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AN ASSESSMENT OF PONT'S INDEX TO PREDICT DENTAL ARCH WIDTH IN HUMAN POPULATIONS

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Submitted in part fulfilment of the requirements
for the degree of Master of Dental Surgery

SEPTEMBER 1990

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SUMMARY

SUMMARY

AN ASSESSMENT OF PONT'S INDEX TO PREDICT DENTAL ARCH WIDTH IN HUMAN POPULATIONS

Various diagnostic indices have been proposed in clinical orthodontics to help predict dental arch growth and assist in treatment planning. Pont's Index was established by Pont in 1909, to predict maxillary dental arch width from the sum of the mesiodistal diameters of the four maxillary incisors. Various authors have either supported or refuted the value of Pont's Index, and as there has been a recent resurgence of interest in its clinical use, reassessment of Pont's Index in different human populations was considered worthwhile.

The study aimed to evaluate Pont's Index and its corresponding indices (W, P, E index) in selected samples of Australian Aborigines, Indonesians and Caucasians; to assess growth changes in dental arch width from mixed dentition to permanent dentition in a longitudinal sample of Australian Aborigines; and to estimate the influence of genetic and environmental factors on variation in tooth size and arch width using data derived from a sample of Caucasian twins.

Measurements were obtained directly from plaster casts; they included mesiodistal crown diameters of the four maxillary incisors, as well as intercanine, interpremolar

maxillary incisors, as well as intercanine, interpremolar and intermolar arch widths in the maxilla and mandible as specified by Pont. A series of double determinations confirmed the reliability of the method.

Data were analyzed statistically using the software package SPSSX on The University of Adelaide's VAX computer. Descriptive statistics for tooth size, arch dimensions and the various indices were computed for both cross-sectional and longitudinal data. Analysis of variance was carried out to test the mean differences between all variables in the cross-sectional study. Correlation coefficients were determined between observed values and those predicted, based on Pont's Index calculations. Intraclass correlations and heritability estimates were computed for the twin sample using analysis of variance methods.

Considerable variability between individuals' values and Pont's estimates was noted in each population, with very few individuals displaying the ideal arch forms predicted by the Index. Dental arch width was generally under-estimated by the Index in Indonesians who tended to display relatively small tooth size and large arch width. A more even distribution of estimates was noted in Australian Aborigines and Caucasians, with Aborigines showing large tooth size and large arch width, and Caucasians displaying small tooth size and small arch width. Correlation coefficients computed between observed and expected values were low in all three populations studied.

There were no significant changes in mandibular intercanine width and maxillary interpremolar width from mixed dentition to permanent dentition in Australian Aborigines. However, significant increases were found in intercanine and intermolar widths in the maxilla and in interpremolar and intermolar widths in the mandible.

Significant genetic variance was noted for incisor crown size, whereas heritability estimates for arch width were generally lower.

Although the concept of a simple index with predictive ability is very appealing to some clinicians, the results of this study have highlighted the marked variation in values of Pont's Index for individuals with apparently good occlusions, representing three different human populations. Furthermore, the Index fails to take account of the complexities of inherent growth-coordinating mechanisms within the dentition that result from an interplay between genetic and environmental influences. It is concluded that Pont's Index is unlikely to be a useful clinical predictor of dental arch width.

SIGNED STATEMENT

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

The author consents to the thesis being made available for photocopying and loan if applicable if accepted for the award of the degree.

Mulyani Dalidjan Bachtiar

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to Dr. G.C. Townsend and Dr. W. J. Sampson of the University of Adelaide for their thorough supervision of this research report.

I am grateful for the availability of study material provided by the Anthropology and Genetics Research Group, Department of Dentistry and also for the willingness of the students of the Faculty of Dentistry, the University of North Sumatera to be subjects in this study.

I would also like to thank Ms. Rebecca Kelly and Ms. Angela Neville for their assistance with data processing, and Mr. Peter Dent for his assistance with photography.

I acknowledge the University of North Sumatera, Indonesia, for making available a Postgraduate Scholarship held during the years 1987 - 1990.

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CHAPTER I: INTRODUCTION

Crowded, irregular and protruding teeth are common problems in modern populations and many regulating devices for orthodontic correction of the teeth have been developed over the years. In the latter half of the nineteenth century emphasis was placed on orthodontic alignment of teeth and the correction of facial proportion. At that time, extractions were frequently used in the treatment of crowded or malaligned teeth. As Edward H. Angle developed his classification of malocclusion, the concept of normal occlusion requiring a complete dentition in both dental arches gained support. Angle strongly opposed extraction for orthodontic purposes and, as maintaining an intact dentition became the objective of orthodontic treatment, less attention was given to facial proportion and esthetics. Extraction of teeth was reintroduced in the 1930s because obligatory non-extraction treatment, apart from neglecting facial esthetics, was unable to achieve satisfactory stability of tooth alignment and occlusal relationships.

Once changes in tooth and jaw positions resulting from orthodontic treatment and dento-facial growth could be accurately assessed by means of cephalometric radiographs, new concepts of treatment developed. For example, functional jaw orthopedics was developed in Europe to enhance dento-facial growth changes. This concept proposed expansion of the jaws to accommodate the teeth, and suggested that treatment should be started as early as possible during the active growth period. It was assumed that if the expansion was performed within the genetic potential of the individual, stability of the treatment would result.

Pont (1909) derived a simple mathematical formula known as Pont's Index. He proposed that the sum of the mesiodistal diameters of four maxillary incisors could be used as a guide in predicting dental arch widths in the premolar and molar areas. This Index has subsequently been utilized by some clinicians who claim it predicts the genetic potential for dental arch development.

The application of Pont's Index is still debated between orthodontists and so-called orthognathic-orthopedists. General dentists have recently become interested in the use of Pont's Index because of its simplicity and apparent value as a treatment goal in arch expansion. Because there are so many different views on Pont's Index, it is clinically relevant to assess the Index in different populations to gain a more thorough understanding of its usefulness.

The present study was initiated to provide estimates of Pont's Index in Australian Aborigines, Indonesians and Caucasians and also to enable comparisons to be made with values derived from other ethnic groups. In addition to these study groups, a sample of Caucasian twins was studied to provide insight into genetic influences on variability of tooth size and arch dimensions. Furthermore, changes in dental arch widths from the mixed dentition period to early permanent dentition were assessed in a sample of Australian Aborigines to determine longitudinal variations in Pont's Index values.

AIMS OF THE STUDY

The specific aims of the study were:

1. to assess the validity of Pont's Index in selected samples of Australian Aborigines, Indonesians and Caucasians.
2. to compare the results obtained from these three ethnic groups with each other and with previously reported findings in other populations.
3. to assess the validity of the corresponding indices (P,W and E indices) in Australian Aborigines, Indonesians and Caucasians.
4. to assess growth and developmental changes of the dental arches in Australian Aborigines and to relate these findings to some of the suggested clinical uses for Pont's Index.
5. to estimate the heritability of tooth size and arch width in a sample of Caucasian twins.

CHAPTER II : LITERATURE REVIEW

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CHAPTER II: LITERATURE REVIEW

PONT'S INDEX

In 1909 Pont described a method which he believed could be useful in determining ideal dental arch form. He concluded that in ideal arches, the ratio of the combined mesiodistal crown diameters of the maxillary incisors (SI) to transverse dental arch width should be 80 in the premolar area and 64 in molar area. He proposed the calculation of the Index as follows:

Premolar Index = SI x 100 / Premolar width

Molar Index = SI x 100 / Molar width

Where,

SI= the sum of mesiodistal crown diameters of the four maxillary incisors

Premolar width = the distance between the maxillary first premolars, measured in the centre of the occlusal surface

Molar width = the distance between the maxillary first molars, measured in the centre of the occlusal surface

Pont measured the mesiodistal width of four maxillary incisors, the distance between the centre of first premolars and the distance between the centre of first molars by means of a compass and obtained mean values of 31 mm, 39 mm and 48.4 mm respectively. He then calculated the Premolar Index and Molar Index of 80 and 64 respectively, using the previously described formulae. These ratios were subsequently translated into a table in which 1 or 2 mm were added to compensate for the tendency of relapse in orthodontic treatment (Appendix 1).

Even though he stated that by using this Index the orthodontist could easily solve space problems, Pont still stressed the importance of assessing facial profile and Angle classification. The relationship of the maxilla and mandible to each other, and the position of the midline, were other essential features to be considered. Pont explained that he obtained his data from a French population but he did not state how many subjects were included in his study.

As Pont was aware of the differences between ethnic groups, he suggested that the reliability of his Index should be confirmed in other populations.

Since then, there has been considerable disagreement concerning Pont's Index. Many authors have assessed the validity and reliability of this index in different populations. The results of these assessments can be divided into two opposing groups. Those in favour of Pont's Index have supported its use as a guide in expanding the dental arch, while those against have found that the validity and reliability of Pont's Index in predicting dental arch width from the sum of the mesiodistal diameters of four maxillary incisors is very poor.

<u>Those in Favour</u>

The following studies which were carried out in various ethnic groups, support the clinical use of Pont's Index as a guide in performing expansion treatments.

Stifter (1958) studied 34 so-called "normal" and 24 ideal occlusions and assessed the analyses of Pont, as well as several others including Howes, Rees, Neff and Bolton. Although he stated that regression equations had been used in the statistical analysis, Stifter did not present values of correlation coefficients. Nevertheless, he concluded that in ideal occlusions there was a significant correlation between combined incisor widths and maxillary molar and premolar arch widths. No significant correlation could be found in the group with normal occlusion, a possible reason being that the study included Americans of many different nationalities. He stressed that Pont's measurements should be a goal to strive for when working toward the ideal.

Henry (1963) studied Pont's Index in 60 Australian children (30 boys and 30 girls) with excellent occlusions.

By comparing mean values he concluded that boys possessed slightly larger teeth and broader arches than girls. Furthermore, he deduced new values for the Premolar Index and Molar Index (81 and 63 respectively) that could be used for Australian children. In addition, he derived a new table using these indices.

Lamons (1964) stated that Pont's Index was an excellent aid in visualizing and establishing good arch form in the upper arch. He studied 50 sets of study models of male students with excellent and ideal occlusions from Emory University, School of Dentistry. He found that molar arch width was almost exactly the same as Pont's predicted values and that premolar width was approximately 5 per cent less than Pont's values. He calculated that this 5 per cent difference would amount to about 2 mm. He concluded that even though he had found a smaller value, Pont's Index was still a helpful aid in diagnosis and treatment planning. Furthermore, he stated that the width between the maxillary first premolars, taken at approximately the tip of the buccal cusps, should be equal to that of the first molars taken at the tip of the mesiolingual cusp.

Gupta et al. (1979) studied 100 dental casts of North Indians with normal occlusions. Measurements were made with Helios calipers to an accuracy of 0.02 mm. New values of 81.66 and 65.44 for the Premolar and Molar Indices were proposed for the North Indian population. Correlation coefficients were computed between combined maxillary incisor diameters and premolar and molar arch widths. The values obtained were 0.46 and 0.49 being significant at the $p<.001$ level. The authors concluded that these values revealed highly significant associations between the mesiodistal diameters of the incisors and arch width in the premolar and molar regions.

Wiebrecht (1975) emphasized that orthodontic treatment should not be viewed as just tooth movement, but as an arch development that must ultimately be in harmony with muscle balance and function. He preferred very early treatment, using the deciduous molars as anchorage during the early mixed dentition stage, to gain stability in the entire dento-facial complex. In this respect he praised Pont's Index and used it as a guide to predict the development of arch width. As Pont's Index dealt only with the maxillary dental arch, Wiebrecht (quoted by Bastien, 1983) developed the P and the W Indices to be used in treating the mandibular arch in relation to the maxillary arch. He also developed the E Index (or Esthetic Index) to control the expansion of maxillary arch.

Those Against

On the other hand, in assessing Pont's Index, some authors found very low correlations between the observed and predicted arch widths. These studies concluded that Pont's Index was not a reliable diagnostic procedure in orthodontic treatment.

Worms et al. (1969) studied Pont's Index in 91 Navajo Indian children with ideal occlusions. All measurements were obtained with a sharpened Boley gauge and the measuring points on premolars and molars were defined as the central grooves and the central pits respectively. At the 1% confidence level they found a significant difference between observed and calculated premolar and molar widths. It was concluded that the reliability of Pont's Index as a diagnostic tool in orthodontics was highly questionable.

Joondeph et al. (1970) assessed Pont's Index in 20 individuals who had received orthodontic treatment and who were ten years post-retention. All cases had been treated without extraction and measurements were taken prior to treatment, at the completion of treatment, and at least ten years after all retention appliances had been discontinued.

Correlation coefficients ("r") were derived between the following variables:

1. The calculated Pont's premolar and molar widths with actual premolar and molar widths ten years out of retention - giving "r" values of 0.23 and 0.20 respectively.

2. The premolar and molar arch widths at the completion of treatment with the same measurements ten years out of retention - giving "r" values of 0.92 and 0.89 respectively.
3. The actual mesiodistal widths of maxillary incisors with the actual premolar and molar widths ten years out of retention - giving "r" values of 0.29 and 0.22.
4. The actual premolar and molar widths prior to treatment and after ten years post retention - giving "r" values of 0.70 and 0.62.

From these findings it was concluded that measuring the mesiodistal widths of incisors to predetermine maxillary interpremolar and intermolar widths was of no value in predicting ultimate arch width.

Marshall (1987) studied 36 American children, comprising 19 females and 17 males, and concluded that since "r" values between observed and expected dental arch dimensions ranged from 0.23 to 0.58, Pont's Index and its corresponding indices (the P Index and the W Index) had no reliable predictive value. He also assessed arch width changes from the mixed dentition (9 years of age) to the permanent dentition (14 years of age) in the intercanine, interpremolar and intermolar regions. He concluded that no significant change in lower arch width was detected but significant changes were found in upper arch widths for both males and females. Maxillary arch widths in males increased approximately twice that in females and the greatest change was found in intercanine dimension. At least 1 mm of change was noted from the mixed dentition stage to the permanent dentition stage in the interpremolar and intermolar arch widths in a 5-year period.

Moyers (1988) claimed that mandibular arch form and mandibular intercanine width have been found to be more reasonable treatment guides for both mandibular and maxillary ultimate arch widths. He stated that Pont's Index is naive in concept and should not be used in orthodontic diagnosis.

CROZAT APPLIANCE

Lamons (1964) published an article on a labiolingual appliance and referred it as the Crozat appliance. Even though Lamons paid some attention to Pont's Index when treating malocclusion, he tended to gain correct arch form with the correction of rotated molars. Most frequently this rotation required a small amount of expansion which was referred to as "regaining of normal molar width". In the following years the concept of molar rotation was modified by set-backs or distal driving of the molar in addition to the rotating movement (Parker, 1985).

Furthermore, Lamons stated that the extraction of premolars as a prescribed therapy did not fit very well into the Crozat concept. In this concept, appliances were not primarily meant to move malposed teeth but rather to deliver stress through the medium of the teeth to the supporting structures, resulting in tissue changes and indirectly in tooth movement. As the appliance exerts a very light force over a considerable time, it was assumed that the teeth were continuously adjusting to each other, as were the supporting and surrounding structures.

This concept was very similar to Wiebrecht's concept in the use of the Crozat appliance. Wiebrecht (1975) stated that the goal of the treatment should be a correct occlusion which was developed in harmony with muscle balance and function within the acceptable intergnathic range. He stressed that the philosophy of treatment was essentially the philosophy of arch development. Holding this philosophy, Wiebrecht found that Pont's Index was the only guidance in performing dental arch expansion using the Crozat appliance. Wiebrecht started his treatment of malocclusion entirely guided by Pont's Index. Active treatment with the Crozat appliance began with rotation of the first molars and arch expansion continued until proper arch width was achieved as indicated by Pont's Index.

Even though the basic concept and treatment philosophy of this modality were quite similar, certain different approaches occurred in the use of the Crozat appliance. Those who initially followed Dr. Crozat's procedure such as Lamons (1964), Smythe (1969), Hitchcock (1972) and Parker

(1985) found that the Crozat appliance, used in a selected case, could produce good results.

An alternative approach was proposed by Wiebrecht (1975), in which Pont's Index became a treatment guide. White and Clark (1976), Bastien (1983), Schwarzkopf and Vogl (1984) were some of the followers who believed that Pont's Index was an excellent index in predicting the genetic potential of the dental arch. More recently Pont's Index has gained strong support from the so-called orthognathic orthopedists and some general dentists.

