Table 3.6.

3. Analysis of Variance

In addition to calculating the Dahlberg statistic, S_e, or technical error of measurement, to quantify the magnitude of errors in the methods, the error variance, S_e^2, was expressed as a percentage of the total observed variance for each variable.

By expressing error variance as a percentage of observed variance, that is $(S_e^2/S_{obs}^2)100$, the extent to which variability due to experimental error affected the observed variance can be determined (Table 3.7).

Results and Discussion

Data were analysed using the statistical package SPSSX. The results of the double determinations of interdental spacing, overbite, overjet, arch breadth, arch depth and arch shape are summarised in Table 3.5. Tests at the 5% level indicated that for only one variable, mandibular arch breadth at the molar, did the mean difference differ significantly from zero.

The average measurement errors as indicated by the Dahlberg statistic ranged in value from 0.05mm for interdental spacing to 0.6mm for arch breadth (Table 3.6). Tests at the 5% level indicated that for none of the variables did the mean difference differ significantly from zero.

The error variance was expressed as a percentage of the total observed variance for each variable and the extent to which variability due to experimental error affected the observed variance was determined. Values ranging from 0.7 % for maxillary arch depth to 22.2% for interdental spacing at mandibular M2 and 25.5% for interdental spacing at maxillary M1 (Table 3.7), indicating that care should be taken in interpreting results involving the latter variables.. This will be discussed in a later section of the thesis titled Reliability of Measuring and Scoring Occlusal Variables.

Concordance between first and second determinations was calculated for the discrete variables, molar relationship, canine relationship and crossbite. The percentage concordance ranged from 91.8% for molar relationship to 100% for crossbite (Tables 3.8, 3.9 and 3.10) indicating that these occlusal variables could be assessed with good reliability from the dental casts.

<u>Summary</u>

Errors can be incorporated into the measurement of occlusal variables in a number of ways, for example, limitations in technique or instruments. Statistical tests allow an assessment of the presence and magnitude of such errors. The results obtained indicated that the errors involved were generally of very small magnitude and therefore unlikely to bias the measurements

Table 3.5: Double determinations of the different occlusal variables (in mm) in Australian children.

Variable		n	$\bar{d}$	SE $\bar{d}$	t
Spacing					
Maxilla	I1	30	-0.003	0.029	-0.10
	I2	30	-0.010	0.024	-0.40
	I3	30	-0.007	0.019	-0.36
	I4	30	-0.050	0.026	-1.90
	I5	30	0.017	0.017	1.00
	C1	30	0.020	0.023	0.86
	C2	30	-0.070	0.044	-1.60
	M1	30	0.020	0.040	0.50
	M2	30	0.037	0.028	1.30
Mandible	I1	28	-0.036	0.042	-0.85
	I2	28	0.014	0.016	0.87
	I3	28	0.004	0.020	0.20
	I4	28	0.032	0.039	0.80
	I5	28	0.021	0.022	0.95
	C1	28	-0.014	0.022	-0.60
	C2	28	-0.014	0.028	-0.50
	M1	28	-0.029	0.018	-1.60
	M2	28	0.046	0.039	1.20
	Overbite	30	-0.040	0.062	-0.60
	Overjet	30	0.033	0.072	0.50
Arch Dimensions	AB Max C	30	-0.080	0.054	-1.48
	AB Max M	30	-0.173	0.100	-1.70
	AB Man C	30	0.183	0.157	1.16
	AB Man M	30	-0.217	0.101	-2.10*
	Max Depth	30	-0.010	0.040	-0.25
	Man Depth	30	0.037	0.046	0.80
Arch Shape					
Maxilla	x	37	-0.031	0.040	-0.45
	x^2	37	0.003	0.002	0.14
	x^3	37	0.000	0.000	0.61
	x^4	37	0.000	0.000	0.13
Mandible	x	35	0.009	0.017	0.61
	x^2	35	0.002	0.001	0.26
	x^3	35	0.000	0.000	0.06
	x^4	35	0.000	0.000	0.85

$$t = \frac{\bar{d}}{SE\bar{d}}$$

with n-1 degrees of freedom

* differs significantly from zero at $p < 0.05$.

Table 3.7 : Error and observed variances (in mm^2) for different occlusal variables in Australian children.

Variable		S_e^2	S_o^2	$100 (S_e^2/S_o^2)$
Spacing				
Maxilla	I1	0.011	0.490	2.2
	I2	0.006	0.360	1.8
	I3	0.005	0.490	1.0
	I4	0.010	0.250	4.0
	I5	0.004	0.490	0.9
	C1	0.006	0.250	2.4
	C2	0.029	0.250	11.6
	M1	0.023	0.090	25.5
	M2	0.010	0.090	11.1
Mandible	I1	0.023	0.250	9.2
	I2	0.003	0.360	0.8
	I3	0.005	0.360	1.3
	I4	0.020	0.360	5.5
	I5	0.020	0.250	8.0
	C1	0.006	0.250	2.4
	C2	0.010	0.250	4.0
	M1	0.004	0.090	4.4
	M2	0.020	0.090	22.2
	Overbite	0.053	1.960	2.7
	Overjet	0.073	2.197	3.3
Arch dimension	ABMaxC	0.044	3.240	1.4
	ABMaxM	0.160	4.326	3.7
	ABManC	0.372	2.789	13.3
	ABManM	0.168	3.312	5.0
	Max Depth	0.023	3.38	0.7
	Man Depth	0.029	1.85	1.5

Table 3.8 : Concordance between duplicate assessments of molar relationship in Australian children.

	First determination				
	class	mesial	distal	straight	total
Second	mesial	23	0	1	24
determination	distal	0	4	0	4
	straight	4	0	29	33
	total	27	4	30	61

Concordance : 56/61 = 91.8%

Table 3.9 : Concordance between duplicate assessments of canine relationship in Australian children.

	First determination				
	class	I	II	III	total
Second	I	78	0	0	78
determination	II	5	10	0	15
	III	0	0	2	2
	total	83	10	2	95

Concordance : 90/95 = 94.7%

Table 3.10: Concordance between duplicate assessments of crossbite in Australian children.

	First determination			
		yes	no	total
Second	yes	9	0	9
determination	no	0	53	53
	total	9	53	62

Concordance : 62/62 = 100

4. RESULTS

Summary statistics for the singleton group

Descriptive statistics of occlusal variables allow their frequency distributions to be summarised in numerical terms. For the continuous variables, means ($\bar{x}$), standard deviations (SD) and coefficients of variation (CV) were computed. Estimates of skewness and kurtosis indicated that most of the variables were normally distributed and, consequently, they could be described adequately in terms of means and standard deviations. However, interdental spacing was not strictly normally distributed as there were very few individuals with crowding or negative spacing, and therefore, care should be taken when interpreting these results. For the discrete variables, frequencies of occurrence were computed.

Summary statistics for each of the occlusal variables in the male and female singleton groups will be presented in this section and summary statistics relating to the twin group may be found in Appendix IV. A significant difference was found between the means of the singleton and twin groups for the following variables:

- birth weight
- polynomial coefficient, Max x^3
- interdental spaces, Max M1, Max M2, Man M1 and Man M2.

No significant difference was found in the variances of variables between the singleton and twin groups.

The genetic analysis included calculation of correlation coefficients between twin pairs and application of a univariate genetic modelling analysis using the program Mx to compute heritability estimates. Christian (1979) discusses basic methodology for the analysis of quantitative twin data and states that "analysis of twin data appears to be a rather simple task" (Christian 1979, pp 35) but, in reality, twin data analysis may be confusing due to the number of choices available for hypothesis testing. Christian suggests that whenever comparisons of MZ and DZ twins are used to estimate genetic variance of a trait, a test of the difference between the means of the twin types should be carried out in the initial stages of the analysis, as differences between twin means provide evidence for an association between twin type and the trait under consideration. In addition, Christian states that associations between the variance of a trait and twin type may point to sources of variation that can bias the analysis of genetic variance. In this thesis, means and variances for MZ and DZ twins were computed for each variable prior to any genetic analysis. Significant differences were found for only two variables: the means for the polynomial coefficient, Max x and the variances for polynomial coefficient Max x^4 and overjet.

Birth weight

Table 4.1 shows descriptive statistics for birth weight in the male and female singleton groups. The mean birth weight for males and females were 3.5 ± 0.55 kg(mean ± SD) and 3.4 ± 0.52 kg respectively. An F-test revealed a significant difference in the variance between the two sexes, but the means did not differ significantly ($p<0.05$).

Table 4.1 : Descriptive statistics for birth weight (kg) in male and female Australian singletons.

males			females		
n	$\bar{x}$	SD	n	$\bar{x}$	SD
42	3.5	0.63‡	45	3.4	0.48

‡ significant difference in variance between males and females ($p<0.05$)

In this study, only six (5.8%) singletons and 18 (6.4%) twins had no interdental spacing or crowding, therefore correlation analyses were not performed. Instead, Z-scores were computed for the birth weights, tooth sizes and arch dimensions of those individuals with no spacing or with crowding. A z-score is defined by the formula:

$z = x- \bar{x} / SD$

where x is the individual value, $\bar{x}$ is the sample mean and SD is the standard deviation of the sample. Under the assumption of a normal distribution, it is expected that approximately 68% of individuals will fall in the range $\bar{x} \pm 1$ SD, 95% will fall in the range $\bar{x} \pm 2$ SD and 99% will fall in the range $\bar{x} \pm 3$ SD.

Z-scores for birth weight in singletons with no spacing or with crowding ranged between -0.8 and +0.6, that is, all individuals fell within one standard deviation of the mean. For tooth size (MDCD) in these individuals, z-scores ranged between +1.1 and +2.2 in the maxilla and between +0.5 and +2.3 in the mandible indicating that tooth size of all singletons with no interdental spacing or with crowding was larger than average. Z-scores for arch dimensions in those individuals with no interdental spacing or with crowding ranged between -1.2 and +1.6. Generally, there was an even spread of z-scores above and below the mean.

Z-scores for birth weight in twins with no spacing or with crowding ranged between -2.8 and +1.0. Z-scores for tooth size ranged between +0.1 and +2.1 in the maxilla and between 0 and +2.1 in the mandible and for arch dimensions, z-scores ranged between -2.5 and +1.2. However, generally z-scores in both MZ and DZ twins were below the mean for all arch dimensions.

Interdental spacing

A wide variation in the pattern of interdental spacing was found within the singleton group. Tables 4.2 and 4.3 show descriptive statistics for interdental spacing in male and female Australian singletons (primate spaces are shown in bold type). Mean values ranged from 0.2 ± 0.25 mm (mean ± SD) to 1.1 ± 0.68 mm in males and from 0.3 ± 0.23 mm to 1.2 ± 0.60 mm in females. Mean values and standard deviations of interdental spacing reported by Joshi and Makhija (1984) were generally smaller than the values found in the present study, although the pattern of interdental spacing (for example, males versus females and anterior versus posterior) was similar. In the present study, t-tests showed no significant difference in mean values between males and females ($p<0.05$), however, the mean values for males tended to be of equal magnitude or slightly higher than those in the female group. A significant difference in variance was found between males and females for Max I2 and Max M1 ($p<0.05$).

Apart from the study by Joshi and Makhija (1984), no other published studies of this nature could be found for comparison.

Table 4.2 : Descriptive statistics for interdental spacing in male Australian singletons (mm).

Maxilla	n	$\bar{x}$	SD	Range
I 1	**58**	**1.1**	**0.68**	**0.0 - 3.1**
I 2	58	0.8	0.54‡	-1.2 - 1.7
I 3	58	0.5	0.71	0.0 - 2.8
I 4	58	0.8	0.49	-0.3 - 1.7
I 5	**58**	**1.2**	**0.68**	**0.0 - 3.3**
C 1	57	0.8	0.42	0.0 - 1.8
C 2	58	0.9	0.44	0.0 - 2.2
M 1	55	0.4	0.39‡	0.0 - 1.7
M 2	54	0.4	0.32	0.0 - 1.3
Mandible				
I 1	56	0.5	0.52	-0.8 - 1.6
I 2	58	0.6	0.61	-1.3 - 1.9
I 3	58	0.6	0.64	-0.4 - 2.4
I 4	58	0.5	0.49	-0.8 - 1.4
I 5	58	0.5	0.49	-1.0 - 1.5
C 1	**58**	**0.8**	**0.51**	**0.9 - 2.0**
C 2	**58**	**0.8**	**0.55**	**0.0 - 1.3**
M 1	56	0.3	0.25	0.0 - 0.9
M 2	57	0.2	0.25	0.0 - 0.9

‡ significant difference in variance between males and females ($p<0.05$)

It is evident that, generally, interdental spacing was larger in the anterior segments than the posterior segments of the arch and also larger in the maxillary arch compared with the mandibular arch. The mean value for interdental spacing was smaller between the molar teeth than anterior teeth in both the maxilla and mandible, in males and females. The mean values, with associated standard deviations, for molar interdental spaces M1, M2, in the maxilla, and molar interdental spaces M1 and M2 in the mandible, were 0.4 ± 0.35 mm, 0.4.± 0.32 mm, 0.3 ± 0.28mm, and 0.3 ± 0.24 mm respectively. Within the singleton group, 0.5mm or less space was present in each of the molar spaces MaxM1, MaxM2, ManM1 and ManM2 in 75.7%, 79.8%, 89.0% and 92.6% of the sample respectively.

females. This contrasts with the findings of Joshi and Makhija (1984) who found the amount of spacing was greater in their male sample when compared with their female sample in both the maxilla and mandible. El-Nofely et al. (1989) reported dental arches with no spacing were more frequent in the mandibular arch, particularly in females.

Table 4.4 : Frequency of occurrence of dental arches with no spacing or with crowding in Australian singletons (percentage frequency).

No space or crowding	Males and females combined	Males	Females
Maxilla	0 (0.0)	0 (0.0)	0 (0.0)
Mandible	6 (5.8)	5 (9.3)	1 (2.0)
Total	103	54	49

Table 4.6 (on page127) shows a comparison of the frequency of occurrence of primate spaces and dental arches with no spacing derived from previous studies. The reported frequency of occurrence of dental arches with no interdental spacing is generally low, ranging from 0.0% to 24% in the maxillary arch and between 5% and 54% in the mandibular arch. Although a general pattern of less spacing in the mandibular arch than in the maxillary arch emerges, comparison between the studies should be interpreted with caution as in a number of the studies, denoted by #, only spacing in the anterior segment of the arches was recorded.

Table 4.5 shows the mean total spacing present in the dental arches in male and female Australian singletons, that is, the total spacing derived by addition of individual interdental spaces in the maxillary and mandibular arches. The mean total interdental spacing was greater in the maxilla than the mandible, in both males and females. This concurs with the findings of other authors, including Moorrees (1950), Kaufman and Koyoumdjisky (1967), Joshi and Makhija (1984) El-Nofely et al. (1989) and Ohno et al. (1990). In the present study, t-tests revealed a significant difference existed in total arch space between the maxilla and mandible, in both males and females.

Table 4.5 : Descriptive statistics for total arch spacing in male and female Australian singletons (mm).

Total space	Males			Females		
	n	$\bar{x}$	SD	n	$\bar{x}$	SD
maxilla	53	6.8	2.96	50	6.6	3.23
mandible	54	4.6	3.01	49	5.1	2.64

no significant difference between mean values for males and females ($p<0.05$).

Primate spaces

Mean values ranged from 1.1 ± 0.65 mm (mean ± SD) in the maxilla to 0.8 ± 0.50mm in the mandible (Tables 4.2 and 4.3). No significant difference was found in the means between males and females in the present study. Unpaired t-tests showed a significant difference in the total average size of the primate spaces between the maxilla and mandible at the 5% level, in males and females.

Mean values for primate spaces were greater in the maxilla than in the mandible and tended to be larger than the other interdental spaces in each arch, in both the male and female groups. Joshi and Makhija (1984) also found primate spaces to be larger than other interdental spaces in the maxilla but not in the mandible in both males and females. El-Nofely et al. (1989) reported that in arches where only primate spaces were present, the frequency of occurrence was greater in the maxillary arch, in both males and females. Ohno et al. (1990) found mandibular primate spaces were considerably less frequent than maxillary primate spaces.

The frequency of occurrence of primate spaces in the maxilla, for males and females combined, was 93.9% and in the mandible, 91.2%, which is consistent with many reports in the literature. When the male and female samples were separated, the frequency of occurrence of primate spaces was greater in males in the maxilla and in females in the mandible. Joshi and Makhija (1984) found that primate spaces were more frequent in males in both maxilla and mandible. The frequencies of occurrence of primate spaces are generally high, ranging from 42.5% to 98% in the maxillary arch and from 21% to 91.2% in the mandibular arch (Table 4.6). In all studies, the frequency of primate spaces is always greater in the maxilla than in the mandible.

The range in both the frequency of occurrence of primate spaces and the frequency of no interdental spacing reflects the variation that exists in these occlusal characteristics between different populations.

Table 4.6 : Comparison of the frequency of occurrence of interdental spacing in the maxillary and mandibular arches, males and females combined (percentage frequencies).

		Primate Spaces		No spacing	
Study	Number (n)	Maxilla	Mandible	Maxilla	Mandible
Kaufman, 1967	313	85.9	64.8	15.8*	
Boyko, 1968	50	98.0	86.0	2.0*	-
Foster, 1969	100	87.0	78.0	3.0*	4.0
Ravn, 1975	310	85-92	85	3.5	5.0
Kisling, 1976	1624	83.0	87.0	-	-
Joshi, 1984	100	42.5	21.0	12.5*	
El-Nofely, 1989#	243	88.6	69.3	11.0	20.5
Tschill, 1997#	789	75.0	45.0	24.0	54.0
Otuyemi, 1997	525	61.0	59.0	24.0	26.0
Thomas, 1999#	328	88.8	72.8	9.6	17.8
Alexander, 1998	1026	-	-	3.1*	
Kaube, 1995#	221	85.0*		4.0	10.0
Present study	114	93.9	91.2	0.0	5.8

* Maxillary and mandibular arches combined

\# Study only included spacing in the anterior segment of the arch

<u>Arch dimensions</u>

Tables 4.7 and 4.8 show descriptive statistics for arch dimensions in male and female Australian singletons. The mean values for each dimension were greater in the maxilla than in the mandible.

A significant difference was found between the means in males and females for each variable except maxillary arch depth and mandibular arch breadth at the canine. In addition, a significant difference was found in the variance for ABManM and Man depth between males and females ($p<0.05$). The variability in arch breadth at the canine was greater than the variability at the molar in both arches and sexes. Maxillary arch depth tended to be more variable than mandibular arch depth.

Table 4.7 : Descriptive statistics for arch dimensions in male Australian singletons (mm).