"IDEAL" DENTAL ARCH FORM

There have been numerous studies of the human dental arch and many authors have tried to describe either the "ideal" or the "average" dental arch form.

Pont (1909) also described a procedure of plotting maxillary arch form according to his Index. He multiplied the combined crown diameters of the maxillary incisors by 1.75, claiming that this should represent the diameter of a circle, of which the dentition, from mesiobuccal cusp of left first molar to the mesiobuccal cusp of right first molar, would represent one-half segment. The second and the third molars could be plotted along a straight side of an equilateral triangle with the base representing intercondylar width (Figure 1).

Furthermore, Pont stated that in brachycephaly the arrangement of the incisors would lie within the circle while in dolichocephaly the incisors would fall out of the circle. He believed that with this arrangement, the form of the dental arch should be in harmony with the form of the face.

Scott (1957) described the catenary curve as the normal dental arch form and believed that any variation from this form was a consequence of alveolar bone growth beyond the normal range. The catenometer, which consists of two stops from which a chain is suspended, was used as a device to measure dental arch perimeter. In the maxilla, the apex of the chain lay over the palatal gingival papilla between the central incisors, whereas the stops lay at the central fossa of the first molars. In the mandible, the stops lay at the buccal cusps of the first molars.

Currier (1969) formulated a computer program for analysing dental arch form. He used 25 radiographs of dental casts of Caucasian adults having normal or ideal occlusions. Each radiograph contained two-dimensional views of a pair of plaster dental casts. In these radiographs he divided the dental arch into the following curves: an outer curve which ran along the buccal tips of the molars and premolars and the incisal edges of the canines and incisors, a middle curve running through the central fossae of molars, occlusal

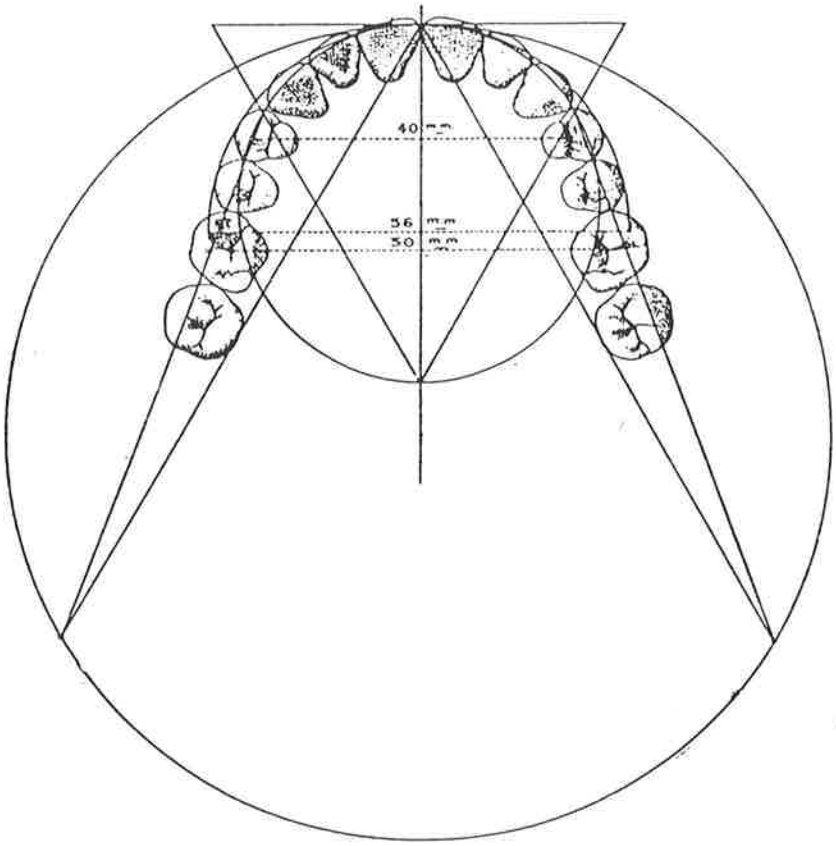

Figure 1: Pont's Arch Form (Pont, 1909)
This diagram was plotted based on the sum of mesiodistal diameters of four maxillary incisors (SI) in which:

- central incisor diameter = 8.5 mm
- lateral incisor diameter = 7.5 mm
- SI = 32 mm
- distance between mesiobuccal cusp of maxillary first molars (the diameter of the circle in which all the teeth mesial to the first molars were drawn) = SI x 1.75 = 56 mm
- according to Pont' Index, interpremolar width = 40 mm; intermolar width = 50 mm

fissures of premolars and the cinguli of canines and incisors, and an inner curve which ran through the most lingual aspect of the teeth. He compared elliptical and parabolic shapes to these three curves, and concluded that the ellipse had a better goodness-of-fit (that is, smaller variance) to the outer curve in both maxilla and mandible, than to either of the middle or inner curves. As orthodontic procedures were performed on the outer surface of the teeth he concluded that the ellipse was a better guide to arch form than the parabola. Furthermore, he noted that the middle curve of the maxilla combined with the outer curve of the mandible, coincided with the "line of occlusion" postulated by Angle in 1907 (cited by Graber, 1982).

Cheng (1972), in studying dental arch morphology of Australian Aborigines, found that fifth-degree polynomial equations described dental arch form better than fourth-degree equations, even though there were deficiencies in representing arch shape in a few individuals. This finding differed from that of Lu (1964) who proposed that fourth-degree polynomial equations satisfactorily described the dental arches.

Brader (1972) concluded that superior dental arch form was approximated by a closed curve with trifocal elliptic properties, with the teeth occupying only a portion of the total curve at its constricted end. This arch form represented a steady state of equilibrium delimited by the counterbalancing force fields of the tongue and of circum-oral tissues.

Worms et al. (1972), in assessing the reliability of Pont's Index in 91 Navajo Indian children and 133 dental students from the University of Minnesota, also plotted the differences between predicted and observed arch widths in the premolar and molar regions. Differences in premolar and molar arch widths of each dental arch were connected with a straight line, so the differences between the predicted and observed measurements of each dental arch could be visualized. The authors concluded that mean arch form could vary between ethnic groups and that arch form varied between individuals.

Musich and Ackerman (1973), in comparing the use of the catenometer and a brass wire for measuring dental arch perimeter, found that the catenometer was more reliable. It was also noted that the chain could be modified to an arch form that did not conform to the catenary shape, by arranging the apex of the chain over the palatal gingival papilla between the incisors.

Rudge (1981), in reviewing the literature on dental arch form, mentioned that the earliest description of dental arch form was provided by Hawley, based on the work of Bonwill. Hawley in 1905 (cited by Rudge, 1981) contended that the anterior teeth, from canine to canine, should be arranged on a segment of a circle with radius equal to the combined witdh of these teeth. The posterior teeth were arranged on the straight side of an equilateral triangle with the base representing intercondylar width.

Although Rudge (1981) concluded that studies of dental arch form had not yet conclusively determined the ideal dental arch shape, he subsequently devised a computer program for the analysis of study models and used the Bonwill-Hawley arch form as a reference during his research (Rudge, 1982). Angular deviation of each tooth from the ideal dental arch form was measured and a table derived to give a numerical score for malocclusion which was called the Index of Discrepancy.

Studies of dental arch form still continue and computer programs to apply mathematical formulae to arch form are being developed and applied.

ORTHODONTIC TREATMENT PHILOSOPHY

According to Proffit (1986), the most recent definition of Orthodontics, provided by the American Association of Orthodontics in 1981, is as follows:

ORTHODONTICS (DENTOFACIAL ORTHOPEDICS); The area of dentistry concerned with the supervision, guidance and correction of the growing and mature dentofacial structures, including those conditions that require movement of teeth or correction of malrelationships and malformations of related structures by the adjustment of the relationship between and among the teeth and facial bones by the application of forces and/or the stimulation and redirection of the functional forces within the craniofacial complex.

This definition includes the creation of the best possible occlusal relationships, within the framework of acceptable facial esthetics and stability of the occlusal result.

Stability is a major concern in orthodontics as it has been found that arch length and width typically reduce with age, with long-term records showing the trend continuing at least into the 30's and 40's age bracket (Little, 1987). This finding is supported by the study of Joondeph et al. (1970), in which slight constriction of arch width was found ten years post-retention. Furthermore, Little (1987) suggested avoidance of expansion of the mandibular arch as he believed that anteroposterior and/or lateral increases in mandibular arch form usually failed and that the dental arch would eventually return to its pre-treatment size and shape.

Lutz and Poulton (1985) performed expansion treatment in the deciduous dentition. Although they found persistence of slight expansion in the intercanine and interpremolar widths, there was no firm conclusion which could be drawn from their study as evidence of unpredictable loss of expansion was noted.

This view is the opposite to those orthodontists who advocate dental arch expansion. On the basis of the functional matrix theory developed by Moss (1962), the expansion of the dental arches and surrounding tissues became a desired treatment modality for some clinicians.

Moss and Salentijn (1969 a, b), have described the head as comprising certain functional cranial components designed to carry out different functions. Each component is considered to be composed of two parts: 1. a functional matrix that actually carries out the function and, 2. a skeletal unit that has a biomechanical role to protect and/or support its specific functional matrix. Skeletal units may be composed of bone, cartilage or tendonous tissues, and can be divided into macro- and micro-skeletal units. Functional matrices include soft tissues such as muscles, glands, nerves and vessels.

All responses of the osseous portions of skeletal units to their functional matrices are thought to be brought about by the complementary and interrelated process of osseous deposition and resorption. The resultant effect of all such skeletal unit responses to periosteal matrices is to alter their size and/or shape.

In other words, the skeletal unit does not grow first but rather it provides a platform upon which the periosteal matrix can alter its function. The total growth changes in all aspects of the skeletal unit are at all times a direct and compensatory response to the morphogenetically and temporally prior demands of the periosteal matrix's function.

The Functional Matrix Theory is relied upon by orofacial orthopedists who treat malocclusion by means of functional appliances. Various functional appliances differ considerably in appearance and often bear the developer's name. One of the appliances is the Functional Regulator (Frankel appliance) developed by Frankel and described in his textbook (Frankel, 1989). The difference between the Frankel appliance and other functional appliances is that, unlike other appliances, the Frankel appliance has limited contact with the teeth. By placing most of the appliance loosely in the vestibule, both mandibular posture and the contour of facial soft tissue can be altered. Furthermore, Frankel stated that the forces exerted by any other functional appliance that stretches muscle and soft tissue, and creates pressures that can be transmitted to the dental and skeletal structures, are more likely to move teeth orthodontically and can not be regarded as truly orthopedic appliances.

Another view, described by Kussick (1985) proposes that bone may be remodeled by using an appliance called a bone remodeler. Bone remodeling depends on the universal bone growth mechanism and periosteal muscle adjustment (periosteal-slippage). Muscle is attached to the bone via the periosteum. It provides a stability to bone-muscle relationships. As bone grows, the attachment adjusts, or slips, to accommodate the new bone size and to maintain normal muscle function. This is the normal readjustment of the superficial muscle attachments on periosteum as young bones grow. A new stable relationship between the muscle and bone results when the growth ends.

Kussick (1987) has indicated that a vital cellular response inherent in the growth potential of adolescent bone is periosteum/muscle adjustment, normal muscle/bone relocation and reattachment. Periosteum/muscle adjustment permits bone drift, local remodeling, condylar growth, and jaw relocation. Immature bone and its connective tissue matrix are most succeptible to evoking these cellular responses. He believes that the bone remodeler can replace both functional jaw orthopedics and multibanded techniques.

Different philosophies have led to different approaches in orthodontic treatment, and it is necessary to have a thorough understanding of the philosophy underlying certain procedures before they can be adequately assessed or applied. Although it is not always easy to judge, only those treatments based on sound scientific evidence in relation to their efficacy should be used clinically.

CHAPTER III: MATERIALS AND METHODS

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- METHODS
- THE INDICES
- ERRORS OF THE METHOD
- TWIN STUDY
- STATISTICAL ANALYSES

CHAPTER III: MATERIALS AND METHODS

THE SAMPLES

The data for this study were obtained from measurements of dental casts of Australian Aborigines, Indonesians, Caucasians and Caucasian twins. Figure 2 illustrates the locations from which the dental casts of the subjects were obtained.

Australian Aborigines

Cross-sectional study

The cross-sectional study sample comprised 40 males and 40 females with average ages of 14.22 years and 14.71 years respectively. The dental casts of these subjects were chosen from the collection of Aboriginal records obtained during a longitudinal study carried out at Yuendumu settlement in Central Australia in the 1960s and 70s (Brown and Barrett, 1973). The Aboriginal population at Yuendumu settlement belonged to the Wailbiri tribe having pure Aboriginal ancestry. In their general mode of life and methods of food preparation and eating habits they were at an intermediate stage of transition from their previous hunting and food

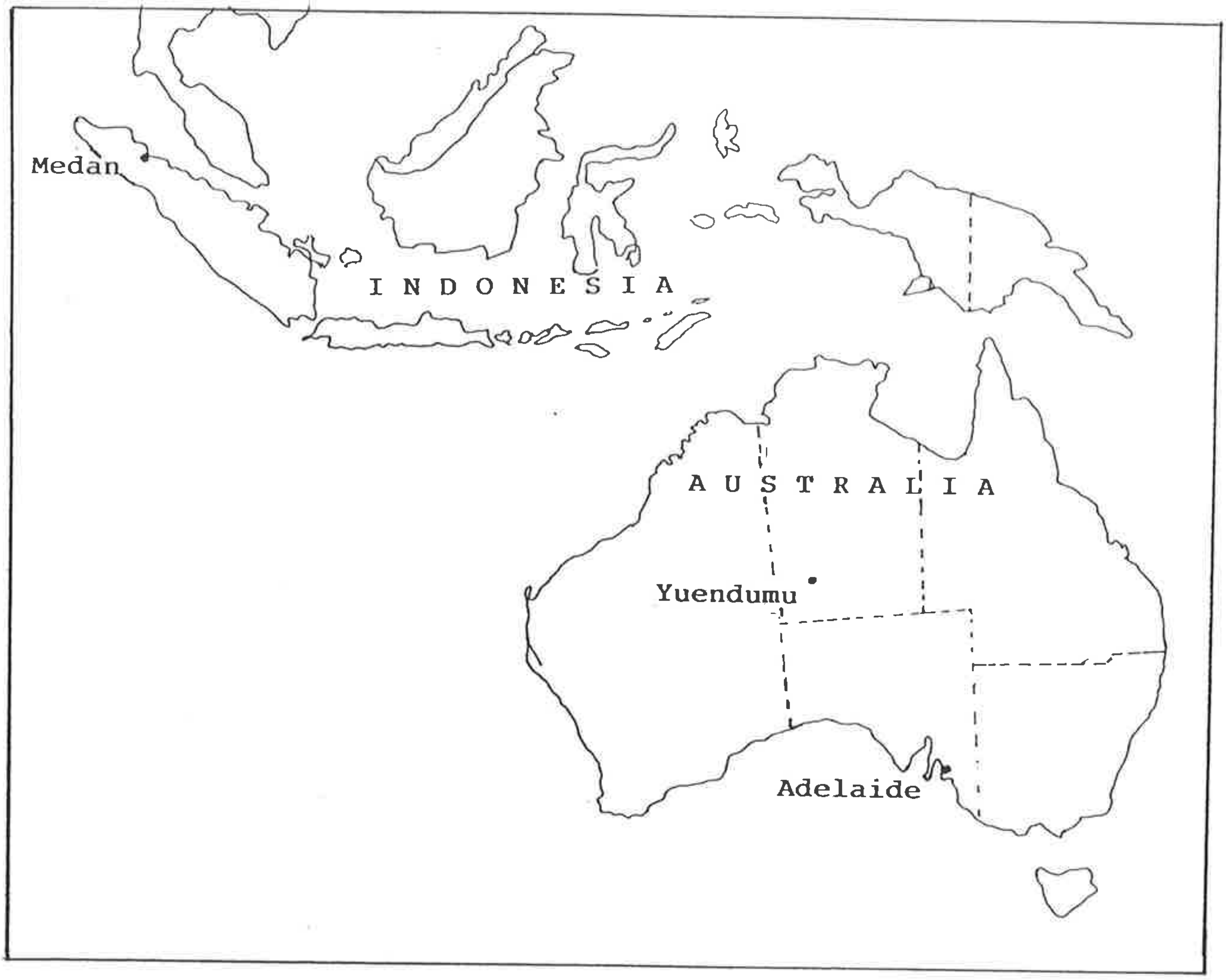


Figure 2 : Map showing the locations from which the dental casts of the subjects were obtained.

gathering existence to the adoption of a civilised way of life. Dental caries was virtually non-existence, because the bore water supply of the settlement contained 1.5 parts per million of fluoride (Barrett, 1965). In addition, vigorous mastication of tough , fibrous foods had a marked cleaning effect on the teeth (Barrett, 1968).

Longitudinal study

Nineteen males and 14 females were included in the longitudinal study of Australian Aborigines. The average ages of the subjects were 8.99 years and 8.21 years for boys and girls respectively at the mixed dentition stage and 14.42 years and 13.81 years respectively at the permanent dentition stage.

Indonesians

Sixty dental casts (30 males and 30 females) were obtained by the author from dental students of the University of North Sumatera in Medan, Indonesia, with average ages of 23.90 years for males and 22.04 years for females. Dental impressions were obtained using alginate hydrocolloid impression material. The impressions were washed free of saliva and were cast immediately with Fujirock dental stone.

Caucasians

The Caucasian sample was selected from a collection of dental casts of dental students in the Department of Dentistry, the University of Adelaide, Adelaide, South Australia. The sample comprised 30 males and 30 females with average ages of 17.87 years for males and 18.03 years for females.

Caucasian Twins

Dental casts of 102 pairs of monozygotic (MZ) twins and 74 pairs of dizygotic (DZ) twins were chosen from the collected material in the Department of Dentistry, The University of Adelaide. The dental casts, as well as other records including intra-oral and extra-oral photographs, finger and palm prints, and blood samples for zygosity determination are being obtained as part of an ongoing study of dento-facial variability in South Australian twins (Brown et al., 1987). The average age of MZ twins was 17.10 years and of DZ twins was 16.59 years. The methods of analysis carried out for the twin sample will be described in more detail on page 42.

METHODS

Cross-sectional study

The samples were carefully selected so that all subjects displayed normal occlusions, defined according to the following criteria:

1. Class I molar relationship
2. Overbite < 4 mm or 70% (measured with a caliper)
3. Overjet < 3 mm (measured with a caliper)
4. Full complement of teeth from second molar to second molar in both arches
5. Minimal crowding or spacing (< 3 mm)
6. No missing teeth
7. No supernumerary teeth
8. No crossbite
9. Minimal rotation
10. No orthodontic treatment
11. Minimal attrition

Longitudinal study

The longitudinal study sample was divided into mixed dentition and permanent dentition groups. The mixed dentition group was chosen after its corresponding permanent dentition group had been determined, following the above criteria. The mixed dentition sample represented subjects who had all permanent incisors and first molars erupted.

Measurement Landmarks

The measurement landmarks were (Appendices 2 and 3):

1. The maximum mesiodistal crown diameters of the four maxillary incisors (Right I_2, Right I_1, Left I_1, Left I_2).
2. Maxillary and mandibular intercanine widths, measured at the cusps tips (Max 3-3, Mand 3-3)
3. Maxillary interpremolar widths, measured at the distal pits of the first premolars (4-4 dist pit), the buccal cusp tips (4-4 bu cusp) and the palatal cusp tips (4-4 pal cusp).
4. Maxillary intermolar widths, measured at central fossae (6-6 cen fossa) and mesiopalatal cusp tips (6-6 mespal cusp) of the first molars.
5. Mandibular interpremolar width, measured at the distal fossae of the first premolars (4-4 dist fossa).
6. Mandibular intermolar width, measured at the distobuccal cusps of the first molars (6-6 distbu cusp).
7. Deciduous maxillary and mandibular intercanine widths (Max. C-C, Mand. C-C), measured at the cusp tips of deciduous canines.
8. Deciduous maxillary and mandibular intermolar widths (Max. D-D, Mand. D-D), measured at the distal fossae of deciduous first molars.

A digital caliper (Figure 3) was used to measure the mesiodistal crown diameters of the maxillary permanent incisors and arch widths directly on the dental casts, to an accuracy of 0.1 mm, and the values obtained were recorded on data sheets (Appendix 4). In those instances where there was slight attrition, the measuring point for arch width was determined as the middle of the facet on the tooth. The predicted arch widths in the premolar (P) and molar (M) areas were estimated using the formulae proposed by Pont (1909).

That is, P width = SI x 100 / 80

M width = SI x 100 / 64

Where,

SI = The sum of mesiodistal crown diameters of four maxillary incisors

P width = the distance between maxillary first premolars

M width = the distance between maxillary first molars

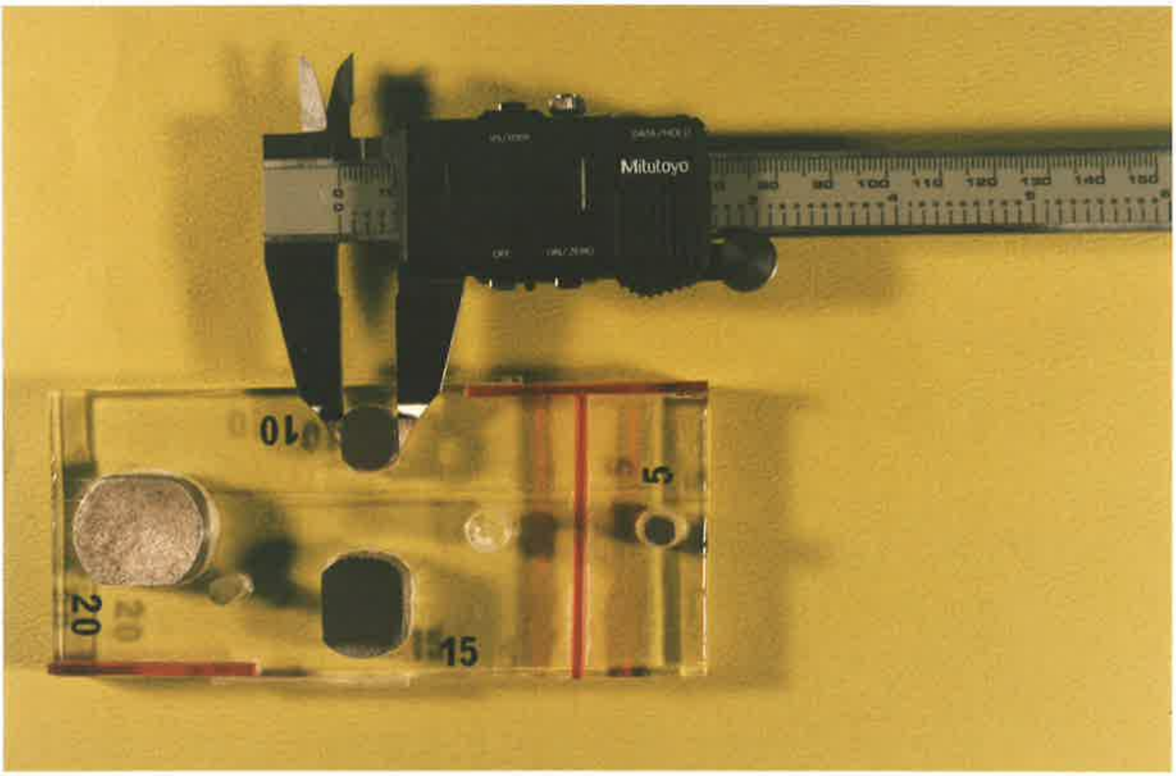


Figure 3: The digital caliper and the calibrator used in the present study

THE INDICES

1. Pont's Index (Figure 4); comprises the Premolar Index and the Molar Index which represent the relation of the diameters of the four maxillary incisors (SI) to the arch widths in the premolar area (4-4 dist pit) and in the molar area (6-6 cen fossa).

2. W Index (Figure 5); represents the width of the mandibular arch in the molar area (6-6 distbu cusp). This Index should coincide with Pont's molar width minus 1 mm.

W Index = (Pont's molar width) - 1 mm

3. P Index (Figure 6); represents the width of the mandibular arch in the premolar area (4-4 dist fossa). This Index should coincide with the maxillary premolar arch width measured at the palatal cusp of the first Premolar (4-4 pal cusp) minus 1 mm. A correction factor (CF) was added in calculating Pont's premolar arch width (4-4 pal cusp). The correction factor was computed as the difference between the observed

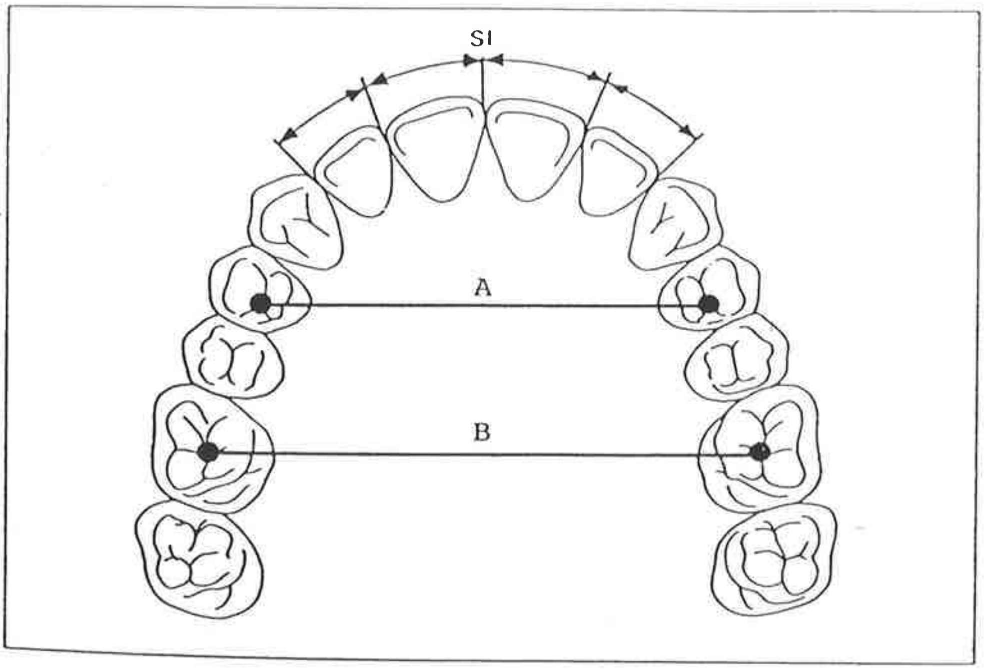


Figure 4: The Pont's Index (Schwarzkopf and Vogl, 1984)
A. The Premolar Index
B. The Molar Index

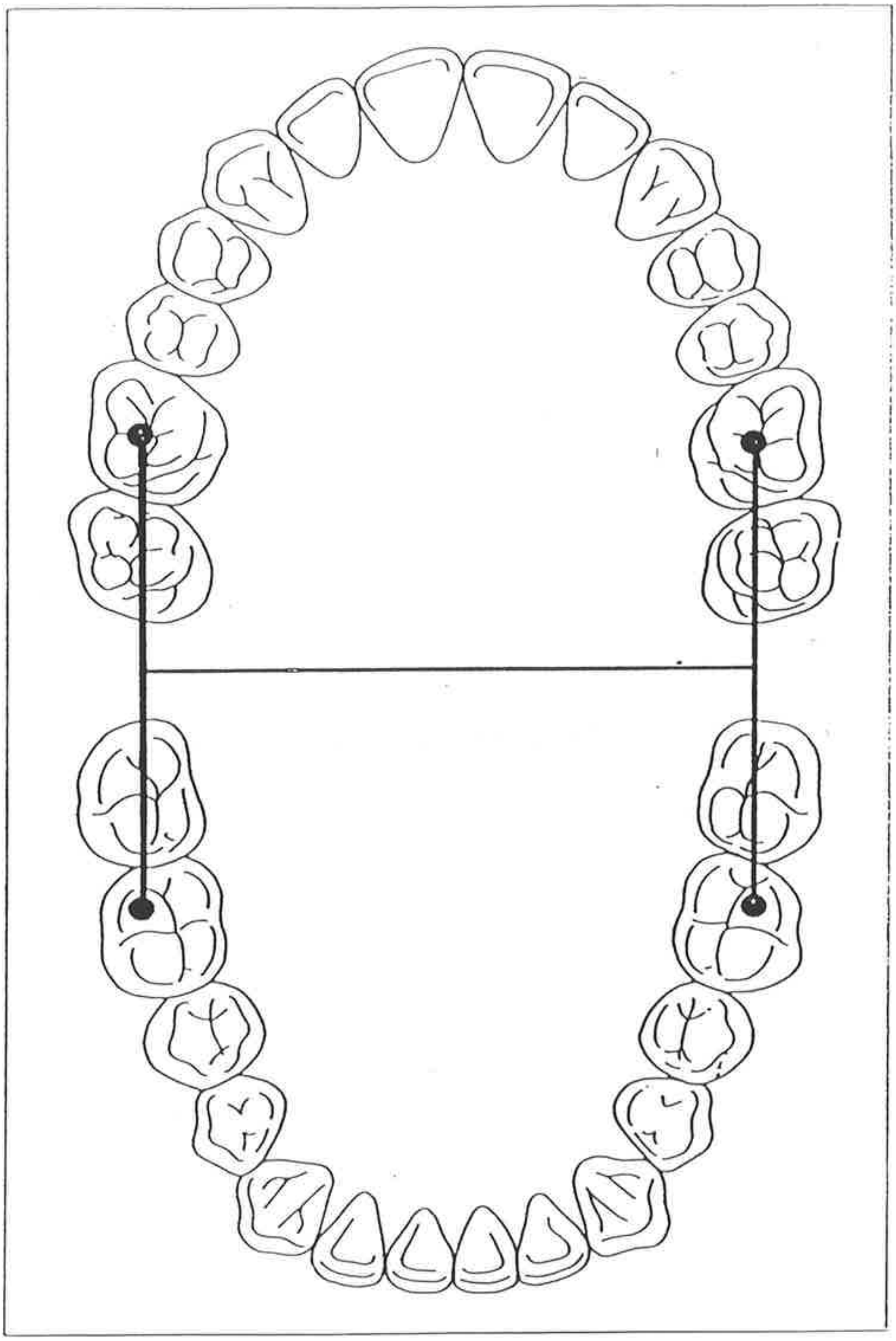


Figure 5: The W Index
(Schwarzkopf and Vogl, 1984)

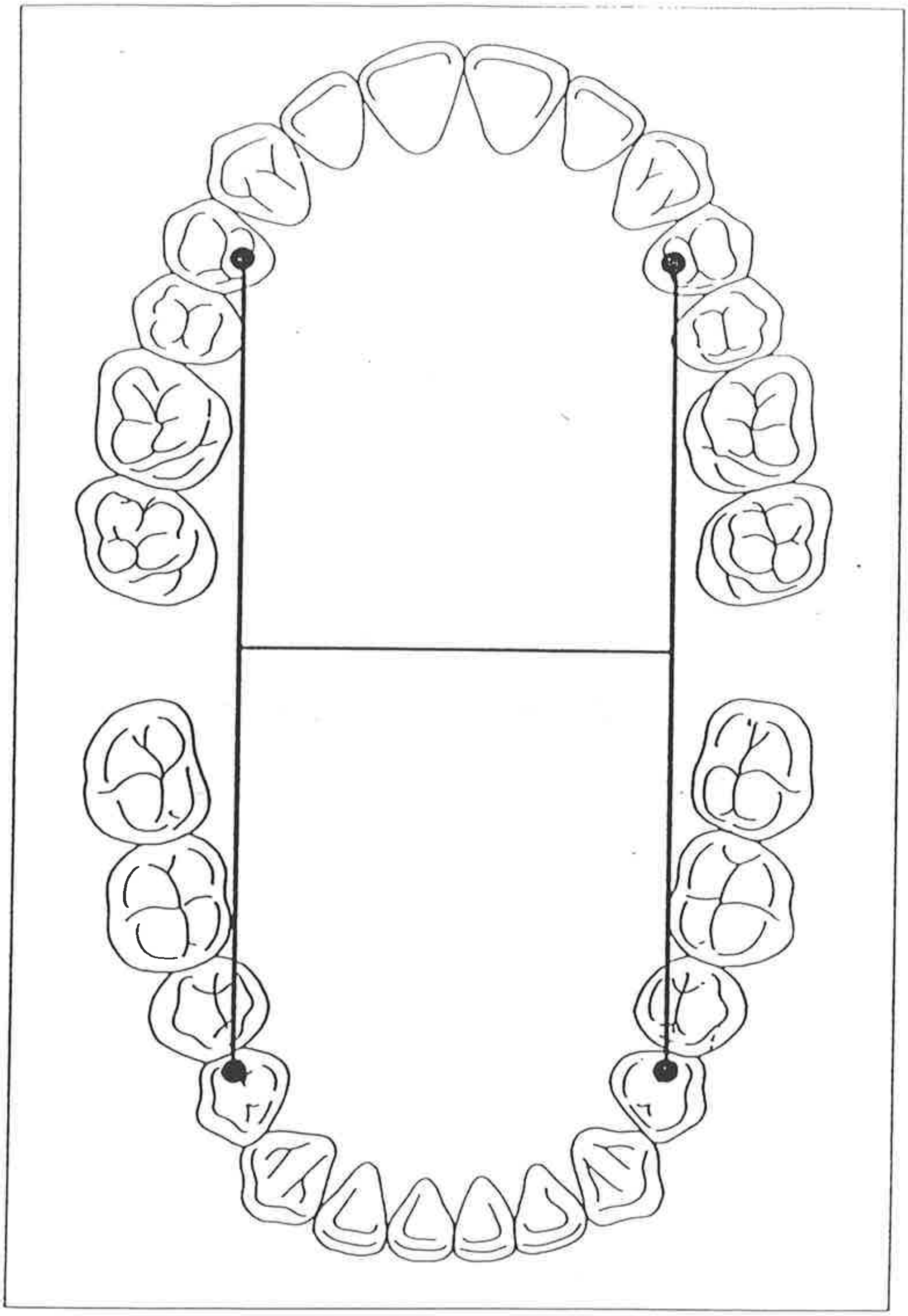


Figure 6: The P Index
(Schwarzkopf and Vogl, 1984)

premolar arch width measured at the distal pit of the first premolar (4-4 dist pit) and the observed premolar arch width measured at the palatal cusp of the first premolar (4-4 pal cusp). The value was subtracted from Pont's premolar width (4-4 dist pit).