Maxilla	n	$\bar{x}$	SD	CV
ABMaxC[a]	57	28.4**	1.99	7.0
ABMaxM[b]	56	34.0**	2.05	6.0
MaxDepth[c]	45	28.3	2.08	7.3
Mandible				
ABManC	58	22.4	1.73	7.7
ABManM	58	29.2*	1.54‡	5.3
ManDepth	57	24.5*	1.48‡	6.0

mean values differ significantly between males and females **($p < 0.01$), *($p<0.05$)
‡ variance differs significantly between males and females ($p<0.05$)
CV = $(SD/\bar{x})100$

[a]Arch breadth at the canine
[b]Arch breadth at the molar
[c]Arch depth

4.8 : Descriptive statistics for arch dimensions in female Australian singletons (mm).

Maxilla	n	$\bar{x}$	SD	CV
ABMaxC	55	27.4	1.69	6.2
ABMaxM	55	32.7	1.92	5.9
MaxDepth	43	27.1	1.79	6.5
Mandible				
ABManC	57	22.2	1.62	7.3
ABManM	55	28.4	1.99	7.0
ManDepth	51	23.9	1.16	4.9

$CV = (SD/\bar{x})100$

The results of the present study were similar to those of Moorrees (1959). Comparison of mean values between the present and other published studies is difficult as different landmarks were used. Foster et al. (1969) found a significant difference existed at the 5% level between males and females for arch breadth at the molar in both maxilla and mandible and for arch depth in the maxilla, and similar standard deviations were found by El-Nofely et al. (1989) in his study of arch dimensions in pre-school children.

<u>Overbite and overjet</u>

Table 4.12 shows descriptive statistics for overbite and overjet in male and female Australian singletons. The mean values for overbite in males and females was 2.0 ± 0.91 mm (mean ±SD) and 1.6 ± 1.76 mm respectively and for overjet 2.5 ± 0.96 mm and 2.5 ± 1.62 mm respectively. No significant difference was found in the mean values between the two groups for either variable; however, a significantly larger variance for overbite and overjet was noted in the female group when compared with the male group ($p<0.01$). The variation in overbite can be accounted for by the fact that 13.1% of the female group had open bites, ranging from -4mm to 0mm, whereas none of the males displayed this feature.

For overjet, the range in the female sample was –1.5 to 8.0mm and for the male sample, 1.0 to 5.5mm. Comparison of mean values between the present and published studies is difficult as most published studies do not report a value for overbite but give overbite in discrete categories according to the degree of overlap of the maxillary incisor over the mandibular incisor.

Overjet, however, is frequently recorded as a metric value and its frequency of magnitude presented. There is general agreement in the literature that the "ideal" overjet in the primary dentition is approximately 2mm (Foster and Hamilton 1969, Otuyemi et al. 1997). The most frequently occurring value for overjet in the majority of published studies is 2mm and this concurs with the findings of the present study.

Table 4.12 : Descriptive statistics for overbite and overjet in male and female Australian singletons (mm).

Variable		n	$\bar{x}$	SD	CV
overbite	male	56	2.0	0.91	45.5
	female	54	1.6	1.76‡	110.0
overjet	male	56	2.5	0.96	38.4
	female	54	2.5	1.62‡	64.8

‡ significant difference in variance between males and females ($p<0.01$).
$CV = (SD/\bar{x})100$

Polynomial coefficients

In all cases, fourth-order polynomial equations fitted the data well with all correlations between the polynomial terms and the data exceeding 0.99.

Tables 4.13 and 4.14 show the distribution of the polynomial coefficients for male and female Australian singletons. The quadratic and quartic terms, reflecting overall arch shape, did not differ significantly between males and females. Similarly, the linear and cubic terms, representing arch asymmetry, did not differ significantly between males and females.

Table 4.13 : Polynomial coefficients for maxillary and mandibular dental arches in male Australian singletons.

Maxilla	n	$\bar{x}$	SD
x	45	2.4	50.8
x^2	45	2.5	1.1
x^3	45	-1.4	3.2
x^4	45	5.1	2.0
Mandible			
x	58	1.2	43.8
x^2	58	3.4	1.0
x^3	58	-11.0	2.2
x^4	58	5.6	3.3

no significant difference between males and females ($p<0.05$).
coefficients scaled: x ($x\ 10^3$), x^2 ($x\ 10^2$), x^3 ($x\ 10^4$), $x^4(10^5)$.

Table 4.14 : Polynomial coefficients for maxillary and mandibular dental arches in female Australian singletons.

Maxilla	n	$\bar{x}$	SD
x	40	-9.3	51.9
x^2	40	2.8	1.1
x^3	40	-1.2	4.0
x^4	40	5.4	1.9
Mandible			
x	53	-7.1	46.7
x^2	53	3.3	1.1
x^3	53	-0.8	2.5
x^4	53	6.5	2.8

coefficients scaled: x ($x\ 10^3$), x^2 ($x\ 10^2$), x^3 ($x\ 10^4$), $x^4(10^5)$.

The very high standard deviation scores for the linear coefficients reflect the variability of these coefficients about the mean. The precise reason for this high variability is unclear, although it presumably reflects considerable variation in linear asymmetry in the samples.

No other similar published studies on dental arch morphology of the primary dentition were available for comparison, but Richards et al. (1990) studied dental arch morphology in a sample of twins with permanent dentitions using fourth-order polynomials. The authors found that, in all cases, the fourth-order polynomial equations fitted their data well with correlations exceeding 0.98 which compares well with the correlation value of 0.99 found in the present study. The authors reported that correlations between age and each of the polynomial coefficients were small ($r<0.16$) indicating that no significant age-related trends in arch shape or asymmetry existed.

Canine relationship

Table 4.16 shows the frequency of occurrence of different canine relationships in Australian singletons. The frequency of a Class I relationship ranged from 66.1% in males on the right side to 52.8% in females on the left side. The lowest frequency was noted for Class III relationships, occurring in 1.9% of females and not at all in the male sample. A chi-squared test showed no significant difference in frequency between males and females ($p<0.05$). A highly significant association was found for canine relationship between the left and right sides ($p<0.01$), concordance between the left and right being 78.0%.

Table 4.16 : Frequency of occurrence of different types of canine relationship in Australian singletons (percentages in parentheses).

Category	Males		Females	
	right	left	right	left
Class I	37 (66.1)	30 (53.6)	29 (54.7)	28 (52.8)
Class II	19 (33.9)	26 (44.8)	23 (43.4)	25 (44.6)
Class III	0 (0.0)	0 (0.0)	1 (1.9)	0 (0.0)
Total	56 (100)	56 (100)	53 (100)	53 (100)

no significant difference between males and females ($p < 0.05$)

Table 4.17 shows a comparison of the frequency of occurrence of different types of canine relationships between published studies. Generally, the frequency of Class I canine relationships was highest followed by Class II and then Class III. The frequencies of occurrence found in the present study compared well with other published studies.

Table 4.17 : Comparison of the frequency of occurrence of bilateral canine relationships, males and females combined (percentage).

Study	n	Class I	Class II	Class III
Foster and Hamilton,1969	100	40.0	45.0	1.0
Ravn, 1975	310	45.5	36.6	0.6
Otuyemi et al. 1997	525	73.3	63.0	14.7
Tschill et al. 1997	789	54.7	26.0	0.5
Present study	114	56.9	41.7	1.9

Molar relationship

Table 4.18 shows the frequency of different types of molar relationship in Australian singletons. The Class I molar relationship or straight terminal plane was most frequent, ranging from 62.5% in females to 84.0% in males, while Class III or mesial terminal plane relationships were the least frequent, ranging from 6.0% in the males to 16.7% in the females. A chi-squared test showed no significant difference between males and females ($p<0.05$). A highly significant association was found between the left and right side molar relationship ($p<0.01$) and concordance between the left and right sides was 81.1%.

Table 4.18 : Frequencies of occurrence of different types of molar relationships in Australian singletons (percentage in parentheses).

Category	Males		Females	
	right	left	right	left
Class I	42 (84.0)	38 (74.5)	39 (79.6)	30 (62.5)
Class II	5 (10.0)	8 (15.7)	5 (10.2)	10 (20.8)
Class III	3 (6.0)	5 (9.8)	5 (10.2)	8 (16.7)
Total	50 (100)	51 (100)	49 (100)	48 (100)

no significant difference between males and females ($p < 0.05$)

Table 4.19 shows a comparison of the frequency of molar or terminal plane relationships between published studies. The percentage frequency of Class I or straight terminal plane relationship ranged from 4.2% to 86.0%. The location of reference points varies slightly between studies. For example, in the study by Kisling and Krebs (1976), the reported frequency of a straight terminal plane relationship was very low compared with other studies. However, two differences should be noted : Kisling and Krebs (1976) used the mesial surface of the second molar tooth as the reference point and not the distal surface as have all other studies, and the percentage reported included only individuals with a normal transverse relationship of the maxilla to mandible, that is, only individuals with no crossbite were included.

The frequency of a Class III or mesial terminal relationship varied between 1.0% and 52.5% and a Class II or distal terminal plane relationship between 1.0% and 23.6%. In the present study, the frequencies of occurrence of straight, mesial and distal terminal plane relationships were 75.1, 10.5 and 14.1% respectively which compare favourably with other published studies. Even though the frequency of occurrence of the different terminal plane relationships varies between studies, a general pattern is evident. That is, the most frequent relationship is the straight terminal plane, followed by a mesial terminal plane and then a distal terminal plane.

Bilateral asymmetry in the terminal plane relationship was reported in a number of the studies and ranged in frequency between 2.7% and 43.0% compared with 18.9% in the present study.

Table 4.19 : Comparison of the frequency of occurrence of terminal plane relationships, males and females combined (percentage frequencies).

Study	n	Straight	Mesial	Distal	Asymmetry
Nanda,1973	603	58.0	25.5	9.0	7.5
Baume, 1950	60	86.0	14.0	0.0	-
Clinch, 1957	61	14.3	33.3	9.55	43.0
Kaufman,1967	330	68.3	28.8	0.0	2.9
Boyko, 1968	50	64.0	14.0	12.0	4.0
Kisling, 1976	1624	4.2	52.5	23.6	19.7
Foster, 1969	100	42.0	1.0	22.0	14.0
Ravn, 1975	310	18.7	31.2	14.8	35.3
Ravn, 1980	269	19.3	30.1	13.8	36.8
Otuyemi, 1997	525	74.5	20.9	1.9	2.7
Infante, 1974	200	76.5	0	23.5	-
Alexander,1998	1036	67.3	24.9	7.8	-
Kaube,1995	221	53.0	43.0	1.0	-
Present study	114	75.1	10.5	14.1	18.9

Crossbite relationships

The frequencies of occurrence of different types of crossbite in Australian singletons are presented in Table 4.20. The highest frequency of occurrence was recorded for no crossbite, ranging from 87.5% in females and 91.4% in males. Unilateral crossbite occurred in 10.7% of females and 8.6% of males and bilateral crossbite was recorded least frequently, 1.8% of the female group and not at all in the male group.

A chi-square test showed no significant difference between males and females ($p<0.05$).

Table 4.20 : Frequency of occurrence of different types of crossbite in Australian singletons (percentage in parentheses).

Category	Males	Females
no crossbite	53 (91.4)	49 (87.5)
unilateral crossbite	5 (8.6)	6 (10.7)
bilateral crossbite	0 (0.0)	1 (1.8)
Total	58 (100)	56 (100)

no significant difference between males and females

Table 4.21 shows that similar results were found by Foster and Hamilton (1969), Ravn (1975), Kisling and Krebs (1976), Otuyemi et al. (1997) and Tschill et al. (1997) for both unilateral and bilateral crossbite relationships.

Table 4.21: Comparison of the percentage frequency of occurrence of crossbite relationships between published studies.

Study	n	unilateral crossbite (%)	bilateral crossbite (%)
Foster and Hamilton, 1969	100	7.0	4.0
Ravn, 1975	310	18.0	4.0
Kisling and Krebs, 1976	1624	13.2	0.7
Otuyemi et al., 1997	525	4.0	0.8
Tschill et al., 1997	789	5.9	4.1
Present study	114	9.7	1.8

Correlations between age and various arch dimensions

Table 4.9 shows values of correlation coefficients between age and various arch dimensions in the singleton group. Correlations between age and arch dimensions were generally low, in both males and females. Within the male sample, correlation values ranged from 0.06 between age and arch breadth at the canine in the maxilla to -0.21 between age and mandibular arch depth (ManDepth). Within the female sample, correlation values ranged from 0.12 between age and arch breadth in the mandible at the canine (ABManC) to -0.13 between age and maxillary arch depth (MaxDepth).

Correlation values between intra-arch breadth dimensions were generally moderate and significant ($p<0.01$) in males and females, ranging from 0.43 to 0.81, indicating that associations existed between arch breadth at the canine and molar, in both, maxillary and mandibular arches.

Table 4.9 : Values of correlation coefficients between age and various primary arch dimensions- male data above diagonal, female data below.

	Age	ABMaxC	ABMaxM	ABManC	ABManM	MaxDepth	ManDepth
Age	1.00	0.06 (42)	-0.08 (41)	-0.13 (43)	-0.10 (43)	0.05 (33)	-0.21 (42)
ABMaxC	-0.01 (46)	1.00	0.76** (56)	0.60** (57)	0.54** (57)	0.37*(45)	0.46** (56)
ABMaxM	0.01 (46)	0.81** (55)	1.00	0.43** (56)	0.61** (56)	0.21 (45)	0.30* (55)
ABManC	0.12 (46)	0.49**55)	0.58** (55)	1.00	0.60**(56)	0.40**(45)	0.40**(57)
ABManM	-0.06 (46)	0.50**(55)	0.74**(55)	0.79**(55)	1.00	0.30 (45)	0.26 (57)
MaxDepth	-0.13 (36)	0.18 (43)	-0.11 (43)	0.21 (43)	0.01 (43)	1.00	0.68**(45)
ManDepth	0.03 (44)	0.42**(51)	0.27 (51)	0.53**(51)	0.30*(51)	0.54**(43)	1.00

Number of pairs indicated in parentheses

*p<0.05, **p<0.01

Correlation values between MaxDepth and arch breadth dimensions were low and not significant in the female group. Within the male group, a significant association was found between MaxDepth and ABMaxC ($p<0.05$) and between MaxDepth and ABManC ($p<0.01$).

Correlation values between ManDepth and arch breadth dimensions were generally low but significant in both males and females. A highly significant association ($p<0.01$) was found between ManDepth and ABMaxC and also between ManDepth and ABManC in both male and female groups. A significant association ($p<0.05$) was found between ManDepth and ABMaxM in the male group and between ManDepth and ABManM in the female group. No statistically significant association was found between ManDepth and ABManM in the male group or between ManDepth and ABMaxM in the female group.

Correlation values between maxillary arch depth and mandibular arch depth were of moderate magnitude but significant statistically ($p<0.01$), in both males and females, values being 0.68 and 0.54 respectively.

Correlations between arch breadths, total interdental arch space and total mesiodistal tooth dimensions

Table 4.10 shows values of correlation coefficients between arch breadths, total interdental arch space and total mesiodistal crown dimensions (MDCD) in the maxillary arch in Australian singletons.

Table 4.10 : Values of correlation coefficients between arch breadths, total interdental spacing and total mesiodistal tooth diameters in the maxillary arch in Australian singletons - males data above diagonal, female data below .

Maxilla	Total ID spacing[a]	ABMaxC	ABMaxM	MDCM Total
Total ID spacing	1.00	0.43**(52)	0.51**951)	0.06 (40)
ABMaxC	0.22 (50)	1.00	0.76**(56)	0.23 (43)
ABMaxM	0.04 (50)	0.81**(50)	1.00	-0.04 (42)
MDCM Total	-0.36 *(36)	0.21 (40)	0.16 (40)	1.00

Numbers of pairs indicated in parentheses

*p<0.05, **p<0.01

[a] Total average interdental spacing

Correlation values between intra-arch breadth dimensions were high and significant ($p<0.01$), ranging from 0.76 to 0.81 for males and females respectively.

Correlation values between total mesiodistal crown dimensions (MDCD) and total interdental spacing and between total MDCD and arch breadths were generally low and not significant in both males and females. However, a low negative but significant ($p<0.05$) correlation value was found between MDCD and interdental spacing in the female group suggesting that as the total MDCD decreased, total interdental spacing increased and vice versa.

Within the male group, a moderate and highly significant ($p<0.01$) correlation value was found between interdental spacing and arch breadth at the canine and molar, indicating that, as interdental spacing increased, so did arch breadth. However, low and non-significant correlation values were noted between these variables in the female group.

Table 4.11 shows values of correlation coefficients between arch-breadths, total interdental spacing and total MDCD in the mandible in Australian singletons. Correlation values between intra-arch breadth dimensions were moderate and highly significant ($p<0.01$), 0.60 and 0.79 in males and females respectively.

Correlation values between total MDCD and total interdental spacing and between total MDCD and arch-breadths were low and non-significant in the male sample, ranging from -0.10 to 0.20. However, in the female sample, correlation values were moderate and significant ($p<0.05$, $p<0.01$) which is the opposite of the trend noted in the maxillary arch between males and females.

Table 4.11 : Values of correlation coefficients between arch breadths, total interdental spacing and total mesiodistal tooth diameters in the mandibular arch in Australian singletons - males data above diagonal, female data below .

Mandible	Total ID spacing[a]	ABManC	ABManM	MDCM Total
Total ID spacing	1.00	0.21 (54)	0.20 (54)	-0.10 (48)
ABManC	0.55**(49)	1.00	0.60**(58)	0.18 (51)
ABManM	0.44**(49)	0.79**(55)	1.00	0.20 (51)
MDCM Total	-0.38 *(43)	0.22 (46)	0.23 (46)	1.00

Numbers of pairs indicated in parentheses

*p<0.05, **p<0.01

[a] Total average interdental spacing

Correlations between age and polynomial coefficients

Table 4.15 shows values of correlation coefficients between age and polynomial coefficients in Australian singletons. Correlations between age and each of the polynomial coefficients were low ($r<0.28$) indicating that there were no significant age-related trends in arch shape and asymmetry.

The correlations between polynomial terms (Table 4.15) include relatively high negative values between quartic and quadratic coefficients in both maxilla and mandible. For example, in the males, a value of -0.54 was found between MaxX2 and MaxX4, and, in the female sample, a value of -0.71 was found between ManX2 and ManX4. This reflects the fact that a particular arch cannot be both tapered (high quadratic term) and square (high quartic term).

Table 4.15 : Values of correlation coefficients between age and polynomial coefficients - male data above diagonal, female data below.