CF = Obs. (4-4 dist pit) - Obs.(4-4 pal cusp)

Pont's (4-4 pal cusp) = Pont's (4-4 dist pit) - CF

P Index = Pont's (4-4 pal cusp) - 1 mm

4. E Index (Figure 7); also called "Esthetic Index", represents the relationship between maxillary premolar and molar arch widths. The premolar arch width measured at the buccal cusp of the first premolar (4-4 bu cusp) should coincide with the molar arch width measured at mesiopalatal cusp of the first molar (6-6 mespal cusp). The correction factor for Pont's premolar width (4-4 bu cusp) was the difference between the observed premolar arch width measured at the buccal cusp (4-4 bu cusp) and the observed premolar width measured at the distal pit (4-4 dist pit); the CF value was added to Pont's premolar width (4-4 dist pit). The correction factor for Pont's molar width (6-6 mespal cusp) was the difference between the observed molar width measured at the central fossa (6-6 cen fossa) and the observed molar width measured at the mesiopalatal cusp (6-6

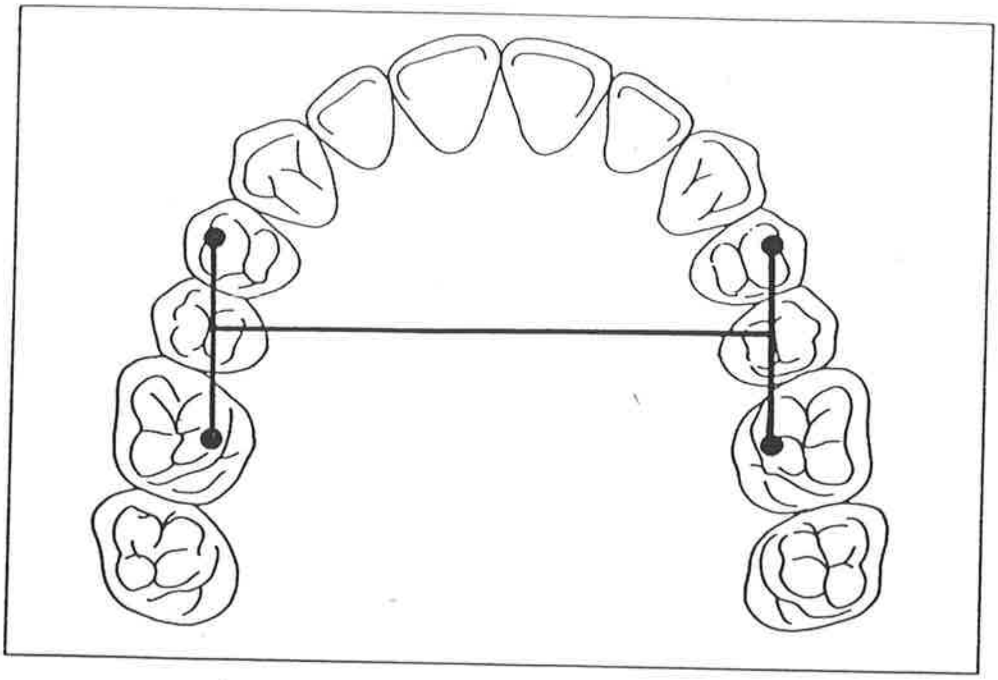


Figure 7: The E Index
(Schwarzkopf and Vogl, 1984)

mespal cusp); the CF value obtained was subtracted from Pont's molar width (6-6 cen fossa).

CF (4-4 bu cusp) = Obs. (4-4 bu cusp) - Obs.(4-4 dist pit)

Pont's (4-4 bu cusp) = Pont's (4-4 dist pit) + CF

CF (6-6 mespal cusp) = Obs(6-6 cen fossa) - Obs(6-6 mespal cusp)

Pont's (6-6 mespal cusp) = Pont's (6-6 cen fossa) - CF

ERRORS OF THE METHOD

Metrical procedures are subject to two types of errors:

- systematic errors (bias) arising from limitations in the materials and methods used, leading to consistent over- or under-estimation, for example, failure to correct for magnification factors;
- random errors (accidental) resulting, for example, from difficulty in identifying landmarks or imprecision of definitions.

Both types of errors can be minimized by rigidly standardizing experimental equipment and procedures. The magnitude of errors and the extent to which they may affect results can be assessed by replicability studies.

In this study these errors were minimized by the use of a finely-pointed caliper to allow access into interproximal areas of the dentition. The calibration of the instrument was checked at the beginning of each sesssion to ensure that it was measuring at optimal accuracy. Only 20 pairs of dental casts were measured in each session to avoid observer fatigue. Routine calculations of z-scores were performed in which values outside the range -3 to +3 were re-checked.

$$z = \frac{(x - \bar{x})}{SD}$$

where $\bar{x}$ = mean
x = individual value
SD = standard deviation

Replicability study

A replicability study was performed in which double determinations were made on separate occasions for 30 subjects from each population selected at random. Values of these two determinations were subjected to the following statistical tests:

I. Paired t-test; to assess the significance of mean differences between two determinations on a paired-comparison basis by calculating the mean of the differences ($\bar{d}$), the standard deviation of the differences ($SD_{\bar{d}}$) and the standard error of the mean difference ($SE_{\bar{d}}$).

$$\bar{d} = \frac{\Sigma d}{n}$$

$$SD_{\bar{d}} = \sqrt{\frac{\Sigma (d - \bar{d})^2}{n - 1}}$$

$$SE_{\bar{d}} = \frac{SD_{\bar{d}}}{\sqrt{n}}$$

where: $\bar{d}$ = difference between two determination
n = number of double determinations

Student's t-test was used to test whether the mean differences differed significantly from zero, according to the equation:

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

with n-1 degrees of freedom

II. The method of Dahlberg (1940); this method, also termed the technical error of the measurement, was used to compute the standard deviation of a single determination (S_E), according to the formula:

$$S_E = \sqrt{\frac{\Sigma\, d^2}{2n}}$$

where d = difference between replicated pairs
n = the number of double determinations

III. Analysis of variance; the extent to which variability due to experimental error affected the observed variance was determined by expressing error variance as a percentage of observed variance. The following formula was used:

$$So^2 = St^2 + Se^2$$

So^2 = observed variance from the sample as determined from the original values. This value includes variance due to measurement error.
St^2 = estimate of the true sample variance
Se^2 = estimate due to experimental error, termed the error variance.

Results of replicability studies

t-test

Although the mean differences between replicated measurements of the mesiodistal diameters of the incisors in Australian Aborigines, and some measurements of arch widths in Australian Aborigines, Indonesians and Caucasians were significantly different from zero, there was no trend for one series of measures to be consistently larger than the other. Furthermore the magnitude of individual differences was small, ranging from -0.6 mm to +0.6 mm for incisor diameters with only two values exceeding -0.5 mm and +0.5 mm and from -2.3 mm to +1.3 mm with only 16 values exceeding -1.0 and +1.0 for the arch width measurements (Appendices 5a, 5b, 5c).

Dahlberg Statistic

Measurement errors as indicated by the Dahlberg statistic are presented in Appendices 6a, 6b, 6c. Values ranged from 0.06 mm to 0.14 mm for mesiodistal measurements and 0.15 mm to 0.86 mm for arch widths measurements for the three populations.

Analysis of variance

From the analysis of variance, the reliability estimates ranged from 90.8% to 99.4% (Appendices 7a, 7b, 7c).

A number of statistical approaches including analysis of variance were used in assessing the measurement errors in this study. Paired t-tests and the Dahlberg statistic allowed an assessment of both systematic and accidental errors. Significant differences were found between the first and second measurements of some arch widths of the three study populations. Measurements of mandibular arch widths at the distobuccal cusps of the mandibular first molars showed the largest error of 0.86 mm (Dahlberg statistic) in Caucasians, and the lowest reliability (90.0%) in Indonesians. These resulted from the difficulties in determining the cusp tips as there was some attrition of the distobuccal cusps of the mandibular first molars.

The results of the replicability studies indicated that experimental errors were generally very small, and unlikely to bias estimates of mean values or variances.

TWIN STUDY

The measurements and landmarks used in the twin sample were the same as those described previously. The sample was divided into two groups; those dental casts in which all measurements could be obtained, and those casts in which only measurements of incisor diameters and some arch widths could be obtained. This procedure was carried out to obtain more data on incisor diameters and some arch widths in the casts that did not fulfil all of the criteria described previously. Furthermore, the aim of this aspect of the study was to explain the causes of variation in tooth size and arch widths in terms of genetic and environmental influences. Rather than including only subjects with "normal" occlusions and all variables measurable, a large sample of subjects was included to provide a better representation of the range of variation possible.

Descriptive statistics for males and females were computed separately including means ($\bar{x}$), standard deviations (SD), and coefficients of variations (CV). The t-test was used to test the differences between mean values in males and females. Where statistically significant differences were noted, correction factors (CF) were computed as the differences between the means of corresponding male and female values. The differences were added to female values before the genetic analyses were carried out so that the distribution of female data more closely approximated those of males in terms of central tendency. Comparisons of mean values for tooth size and arch width between monozygotic and dizygotic twins were performed after the addition of the correction factors.

STATISTICAL ANALYSES

Descriptive statistics

For both cross-sectional and longitudinal data, incisor diameters and arch widths for all subjects were described in terms of mean values, standard deviations and coefficients of variation for males and females separately. The forms of the distributions were analyzed by computing estimates of the parameters for skewness and kurtosis. Premolar and Molar Indices were computed for each population using Pont's formulae.

t-test

The t-test for independent samples was applied to analyse the differences between values for males and females in the cross-sectional studies and the paired t-test was applied to analyze differences between variables in the mixed dentition and permanent dentition of individuals in the longitudinal study.

Correlation coefficients

Correlation coefficients were computed between observed arch widths and those predicted according to Pont's, W, P Indices, for both cross-sectional and longitudinal studies in each population group. Coefficients of determination were also computed and scatter diagrams were plotted. The coefficient of determination, calculated as the square of the correlation coefficient, provides a measure of the proportion of the variation of one variable determined by variation of the other variable (Sokal and Rohlf, 1981). For the E Index, comparisons were computed between observed interpremolar and intermolar widths, as well as between predicted interpremolar and intermolar widths. Correlation coefficients were also computed to quantify the associations between all variables in each population in the cross-sectional study. The z-transformation developed by R. A. Fisher was used when testing significance of the "r" values (Sokal and Rohlf, 1981).

Analysis of variance

One-way analysis of variance and post-operative tests using Scheffe's method at the 0.05 probability level were carried out to test the significance of differences for all variables between the three populations in the cross-sectional study.

Genetic analysis of the twin sample

The approach used in the genetic analysis followed that of previous twin studies of the dentition (Townsend et al., 1988). Nested analysis of variance was performed to calculate the variations within and among pairs of MZ and DZ twins. Intraclass correlation coefficients ("r") were then determined, with theoretical maximum values assuming polygenic inheritance being unity for MZ twins and 0.50 for DZ twins. Several hidden assumptions implicit in the traditional twin model were tested before proceeding to calculate estimates of genetic variance. These assumptions can be explained as follows:

1. Twin zygosities should not be associated with the mean of the trait under consideration. Significant differences in mean values between MZ and DZ twins would reflect inherent biological differences associated with the twinning process. A modified t-test based on nested twin data has been recommended (Christian and Norton, 1977) to test for equality of mean values between zygosities in which among-pair mean squares are used as the error term and degrees of freedom are approximated.

2. Total variance within zygosities must be equal for the model to hold. If there is evidence of heterogeneity of total variance, environmental factors are postulated to be unequal for MZ and DZ twins. To test heterogeneity of total variances, one-way analysis of variance is performed, first treating twin pairs as groups of two to provide among-pair mean squares for MZ or DZ twins (AMZ or ADZ) and within-pair mean squares for MZ and DZ twins (WMZ or WDZ), then an F'test compares total mean squares, TMZ(AMZ+WMZ) and TDZ(ADZ+WDZ). The larger

value is used as the numerator of a two-tailed F'test, and the 0.2 probability level is used to minimize type 2 error (Christian et al., 1974)

3. Genetic variance estimates will also be biased by inequality of environmental covariances of MZ and DZ twins. If environmental covariance is relatively greater for MZ than for DZ twins, heritability estimates will be exaggerated. An F test can be used to contrast the among-pair and within-pair mean squares of DZ twins (F=ADZ/WDZ). If this ratio fails to appreciably exceed a value of 1, then the evidence for genetic variance rests solely in the MZ twins, and it is unlikely that any substantial proportion of the total variance is genetic (Christian et al., 1975)

If the data pass the above tests, the classic Genetic Variance Ratio (GVR) is calculated as F = WDZ/WMZ and tested for significance. If the F' test yields a significant result, a modified among-component ratio, F_{ac} = (WDZ+AMZ)/(WMZ+ADZ), is used to provide an unbiased estimate of GVR.

Different estimates of heritability were calculated to quantify the proportion of total variance attributable to genetic influence. Heritability refers to the amount of variation in a population attributable to genetic differences between individuals. Twin data provide an opportunity to obtain so-called "broad" estimates of heritability only, as similarities between twins may reflect similar environmental influences as well as genetic similarities (Vogel and Motulsky, 1986).

The computation of heritability estimates was carried out as follows:

1. The within-pair heritability estimate was computed as:

$$h^2_{wp} = (WDZ-WMZ)/(TMZ+TDZ)/4$$

where:
h^2_{wp} : within-pair heritability estimate
WDZ : within mean square for DZ
WMZ : within mean square for MZ
TDZ : total mean square for DZ
TMZ : total mean square for MZ

2. The Holzinger heritability coefficient was computed as:

$$h^2_H = (r_{MZ} - r_{DZ}) / (1 - r_{DZ})$$

where:
h^2_H : Holzinger heritability coefficient
r_{MZ} : intraclass correlation coefficient for MZ
r_{DZ} : intraclass correlation coefficient for DZ

3. Path analysis model heritability estimate was computed as:

$$h_r^2 = 2(r_{MZ} - r_{DZ})$$

Where:
- h_r^2 = intraclass heritability estimate
- r_{MZ} = intraclass correlation coefficient for MZ
- r_{DZ} = intraclass correlation coefficient for DZ

However, Christian et al. (1974) proposed if the F' test comparing total variance between zygosities yielded a significant result at the 0.2 probability level, then the among-component heritability estimate (h^2) should be used rather than the within-pair estimates (h^2). In this case,

$$h_{ac}^2 = 2\ GV_{ac} / (TMZ + TDZ)/4$$

Where:
- h_{ac}^2 : among-component heritability estimate
- GV_{ac} : among-component genetic variance
- TMZ : total mean square for MZ
- TDZ : total mean square for DZ

CHAPTER IV: RESULTS

- CROSS-SECTIONAL STUDY
- LONGITUDINAL STUDY
- TWIN STUDY

CHAPTER IV: RESULTS

Cross-sectional Study

Maxillary incisor crown diameters and maxillary and mandibular arch widths in both males and females for Australian Aborigines, Indonesians and Caucasians were described in terms of means, standard deviations and coefficients of variation.

Analysis of variance revealed significant differences between mean values of most variables in the three study populations (Tables 1 and 2). Tooth size in Aboriginal males and females was significantly larger than that of both Indonesians and Caucasians, whereas no significant difference was found between Indonesians and Caucasians. The ratio between maxillary lateral and central incisors ranged from .80 to .81 in Aboriginal males and females and Indonesian males while in Indonesian females and Caucasian males and females the values ranged from .75 to .76. Sexual dimorphism, calculated as $100(\bar{x}_M-\bar{x}_F)/\bar{x}_F$ was low, values ranging from 1.2% to 4.7% in the three study populations. Aboriginal and Indonesian maxillary right lateral incisors showed values of 4.3% and 4.7% respectively. In males, although nearly all of the arch width measurements in Caucasians differed significantly from Australian Aborigines, only maxillary and mandibular intermolar widths

Table 1: Tooth size and dental arch width (in mm) in Australian Aborigines, Indonesians and Caucasians (males)

Variables	Aborigines (n = 40)			Indonesians (n = 30)			Caucasians (n = 30)		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Crown diameters									
right I2	7.3*	0.54	7.4	6.7	0.48	7.3	6.4+	0.59	9.2
right I1	9.0*	0.69	7.6	8.4	0.51	6.0	8.5+	0.51	5.9
left I1	9.1*	0.70	7.7	8.3	0.50	6.0	8.3+	0.55	6.5
left I2	7.3*	0.60	8.2	6.6	0.51	7.8	6.4+	0.57	9.0
Arch widths									
Maxilla									
3-3 (cusp tip)	39.2*	2.27	5.8	35.1	1.98	5.6	34.8+	2.20	6.3
4-4 (dist pit)	41.1*	1.89	4.6	38.8	1.92	4.9	37.8+	2.26	6.0
4-4 (bu cusp)	47.1*	2.16	4.6	43.7	2.21	5.1	42.5+	2.58	6.1
4-4 (pal cusp)	34.8*	1.90	5.5	33.1	1.84	5.6	32.8+	2.36	7.2
6-6 (cen fossa)	50.8	2.54	5.0	50.1#	1.94	3.9	47.9+	2.88	6.0
6-6 (mespal cusp)	42.5	2.53	6.0	43.2	1.95	4.5	42.4	2.76	6.5
mandible									
3-3 (cusp tip)	29.9*	1.97	6.6	27.4	1.58	5.8	26.2+	1.88	7.2
4-4 (dist fossa)	34.1	1.89	5.5	33.9	1.97	5.8	32.8+	2.05	6.3
6-6 (distbu cusp)	51.9*	2.58	5.0	49.9#	2.11	4.2	47.9+	2.95	6.2

* significant difference between Aborigines and Indonesians at $p < 0.05$
\# significant difference between Indonesians and Caucasians at $p < 0.05$
\+ significant difference between Aborigines and Caucasians at $p < 0.05$

Table 2: Tooth size and dental arch width (in mm) in Australian Aborigines, Indonesians and Caucasians (females)

Variables	Aborigines (n = 40)			Indonesians (n = 30)			Caucasians (n = 30)		
	$\overline{x}$	SD	CV	$\overline{x}$	SD	CV	$\overline{x}$	SD	CV
Crown diameters									
right I2	7.0*	0.65	9.3	6.4	0.54	8.2	6.3+	0.50	8.0
right I1	8.8*	0.50	5.6	8.3	0.46	5.6	8.4+	0.38	4.5
left I1	8.8*	0.57	6.5	8.2	0.44	5.4	8.5+	0.38	4.5
left I2	7.1*	0.64	9.1	6.4	0.47	7.4	6.3+	0.27	8.2
Arch widths									
Maxilla									
3-3 (cusp tip)	37.1*	1.73	4.5	34.4	1.32	3.8	33.7+	1.79	5.3
4-4 (dist pit)	39.4*	1.86	4.7	37.7#	1.52	4.0	36.2+	2.00	5.5
4-4 (bu cusp)	44.9*	1.78	4.0	42.5#	1.60	3.8	40.9+	2.28	5.6
4-4 (pal cusp)	33.0*	1.74	5.3	31.8#	1.34	4.2	30.7+	1.98	6.5
6-6 (cen fossa)	48.8	1.94	4.0	48.9#	2.41	4.9	46.7+	2.81	6.0
6-6 (mespal cusp)	40.8	1.95	4.9	42.2	2.37	5.6	41.3	2.79	6.8
mandible									
3-3 (cusp tip)	28.4*	1.56	5.5	26.8#	1.22	4.6	25.7+	1.38	5.4
4-4 (dist fossa)	33.2	2.00	6.0	33.0#	1.50	4.6	31.6+	2.30	7.3
6-6 (distbu cusp)	50.4*	1.85	3.7	48.9#	2.44	5.0	46.5+	3.01	6.5

* significant difference between Aborigines and Indonesians at $p < 0.05$
\# significant difference between Indonesians and Caucasians at $P < 0.05$
\+ significant difference between Aborigines and Caucasians at $P < 0.05$

in Caucasians differed significantly from Indonesians. In contrast, there was no significant difference between maxillary intermolar widths in Australian Aborigines and Indonesians. A similar pattern was found in females with the exception that mandibular intercanine width and maxillary and mandibular interpremolar widths in Indonesians were significantly greater than those of Caucasians.

Comparisons of mean values for crown diameters and arch widths between males and females in Australian Aborigines, Indonesians and Caucasians are presented in Table 3. In Australian Aborigines almost all variables except the crown diameters of the right central incisor and the left lateral incisor and the mandibular interpremolar widths differed significantly between males and females. In Indonesians and Caucasians, there was no significant difference in tooth size between males and females, whereas some arch widths in males were significantly greater than those of females.

Correlation coefficients determined between the observed values and those predicted according to Pont's and its corresponding Indices are presented in Table 4. In all study populations, males showed slightly greater values than females. For the Premolar Index, Indonesian males showed the greatest "r" value (.56) followed by Australian Aboriginal males and females (.44 and .40). Indonesian females showed smaller value (.28) followed by Caucasian males and females (.26 and .22 respectively). Again Indonesian males showed

Table 3: Comparisons of mean values for crown diameters and arch widths between males and females in each of the three study populations

Variables	Aborigines (n = 40)			Indonesians (n = 30)			Caucasians (n = 30)		
	$\bar{x}_M$	$\bar{x}_F$	t	$\bar{x}_M$	$\bar{x}_F$	t	$\bar{x}_M$	$\bar{x}_F$	t
Crown diameters									
right I2	7.3	7.0	2.20*	6.7	6.4	1.81	6.4	6.3	0.99
right I1	9.0	8.8	1.62	8.4	8.3	1.17	8.5	8.4	0.58
left I1	9.1	8.8	2.48*	8.3	8.2	1.01	8.3	8.5	0.49
left I2	7.3	7.1	1.51	6.6	6.4	1.52	6.4	6.3	0.31
Arch widths									
Maxilla									
3-3 (cusp tip)	39.2	37.1	4.69**	35.1	34.4	1.65	34.8	33.7	2.13*
4-4 (dist pit)	41.1	39.4	4.11**	38.8	37.7	2.59*	37.8	36.2	2.85*
4-4 (bu cusp)	47.1	44.9	4.93**	43.7	42.5	2.40*	42.5	40.9	2.53*
4-4 (pal cusp)	34.8	33.0	4.33**	33.1	31.8	3.07**	32.8	30.7	3.85*
6-6 (cen fossa)	50.8	48.8	4.06**	50.1	48.9	2.14*	47.9	46.7	1.66
6-6 (mespal cusp)	42.5	40.8	3.34**	43.2	42.2	1.84	42.4	41.3	1.55
mandible									
3-3 (cusp tip)	29.9	28.4	3.73**	27.4	26.8	1.59	26.2	25.7	1.25
4-4 (dist fossa)	34.1	33.2	1.78	33.9	33.0	2.04*	32.8	31.6	2.13*
6-6 (distbu cusp)	51.9	50.4	3.07*	49.9	48.9	1.70	47.9	46.5	1.93

* Mean values differ significantly at $p < 0.05$
** Mean values differ significantly at $p < 0.01$

Table 4: Correlation coefficients (r) and coefficients of determination (r^2) between predicted (according to the Indices) and the observed values, in Australian Aborigines, Indonesians and Caucasians (females and males)

Indices		Aborigines (n = 40) F	Aborigines (n = 40) M	Indonesians (n = 30) F	Indonesians (n = 30) M	Caucasians (n = 30) F	Caucasians (n = 30) M
Premolar Index	r	.40*	.44*	.28	.56*	.22	.26
	r^2	.16	.20	.08	.32	.05	.07
Molar Index	r	.24	.29	.12	.56*	.26	.28
	r^2	.06	.08	.01	.32	.07	.08
P Index	r	.34*	.42*	.15	.33	.11	.18
	r^2	.12	.17	.02	.11	.01	.03
W Index	r	.16	.27	.09	.30	.18	.20
	r^2	.03	.07	.01	.09	.03	.04

* "r" values differ significantly from zero at $p < 0.05$

highest value for Molar Index (.56) followed by Aboriginal and Caucasian males (.29 and .28 respectively). Indonesian females showed the smallest value for Molar Index (.12), while "r" values of .24 and .26 were found in Australian Aboriginal and Caucasian females. The "r" values for the P and W Indices were generally lower than the values of Premolar and Molar Indices in the three study populations. The values for the P Index ranged from .11 in Caucasian females to .42 in Australian Aboriginal males. For the W Index, values ranged from .09 in females to .30 in Indonesian males.

Coefficients of determination were very low for all study populations, ranging from .01 to .32. That is, only 1% to 32% of the variation in observed arch widths could be explained by the variation in predicted arch widths. The smallest values (.01) were shown by Indonesian females for the Molar Index and W Index, and Caucasian females for the P Index. The greatest value (.32) was found in Indonesian males for Premolar and Molar Indices.

Correlations between interpremolar widths (4-4 bu cusp) and intermolar widths (6-6 mespal cusp) were computed for observed and predicted values separately. Table 5 presents correlation coefficients and coefficients of determination for the observed and predicted E Index of the three study populations. The "r" and "r^2" values of the predicted E Index were larger than the "r" and "r^2" values of the

Table 5: Correlation coefficients and coefficients of determination of E Index for observed and predicted values in the three study population (males and females)

Population	observed. E Index		Predicted E Index	
	r	r^2	r	r^2
Aborigines				
40 males	.77*	.59	.92*	.84
40 females	.62*	.38	.83*	.69
Indonesians				
30 males	.71*	.50	.92*	.84
30 females	.73*	.53	.91*	.83
Caucasians				
30 males	.80*	.64	.95*	.90
30 females	.71*	.50	.80*	.64

* "r" values differ significantly from zero at $p < 0.05$

observed E Index. The "r" values for the observed E Index ranged from .62 to .80, while the "r" values for the predicted E Index ranged from .80 to .95.

Table 6 presents correlations between the sum of the mesiodistal diameters of four maxillary incisors (SI) and the maxillary interpremolar and intermolar widths. Indonesian females showed the lowest value for the correlation between SI and maxillary intermolar width (.12) followed by Aboriginal females (.24). Caucasian males and females showed similar values for all correlations, ranging from .22 to .28.

The correlations between mesiodistal diameters of the maxillary lateral and central incisors and maxillary interpremolar and intermolar widths are presented in Table 7. The correlations between the mesiodistal diameters of the maxillary right and left lateral incisors and intermolar widths in Aboriginal females were low (.15 and .19). Lowest value was shown by Indonesian females for the correlation between the size of the maxillary left central incisor and intermolar widths (.01). Low values were noted in Caucasian males for the correlations between the mesiodistal diameter of the maxillary right lateral incisor and interpremolar and intermolar widths (.17 and .18).

Table 6: Correlations between the sum of mesiodistal diameters of maxillary incisors (SI) and maxillary interpremolar and intermolar arch widths in males and females for each of the three study populations

Groups	SI with	
	max 4-4	max 6-6
Aborigines		
40 males	.44*	.29
40 females	.40*	.24
Indonesians		
30 males	.56*	.56*
30 females	.28	.12
Caucasians		
30 males	.26	.28
30 females	.22	.26

* "r" values differ significantly from zero at $p < 0.05$

Table 7: Correlations between mesiodistal diameters of maxillary incisors and maxillary interpremolar (PW) and intermolar (MW) widths in males and females in each of the three study populations

Groups	right I2 with		right I1 with		left I1 with		left I2 with	
	PW	MW	PW	MW	PW	MW	PW	MW
Aborigines								
male	.38*	.25	.50*	.37*	.46*	.31	.25	.08
female	.29	.15	.37*	.22	.38*	.28	.37*	.19
Indonesians								
male	.41*	.38*	.57*	.61*	.56*	.60*	.41*	.35
female	.31	.16	.20	.12	.25	.12	.19	.01
Caucasians								
male	.17	.18	.19	.23	.24	.32	.27	.22
female	.20	.21	.12	.21	.20	.23	.24	.25

* "r" values differ significantly from zero at $p < 0.05$

Correlation coefficients between mesiodistal diameters of maxillary lateral incisors and central incisors were computed and results are presented in Table 8. The Aboriginal and Indonesian females showed low correlations between maxillary left lateral incisors and maxillary right central incisors (.47 and .37 respectively); Caucasian males also showed low correlation between maxillary right lateral incisor and maxillary right central incisors (.36).

Individual variations in the differences between the observed and predicted interpremolar and intermolar widths are illustrated for males and females separately in each population (Figure 8 - Figure 19). "Over Pont's prediction" refers to arch widths in which the observed values are larger than those predicted according to Pont's Index, whereas "under Pont's prediction" refers to those in which the observed values are smaller than the predicted values.

Australian Aboriginal males and females displayed a uniform distribution of under and over Pont's prediction in interpremolar and intermolar arch widths, in which only 20.6% arch widths showing differences between -1 mm to 1 mm. The largest difference in under Pont's prediction values was -8.9 mm found in intermolar width in males while 6.0 mm difference was found as the largest difference in over Pont's prediction values also in intermolar width in males.