	Age	ManX1	ManX2	ManX3	ManX4	MaxX1	MaxX2	MaxX3	MaxX4
Age	1.00	-0.17 (43)	0.04 (43)	0.07 (43)	0.11 (43)	0.24 (33)	-0.8 (33)	0.12 (33)	0.28 (33)
ManX1	-0.01 (45)	1.00	0.61 (58)	-0.10 (58)	0.16 (58)	0.10 (45)	-0.21 (45)	-0.02 (45)	0.19 (45)
ManX2	-0.15 (45)	-0.02 (53)	1.00	-0.19 (58)	-0.28* (58)	0.07 (45)	0.29 (45)	-0.05 (45)	0.11 (45)
ManX3	-0.15 (45)	-0.05 (53)	-0.11 (53)	1.00	0.37**(58)	-0.11 (45)	0.01 (45)	-0.14 (45)	-0.06 (45)
ManX4	0.17 (45)	0.12 (53)	-0.71**(53)	0.18 (53)	1.00	-0.07 (45)	-0.03 (45)	-0.05 (45)	-0.02 (45)
MaxX1	-0.20 (34)	0.18 (40)	0.01 (40)	0.34*(40)	-0.05 (40)	1.00	-0.50**(45)	-0.02 (45)	0.93**(45)
MaxX2	-0.04 (34)	0.11 (40)	0.33*(40)	-0.28 (40)	-0.01 (40)	-0.50**(40)	1.00	0.01 (45)	-0.54**(45)
MaxX3	0.19 (34)	0.10 (40)	-0.03 (40)	0.03 (40)	-0.02 (40)	0.06 (40)	0.07 (40)	1.00	-0.05 (45)
MaxX4	-0.05 (34)	-0.03 (40)	-0.20 (40)	0.33*(40)	0.07 (40)	0.34*(40)	-0.80**(40)	-0.10 (40)	1.00

Number of pairs in parentheses

*p<0.05, **p<0.

Genetic Analysis

Correlation analysis between twin pairs

Tables 4.22 to 4.25 show the values of correlation coefficients between monozygous (MZ) and dizygous (DZ) twin pairs for various occlusal traits. Pooling of the data from same-sex DZ and opposite-sex DZ twins was carried out because there was no significant gender differences in the means or variances.

Assuming a polygenic mode of inheritance for occlusal traits, we would expect to find maximum values for correlation coefficients of 1.00 for MZ twins and 0.5 for DZ twins. In terms of additive genetic (V_A) and dominance genetic (V_D) components, the expected correlation for MZ twins is $r_{MZ} = V_A + V_D$ while for DZ twins, $r_{DZ} = 0.5V_A + 0.25V_D$, as MZ twins all of their genes and DZ twins share on average only half of their genes. Recorded values for the MZ twins were all less than 1.00 indicating that environmental factors modify the phenotypic expression of occlusal traits. Where r values for the DZ twins are less then half the r value recorded for the MZ twins, there is some evidence that a contribution of genetic dominance, as well as additive genetic variance, is important for the particular variable, for example, for MaxI2. Conversely, when r values for the DZ twins are greater than half the r value recorded for MZ twins, this suggests that common environment is playing an important role; for example, for Max M2, Man M1 and Man M2.

<u>Interdental spacing</u>

Within the MZ twin group, correlations were generally moderate to high, with significant values ranging from 0.39 to 0.83 (Table 4.22). In the mandibular arch, correlation coefficients for M1 and M2 were 0.13 and 0.29 respectively with no significant difference from zero at the 5% probability level. This suggests that genetic factors were not greatly important in determining variation in these variables.

Within the DZ group, correlations were low to moderate with significant values ranging from 0.34 to 0.53 (Table 4.22). Six values showed no significant difference from zero, suggesting that environmental factors played an important role for these variables.

Table 4.22: Correlation coefficients between twin pairs for interdental spacing.

	MZ		*DZ*	
Variable	*n*	*r*	*n*	*r*
MaxI1	35	0.79	44	0.35
MaxI2	35	0.69	42	0.19[#]
MaxI3	34	0.83	44	0.26[#]
MaxI4	33	0.76	44	0.28[#]
MaxI5	34	0.80	44	0.34
MaxC1	35	0.78	44	0.37
MaxC2	34	0.69	43	0.39
MaxM1	30	0.46	40	0.25[#]
MaxM2	26	0.39	39	0.34
ManI1	35	0.78	45	0.31[#]
ManI2	35	0.65	45	0.48
ManI3	35	0.78	45	0.41
ManI4	33	0.74	45	0.49
ManI5	35	0.75	44	0.47
ManC1	35	0.79	44	0.53
ManC2	35	0.74	45	0.51
ManM1	32	0.13[#]	40	0.25[#]
ManM2	30	0.29[#]	44	0.35

[#] Not significantly different from zero at the 5% probability level

Arch Dimensions

Correlation coefficients for arch dimensions are reported in Table 4.23. Within the MZ twin group, values were generally high, with significant values ranging from 0.73 to 0.92. Within the DZ group, values ranged between 0.27 and 0.48, approximately half those for MZ twins. A significant difference from zero was noted for all variables, except ABManC, suggesting that environmental factors play an important role in the variation of this variable.

Table 4.23: Correlation coefficients between twin pairs for arch dimensions.

	MZ		*DZ*	
Variable	*n*	*r*	*n*	*r*
ABMaxC	35	0.82	45	0.30
ABMaxM	34	0.89	45	0.48
ABManC	34	0.73	45	0.27[#]
ABManM	35	0.92	45	0.32
MaxDepth	33	0.81	40	0.31
ManDepth	33	0.88	42	0.43

[#] Not significantly different from zero at the 5% probability level

Overbite and Overjet

Correlation coefficients for overbite and overjet are reported in Table 4.24. Within the MZ group, significant values were recorded, 0.63 and 0.35 respectively, and within the DZ group, values were 0.00 and 0.04 respectively. No significant difference from zero was noted for either variable within the DZ twin group suggesting that environmental factors were important in variation of overbite and overjet.

Table 4.24 : Correlation coefficients between twin pairs for overbite and overjet.

Variable	MZ		DZ	
	n	r	n	r
Overbite	35	0.63	44	0.00#
Overjet	35	0.35	44	0.04#

Not significantly different from zero at the 5% probability level

Polynomial coefficients

Within the MZ twin group, values of correlations between pairs for arch shape, that is the quadratic X^2 and quartic X^4 terms, tended to be moderate to high with significant values ranging from 0.64 to 0.82, whereas values for arch asymmetry, that is the linear X and cubic X^3 terms, tended to be low and not significant, ranging from -0.11 to 0.30. These findings indicated that genetic factors significantly influenced arch shape but that environmental factors significantly influenced arch asymmetry (Table 4.25). Within the DZ twin group, correlations were generally lower than the MZ group and generally not significantly different from zero, but no particular pattern emerged for any coefficients. Values of correlations between DZ twin pairs for two coefficients, MaxX and ManX^4, showed no significant difference from zero ($p<0.05$). This may be due, in part, to Type II errors caused by low sample size so results should be interpreted with caution.

Richards et al. (1990) found a similar pattern for correlation values in their sample of twins, although values for the polynomial coefficients describing both arch shape and asymmetry were generally higher in the present study.

Table 4.25 : Correlation coefficients between twin pairs for maxillary and mandibular polynomial coefficients.

	MZ		DZ	
Variable	*n*	*r*	*n*	*r*
ManX	33	0.13#	41	0.11#
ManX²	33	0.64	41	0.30#
ManX³	33	-0.12#	41	-0.25#
ManX⁴	33	0.71	41	0.55
MaxX	33	-0.04#	41	0.43
MaxX²	33	0.82	41	0.11#
MaxX³	33	0.30#	41	0.17#
MaxX⁴	33	0.82	41	0.08#

Not significantly different from zero at the 5% probability level

Birth weight

Within the MZ twin group (n = 32), a correlation coefficient of 0.58 was found for birth weight and for the DZ group (n = 45) a value of 0.68 was reported suggesting that although genetic factors contribute to birth weight, environmental factors play an important role.

Genetic Modelling

Genetic modelling indicated that a model incorporating additive genetic (A) and unique environmental (E) variation was the most parsimonious for most occlusal variables. The exceptions for which a shared environmental model (CE) or unique environmental (E) model was the model of best fit included birth weight, molar interdental spaces M1 and M2 in both maxilla and mandible and polynomial coefficients describing arch asymmetry. There was significant heterogeneity between the sexes for variance components of interdental spaces MaxI2, Max I3 and ManI2. For these variables, generally females displayed higher additive genetic variance and lower unique environmental variance than males.

Tables 4.26 to 4.28 list heritability estimates (h^2) with associated 95% confidence intervals for various occlusal traits in Australian twins. Values were generally moderate to high and ranged from 0.28 to 0.89.

Interdental spacing

Table 4.26 presents heritabilities for interdental spacing in Australian twins with values ranging from 0.62 to 0.81. Generally, the AE model was adequate for all interdental spaces except the molar spaces M1 and M2 in both arches for which a CE model was generally the model of best fit. This would suggest that the interdental spaces in the posterior region of the arch were under environmental control and had no heritable component. The primate spaces, MaxI1, MaxI5, ManC1 and ManC2, (thought to be genetically determined as opposed to other developmental spaces) showed heritabilities similar to those of other interdental spaces in the present study.

Significant heterogeneity in variance between males and females for interdental spaces MaxI2, MaxI3 and ManI2 revealed that females showed a higher additive genetic variance for MaxI3 and ManI2, 0.83 and 0.77 respectively, compared with males, 0.75 and 0.65 respectively. For MaxI2, the reverse applied with the female and male values being 0.55 and 0.71 respectively. This suggests that unique environmental variance could play a more significant role in males than in females for spaces MaxI3 and ManI2, the reverse being true for MaxI2, but it is quite likely that the result merely reflects a sampling effect.

Harris and Smith (1980) and Potter et al. (1981) found lower heritability estimates (0.6 and 0.26 respectively) for spacing in the permanent dentition compared with the present study. However, the method of data collection and analysis differed to the present study, so comparisons should be made with caution.

Table 4.26 : Estimates of heritabilities and associated 95% confidence intervals for interdental spacing.

Variable	h^2	*95% CI*
MaxI1	0.74	0.58-0.84
MaxI2	0.62 (0.71, 0.55)[a]	0.40-0.77
MaxI3	0.81 (0.75, 0.83)[a]	0.66-0.89
MaxI4	0.74	0.54-0.85
MaxI5	0.76	0.59-0.85
MaxC1	0.79	0.64-0.88
MaxC2	0.68	0.48-0.80
MaxM1	0.00	0.00
MaxM2	0.00	0.00
ManI1	0.81	0.65-0.89
ManI2	0.68 (0.65, 0.77)[a]	0.48-0.80
ManI3	0.73	0.58-0.83
ManI4	0.78	0.61-0.87
ManI5	0.76	0.59-0.86
ManC1	0.80	0.66-0.88
ManC2	0.76	0.60-0.85
ManM1	0.00	0.00
ManM2	0.00	0.00

[a] Numbers in parentheses indicate male and female values for variables with significant heterogeneity between sexes

Arch Dimensions

The AE model was adequate for all variables describing arch breadth and depth. Values were moderate to high, ranging from 0.69 to 0.89, indicating that both maxillary and mandibular dimensions were under strong genetic control (Table 4.27). This concurs with the findings of other authors (Harris and Smith 1980, Corruccini and Potter 1980, Harris and Smith 1982, Boraas et al. 1988, Richards et al. 1990, Hu et al. 1991), although the present study revealed higher heritability values generally than those previously reported.

Table 4.27: Heritability estimates and associated 95% confidence intervals for arch dimensions.

Variable	h^2	*95%CI*
ABMaxC	0.84	0.70-0.91
ABMaxM	0.87	0.77-0.92
ABManC	0.69	0.47-0.82
ABManM	0.89	0.80-0.93
MaxDepth	0.79	0.63-0.88
ManDepth	0.87	0.76-0.93

Overbite and Overjet

An AE model adequately described the variables overbite and overjet with heritability values (and 95% confidence intervals) of 0.53 (0.28-0.71) and 0.28 (0.02-0.50) respectively, emphasising the importance of environmental factors on both variables. The low to moderate values concur with previous studies

(Corruccini and Potter 1980, Harris and Smith 1980, Potter at al. 1981, Harris and Smith 1982, Boraas et al. 1988, Townsend et al. 1988, Corruccini et al. 1990). However there is disagreement in the literature as to whether overbite or overjet has the greater genetic component to variation.

Polynomial Coefficients

Table 4.28 displays heritability estimates and 95% confidence intervals for maxillary and mandibular polynomial coefficients. An AE model adequately described arch shape with heritability values ranging from 0.0 to 0.87. However, arch asymmetry was adequately described by a model incorporating only unique environmental variation (E).

Table 4.28 : Estimates of heritabilities and associated 95% confidence intervals for maxillary and mandibular polynomial coefficients.

Variable	h^2	*95% CI*
ManX	0.00	0.00
ManX^2	0.87	0.46-0.80
ManX^3	_ #	_
ManX^4	_	_
MaxX	0.00	0.00
MaxX^2	0.79	0.61-0.88
MaxX^3	_	_
MaxX^4	_	_

Heritabiliy estimates could not be calculated due to the small magnitude of the polynomial coefficients and the small sample size.

Richards et al. (1990) reported that genetic factors appeared to contribute to variation in maxillary arch shape and to a lesser extent variation in mandibular arch shape but not to arch asymmetry.

5. DISCUSSION

Introduction

Knowledge of the nature and extent of variation in dental occlusion is important for anthropologists, orthodontists and paediatric dentists. There are many references in the literature relating to occlusal variation in the permanent dentition, but detailed and thorough descriptions of the primary dentition are rare. Consequently, there are many avenues to explore and clarify.

There are many clinical applications to the knowledge of occlusal variation. In the field of paediatric dentistry and orthodontics, knowledge of the development of the teeth and occlusion in the young child is important in diagnosis and treatment planning.

Reports of occlusal patterns in the primary dentition provide valuable data for comparison of human populations. Some general trends have been disclosed:

- crowding is not a common feature of the primary dentition
- the most common type of canine and terminal plane relationships are Class I and a straight terminal plane respectively
- interdental spacing occurs more frequently in the maxillary arch than mandibular arch.

Epidemiological data on various occlusal features may show wide variations, depending primarily on the population under consideration and the methods employed in recording the data. However, some common patterns in occlusal variation are evident within racial groups and any strong deviations may be considered as true malocclusions.

Developments in craniofacial biology and clinical orthodontics have led to an interest in the possibility of early prevention and intervention. Recent research has been directed toward true prevention and early orthopaedic treatment of developing malocclusions. Clinical trials in Finland where treatment was initiated with orthopaedic appliances in children aged five or six years have shown good treatment results may be achieved with a favourable cost-effectiveness ratio (Varrela and Alanen 1995). Continuing research in this area may provide rewarding results for clinicians and their patients.

Major Findings

The results of this study compare well with published studies on occlusal variation in the primary dentition. The major findings were as follows:

- crowding was present in very few individuals
- total arch spacing was greater in the maxillary arch compared with the mandibular arch
- interdental spacing did not differ significantly between males and females
- primate spaces were found more frequently in the maxilla than the mandible
- arch dimensions were generally significantly larger in males compared with females
- arch shape could be described accurately in terms of fourth-order polynomial equations
- interdental spacing was related to mesiodistal tooth diameter and arch breadth

- a significant correlation was not found between total mesiodistal tooth diameter and arch breadth
- a class I canine relationship occurred most frequently
- a straight terminal plane relationship occurred most frequently
- crossbite was present in few individuals and a bilateral crossbite occurred less frequently than unilateral crossbite
- concordance between a Class I canine and a Class I molar relationship was moderate
- the pattern of occlusal variability, generally, did not differ significantly between singletons and twins
- there was a significant, moderate to high, genetic contribution to variation in primate and developmental spaces in the dentition
- there was a significant, moderate to high genetic contribution to variation in arch size
- there was a significant, but low genetic contribution to variation in overjet
- there was a significant, moderate genetic contribution to variation in overbite
- there was a significant, moderate to high genetic contribution to variation in arch shape but not to arch asymmetry

Reliability of Measuring and Scoring Occlusal Variables

The reliability of assessing occlusal variables from dental models was tested by scoring 10% of the combined singleton and twin samples twice. A paired t-test was conducted to detect systematic errors and results are given in Table 3.5. For only one of 34 variables, arch breadth at the molar in the mandibular arch, was there a significant difference from zero at $p<0.05$.

Dahlberg's statistic was calculated to determine the magnitude of random error and the results are presented in Table 3.6. Measurement errors ranged in value from 0.05 to 0.6mm for interdental spacing and arch breadth respectively. The results obtained indicate that the errors involved were small and therefore unlikely to bias the measurements.

The error variance was calculated as the square of the Dahlberg statistic and then expressed as a percentage of the total observed variance for each variable. Generally, errors were less than 10% indicating that variability due to experimental error was low.

Error variances were highest for two variables, interdental spaces MaxM1 and ManM2 being 25.5 and 22.2% respectively. Indeed, the technical error of measurement or Dahlberg statistic for MaxM1 and ManM2 was larger when compared with other spacing values. The reason for this may be found by examining the values recorded for the first and second determinations for each variable. For MaxM1, in three cases a difference between the first and second determination was found ranging from 0.3 to 0.6mm and for ManM2, in two cases a difference of 0.4 and 0.6mm between the first and second determinations was recorded. In addition, the observed variance for the variables MaxM1 and ManM2 was low in comparison with that for other interdental spaces. These two factors in combination resulted in a high percentage error variance and may, in part, be attributed to the fact that the molar interdental spaces were generally more difficult to measure due to the small magnitude of the interdental space and broader nature of the contact point between the teeth.

For the discrete variables, concordance between first and second determinations, shown in Tables 3.8, 3.9 and 3.10 ranged between 91.8% and 100% indicating that these occlusal variables could be assessed with good reliability from dental casts.

Birth weight

There are many reports in the literature on prematurely born, low birth-weight children and the relationship with enamel hypoplasia and palatal deformities in the primary dentition. However, other aspects of dental development are not so well researched (Seow 1996).

The mean birth weight of the singleton and twin groups in the present study were similar to other published studies (Avery et al. 1994, Kempe et al. 1970, McKeown and Record 1952). A significant difference was not found between males and females within the singleton or twin groups, however, between the singleton and twin groups, a significant difference existed ($p<0.01$).

The main cause of low birth weight is pre-term delivery and this is more common in monozygous than dizygous twin pregnancies (MacGillivray 1983). The combined birth weight of twins is greater than that of singleton babies but, individually, each twin baby is usually lighter. The foetal growth pattern of twins is different from that of singleton babies. Each twin grows at approximately the same rate as the singleton until about the 34th week of gestation. The rate of weight gain then decreases in the twin babies so that by the 40th week of gestation the median weight is at the 10th percentile rather than the 50th percentile. This may be due to late gestational placental insufficiency, undernutrition in utero or intrauterine growth retardation (Kempe et al. 1970).

Birth weight has been used as an indicator of the quality of the uterine environment and has been negatively correlated with dental development (Gyulavari 1966, Seow 1997). Seow (1996) found that, overall, very low birth weight (VLBW) children

(< 1500gm) had a delay in dental maturation of approximately 0.29 ± 0.54 years when compared with normal birth weight children and the greatest delay was found in the VLBW children younger than 6 years of age (0.31 ± 0.68 years).