Table 8 : Correlations between mesiodistal diameters of maxillary lateral incisors and maxillary central incisors in males and females for each of the three study populations

Group	right I2, with		left I2, with	
	right I1	left I1	right I1	left I1
Aborigines				
40 males	.72*	.71*	.69*	.66*
40 females	.52*	.56*	.47*	.56*
Indonesians				
30 males	.54*	.59*	.53*	.52*
30 females	.57*	.64*	.37*	.51*
Caucasians				
30 males	.36*	.42*	.48*	.60*
30 females	.45*	.57*	.63*	.76*

* "r" values differ significantly from zero at $p < 0.05$

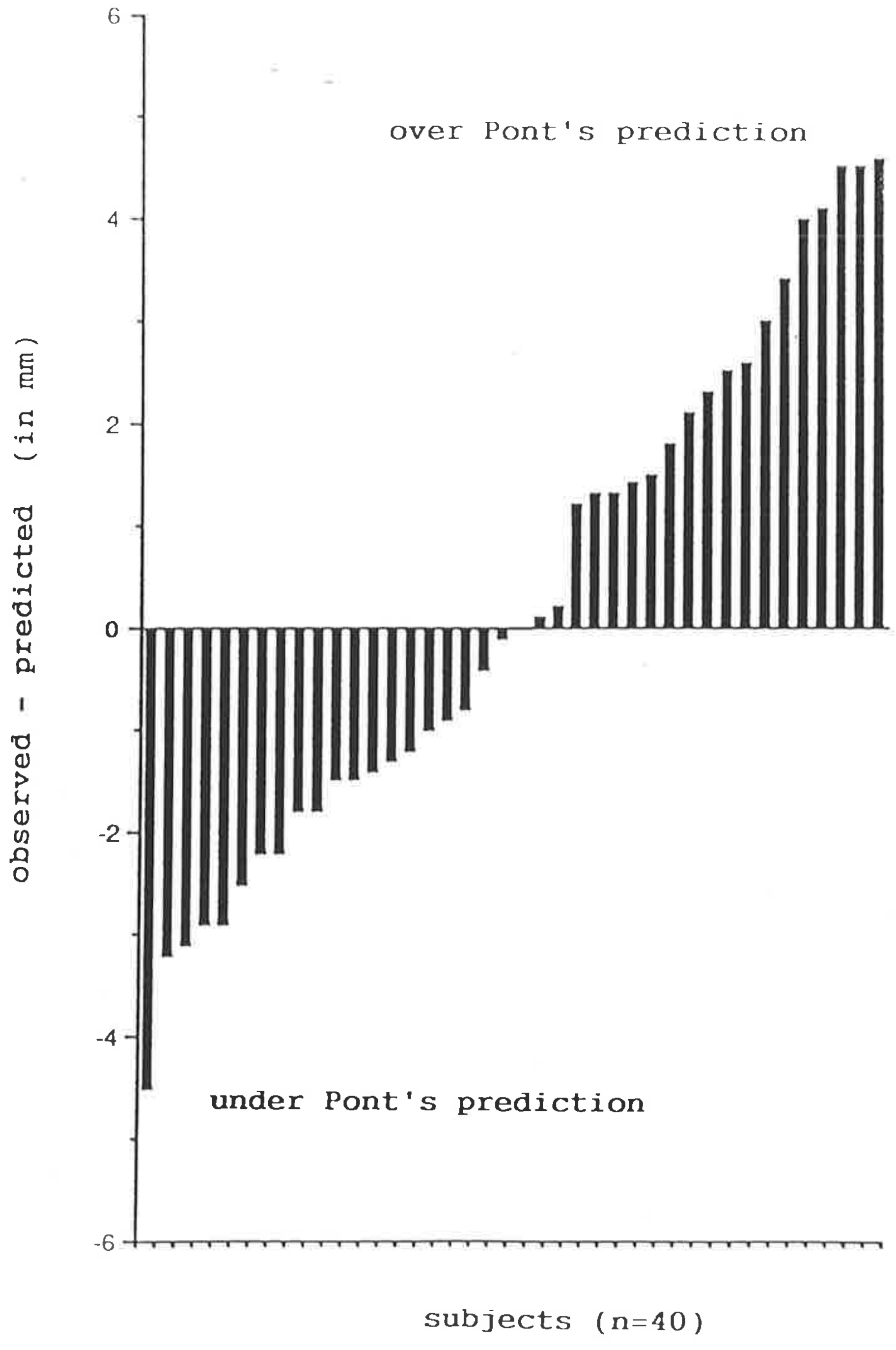


Figure 8:
Differences between observed and predicted interpremolar widths according to Pont's Index in Aboriginal females (N=40)

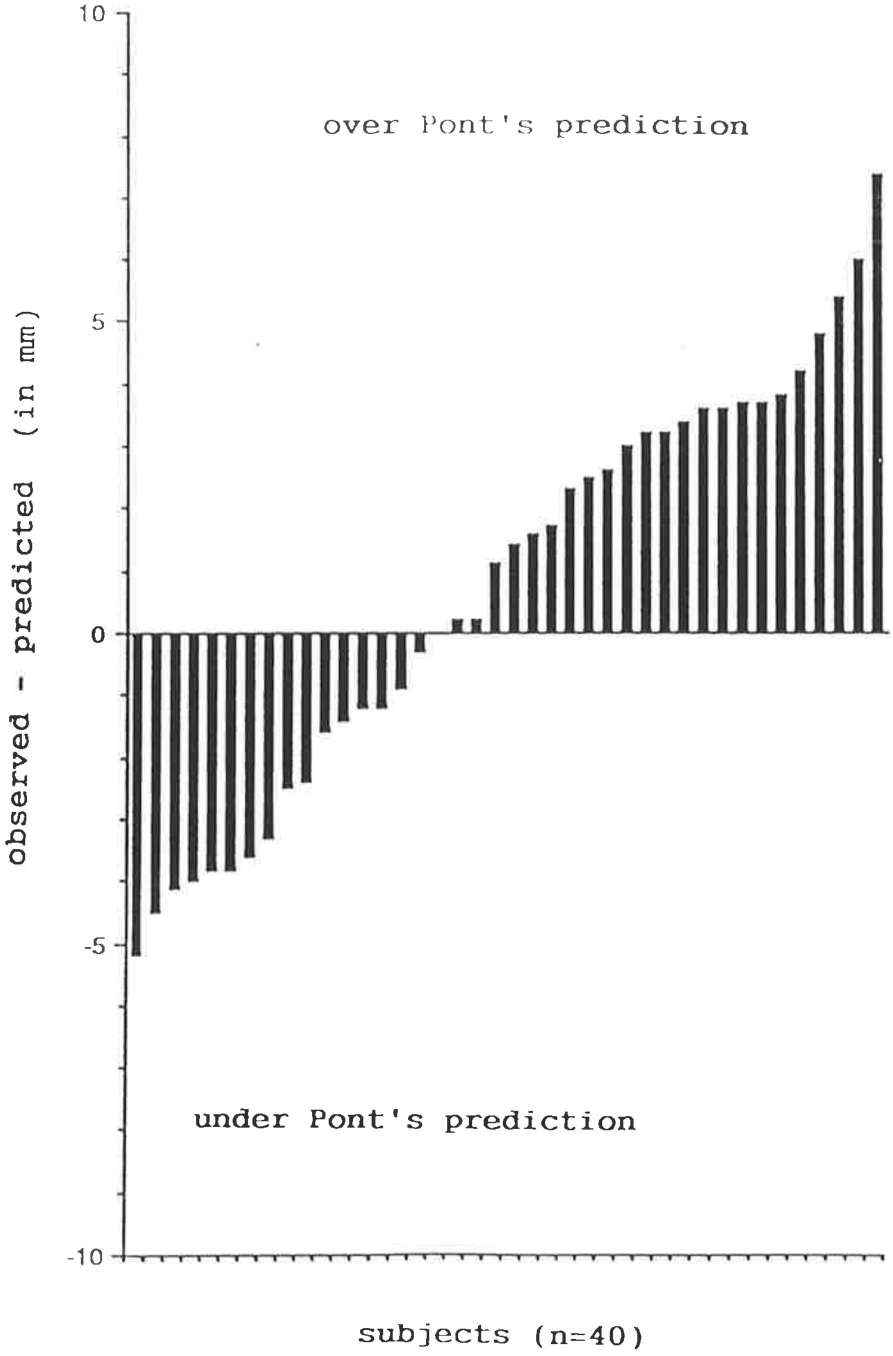


Figure 9:
Differences between observed and predicted intermolar widths according to Pont's Index in Aboriginal females (N=40)

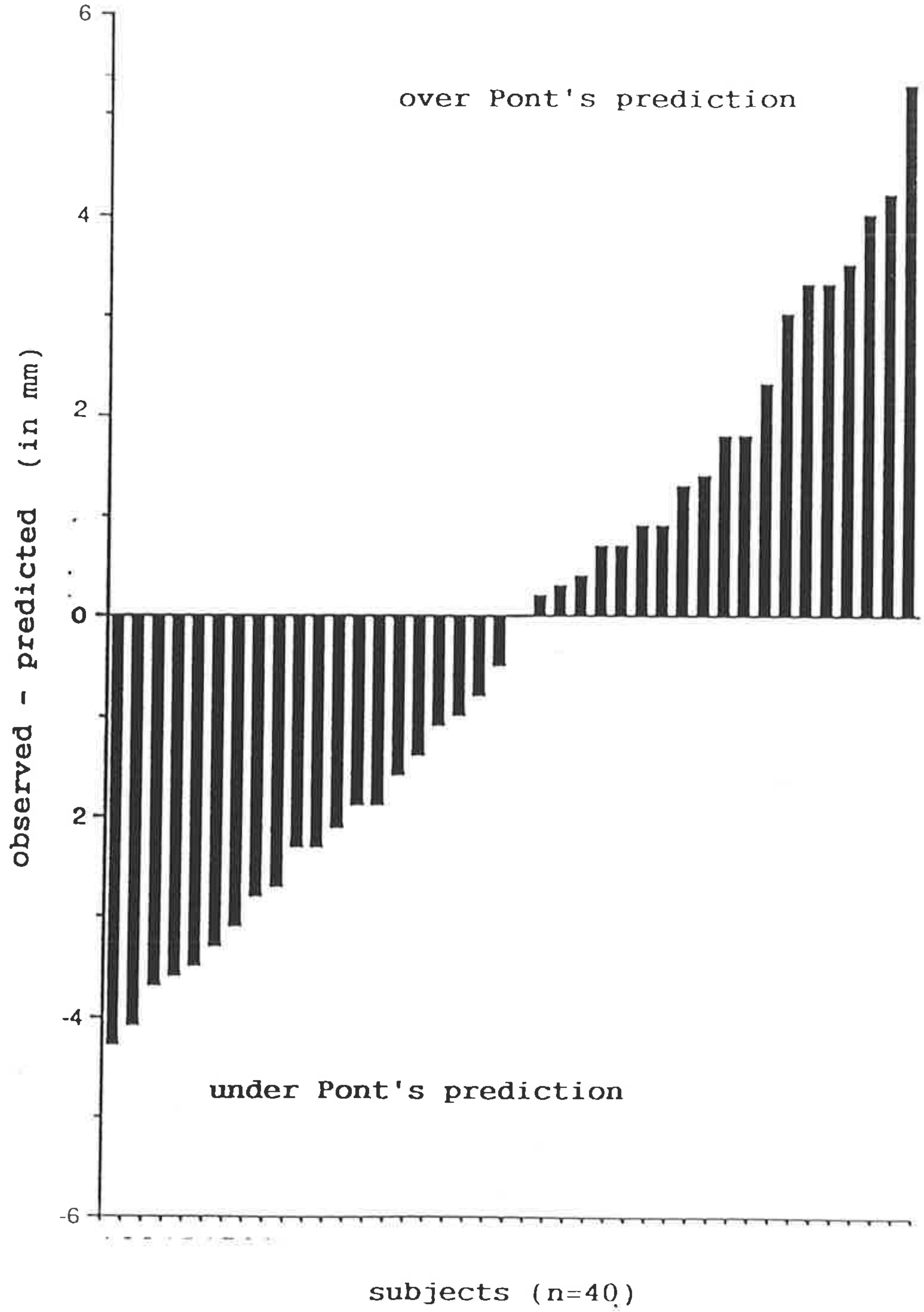


Figure 10:
Differences between observed and predicted interpremolar widths according to Pont's Index in Aboriginal males (N=40)

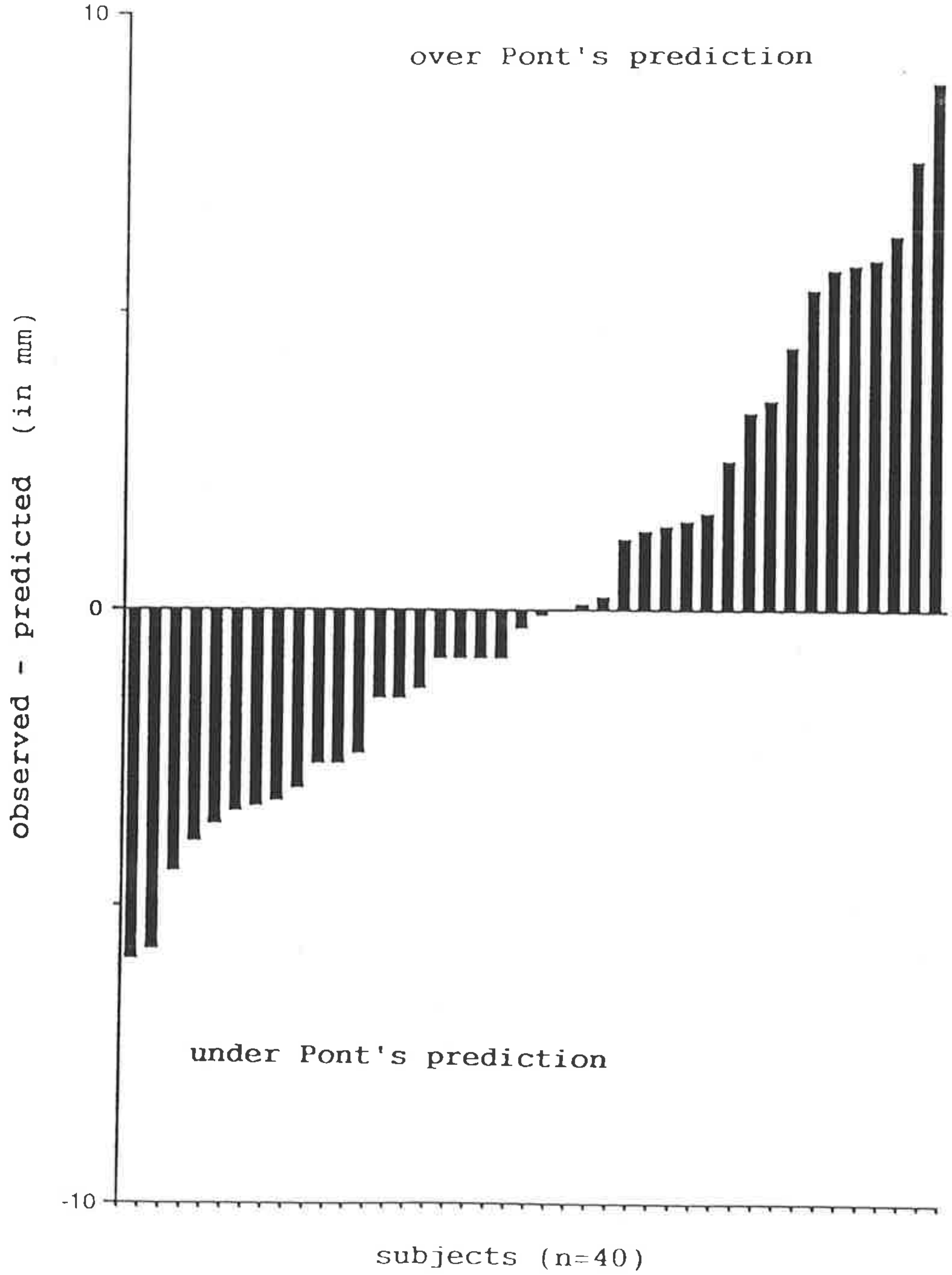


Figure 11:
Differences between observed and predicted intermolar widths according to Pont's Index in Aboriginal males (N=40)

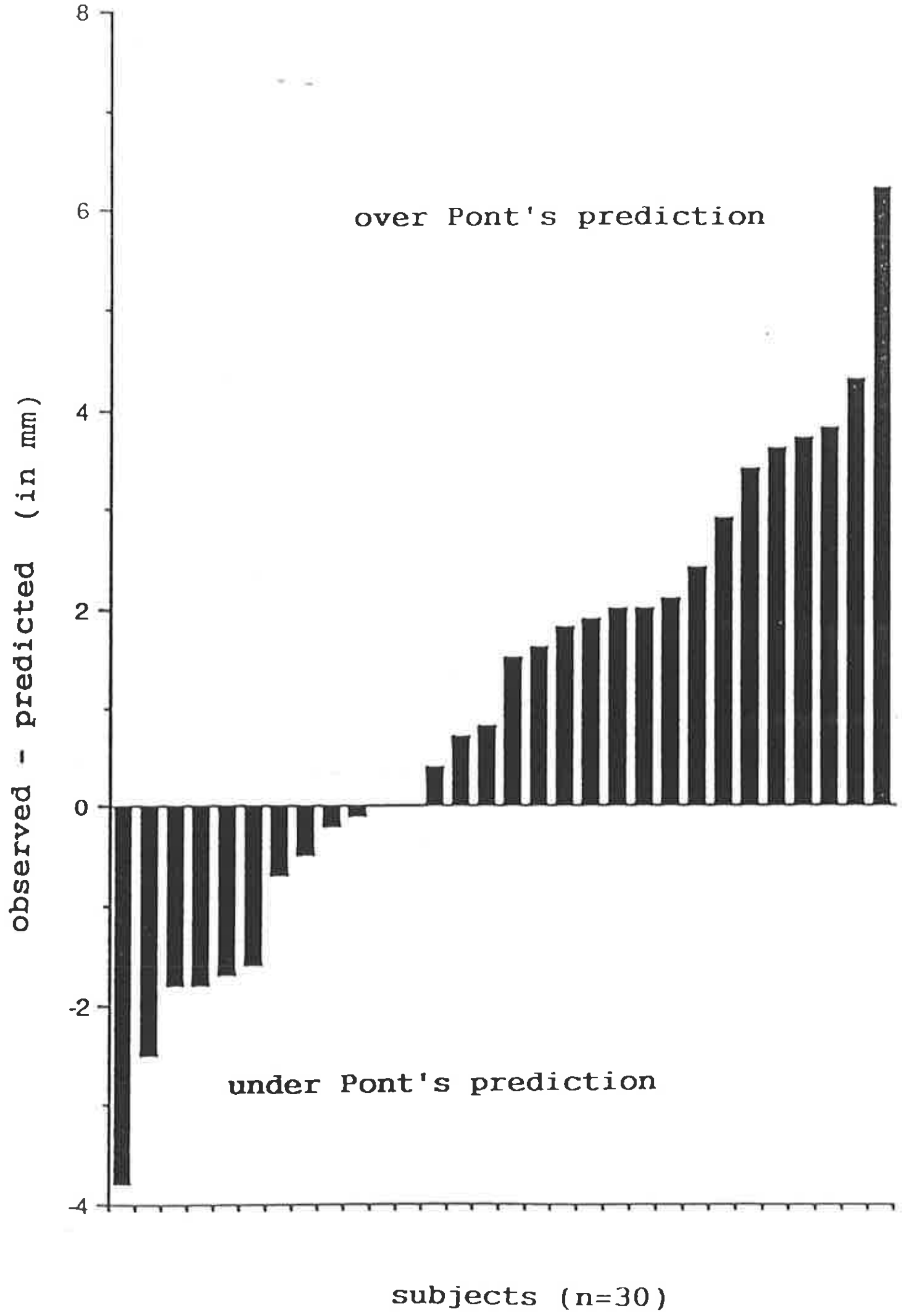


Figure 12:
Differences between observed and predicted interpremolar widths according to Pont's Index in Indonesian females (N=30)

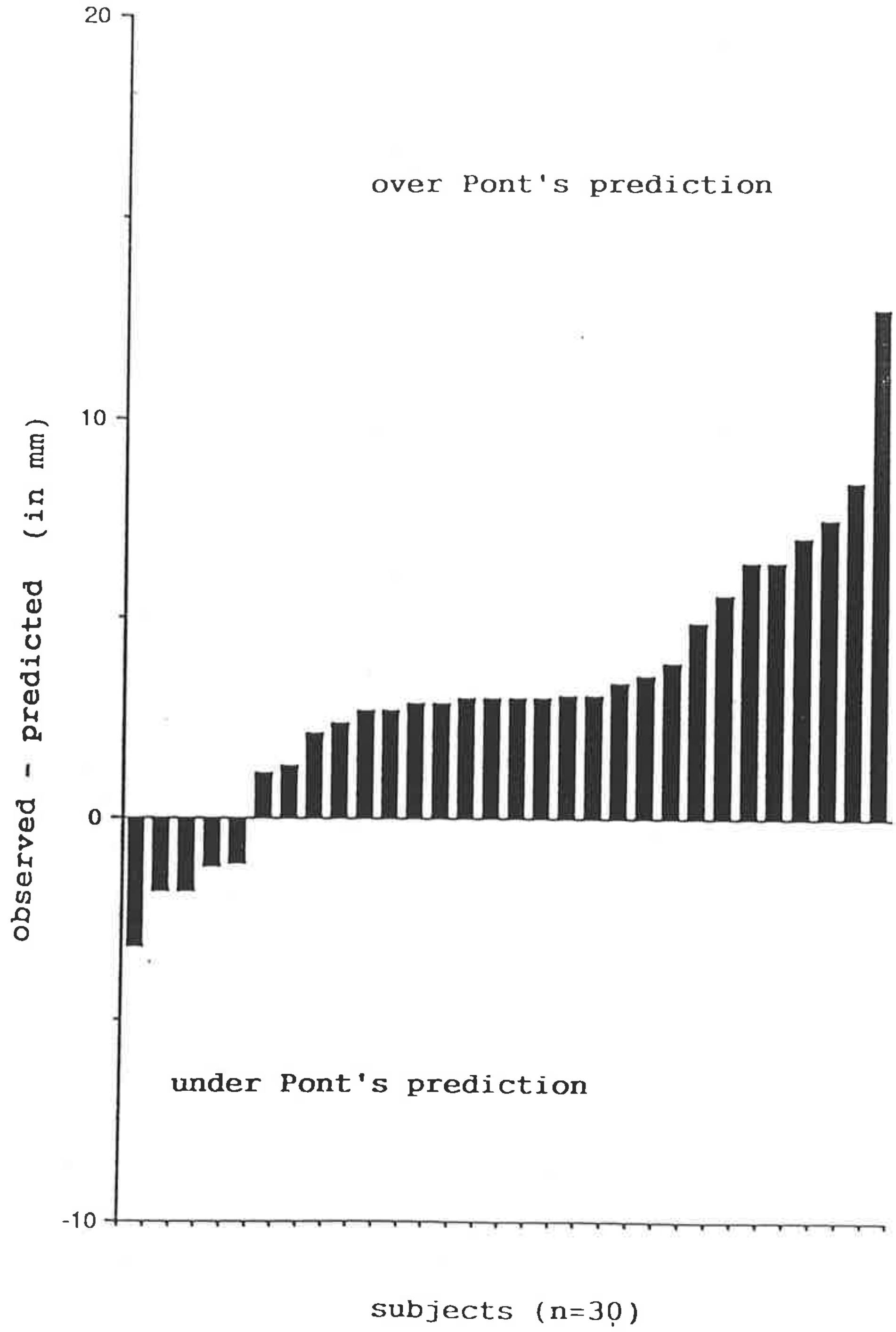


Figure 13:
Differences between observed and predicted intermolar widths according to Pont's Index in Indonesian females (N=30)

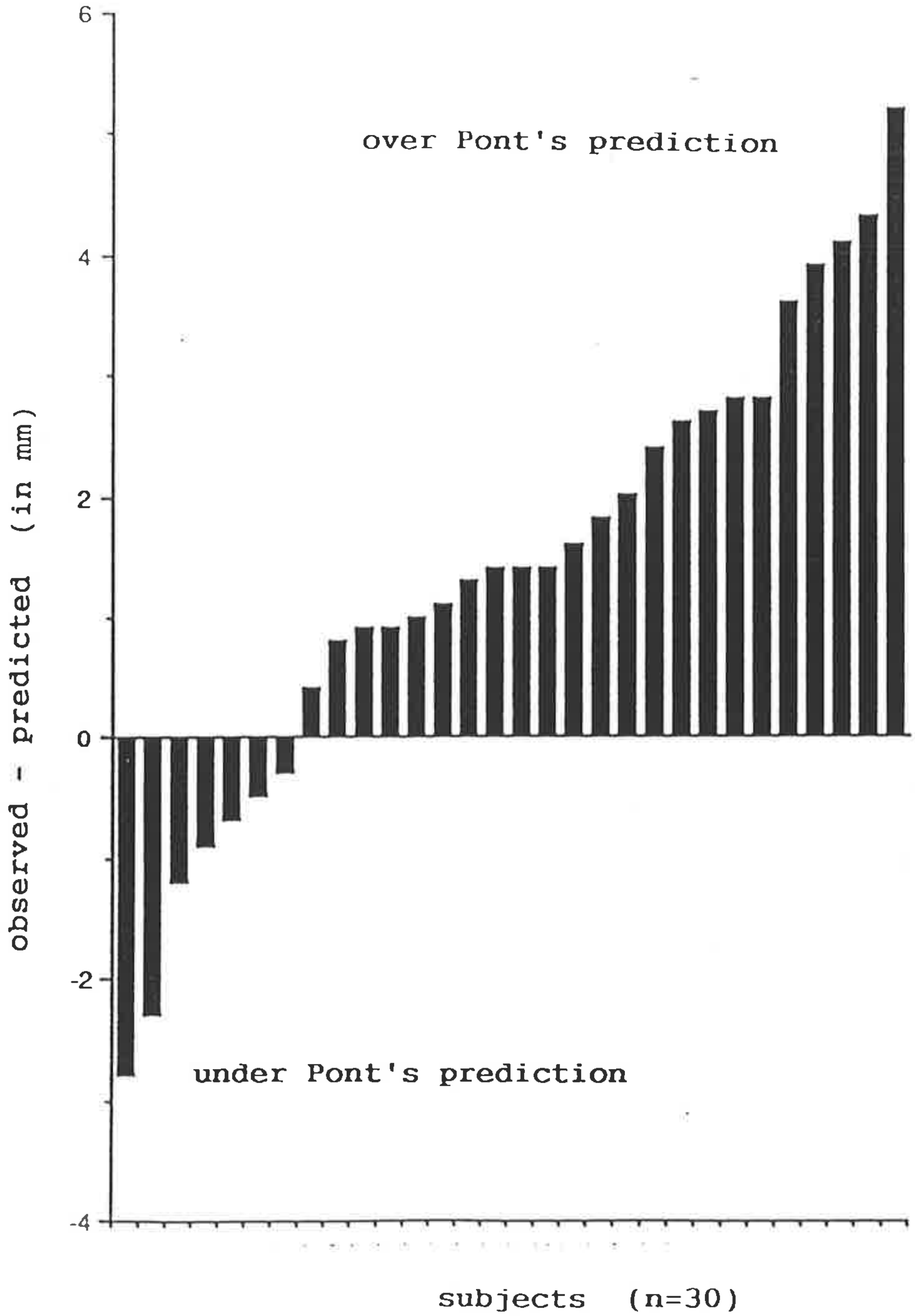


Figure 14:
Differences between observed and predicted interpremolar widths according to Pont's Index in Indonesian males (N=30)

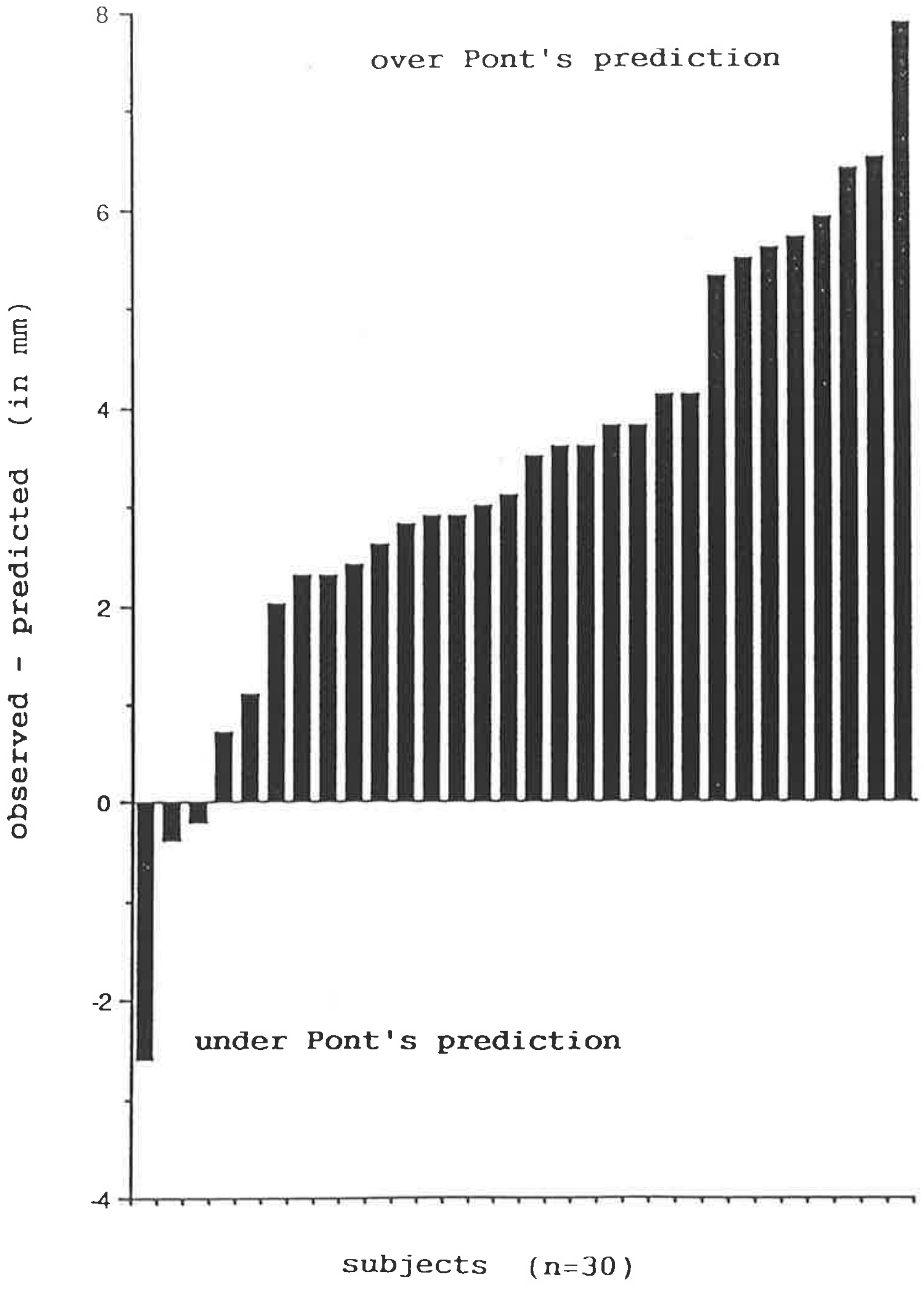


Figure 15:
Differences between observed and predicted intermolar widths according to Pont's Index in Indonesian males (N=30)

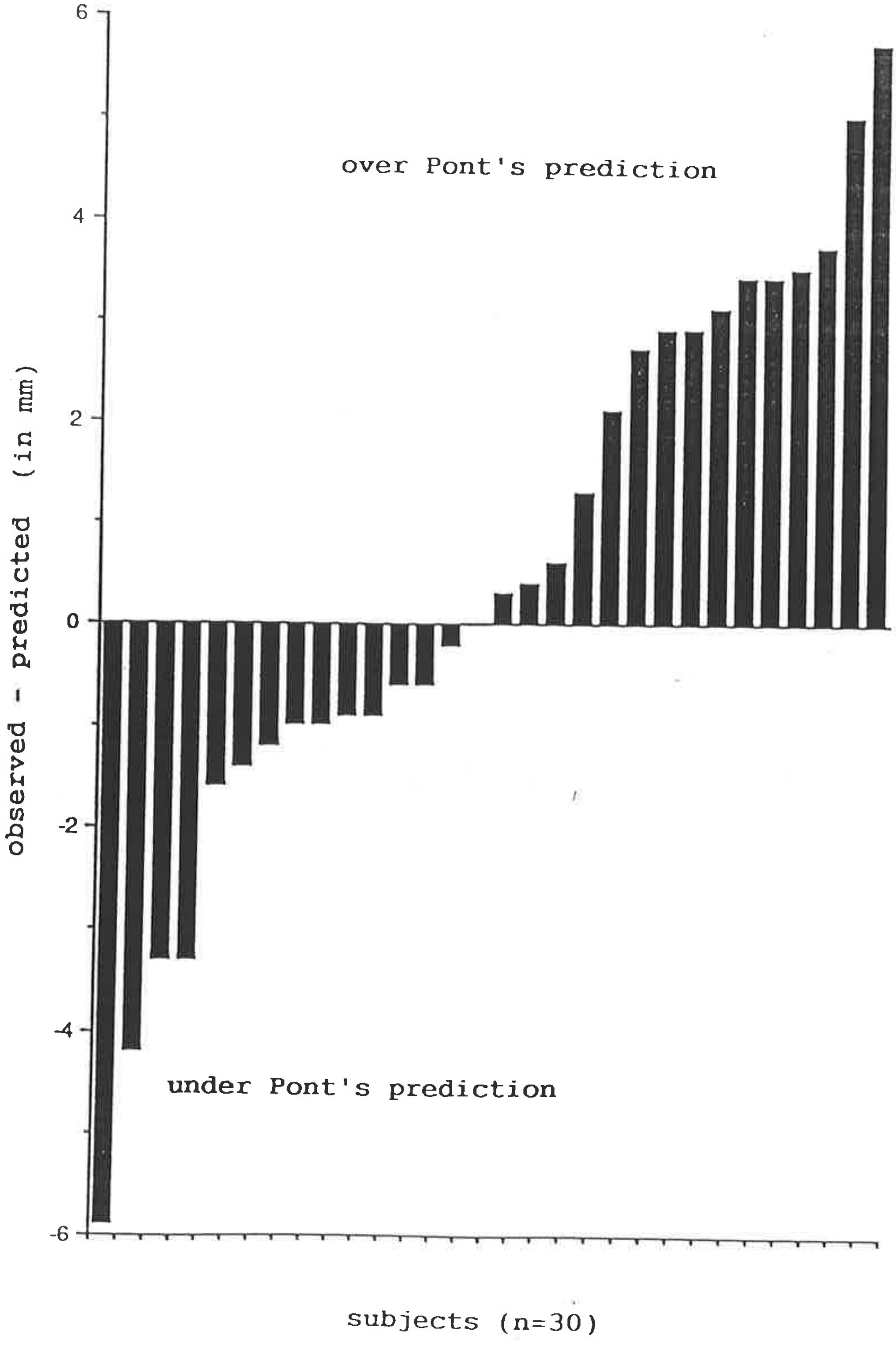


Figure 16:
Differences between observed and predicted interpremolar widths according to Pont's Index in Caucasian females (N=30)