Defects in the enamel are seen more commonly in low birth weight (LBW) children

(< 2500gm) and affect both the primary and permanent dentitions. Likely aetiological factors include the greater systemic derangement associated with VLBW and the greater need for prolonged endotracheal intubation (Seow et al. 1984, Lai et al. 1997). However, the association between birth weight and enamel defects and birth weight and dental development was not considered in this thesis.

Farmer (1990) in her Master's thesis " Odontometric and Morphologic Variability in the Deciduous Dentition" found a significant but low correlation between birth weight and tooth size. The highest correlations between birth weight and maxillary mesiodistal crown diameter (MDCD) in the male sample. were for the lateral incisor and second molar, 0.27 and 0.38 respectively. In the mandibular arch, the highest correlation in the male sample, was for the central and lateral incisors and the first molar reported as 0.35, 0.32 and 0.28 respectively. In the female sample, the highest correlation between birth weight and MDCD was for the central incisor teeth with a value of 0.34 reported. The author concluded that the significant but low correlations found indicate "that the deciduous dentition is buffered against developmental disturbances, and that only severe perturbations during pre- and early post-natal periods are likely to influence crown size"(Farmer 1990, pp 195).

In the present study, individuals with no spacing or with crowding were investigated and z-scores computed for birth weight and tooth size to ascertain if a relationship existed between these variables, firstly, birth-weight. A greater range in z-scores for birth-weight was found in the twin group compared with the singleton group. This reflects the significant difference ($p<0.01$) found in the mean birth-weight between the singleton and twin groups. Within the singleton group, all individuals with no spacing were within one standard deviation of the mean and therefore unremarkable. Within the twin group, three individuals (13.6%) had a z-score below -1.0, that is, 86.4% had a z-score between -1.0 and +1.0. This finding suggests that, within this population, the presence of no interdental spacing or crowding did not have a strong correlation with birth weight.

Z-scores for tooth size (MDCD) were similar for both singletons and twins, ranging between 0 and +2.3. However, the z-scores were generally within one standard deviation of the mean and this reflects the significant but low correlation found between birth weight and MDCD by Farmer (1990). Therefore, children with no interdental spacing or with crowding did not generally appear to have "large" teeth and other contributing factors should be sought. This will be discussed in a later section of this thesis.

Descriptive Summary of Occlusal Features in Australian Singletons

Interdental Spacing

Most published studies on interdental spacing report data in terms of discrete categories, some in terms of metric values and others in terms of "absent" or "present", so it is difficult to compare directly the results of the present study with most other published studies: However, general trends may be compared.

Mean values and standard deviations

Tables 4.2 and 4.3 show descriptive statistics for male and female singletons. Mean values ranged from 0.2 ± 0.25 mm (mean ± SD) to 1.1 ± 0.68 mm in males and from 0.3 ± 0.23 mm to 1.2 ± 0.60 mm in females. Mean values and standard deviations of interdental spacing reported by Joshi and Makhija (1984) were generally smaller than the values found in the present study, although the pattern of interdental spacing (for example, male versus female and anterior versus posterior) was similar. In the present study, t-tests showed no significant difference in mean values between males and females ($p<0.05$); however, the mean values for males tended to be of equal magnitude or slightly higher than those in the female group. A significant difference in variance was found between males and females for Max I2 and Max M1 ($p<0.05$). Apart from the study by Joshi and Makhija (1984), no other published studies of this nature could be found for comparison.

Joshi and Makhija (1984) reported that the greatest mean interdental spacing was found between the mandibular incisors. This does not concur with the findings of the present study where the primate spaces had the greatest mean values in both males and female and maxilla and mandible. Interdental spacing between the molar teeth was found to be smaller when compared with other segments of the arch and, on average, 84.3% of the sample has 0.5mm or less interdental spacing between the molar teeth. Joshi and Makhija (1984) reported that spacing between the primary molars in their sample was almost zero. Leighton (1971) also reported early closure of interdental spaces between primary molars.

No significant difference existed in mean values of interdental spacing between the maxilla and mandible; however, the frequency of occurrence of interdental spaces between the anterior teeth differed, 79.0% and 65.9% in the maxilla and mandible respectively. Similar frequencies were reported by El-Nofely et al. (1989), 89.0% and 79.6% for maxilla and mandible respectively. In addition, Kaufman and Koyoumdjisky (1967) found spacing to be more pronounced in the maxilla than in the mandible.

<u>Range of interdental spacing</u>

Joshi and Makhija (1984) reported the range of total interdental spacing to be 0.0 to 9.9mm and 0.0 to 8.5mm in the maxilla and 0.0 to 9.6mm and 0.0 to 8.2mm in the mandible in males and females respectively. Moorrees (1950) found the range of total interdental spacing in the maxilla, at age five years, to be -1.1 to 7.9 and 0.0 to 5.9mm in males and females respectively. In the mandible, the values reported were -2.0 to 5.9mm and -1.0 to 5.8mm in males and females respectively. The range found in the present study was greater than both of the aforementioned studies, being 1.6 to 14.7mm and 1.1 to 17.5mm in the maxilla and -4.1 to 9.9mm and -0.2 to 11.5mm in the mandible in males and females respectively.

Considering the mean value ± standard deviation for total interdental spacing for females in the maxilla was 6.6 ± 3.23mm, a value of 17.5mm for total maxillary interdental spacing in singleton 159 warranted investigation (Figure 5.1). The z-score for spacing was +3, indicating that less than 0.5% of individuals would fall in this area in any given population.

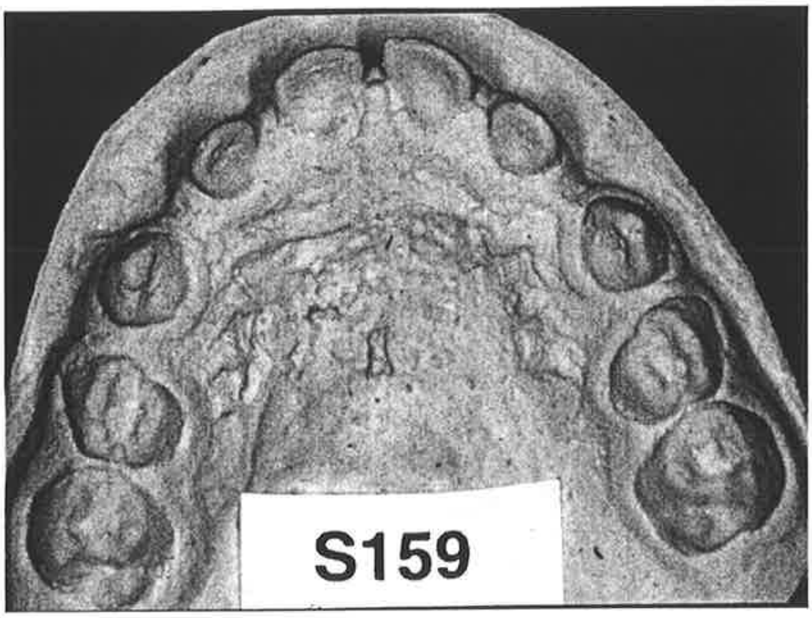


Figure 5.1 : The maxillary model of female singleton 159 showing above average interdental spacing

Computation of z-scores for maxillary arch dimensions and total MDCD of this individual (Singleton 159) revealed the following:

- z-score for maxillary arch breadth at the canine and molar were +1 and 0 respectively
- z-score for maxillary arch depth, +3.
- z-score for maxillary mesiodistal crown diameter (MDCD), -2

Consequently, a greater than average arch depth and small teeth appear to have contributed to the spacing.

Similarly, the mean ±standard deviation for total interdental spacing of males in the maxilla was 6.8 ± 2.96mm The z-score for spacing of Singleton 134 who had 14.7mm of total interdental space in the maxilla was +3 (Figure 5.2) and computation of z-scores for maxillary arch dimensions and total MDCD revealed the following:

- z-score for maxillary arch breadth at the canine and molar, both +2
- z-score for maxillary arch depth, +2
- z-score for maxillary MDCD, -1

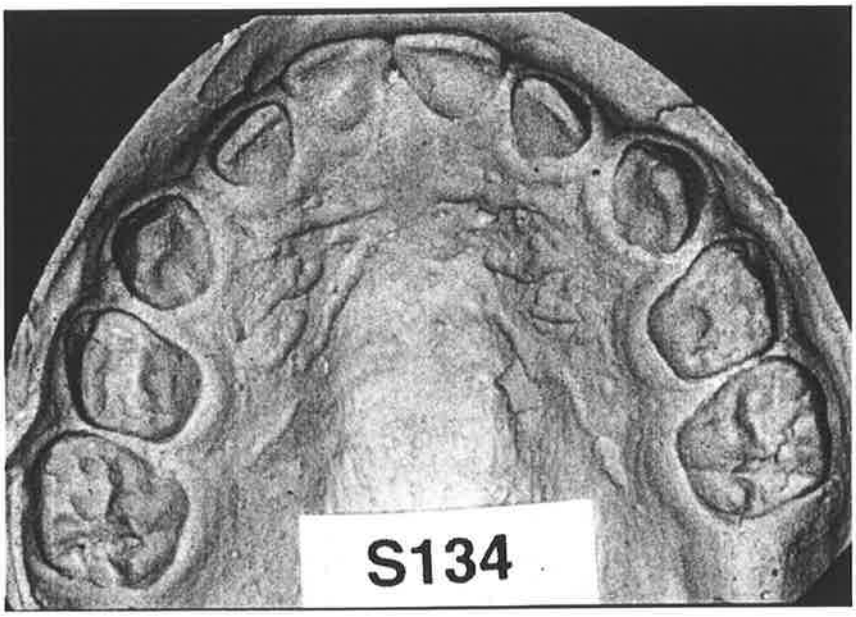


Figure 5.2 : The maxillary model of male singleton 134 showing above average interdental spacing

Therefore larger than average arch dimensions and small teeth appear to be associated with the spacing in the maxilla.

Dental arches with no interdental spacing

Interdental spacing in the primary dentition appears to be a common phenomenon and, indeed, Proffit (1986) reports that spacing between incisors is normal and, in fact, necessary for the alignment of the succedaneous teeth. It is not surprising then that the frequency of individuals with no interdental spaces was found to be low, 9.3% and 2.0% in males and females respectively in the mandible (Figure 5.3) and not occurring at all in the maxilla (Table 4.4). Indeed, a significant difference in spacing between maxilla and mandible was found in both males and females ($p<0.05$).

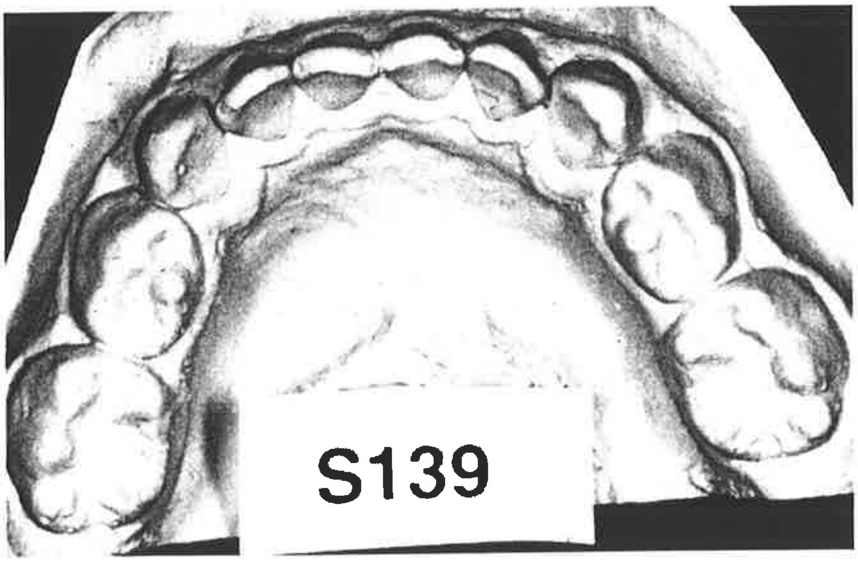


Figure 5.3 : The mandibular model of singleton 139 showing no interdental spacing.

A comparison of the frequency of occurrence of dental arches with no interdental spacing is presented in Table 4.6. In the maxilla, the frequency ranges from 0.0% to 24.0% and in the mandible, from 4.0% to 54.0%. Although the percentage frequencies vary between studies, a general pattern emerges. In all reported studies, interdental spacing is more common in the maxilla than the mandible

Total arch spacing

In the present study, mean total arch spacing ± standard deviation (SD) in the maxilla were found to be 6.8 ± 2.96 mm and 6.6 ± 3.23 mm and in the mandible, 4.6 ± 3.01 mm and 5.1 ± 2.46 mm in males and females respectively. No significant difference in total arch space between males and females in either arch was found; however, a significant difference was found between maxilla and mandible ($p<0.05$) in both sexes. Foster et al. (1969) found similar mean values to the present study in both sexes except in the maxilla in the female group, and Kaufman and Koyoumdjisky (1967), who recorded interdental spaces as present or absent, found spacing to be more pronounced in the maxilla than in the mandible.

Joshi and Makhija (1984) studied spacing in a sample of Indian children with primary dentitions. Their method of data collection involved measuring interdental spacing with vernier calipers directly from plaster casts to the nearest 0.1mm. In the present study, the author found data collection was easier and more reliable from elastomeric impressions of the casts, measured to the nearest 0.1mm. Joshi and Makhija found the amount of spacing in males to be greater than in females in both arches; however, statistical significance was not indicated. Similarly, Foster et al. (1969) found males had more interdental space than females in both arches and reported a statistically significant difference existed ($p<0.01$) in total interdental spacing values between males and females in the maxilla but not in the mandible. Kaufman and Koyoumdjisky (1967), however, reported that males had significantly more spacing than females in the mandible but not in the maxilla ($p<0.05$). Mean total interdental spacing and standard deviations found in the present study (Table 4.5) were generally twice as large for both sexes in the maxilla and mandible as those reported by Joshi and Makhija (1984) and Moorrees (1950) highlighting the difference that may exist between populations.

Primate spaces

Primate spacing in the primary dentition is located between the lateral incisor and canine in the maxilla and between the canine and first molar in the mandible. The frequency of occurrence of primate spaces in the present study was found to be 93.9% and 91.2% in the maxilla and mandible respectively. Table 4.6 shows a comparison of the frequency of occurrence of primate spaces in the maxillary and mandibular arches in previously published studies with frequencies ranging from 42.5 to 98.0% in the maxilla and from 21.0 to 87.0% in the mandible. In all published studies, the frequency of occurrence of primate spaces is greater in the maxilla than in the mandible.

In the present study, the frequency of occurrence of primate spaces was found to be greater in males in the maxilla and in females in the mandible. This finding may be related, in part, to the fact that in the mandible, a higher percentage of males (9.3%) had no spacing compared with the females (2.0%) and, in addition, in the mandible, mean total arch spacing was greater in females (5.1mm) than in males (4.6mm).

Joshi and Makhija (1984) found that primate spaces were more frequent in males in both maxilla and mandible while El-Nofely et al. (1989) reported the frequency of primate spaces was lowest in the mandibular arch, especially in females and highest in the maxillary arch. Ohno et al. (1990) found mandibular primate spaces were considerably less frequent than the maxillary primate spaces.

Mean values and associated standard deviations for the primate spaces were found to be greater in the maxilla (1.0 ± 0.64mm) than in the mandible (0.75 ± 0.50mm). An unpaired t-test showed a significant difference existed ($p<0.05$) in the means between the maxilla and mandible in both males and females This concurs with the findings of El-Nofely et al. (1989).

There are many aspects of interdental spacing to be considered, and it is evident from the discussion that mean values, standard deviations and frequencies of occurrence of the different occlusal features studied show a wide range of variation both within and between populations; however, general patterns may be found in most.

Arch Dimensions

There are few recent studies on arch dimensions in children with complete primary dentitions. Mean values and associated standard deviations found in the present study are presented in Tables 4.7 and 4.8. For all arch dimensions, mean values and standard deviations were found to be greater in males compared with females. A significant difference in the means was found between the sexes for the following dimensions: ABMaxC and ABMaxM ($p<0.01$); ABManM and ManDepth ($p<0.05$).

Foster et al. (1969) found a significant difference ($p<0.05$) existed between the sexes for arch breadth at the molar in the maxilla and mandible and for arch depth in the maxilla. Tsujino (1998), however, found no significant difference between males and females in arch breadth at the canine or molar in Japanese children.

It is difficult to compare the results of measurements of arch dimensions with many other studies because different landmarks are often used. However, studies by Lewis and Lehman (1929), Cohen (1940), Burson (1952), Meredith and Hopp (1956), Moorrees (1959) and Bishara et al. (1997) used the same landmarks as in the present study and, generally, similar means and standard deviations were found between these studies and the present study. Indeed, each study reviewed found that:

- maxillary arch dimensions were greater than mandibular arch dimensions
- average dimensions for males were greater than for females

Correlations between age and various arch dimensions

Values of correlation coefficients between age and various arch dimensions are shown in Table 4.9. In both males and females, values were low and not significant. In the male sample, values ranged from 0.06 between age and arch breadth at the canine in the maxilla to -0.21 between age and mandibular arch depth. This suggests that, as age increases, arch breadth at the canine increases and, conversely, as age increases, mandibular arch depth decreases. In the female sample, values ranged from 0.12 between age and arch breadth at the canine in the mandible to -0.13 between age and maxillary arch depth, suggesting that, as age increases, arch breadth at the canine increases and maxillary arch depth decreases.

Similar changes in arch dimensions with age have been reported by other authors (Moorrees 1959, Ohno et al. 1990 , Proffit 1993, Bishara et al. 1997, Tsujino 1998).

Correlations between arch breadths, total interdental spacing and total mesiodistal crown diameters.

Table 4.10 shows the correlation coefficients for the maxillary arch. Values between intra-arch dimensions arch breadth in the maxilla at the canine (ABMaxC) and arch breadth in the maxilla at the molar (ABMaxM) were high and significant ($p<0.01$),

$r = 0.76$ and 0.81 in males and females respectively, suggesting that a large proportion of the variation in ABMaxC could be explained by ABMaxM.

In the male sample, interdental spacing was significantly correlated with arch breadth at the canine and molar, $r = 0.43$ and 0.51 respectively ($p<0.01$), but not with mesiodistal crown diameters (MDCD), where $r = 0.06$, suggesting that wider arches had more interdental spacing but that the total MDCD were not as important.

In the female sample, interdental spacing was found to have a significant and negative correlation with the total MDCD, $r = -0.36$, ($p<0.05$) but was not significantly correlated with ABMaxC or ABMaxM, $r = 0.22$ and 0.04 respectively, suggesting that, as tooth size decreases, interdental spacing increases, but that variation in arch dimensions could not be explained to any great extent by interdental spacing. Hence, the pattern found in the male sample was the reverse of that found in the female sample. Differences between males and females may be expressed in terms of percentage sexual dimorphism of a particular variable and may be defined as:

$100\ (\bar{x}_M - \bar{x}_F / \bar{x}_F)$

where $\bar{x}_M$ is the mean value in the male sample and $\bar{x}_F$ is the mean value in the female sample of the variable under consideration. However, the percentage sexual dimorphism for tooth size, arch dimensions at the canine and molar and interdental spacing between the sexes was found to be low, 1.8, 3.6, 4.0 and 3.3% respectively. The percent sexual dimorphism for arch dimensions between males and females was larger than the other two variables, although only marginally.

Table 4.11 shows values of correlation coefficients in the mandibular arch. Correlation values between intra-arch dimensions, ABManC and ABManM were moderate, r = 0.60, and significant (p<0.01) in the male sample and high, r = 0.79, and significant (p<0.01) in the female sample and is as expected.

In the male sample, values between total MDCD and total interdental spacing (r = -0.10) and between arch dimensions, ABManC and ABManM)and total interdental spacing (r = 0.21 and 0.20 respectively) were low and not significant, indicating that little variation in one variable could be explained in terms of the other.

In comparison, in the female sample, moderate and significant (p<0.05) values were found between total interdental spacing and total MDCD (r = -0.38). Between total interdental spacing and ABManC (r = 0.55) and between total interdental spacing and ABManM (r = 0.44) a moderate and significant relationship was found (p<0.01). The values found suggest that interdental spacing was positively correlated with arch dimensions, that is, as interdental spacing increased, so did arch dimensions and negatively correlated with total MDCD, that is, as interdental spacing increased, total MDCD decreased.

interdental spacing and visa versa. Similarly, Ohno et al. (1990) found that, generally, interdental spacing was significantly related to mesiodistal tooth diameter, intercanine and intermolar width. The results of the aforementioned studies concur with the findings of the present study.

No singletons with no spacing or with crowding in the maxilla were found in the present study and only 5.8% (6) of singletons had no interdental spacing in the mandible. Consequently, statistical tests between spacing, MDCD and arch dimensions were not performed. However, for the individuals with no spacing or with crowding , z-scores for total MDCD and arch dimensions in the mandible were computed and the following scores were found:

- For total MDCD, z-scores ranged between +0.5 and +2.3
- For arch dimensions, z-scores ranged between -1.2 and +0.9

Within the twin group, 18 (6.4%) twins had no interdental spacing or crowding. Z-scores for tooth size and arch dimensions in these individuals were computed and the following values found:

- For total MDCD, z-scores ranged between 0 and +2.1
- For arch dimensions, z-scores ranged between -2.5 and +1.2

These results suggest that a combination of large teeth and small arches appear to have contributed to the lack of interdental spacing in some individuals in both singleton and twin groups.

Overbite and Overjet

Oral habits, such as thumb sucking and tongue thrusting are important aetiologic factors of malocclusion and may result in an openbite, an increased overjet or a transverse discrepancy between the maxillary and mandibular arches (Nanda et al. 1972). However, there is limited information available in the literature regarding their effects on the primary dentition.

Descriptive statistics for overbite and overjet are presented in Table 4.12. Mean values and standard deviations compare favourably with other published studies and will be discussed in the following section. Methodologies, however, vary between studies and results must be interpreted with caution.

Overbite

The mean values for overbite in males and females was 2.0 ± 0.91mm (mean ± SD) and 1.6 ± 1.76mm respectively. Moorrees (1959) reported values of 1.7 ± 1.17mm and 1.9 ± 1.10mm for males and females respectively in a sample of five to six year old children. Kaufman and Koyoumdjisky (1967) reported a mean value of 1.8 ± 0.07mm (mean ± SE), males and females combined in their sample of children, 3.5 to 5.5 years old.

A number of published studies have reported overbite as ideal, increased or reduced according to the degree of overlap of the maxillary incisor crown over the mandibular incisor crown, but precise measurements were not given (Baume 1950, Foster and Hamilton 1969, Otuyemi et al. 1997). This makes direct comparison with the present study difficult. However, there is general agreement in the literature that the most common relationship in the primary dentition is when the lower central incisal edge contacts the palatal surface of the upper central incisor in centric occlusion. Given the relatively small size, occlusogingivally of primary incisor teeth, the metric values found in the aforementioned studies equate well with the categorical method of presentation.

No significant difference was found in the mean values between males and females. This concurs with the findings of Otuyemi et al. (1997) but is contrary to the findings of Tschill et al. (1997) and Kaufman and Koyoumdjisky (1967), the former study finding mean overbite in males greater than in females and the latter finding the opposite.

A relatively low incidence (11.8%) of open bites (edge-to-edge or negative overbite) was found in the present study. Similar figures were given by Kerosuo (1990), Kaube et al. (1995) and Otuyemi et al. (1997) where open bites existed in 11%, 12% and 5.3% of the samples respectively. However, studies by Foster and Hamilton (1969), Ravn (1975) and Tschill et al. (1997) revealed the incidence of open bite to be 24.0%, 34.2% and 37.4% respectively. No reasons were given for the high incidence of open bites in any of the studies; however, a number of authors have reported a significantly higher incidence of open bite in children with oral habits, for example, thumb sucking (Nanda et al. 1972, Myllariemi 1973).

Both deep bite and open bite malocclusions occur in the primary dentition, a deep bite usually being the result of a skeletal imbalance. An open bite, on the other hand, is often seen in children with a sucking habit but good skeletal proportions and usually needs no treatment as there is a good chance of spontaneous correction once the sucking habit ceases (Proffit 1993, Holm and Arvidsson 1974).

The range of over bite varies between populations and, in the present study, a range of between 0 and 4mm and -4.0 and 4.5mm in males and females respectively was found. An F-test revealed a significant difference existed in variance between males and females ($p<0.01$). Moorrees (1959) reported a similar range, -1.5 to 4.5mm

and -1.2 to 4.5mm for males and females respectively, and Tschill et al. (1997) also found a significant difference existed between the sexes ($p<0.01$), with values ranging from -8.0 to 5.0mm and -5.0 to 5.0mm in males and females respectively.

<u>Overjet</u>

The mean values for overjet were 2.5 ± 0.96mm (mean ±SD) and 2.5 ± 1.62mm in males and females respectively. Kaufman and Koyoumdjisky (1967) reported a mean value of 1.8 ± 0.07mm (mean ± SE) for their sample of children, males and females combined. No significant difference was found in the mean values between the sexes in the present study. This was also reported by Otuyemi et al. (1997) and Tschill et al. (1997).

In the present study, the range of overjet recorded was between 1.0 and 5.5mm and

-1.5 and 8.0mm in males and females respectively and, consequently, a significant difference in variance ($p<0.05$) was found between the sexes. Tschill et al. (1997) reported a range from -2 to 12mm and -1 to 12mm for males and females respectively, with no statistical difference between the sexes.

Children with an overjet between 1 and 3mm accounted for 76.4% of the sample which is similar to the value reported by Tschill et al. (1997) of 76.0%. A number of published studies report the "ideal" overjet to be 2mm and greater than 2mm to be "increased" (Foster and Hamilton 1969, Otuyemi et al. 1997). The authors of the aforementioned studies reported the frequency of "ideal" overjet to be 25 and 68.8% respectively. In comparison, the present study found the frequency to be 48.2%. However, Ravn (1975) found 57% of his sample had an overjet between 2mm and 4mm and suggested that it would be reasonable to classify an overjet of 2-4mm as "normal" and reserve the term "increased" overjet for cases exceeding 4mm.

Sucking habits may result in an increased overjet through the forward displacement of the upper incisors and backward displacement of the lower incisors; however, the incisor displacement usually self-corrects if the sucking habit stops before the permanent incisors erupt (Proffit 1993).

Polynomial Coefficients

Fourth-order polynomials were used to describe arch shape and in all cases, the data fitted the polynomial equations well, with correlations exceeding 0.99.

Fourth-order polynomials of the form $y = a + bx + cx^2 + dx^3 + ex^4$ have a number of advantages in describing arch shape, the most significant being the ease with which the coefficients may be interpreted (Richards et al. 1990) and, in addition, comparison between individuals can easily be performed by evaluating the coefficients.

The quadratic and quartic terms, reflecting arch shape, did not differ significantly between males and females. Similarly, the linear and cubic terms, representing arch asymmetry, did not differ significantly suggesting that there were no consistent differences in shape or asymmetry between the sexes.

The maxillary and mandibular linear terms tended to be more variable than the quartic, cubic and quadratic terms in both males and females. The mandibular cubic term in the female group and the maxillary linear term in the male group tended to be large and negative. This was probably related to individuals with minor crowding or displacement of left lateral and canine teeth.

Figure 5.4 shows maxillary models of selected singletons illustrating arches with ;

(a) a large quadratic polynomial coefficient- the quadratic term reflected a tapered arch form

(b) a large quartic polynomial coefficient- the quartic term reflected a square arch form

(c) a large linear polynomial coefficient- a large linear coefficient resulted from lingual displacement of the left teeth and buccal displacement of the teeth on the right side

(d) a large cubic polynomial coefficient- a large cubic coefficient described similar arch shapes as the linear coefficient. In addition, there was a tendency for displacement of the midline to the right and for the anterior left teeth to be displaced labially and anterior right teeth to be displaced lingually.

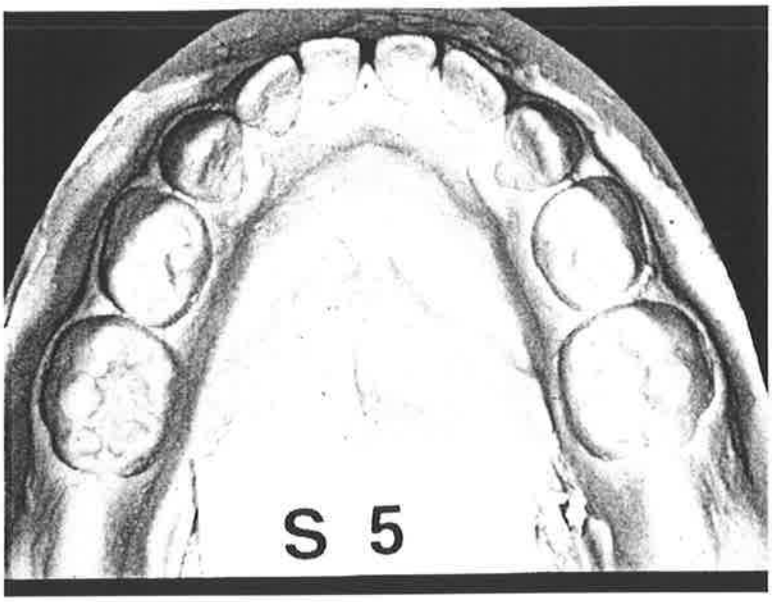


Figure 5.4 : (a) The mandibular model of singleton 5 showing a tapered arch form demonstrating a large positive quadratic coefficient;

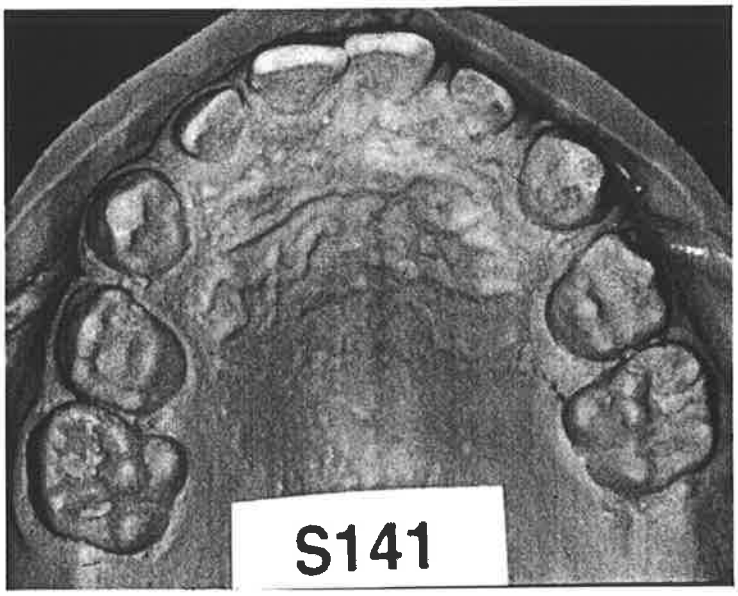


Figure 5.4 : (b) The maxillary model of singleton 141 showing a square arch form demonstrating a large positive quartic polynomial coefficient.

Figure 5.4 : (c) The maxillary model of singleton 122 showing an asymmetrical arch form demonstrating a large positive linear coefficient as a result of buccal displacement of the right teeth

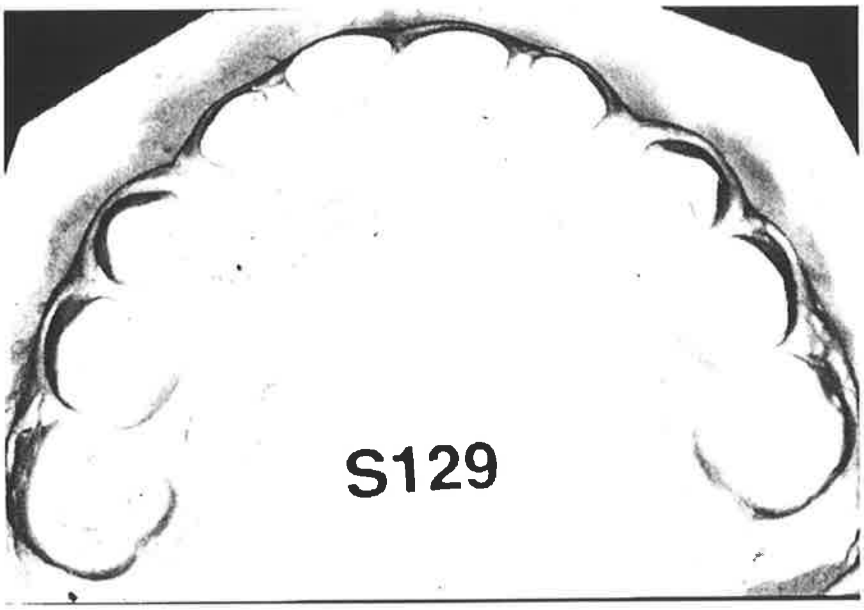


Figure 5.4 : (d) The maxillary model of singleton 129 showing an asymmetrical arch form demonstrating a large positive cubic coefficient as a result of buccal displacement of the right teeth and lingual displacement of the left central incisor.

Correlations between age and polynomial coefficients

Values of correlation coefficients between age and polynomial coefficients (Table 4.15) were low ($r < 0.28$), indicating that there were no significant age related trends in arch shape or asymmetry.

Correlations between polynomial terms included relatively high negative values between quadratic and quartic terms in both males and females. For example, a value of -0.54 was found between Max X2 and Max X 4 in the female sample. This reflects the fact that a particular arch cannot be both tapered (high quadratic term) and square (high quartic term).

No other published studies on primary dental arch morphology using fourth-order polynomial equations could be found for comparison. However, Richards et al. (1990) studied arch shape in a group of Australian children with permanent dentitions using fourth-order polynomials. The authors reported that, in all cases,the fourth-order polynomial equations fitted their data well with all correlations exceeding 0.98, a similar finding to the present study. In addition, correlations between age and each of the polynomial coefficients were small ($r < 0.16$).

Canine relationship

The frequencies of occurrence of Class I, II and III canine relationships found in the present study (Table 4.16) compare well with other published studies (Foster and Hamilton 1969, Ravn 1975, 1980, Otuyemi et al. 1997, Tschill et al. 1997).

Generally, the frequency of Class I canine relationships was highest, followed by Class II and then Class III.

A chi-square test revealed no significant difference existed between males and females. This concurs with the findings of Otuyemi et al. (1997) and Tschill et al. (1997).

A significant association was found between left and right sides ($p<0.01$) and concordance between sides was 78.0%, which is similar to the value reported by Ravn (1975) of 79.7%.

Ravn (1980) reported the canine relationship to be a very unstable entity during the period of the primary dentition and found the relationship may be influenced by such factors as sucking habits, premature extraction of primary teeth or caries.

In a study of oral habits and occlusion in preschool children, Nanda et al. (1972) found a significantly greater frequency of Class II canine and molar relationships ($p<0.001$) in children who had an oral habit compared with those who did not. A similar result was found by Popovich and Thompson (1973).

Molar relationship

Reports on the frequency of different types of molar or terminal plane relationships are more numerous compared with canine relationships. This may be due, in part, to the fact that the terminal plane relationship is often used to forecast the interocclusal relationship of the permanent molars (Proffit 1993).

The frequencies of occurrence of different types of molar relationships found in the present study are presented in Table 4.18. A Class I or straight terminal plane relationship was the most frequent, occurring in 75.1% of individuals and a Class III or mesial terminal plane relationship was the least frequent, occurring in 10.5% of individuals. A Class II or distal terminal plane relationship was found in 14.1% of individuals.

A chi-square test revealed no significant difference existed between the sexes. This concurs with the findings of Kaufman and Koyoumdjisky 1967, Infante 1974, Otuyemi et al. 1997, Alexander and Prabhu 1998).

A highly significant association was found between the left and right side molar relationship ($p<0.01$) and concordance between sided was 81.1%. Ravn (1975) reported a similar concordance of 78.7%.

Table 4.19 presents a comparison of the frequency of occurrence of terminal plane relationships in a number of published studies. The frequency of occurrence of a straight terminal plane ranged between 14.3% and 86.0% for those studies that used the distal surface of the second molar as the reference point. The frequency of occurrence of a mesial terminal plane relationship ranged between 0% and 33.3% and for a distal relationship, between 0% and 23.5%. Although the frequencies differ between studies, generally, a straight terminal plane is the most frequently occurring relationship in the primary dentition. In fact, Proffit (1993) and Alexander and Prabhu (1998) report that a straight terminal plane is the "normal" relationship of the primary molars and it is this relationship which determines the initial relationship of the erupting permanent molars (Carlson and Meredith 1960, Moyers 1973). However, the final relationship will be modified by forward growth of the mandible and mesial migration of the teeth (Proffit 1993).

Many studies have been undertaken to determine the changing pattern of terminal plane relationships during the transition from the primary to permanent dentitions. An understanding of these changes is crucial for the clinician involved with early interceptive treatment.

Ayra et al. (1973) found that a mesial and distal terminal plane relationship of the primary molars was transferred unchanged to the permanent dentition. Similarly, Frolich (1961), Nanda et al. (1973) and Ravn (1980) found that a distal terminal relationship was always transferred unchanged to the permanent dentition. Proffit (1993) suggests that the presence of a mesial terminal plane relationship in the primary dentition indicates the possibility of excessive mandibular development and should be a concern to the clinician.

Moyers and Wainwright (1977) and Proffit (1993) state that a distal terminal plane relationship in the primary dentition usually reflects an underlying skeletal Class II relationship which typically leads to a Class II malocclusion in the permanent dentition. In most children, this skeletal pattern may be recognised by the age of three years (Proffit 1993).

An asymmetrical terminal plane relationship was observed in 18.9% of individuals in the present study. This lies within the range reported in other published studies of between 2.7% and 43.0%. An asymmetrical relationship could be attributed to a difference in the space distribution between the teeth on the left and right sides of the arch or rotation or inclination of a molar on one side only or, indeed, following caries and space loss on one side of the arch.

Concordance between canine and molar relationships

Concordance between a Class I canine and a Class I molar relationship was found to be 45.6% and 32.4% on the right and left sides respectively. There were no individuals with Class II canine and molar or Class III canine and molar relationships. This contrasts with the findings of Ravn (1975) who reported that 90% of individuals with a Class I canine relationship also had a Class I molar relationship. However, Ravn found 68% of the sample studied had a Class I molar relationship compared with 75.1% in the present study.

As has been previously discussed, the canine relationship appears to be relatively unstable (Ravn 1980), affected in particular by sucking habits which is perhaps the most common type of occlusal parafunction in children (Proffit 1993). This may account, in part, for the difference in the reported frequencies of concordance between the two variables.

Crossbite relationship

Transverse discrepancies in the primary dentition are often associated with a sucking habit (Kisling and Krebs 1976). There is, however, continuing debate whether, following cessation of the habit, spontaneous resolution of a crossbite occurs. A number of authors suggest that significant improvement with increasing age is questionable (Infante 1974, Ravn 1975, Tschill et al. 1997) and that treatment should be instituted in the primary dentition either by occlusal adjustment or by maxillary expansion (Proffit 1993).

The frequencies of unilateral and bilateral crossbite in the present study are in accordance with frequencies reported in earlier studies (Table 4.21). In all reported studies, the frequency of bilateral crossbite is lower than unilateral crossbite and the present study follows that pattern. A unilateral crossbite in the primary dentition is, in most cases, the result of a symmetrically narrow maxilla with a functional mandibular shift on closure and not from a true skeletal or dental asymmetry (Proffit 1993).

No significant difference between males and females was noted in the present study; however, in the female sample the incidence of crossbite tended to be greater. A similar finding was reported by Kisling and Krebs (1976), Infante (1974), Myllarniemi (1973) and Tschill et al. (1997).

When direct comparisons are made between studies, the researcher should keep in mind the great variation in methods and definitions used, as well as age and sample size and, therefore, extrapolate the findings with caution.

Concordance within MZ and DZ twin pairs for the discrete variables

Assuming a polygenic mode of inheritance, maximum percentage concordances for MZ twin pairs would be 100% and for DZ twins, 50%. In the present study, concordance values for MZ twins were generally high compared with the DZ twins, where moderate concordance values were found. Values for MZ twins ranged from 54.3% for canine relationship to 91.4% for crossbite, and for DZ twins from 45.2% for terminal plane relationship to 77.8% for crossbite (Tables 6.5 to 6.14). However, for crossbite relationship, the most common category was 0-0, that is, both members of the twin pair did not show the feature, hence, care should be taken in interpreting these results. Higher concordance values for the MZ twins may suggest a greater genetic influence on the phenotypic expression of these occlusal features compared with the DZ twins. For one variable, canine relationship on the left, percent concordance was higher in the DZ twins. The reason for this is unclear, but reports in the literature suggest that the canine relationship is more unstable than the terminal plane relationship and is influenced more by local factors, for example, sucking habits. It is possible that this result may have resulted from a sampling effect.

Chi-square analyses performed to test whether associations between members of twin pairs were statistically significant revealed a significant association between MZ twin pairs at the 1% level of probability for canine relationship on the right side, terminal plane relationship on the left side, and at the 5% level of significance for crossbite relationship. This finding suggests that genetic factors may play an important role in the expression of these variables. Between the DZ twin pairs, a significant association existed at the 5% level of probability for canine relationship on the left side and for crossbite. This finding suggests genetic and / or an important shared environmental effects in the phenotypic expression of canine relationship and for crossbite.

In considering these results, some limitations of the analyses need to be noted including:

- only a small number of categories was used to describe variation for each variable. A larger number of categories, for example, five or six, would allow the assumption of normality to be tested and polychoric correlations computed. However, this is not possible when only two categories are used.
- only a small number of subjects was included within each of the occlusal categories. A small sample size reduces the power of the statistical process, decreasing the ability to detect significant associations within groups.
- only a small number of subjects displayed "positive" expressions for some of the study variables. For some occlusal features, the most common category in the chi-square tables was zero-zero; that is, the feature was not displayed in either member of the twin pair. These results should be interpreted cautiously as higher percentage concordances could be obtained even though most of the twins did not display the feature being analysed.

Genetic Analysis

There are few published studies that have analysed family data on individual occlusal traits using correlation coefficients and fewer still that have employed a structural equation modelling package, for example LISREL or Mx. Consequently studies available for comparisons are limited.

Significant genetic variance of occlusal parameters including arch size and shape, overjet and overbite has been reported by a number of authors (Corruccini and Potter 1980, Harris and Smith 1980, Potter et al. 1981, Harris and Smith 1982, Boraas et al 1988; Townsend et al. 1988, Corruccini et al. 1990). However, heritability values have been low to moderate and values vary between studies due, in part, to different methods of data collection and analysis. Therefore, interpretation of the results should be made with caution. Further research should reveal a range of non-random environmental causes to variation of occlusal traits in the primary dentition including familial and non-familial, prenatal and postnatal factors.

<u>Interdental spacing</u>

There are very few published papers addressing genetic analysis of interdental spacing in the human dentition. In the present study, an AE model provided an adequate description for all interdental spaces except the molar spaces M1 and M2 in both arches for which an CE model was generally the model of best fit. For the molar interdental spaces, M1 and M2 in both arches, heritability was found to be zero. This may be related to the fact that, following eruption of the posterior deciduous teeth into the mouth, there is gradual closure of the posterior interdental spaces due to mesial drift of these teeth. This results in spaces that are absent or of small magnitude towards the end of the complete primary dentition (Leighton 1971, Joshi and Makhija 1984 and Varrela, personal communication).

Of interest is the fact that the primate spaces, MaxI1, MaxI5, ManC1 and ManC2, showed heritabilities similar to that of other developmental spaces within the arch. Primate spaces are thought to be genetically determined and a characteristic of our ancestral and modern primate dentitions (El-Nofely et al. 1989).

Significant heterogeneities between males and females in variance noted for spaces MaxI2, MaxI3 and ManI2 did not follow a consistent pattern. Heritability values suggested that for spaces MaxI3 (the central diastema) and ManI2, females showed a higher additive genetic component to variation, but for space MaxI2 females showed lower additive genetic variance and greater environmental variance. The reasons for this remain unclear but may, in part, be due to Type II errors caused by a small sample size.

The moderate to high heritability values found for interdental spacing show that genetic variation had a major effect on arch spacing in this group of Australian twins. Figure 5.5 shows the maxillary and mandibular models of a pair of monozygous twins and illustrates a similar interdental spacing pattern between Twin A and Twin B.

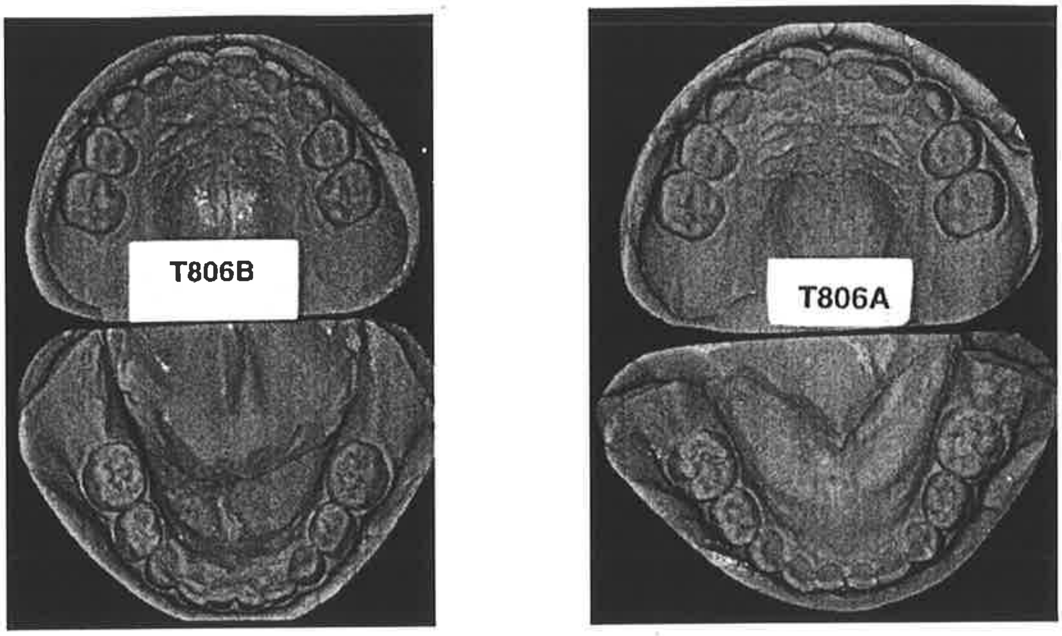


Figure 5.5 : The maxillary and mandibular models of a monozygous twin pair showing a similar pattern of interdental spacing.

Harris and Smith (1980) and Potter et al. (1981) studied variance of occlusal traits in families including spacing and found lower heritability estimates of 0.6 and 0.26 respectively for spacing. However, the method of data collection and analysis differed from the present study, so comparisons should be made with caution. Potter et al. (1981) were able to detect a significant genetic source of variation for spacing as opposed to Harris and Smith (1980) who reported that, when the influence of shared environment was removed, variation in tooth position including crowding was "just about entirely due to non-genetic causes" (Harris and Smith 1980, pp 160).

<u>Arch Dimensions</u>

An AE model adequately described variation in arch dimensions, with heritability values ranging from 0.69 to 0.89, indicating that additive genetic factors played a definite role in determining arch dimensions. This finding reflects a general consensus of the literature (Harris and Smith 1980, Corruccini and Potter 1980, Harris and Smith 1982, Boraas et al. 1988, Richards et al. 1990, Hu et al. 1991).

No clear trend was evident between maxillary and mandibular arches; however, heritability estimates for anterior arch dimensions were lower compared with posterior dimensions, although only marginally. Similarly, Hu et al. (1991) reported heritability values for anterior arch dimensions were significantly smaller than for overall arch dimensions. Hu and colleagues proposed two reasons to explain this finding:

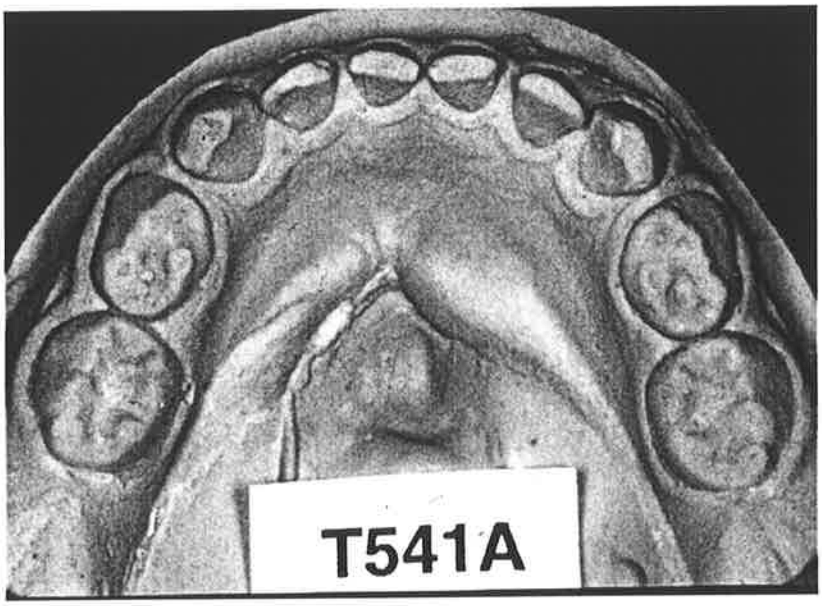
- functional and habitual activities have a greater effect on the anterior segment of the arch
- smaller roots of the anterior teeth offer less resistance to displacement by pressures exerted on them.

Harris and Smith (1980) found heritability values for arch dimensions to be high but, in contrast to the aforementioned study, lower values were noted for intermolar arch width than for intercanine arch width. In conclusion, the authors mentioned that the genotypic background of the population studied must be considered when evaluating and comparing heritability estimates.

Overbite and Overjet

An AE model was adequate to describe variation for the variables overbite and overjet. Heritability values found were 0.53 and 0.28 respectively, suggesting that the environment played a significant role in observed variation.

discrepancy, most commonly the result of a constricted maxillary arch associated with a sucking habit. The maxillary arch fails to develop in width due to an imbalance in muscle activity between the cheek and tongue (Proffit 1993). Mouth breathing is also known to influence the development of the dentition through alteration in head and tongue posture and may result in arch asymmetry (Linder-Aronson 1970). Richards et al. (1990) reported that genetic factors appeared to contribute to variation in maxillary arch shape and to a lesser extent variation in mandibular arch shape but not to arch asymmetry. Figures 5.6 (a) and (b) shows models of MZ twins with similar arch shape whereas Figure 5.7 (a),(b) and (c) shows models of another pair of MZ twins with dissimilar arch shape and symmetry.



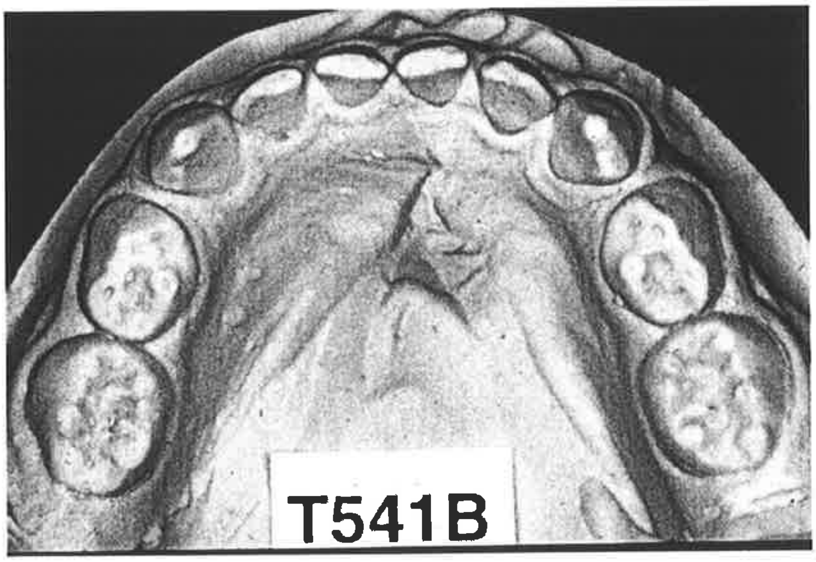


Figure 5.6 : (a) Mandibular models of Twins 541 showing similar square arch forms demonstrating large quartic coefficients.

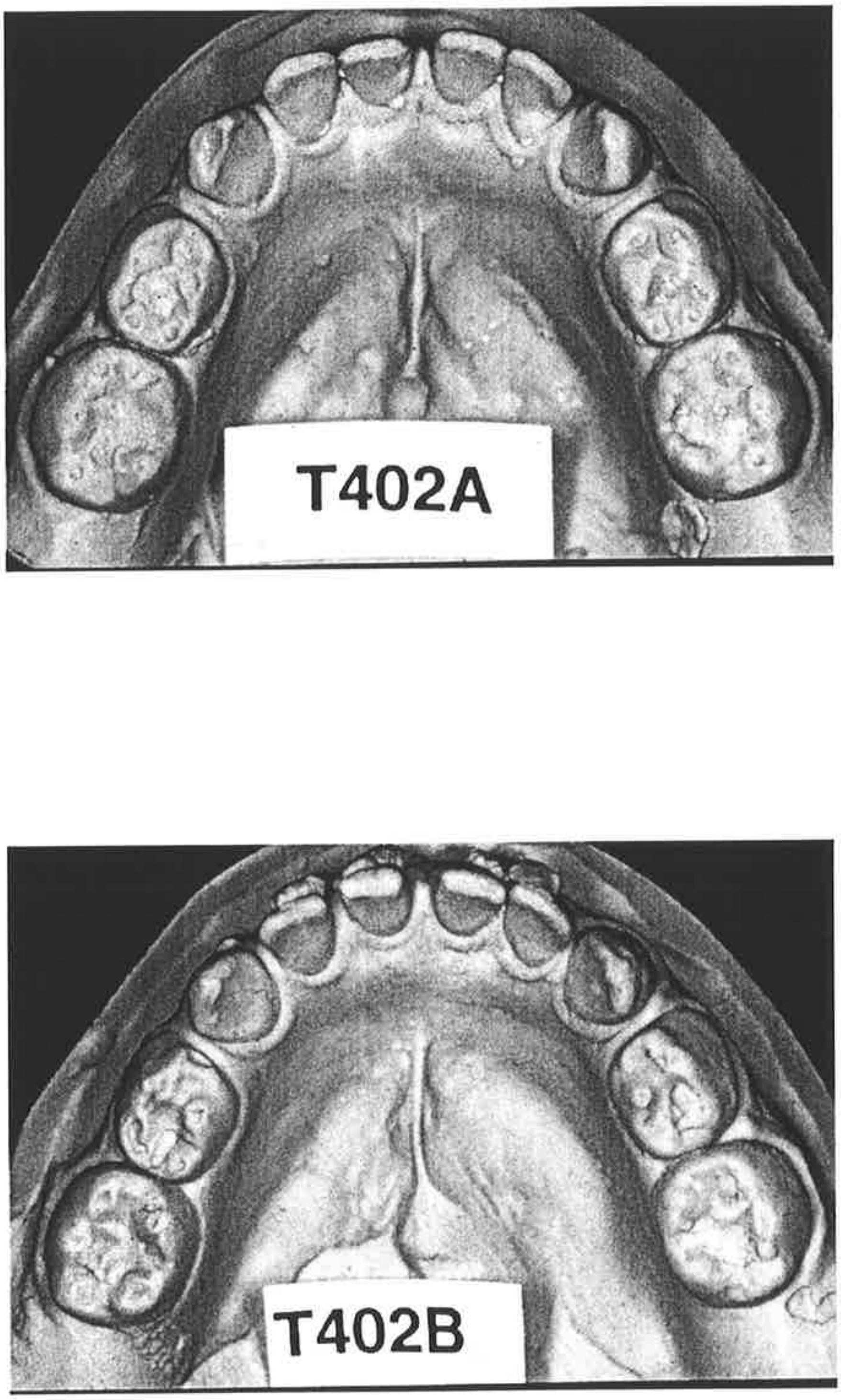
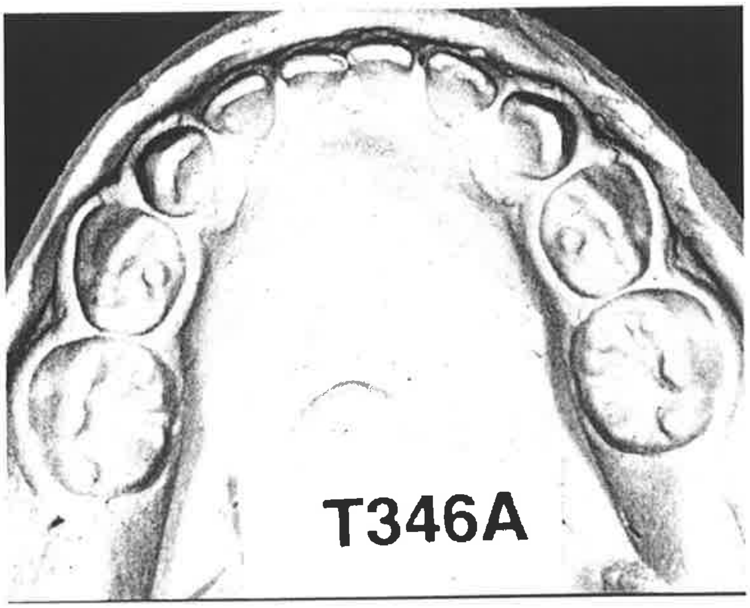


Figure 5.6 : (b) Mandibular models of Twins 402 showing similar tapered arch forms demonstrating large quadratic coefficients.



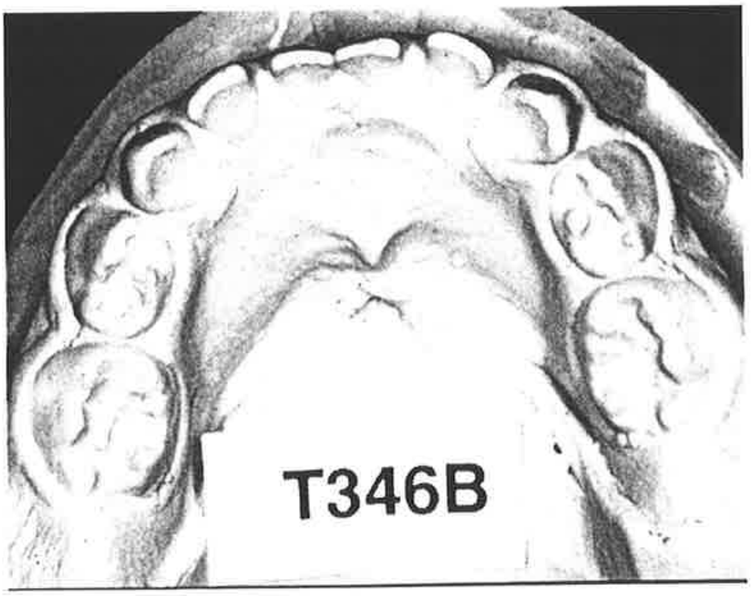


Figure 5.7 : (a) Mandibular models of twins 346 showing dissimilar arch forms, Twin A showing a tapered arch (a high quadratic coefficient) and Twin B showing a square arch form (a high quartic coefficient)

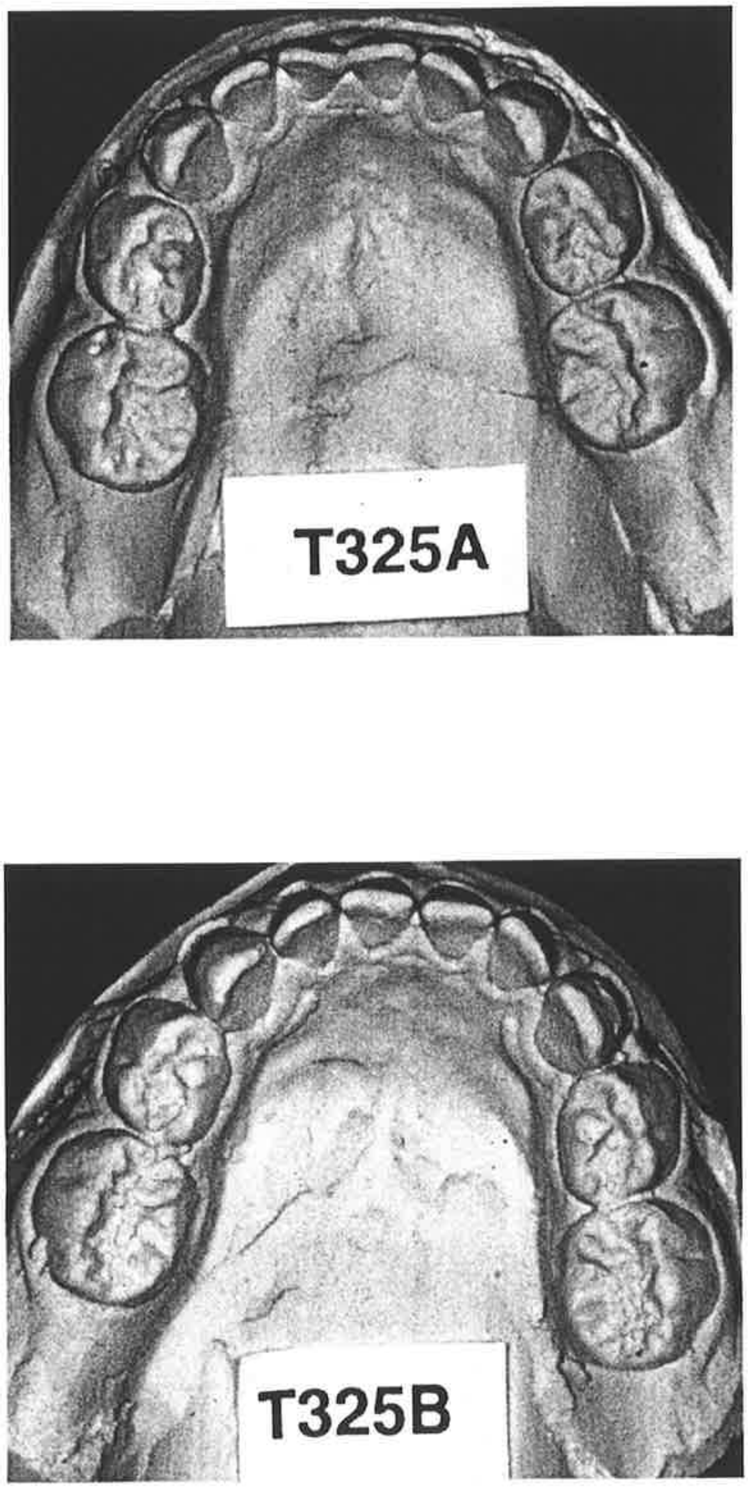
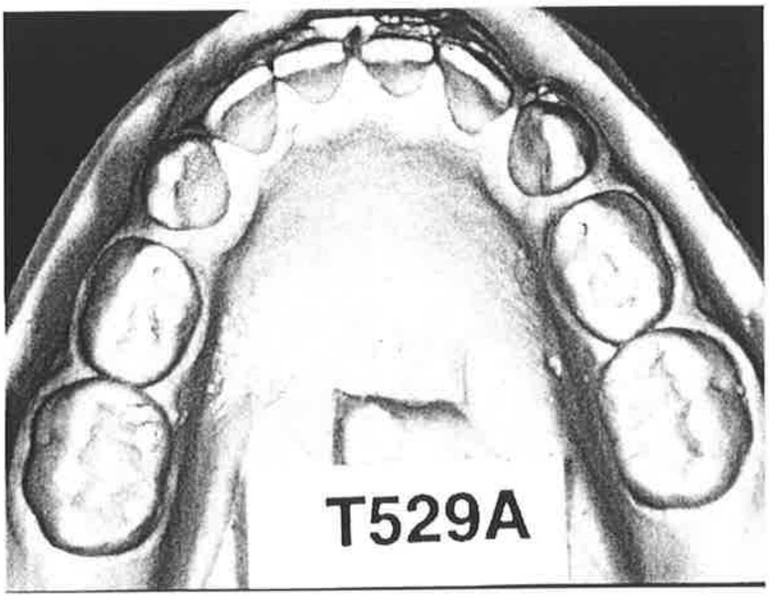


Figure 5.7 : (b) Mandibular models of twins 325 showing dissimilar arch forms, Twin A showing a square arch form (a high quartic coefficient) and Twin B showing tapered arch form (a high quadratic coefficient).



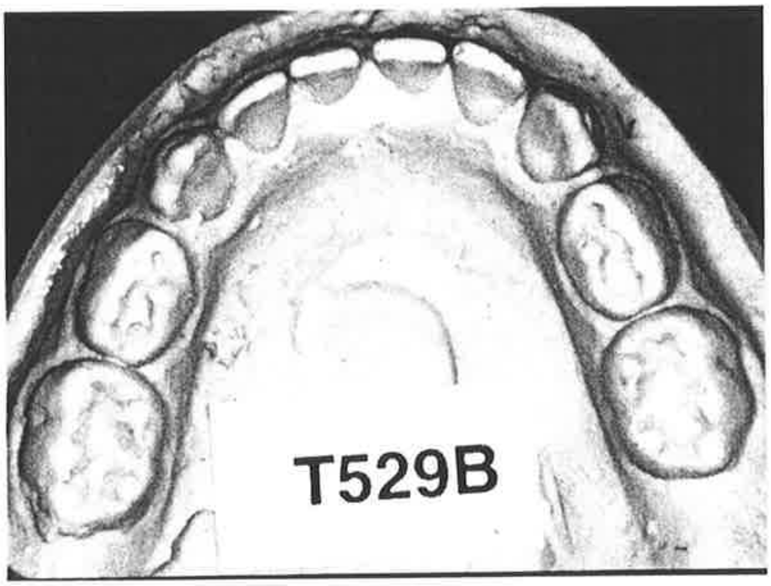


Figure 5.7 : (c) Mandibular models of twins 529 with dissimilar arch asymmetry, Twin B showing buccal displacement of the right teeth (demonstrating a large difference in cubic coefficients between Twin A and Twin B).

Birth weight

A CE model adequately described the observed variation in birth weight. This is not an unexpected finding due to a number of reasons. Indeed, there is an interaction between the twins in utero via the circulatory system and twin-to-twin transfusion. An intrauterine abnormality of foetal circulation in monozygous twins, in which blood is shunted directly from one twin to the other, may result in significant differences between the twins, for example, in birth weight. In addition, foetal growth of twins is reduced after approximately the 34th week of gestation which may be due, in part, to late gestational placental insufficiency, undernutrition in utero or intrauterine growth retardation (Kempe et al., 1970) so that by the 40th week of gestation, the median weight is at the 10th percentile rather than the 50th percentile.

In summary:

Previous heritability studies of occlusal variables have all been conducted on the permanent dentition. To the author's knowledge, no other studies on the primary dentition are available for comparison.

Heritability values found in this study were generally higher than those reported in earlier studies of the permanent dentition (for example, Potter et al., 1981; Harris and Smith, 1982), possibly due to the sensitive nature of path analysis which allows a powerful resolution of phenotypic variation into genetic and environmental components. However, the researcher should keep in mind that heritability estimates should be viewed in relation to the particular genotypic background of the population under study, and so comparisons between populations should be carried out with caution. The pattern of heritability values for the various occlusal traits in this study (that is, highest for arch dimensions and lowest for overjet) was similar to previous studies of the permanent dentition. However, whether both the primary and permanent dentitions are under control of the same set of genes is not yet known.

This study found that, generally, occlusal variation in the primary dentition appears to be under moderate to high genetic control. Genetic factors seem to be most important for arch dimensions and arch shape. Environmental factors are more important than genetic factors for some occlusal variables, for example, overbite, overjet and arch asymmetry. Indeed, which environmental factors are important is not yet clear, however, subtle environmental influences, for example, consistency of the diet, head posture, pre- and peri-natal factors and peri-oral muscular activity have been reported as important factors affecting variation in craniofacial morphology.

Further research involving a multivariate analysis of the data to determine genetic and environmental influences on co-variation within the primary dentition is required. Elucidation of these factors is important to provide a scientific basis to early preventive and interceptive orthodontic management of the child.

have noted that, during the period of the complete primary dentition, a gradual closure of interdental spaces occurs between the posterior teeth through mesial migration of the teeth (Morrees 1959, Leighton 1971, Nanda et al. 1973, Ravn 1980, and Varrela, personal communication) accounting for smaller interdental spaces in the twin sample.

A comparison of occlusal features between monozygous and dizygous twins

Generally no significant difference was found in the means or variances between the MZ and DZ twin groups. However, a significant difference ($p<0.05$) was found in the mean for the polynomial coefficient, Max X, which reflects arch asymmetry in the maxillary arch.

A significant difference was found in the variance for the polynomial coefficient, Max X^4, which reflects arch shape in the maxillary arch and for overjet. The range of overjet recorded was between 0.5 and 7.5mm and -1.5 and 7.0mm in DZ and MZ twins respectively.

Conclusion

This thesis describes the occlusal characteristics of the primary dentition in a sample of Australian children and investigates the similarities and differences between males and females, between singletons and twins and between the results of this study and published data for other populations.

Documentation of occlusal patterns present in the primary dentition is the first step towards cross-comparison with data in the adult dentition and enables researchers to assess whether certain occlusal trends present in the primary dentition are accurate predictors of occlusal characteristics in the permanent dentition.

With the realisation that the role of genetic factors in the aetiology of malocclusion is considerably less than was thought 20 or 30 years ago, interest in environmental influences, including their identification and possible control, has come to the fore. Consequently, early prevention may become a real alternative to late corrective therapy.

There is a clear need for continuing research into occlusal variation in the primary dentition and the continuum that exists with the permanent dentiton. In addition, identification of the factors influencing growth and development of craniofacial structures and orofacial musculature are crucial next steps, the aim being to circumvent unbalanced craniofacial development and occlusal disharmonies.

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Appendix I

A STUDY OF THE DECIDUOUS TEETH OF SOUTH AUSTRALIAN CHILDREN

CHILD'S NAME: ______________________________

Dear Parent,

Thankyou for participating in this study. These questions relate to the birth and early life of your child, and the age and brief medical history of the mother when the child was born. This information will be treated with strict confidentiality and will greatly assist in the analysis of the dental data.

(1) Date if birth of child:________________

(2) Age of mother when child was born:________________years.

(3) Were there any problems during pregnancy? e.g. blood pressure, anaemia, diabetes, infections, etc.

Yes / No	If yes, please specify:______________________________

(4) Was you child premature?

Yes / No	If so, how many weeks:______________________________

(5) Were there any problems at delivery? e.g. maternal haemorrhage, slowing of baby's heartbeat, oxygen lack, etc.

Yes / No	If yes, please specify:______________________________

(6) What was the weight of the baby at birth:____________(kgs)

(7) What was the length of the baby at birth:____________(cms)

(8) Has you child suffered any severe illnesses needing hospitalisation?

Yes / No	If yes, please specify type of illness and child's age:______

____

I consent to the use of any records (e.g. dental study casts, photographs) or data obtained in this study for scientific investigation, including the publication of results. I understand that under no circumstances will my identity or my child's identity be disclosed without my written permission. I understand that I may withdraw my child from this study at any time.

Parent's Signature:____________________________________Date:_______________

Appendix II

T__________

Dear Parent,

These questions relate to the pregnancy, birth and early life of your twins. They will help us when we begin analysing the dental data and will be treated with strict confidentiality.

Twins' Names____

1. Did you have any problems during pregnancy? e.g. high blood pressure, anaemia, infections, etc.

   Yes ☐ No ☐ If yes, please specify__________________

2. In which hospital were the twins born?__________________________

3. May we have your permission to access the hospital records so we can gain information about the twins' blood groupings, etc. Yes ☐ ☐

   No

4. Were the twins premature? Yes ☐ No ☐

   If so, how many weeks?___________Days?____________

5. What was the type of delivery?

First born name ________________		Second born name ______________	
Normal	☐	Normal	☐
Breech	☐	Breech	☐
Planned caesarian	☐	Planned caesarian	☐
Unplanned caesarian	☐	Unplanned caesarian	☐

6. Were there any problems at delivery? e.g. maternal haemorrhage, slowing of babies' heartbeat, oxygen lack, etc.

Yes ☐ No ☐ If yes please specify________________

7. What was the time between the delivery of the first and second born twin?

Hours____________Minutes__________(Approximately)

8. Was the placenta
   - Single? ☐
   - Fused? ☐
   - Two separate? ☐
   - Unsure? ☐

9. What was the weight of the babies at birth?

First born name ________________ Weight__________

Second born name ________________ Weight__________

10. What was the length of the babies at birth?

First born name ________________ Length__________

Second born name ________________ Length__________

11. Was either baby in an incubator after birth? Yes ☐ No ☐

First born name ________________ How long________

Second born name ________________ How long________

12. How old was each twin at discharge from the hospital?

First born name ________________ Weeks old________

Second born name ________________ Weeks old________

13. Have the twins suffered any severe illnesses needing hospitalisation?

Yes ☐ No ☐ If yes, please specify____________________

14. Have the twins shown any language problems? (If you feel the twins are not yet old enough to have reached this stage, please disregard this question).

First born name ____________________ Second born name__________________

Delays in speech development? ☐

Hard to understand? ☐

Stuttering or stammering? ☐

Lisping (incorrect "s")? ☐

Other? Please specify____

15. To determine hand preferences, it would be appreciated if you could observe the twins during normal behaviour and see if they use the left or right hand whilst carrying out the actions below.

First born name ____________________ Second born name__________________

Writing ☐

Drawing ☐

Throwing a ball ☐

16. What are the hand preferences of the other members of the family?

Mother ☐ Father ☐

Sister (1) ☐ Sister (2) ☐

Brother (1) ☐ Brother (2) ☐

Appendix III

DATA SHEET

NAME
I.D. NUMBER
GENDER
ZYGOSITY
BIRTHWEIGHT

VARIABLES

<u>DIRECT MEASUREMENT</u>

SPACING

MAXILLA	INCISOR	☐	☐	☐	☐	☐
	CANINE	☐	☐			
	MOLAR	☐	☐	☐	☐	☐
MANDIBLE	INCISOR	☐	☐			
	CANINE	☐	☐			
	MOLAR	☐	☐			

OVERBITE ☐

OVERJET ☐

MOLAR RELATIONSHIP

TERMINAL PLANE ☐ ☐

CANINE RELATION ☐ ☐

CROSSBITE

UNILATERAL ☐

BILATERAL ☐

<u>INDIRECT MEASUREMENT</u>

ARCH SHAPE

MAXILLA		
MANDIBLE		

ARCH BREADTH

MAXILLA	CANINE	
	MOLAR	
MANDIBLE	CANINE	
	MOLAR	

ARCH DEPTH

MAXILLA	
MANDIBLE	

Appendix IV.

Table 1.1 : Descriptive statistics for birth weight (kg) in male and female Australian twins.

	n	$\bar{x}$	SD	CV
male	77	2.6	0.41	15.4
female	77	2.5	0.50	20.0

no significant difference between males and females

A significant difference was found between the mean birth weight of the twin and singleton groups (Table 1.1). The mean birth weight for the twin and singletons groups were 2.6 □ 0.44mm (mean □ SD) and 3.4 □ 0.56mm respectively. The mean birth weights of the singleton and twin groups in this study are similar to other published studies (McKeown 1952, Kempe et al. 1970, Avery et al. 1994).

Table 1.2 : Descriptive statistics for birth weight (kg) of Australian twins and singletons.

	Twins			Singleton	
n	$\bar{x}$	SD	n	$\bar{x}$	SD
154	2.6 *	0.44	87	3.4	0.56

* mean values differ significantly between twins and singletons ($p < 0.01$)

Table 2.1 : Descriptive statistics for interdental spacing of male Australian twins (mm).

Maxilla	n	$\bar{x}$	SD
I1	**80**	**1.1**	**0.63**
I2	80	0.7*	0.57
I3	80	0.4*	0.56‡
I4	79	0.7	0.56
I5	**80**	**1.2***	**0.64**
C1	80	0.7	0.48
C2	80	0.9	0.49
M1	75	0.2	0.31
M2	70	0.2	0.35
Mandible			
I1	81	0.3	0.53
I2	81	0.5*	0.61
I3	81	0.5	0.66
I4	80	0.5*	0.53
I5	81	0.4	0.50
C1	**81**	**0.8**	**0.53**
C2	**81**	**0.9**	**0.53**
M1	78	0.2	0.30
M2	77	0.1	0.22‡

* mean values differ significantly between males and females ($p < 0.05$)
‡ variance differs significantly between males and females ($p<0.01$)

Table 2.2 : Descriptive statistics for interdental spacing of female Australian twins (mm).

Maxilla	n	$\bar{x}$	SD
I1	**79**	**0.9**	**0.66**
I2	77	0.5	0.57
I3	78	0.7	0.86
I4	78	0.6	0.56
I5	**78**	**0.9**	**0.66**
C1	79	0.7	0.49
C2	77	0.8	0.51
M1	70	0.2	0.33
M2	70	0.3	0.31
Mandible			
I1	79	0.4	0.62
I2	79	0.7	0.64
I3	79	0.6	0.69
I4	78	0.7	0.60
I5	78	0.5	0.53
C1	**78**	**0.7**	**0.57**
C2	**79**	**0.7**	**0.59**
M1	72	0.2	0.29
M2	75	0.1	0.29

Mean values for interdental spaces MaxI2, MaxI5 and ManI4 differed significantly between males and females within the twin group but not within the singleton group.

Table 2.3 shows a statistically significant difference was found between twins and singletons for interdental spaces M1 and M2 in both the maxilla and mandible. In each case, the mean value for the singletons was twice the mean value for the twins, although the standard deviations were similar between the groups.

This finding may be the result of the lower mean age of the singleton group of 4.7 □ 0.62 years (mean age □ standard deviation) compared with the twin group, 5.4 □ 0.57 years. During the course of the complete primary dentition, there is a gradual closure of interdental spacing in the posterior segments through mesial migration of the teeth (Varrela, personal communication). Leighton (1971) also observed early closure of interdental spaces between the primary molar teeth.

Table 2.3 : Descriptive statistics for interdental spacing between the molars in Australian twins and singletons (mm).

	Twins			Singletons		
	n	$\bar{x}$	SD	n	$\bar{x}$	SD
Maxilla						
M1	145	0.24 *	0.32	107	0.41	0.35
M2	140	0.25 *	0.32	104	0.42	0.32
Mandible						
M1	150	0.17 *	0.29	109	0.31	0.28
M2	152	0.13 *	0.25	109	0.26	0.24

* mean values differ significantly between twins and singletons ($p<0.05$)

Table 2.4 : Frequency of occurrence of dental arches with no spacing or with crowding in Australian twins (percentage frequency).

	Male and female combined	Male	Female
Maxilla	6 (2.2)	2 (1.4)	5 (3.1)
Mandible	12 (4.1)	9 (2.7)	5 (5.6)
Total	134	69	65

Table 2.5 : Descriptive statistics for total arch spacing in male and female Australian twins (mm).

	Male			Female		
	n	$\bar{x}$	SD	n	$\bar{x}$	SD
maxilla	69	6.2	3.33	65	5.4	3.51
mandible	75	4.4	3.03	71	4.7	3.45

no significant difference between males and females

In the male sample only, a significant difference in mean total arch spacing was found between maxilla and mandible ($p<0.01$).

Table 3.1 : Descriptive statistics for arch dimensions in male Australian twins (mm).

Maxilla	n	$\bar{x}$	SD	CV
ABMaxC	81	28.1*	1.54‡	5.3
ABMaxM	80	33.9*	1.94	5.6
MaxDepth	78	27.9*	1.47	5.4
Mandible				
ABManC	80	22.3	1.54	6.7
ABManM	81	29.1*	1.89	6.5
ManDepth	77	24.6	1.29‡‡	5.3

$CV = (SD/\bar{x})100$

mean values differ significantly between males and females *(p < 0.05). **(p,0.01)

variance differs significantly between males and females ‡(p<0.05), ‡‡ (p,0.01)

Table 3.2 : Descriptive statistics for arch dimensions in female Australian twins (mm).

Maxilla	n	$\bar{x}$	SD	CV
ABMaxC	79	27.5	1.91	6.9
ABMaxM	79	32.6	2.05	6.1
MaxDepth	74	27.3	1.62	5.9
Mandible				
ABManC	79	22.3	1.77	8.1
ABManM	79	28.4	1.77	6.3
ManDepth	77	24.2	1.77	7.4

$CV = (SD/\bar{x})100$

No significant difference in mean values or variance was noted between singletons and twins.

Table 3.3 : Values of correlation coefficients between age and various primary arch dimensions in Australian twins- male data above diagonal, female data below.

	Age	ABMaxC	ABMaxM	ABManC	ABManM	MaxDepth	ManDepth
Age	1.00	0.16 (81)	0.31**(80)	0.09 (80)	0.21 (81)	-0.09 (78)	0.11 (77)
ABMaxC	-0.09 (79)	1.00	0.68**(80)	0.52**(80)	0.44**(81)	0.27*(78)	0.35**(77)
ABMaxM	-0.03 (79)	0.71**(79)	1.00	0.44**(80)	0.75**(80)	0.12 (77)	0.26*(77)
ABManC	0.08 (79)	0.41**(79)	0.34**(79)	1.00	0.54**(80)	0.08 (77)	0.35**(77)
ABManM	0.03 (79)	0.33**(79)	0.64**(79)	0.69**(79)	1.00	0.01 (78)	0.17 (77)
MaxDepth	-0.12 (74)	0.48**(74)	0.18 (74)	0.32**(74)	0.05 (74)	1.00	0.65**(75)
ManDepth	-0.10 (77)	0.47**(77)	0.27*(77)	0.56**(77)	0.27*(77)	0.58**(74)	1.00

Number of pairs indicated in parentheses
*p<0.05, **p<0.01

A similar pattern was noted in general in the values of correlation coefficients between age and various arch dimensions between male and female singletons and twins. A low but significant (p<0.01) correlation was noted between age and ABMaxM in the male twin group.

Table 3.4 : Values of correlation coefficients between arch breadths, total interdental spacing and total mesiodistal tooth diameters in the maxillary arch in Australian twins- male data above diagonal, female data below .

Maxilla	Total ID spacing[a]	ABMaxC	ABMaxM	MDCM Total
Total ID spacing	1.00	0.40**(69)	0.12 (69)	-0.49**(59)
ABMaxC	0.45**(65)	1.00	0.68**(80)	0.30*(63)
ABMaxM	0.39**(65)	0.71**(79)	1.00	0.41**(63)
MDCM Total	-0.35**(56)	0.37**(66)	0.12 (66)	1.00

Numbers of pairs indicated in parentheses
*p<0.05, **p<0.01
[a] Total average interdental spacing

A similar pattern, in general, was noted in the values of correlation coefficients between arch breadths, total interdental spacing and mesiodistal tooth diameters in male and female singletons and twins. A moderate and significant ($p<0.05$) correlation was found between MDCM total and arch dimension, ABMaxC and ABMaxM, in both male and female twins but not in the singleton group.

Table 3.5 : Values of correlation coefficients between arch breadths, total interdental spacing and total mesiodistal tooth diameters in the mandibular arch in Australian twins- male data above diagonal, female data below .

Mandible	Total ID spacing[a]	ABManC	ABManM	MDCM Total
Total ID spacing	1.00	0.30**(75)	0.26*(75)	-0.29*(68)
ABManC	0.63**(71)	1.00	0.56**(77)	0.34**(72)
ABManM	0.64**(71)	0.69**(79)	1.00	0.23 (72)
MDCM Total	-0.27*(64)	0.06 (70)	-0.05 (70)	1.00

Numbers of pairs indicated in parentheses
* $p<0.05$, ** $p<0.01$
[a] Total average interdental spacing

A similar pattern, in general, was noted in the values of correlation coefficients between arch breadths, total interdental spacing and mesiodistal tooth diameters in male and female singletons and twins.

Table 4.1 : Descriptive statistics for overbite and overjet in male and female Australian twins (mm).

		n	$\bar{x}$	SD	CV
Overbite	male	80	2.1**	1.18‡	56.2
	female	79	1.4	1.50	107.1
Overjet	male	80	2.4	1.20	50.0
	female	79	2.2	1.34	60.9

CV = $(SD/\bar{x})100$
** mean values differ significantly between males and females ($p<0.01$)
‡ variance differs significantly between males and females ($p<0.05$)

No significant difference in mean values or variance was noted between singletons and twins.

Table 5.1 and 5.2 show polynomial coefficients for maxillary and mandibular arches in male and female Australian twins. Generally, no significant difference in mean values or variance existed between the twin and singleton groups; however, a significant difference in mean values existed between the singleton and twin groups for one coefficient, max x^3 ($p<0.01$), indicating a significant difference existed in arch asymmetry in the maxilla.

Table 5.3 : Values of correlation coefficients between age and polynomial coefficients in Australian twins- male data above diagonal, female data below.

	Age	ManX1	ManX2	ManX3	ManX4	MaxX1	MaxX2	MaxX3	MaxX4
Age	1.00	-0.21 (77)	-0.06 (77)	-0.19 (77)	-0.12 (77)	-0.02 (77)	0.06 (77)	0.11 (77)	-0.30**(77)
ManX1	0.06 (75)	1.00	-0.10 (77)	-0.08 (77)	0.02 (77)	0.22 (74)	-0.18 (74)	0.12 (74)	-0.07 (74)
ManX2	-0.10 (75)	-0.04 (75)	1.00	0.05 (77)	-0.25 (77)	-0.05 (74)	0.38**(74)	0.18 (74)	-0.22 (74)
ManX3	-0.07 (75)	0.01 (75)	-0.02 (75)	1.00	-0.06 (77)	-0.05 (74)	0.09 (74)	0.16 (74)	0.02 (74)
ManX4	0.11 (75)	0.20 (75)	-0.30**(75)	0.14 (75)	1.00	0.06 (74)	-0.10 (74)	-0.06 (74)	0.10 (74)
ManX1	-0.24*(74)	-0.02 (72)	0.14 (72)	0.26*(72)	-0.03 (72)	1.00	-0.31**(77)	-0.01 (77)	-0.09 (77)
MaxX2	0.01 (74)	-0.02 (72)	0.18 (72)	0.01 (72)	-0.18 (72)	0.14 (74)	1.00	0.18 (77)	-0.60**(77)
MaxX3	0.03 (74)	0.08 (72)	-0.13 (72)	-0.17 (72)	-0.07 (72)	-0.16 (74)	-0.14 (74)	1.00	-0.15 (77)
MaxX4	0.05 (74)	-0.09 (72)	-0.30**(72)	0.04 (72)	0.06 (72)	0.01 (74)	-0.35**(74)	0.09 (74)	1.00

Number of pairs in parentheses
*p<0.05, **p<0.01

A similar pattern, in general, was noted in the values of correlation coefficients between age and polynomial coefficients in male and female singletons and twins. A low and significant association ($p<0.01$) was found between age and MaxX4 in the male twin group.

The correlations between polynomial terms (Table5.3) include moderate negative values between quartic and quadratic coefficients in both maxilla and mandible. For example, in the males, a value of -0.60 was found between MaxX2 and MaxX4 and, in the female sample, a value of -0.35 was found between the same coefficients. This reflects the fact that a particular arch cannot be both tapered (high quadratic term) and square (high quartic term).

Table 6.1 : Frequency of different types of canine relationship in Australian twins (percentage in parentheses).

Category	Male		Female	
	right	left	right	left
Class I	58 (72.5)*	47 (58.8)	48 (60.8)	48 (60.8)
Class II	22 (27.5)	31 (38.8)	28 (35.4)	29 (36.7)
Class III	0	2 (2.5)	3 (3.8)	2 (2.5)
Total	80 (100)	80 (100)	79 (100)	79 (100)

* differs significantly between males and females (p<0.05)

Table 6.2 : Frequency of different types of molar relationship in Australian twins (percentage in parentheses).

Category	Male		Female	
	right	left	right	left
Class I	63 (80.8)	60 (75.9)	57 (74.0)	50 (64.9)
Class II	7 (9.0)	11 (13.9)	14 (18.2)	18 (23.4)
Class III	8 (9.9)	8 (10.1)	6 (7.8)	9 (11.7)
Total	78 (100)	79 (100)	77 (100)	77 (100)

no significant difference between males and females

Table 6.3 : Frequency of different types of crossbite relationship in Australian twins (percentage in parentheses).

Category	Male	Female
no crossbite	73 (90.1)	71 (89.9)
unilateral crossbite	7 (8.6)	6 (7.6)
bilateral crossbite	1 (1.2)	2 (2.5)
Total	81 (100)	79 (100)

no significant difference between males and females

Chi-square tests showed no significant difference in frequencies between the singleton and twin groups and between MZ and DZ twins for any of the discrete variables, canine relationship, molar relationship or crossbite relationship (p<0.05).

Concordance between left and right sides for canine and molar relationships

Concordances between left and right sides for canine and terminal plane relationships, within the twin group are presented in Table 6.4. A significant association was found between left and right sides for both variables ($p<0.01$). The percentage concordance between left and right sides for canine relationship is lower than for the terminal plane relationship, possibly because the canine relationship is influenced more by local factors, for example, sucking habits, than is the terminal plane relationship

Table 6.4 : Concordance between left and right sides for canine and terminal plane relationships in Australian twins (males and females combined).

Variable	Percentage concordance
Canine relationship	72.9
Terminal plane relationship	82.4

Concordance within MZ and DZ twin pairs for canine and molar relationship and crossbite relationship

Concordances within MZ twin pairs for each of the discrete variables are presented in Tables 6.5 to 6.9 and, for DZ twin pairs, in Tables 6.10 to 6.14. For some variables, the most common category was zero-zero, therefore care should be used in interpretation of the results.

Table 6.5 : Concordance between MZ Twin A and Twin B for terminal plane relationship on the right side

		Twin A			
	Category	I	II	III	Total
	I	23	3	3	29
Twin B	II	1	2	0	3
	III	2	0	0	2
	Total	26	5	3	34

Chi-square = 7.60, 4 dof, p = 0.11

% Concordance = (25/34)100 = 73.5%

Table 6.6 : Concordance between MZ Twin A and Twin B for terminal plane relationship on the left side

		Twin A			
	Category	I	II	III	Total
	I	20	2	3	25
Twin B	II	2	4	0	6
	III	2	0	1	3
	Total	24	6	4	34

Chi-square = 13.41, dof = 4, p < 0.01

% Concordance = (25/34)100 = 73.5%

Table 6.7 : Concordance between MZ Twin A and Twin B for canine relationship on the right side

		Twin A			
	Category	I	II	III	Total
	I	20	4	2	26
Twin B	II	2	7	0	9
	III	0	0	0	0
	Total	22	11	2	35

Chi-square = 12.26, dof = 2, p < 0.01

% Concordance = (27/35)100 = 77.1%

Table 6.8 : Concordance between MZ Twin A and Twin B for canine relationship on the left side

		Twin A			
	Category	I	II	III	Total
	I	11	6	1	18
Twin B	II	8	7	0	15
	III	1	0	1	2
	Total	20	13	2	35

Chi-square = 9.01, dof = 4, p = 0.06

% Concordance = (19/35)100 = 54.3%

Table 6.9 : Concordance between MZ Twin A and Twin B for crossbite relationship

		Twin A			
	Category	0	I	II	Total
	0	31	1	1	33
Twin B	I	1	1	0	2
	II	0	0	0	0
	Total	32	2	1	35

Chi-square = 7.74, dof = 2, p < 0.05

% Concordance = (32/35)100 = 91.4%

Table 6.10: Concordance between DZ Twin A and Twin B for terminal plane relationship on the right side

		Twin A			
	Category	I	II	III	Total
	I	24	4	3	31
Twin B	II	7	0	0	7
	III	3	1	1	5
	Total	34	5	4	43

Chi-square = 3.06, dof = 4, p = 0.55

% Concordance = (25/43)100 = 58.1%

Table 6.11: Concordance between DZ Twin A and Twin B for terminal plane relationship on the left side

		Twin A			
	Category	I	II	III	Total
	I	18	10	3	31
Twin B	II	4	1	0	5
	III	5	1	0	6
	Total	27	12	3	42

Chi-square = 2.35, dof = 4, p = 0.67

% Concordance = (19/42)100 = 45.2%

Table 6.12 : Concordance between DZ Twin A and Twin B for canine relationship on the right side

		Twin A			
	Category	I	II	III	Total
	I	20	4	0	24
Twin B	II	12	7	0	19
	III	1	0	0	1
	Total	33	11	0	44

Chi-square = 2.64, dof = 2, p = 0.27

% Concordance = (27/44)100 = 61.4%

Table 6.13 : Concordance between DZ Twin A and Twin B for canine relationship on the left side

		Twin A			
	Category	I	II	III	Total
	I	22	6	0	28
Twin B	II	7	9	0	16
	III	0	0	0	0
	Total	29	15	0	44

Chi-square = 5.49, dof = 1, $p < 0.05$

% Concordance = (31/44)100 = 70.5%

Table 6.14 : Concordance between DZ Twin A and Twin B for crossbite relationship

		Twin A			
	Category	0	I	II	Total
	0	35	5	0	40
Twin B	I	3	0	1	4
	II	1	0	0	1
	Total	39	5	1	45

Chi-square = 10.96, dof = 4, $p < 0.05$

% Concordance = (35/45)100 = 77.8%

<u>Polychoric Correlations for the discrete variables</u>

Table 6.15 : Polychoric correlations for MZ and DZ twin pairs for right (I) and left (II) terminal plane (TP) and canine (CR) relationship.

	MZ	DZ
TP I	0.05	-0.23
TP II	0.33	-0.26
CR I	0.53**	0.08
CR II	0.22	-

** significantly different from zero $p < 0.01$