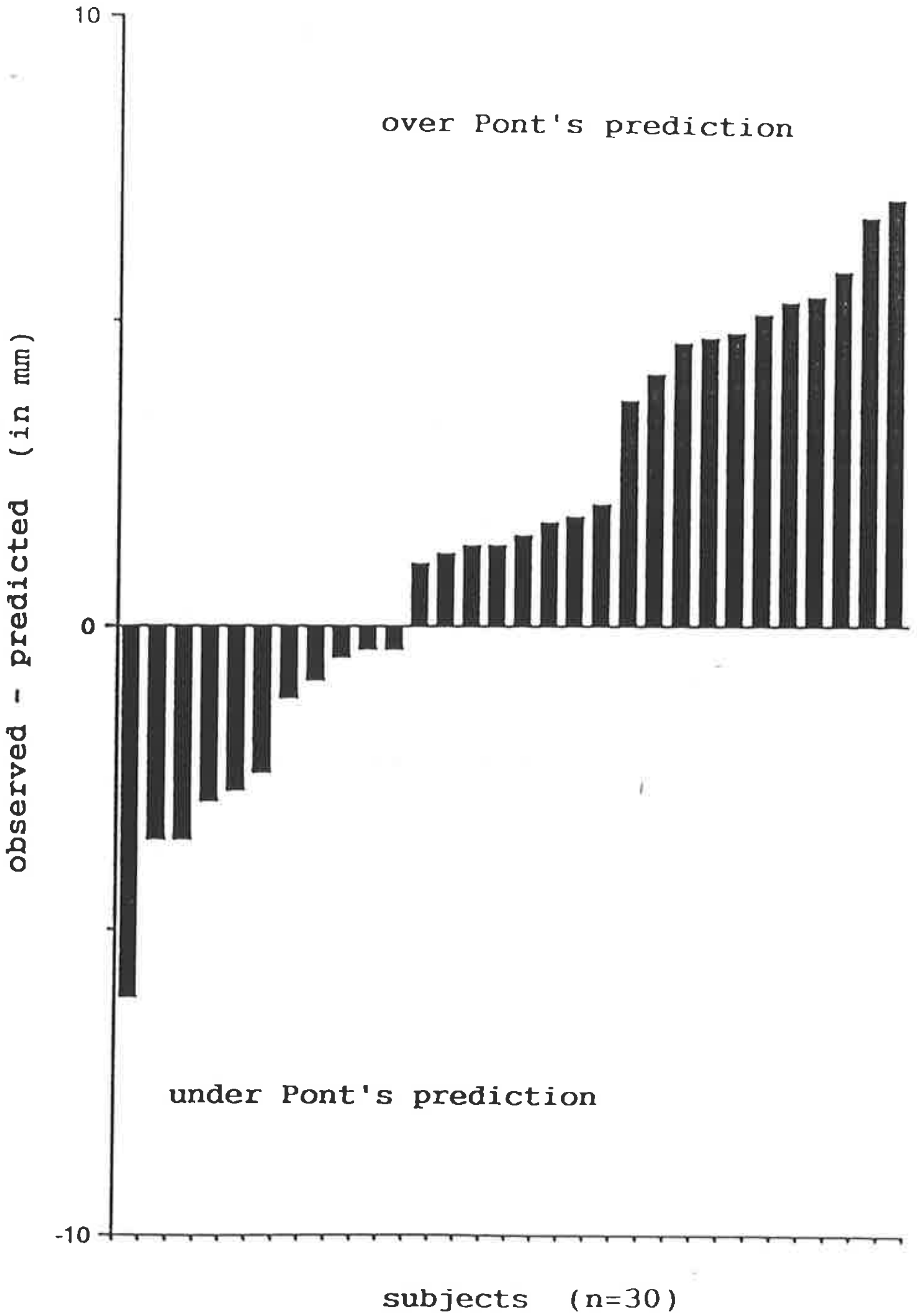


Figure 17:
Differences between observed and predicted intermolar widths according to Pont's Index in Caucasian females (N=30)

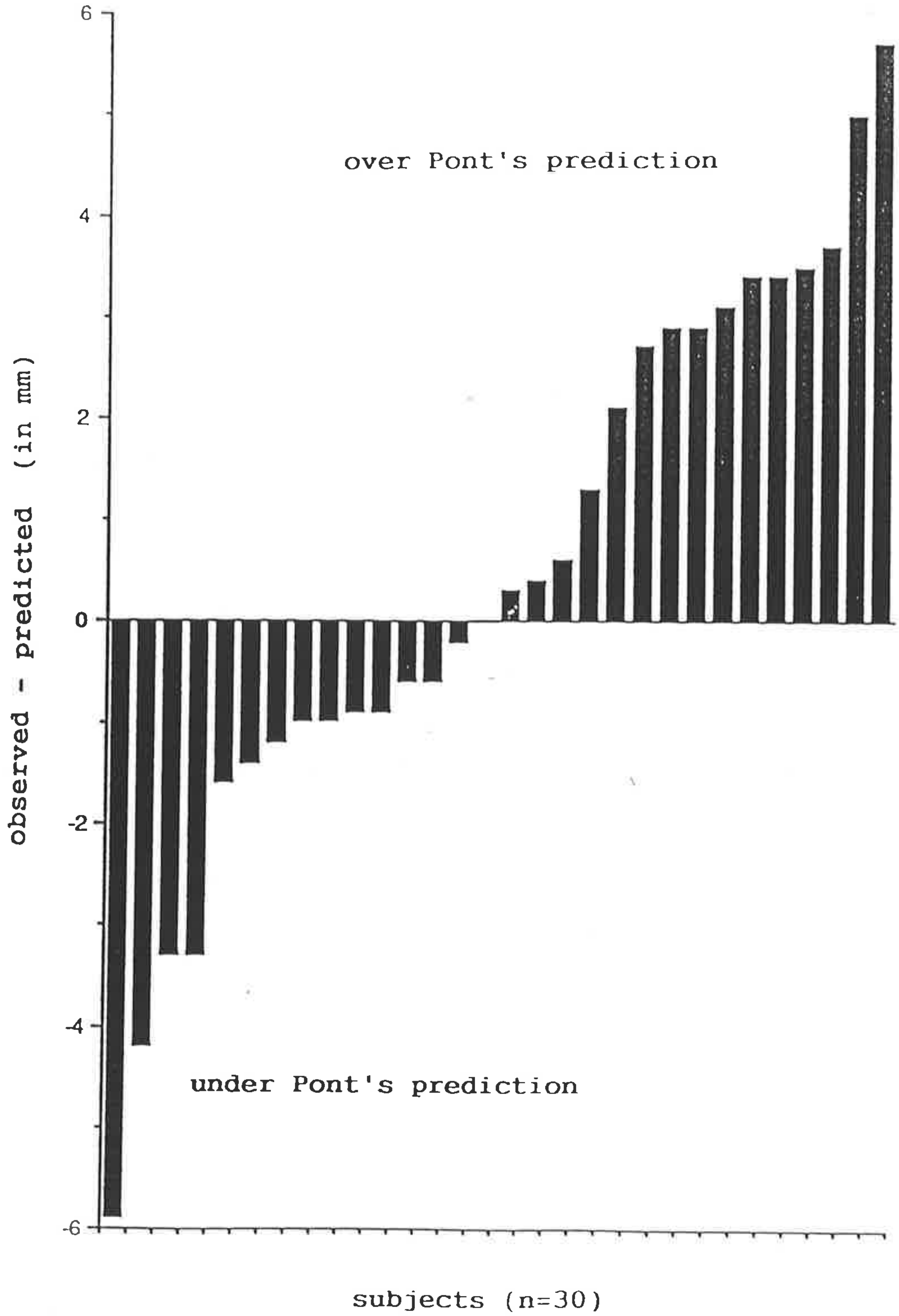


Figure 18:
Differences between observed and predicted interpremolar widths according to Pont's Index in Caucasian males (N=30)

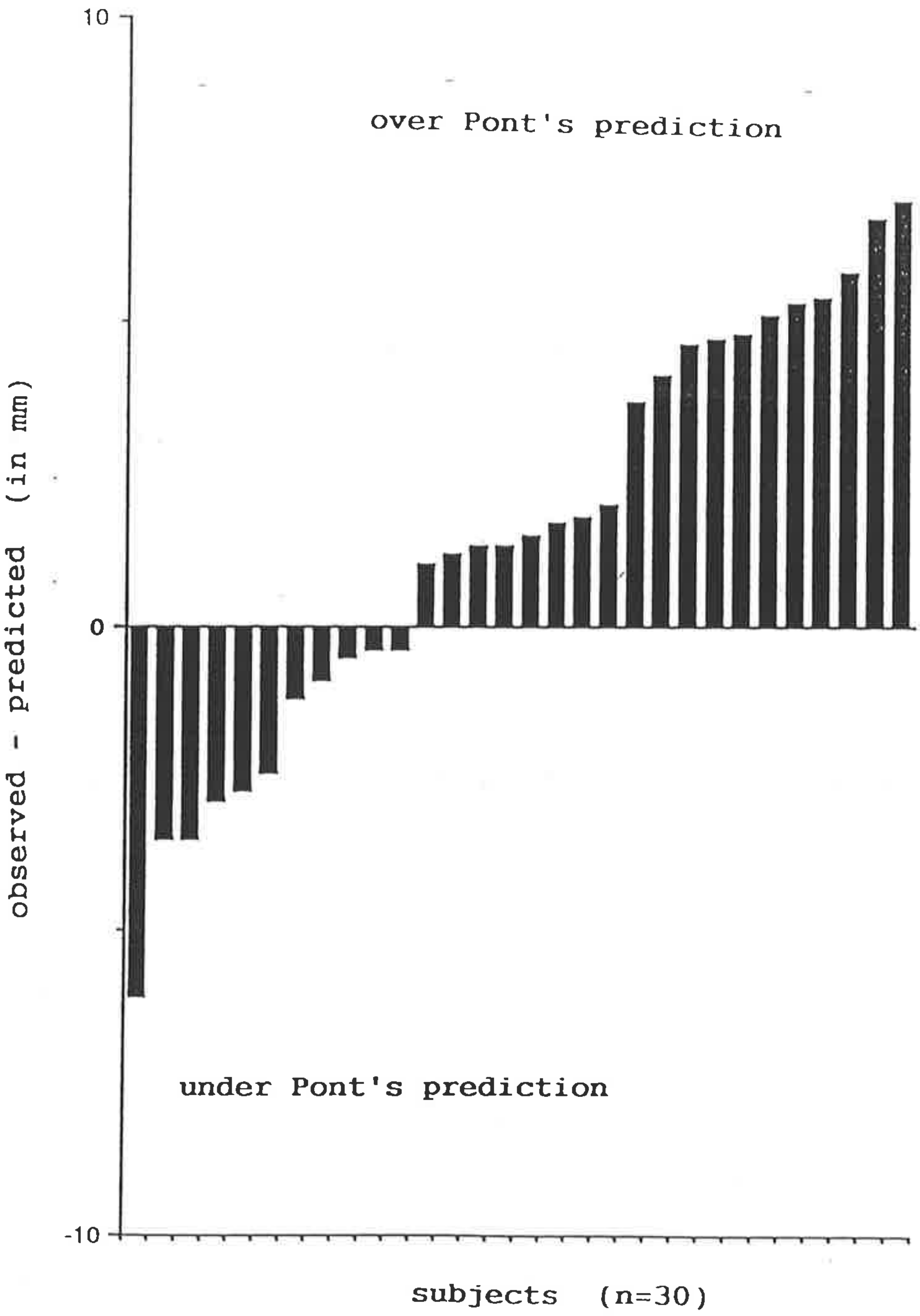


Figure 19:
Differences between observed and predicted intermolar widths according to Pont's Index in Caucasian males (N=30)

Caucasians displayed a similar pattern to Aborigines with the largest differences in under and over Pont's prediction values of -6.4 mm for interpremolar width in females and 10.0 mm for intermolar width, also in females. About 30.8% Caucasian arch widths showing differences between -1 mm to 1 mm. Indonesians generally displayed arch widths which were over Pont's prediction with few individuals displaying under Pont's prediction arch widths. The largest differences in under and over Pont's prediction values were -3.8 mm for interpremolar width and 12.7 mm for intermolar width in females, with only 17.5% showing differences between -1 mm to 1 mm.

Crown diameters and arch widths were described in terms of z-scores (standard normal deviates), and the data tabulated according to those individuals who were over Pont's prediction and those under Pont's prediction. Positive z-scores indicate that the values of the variables are above the mean for the population group, while negative z-scores are associated with values less then the mean.

Table 9 presents percentages of subjects, grouped according to z-scores for the measured variables, whose observed arch widths were over Pont's prediction. In Australian Aborigines 81.3% and 47.9% of individuals whose arch widths were over Pont's prediction had negative z-scores for the sum of crown diameters (SI) and arch width

Table 9: Percentage of subjects whose observed arch widths were over Pont's predictions, grouped according to their z-scores for the sum of crown diameters (SI) and arch widths

z-score ranges	SI			arch widths		
	Abor.	Ind.	Cauc	Abor.	Ind.	Cauc
	subjects %			subjects %		
< -3	-	-	-	-	-	-
-3 - -2	4.9	1.1	3.3	-	-	-
-2 - -1	29.2	16.6	31.5	9.9	11.9	4.3
-1 - 0	47.2	56.0	35.9	38.0	38.1	34.8
Total	81.3	73.7	70.7	47.9	50.0	39.1
0 - 1	17.4	17.3	25.0	35.2	28.6	28.3
1 - 2	1.3	6.0	4.3	14.1	19.0	30.4
2 - 3	-	3.0	-	-	2.4	2.2
>3	-	-	-	2.8	-	-
Total	18.7	26.3	29.3	52.1	50.0	60.9

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

where: $\bar{x}$ = mean
x = individual value
SD = standard deviation

respectively. In Indonesians 73.7% and 50% of individuals over Pont's prediction had negative z-scores for SI and arch width respectively, while in Caucasians percentages of negative z-scores were 70.7% and 39.1% respectively.

Percentages of z-scores in the under Pont's prediction group are presented in Table 10. In Australian Aborigines, 20.4 % and 54.5 % of individuals whose arch widths were under Pont's prediction had negative z-score for SI and arch width respectively followed by Indonesians (22.2 % and 58.3 %) and Caucasians (31.7 % and 64.8%).

It is clear that those Australian Aborigines and Indonesians whose arch widths were over Pont's prediction generally had relatively small teeth in average arch widths, while Caucasians had relatively small teeth in arches that tended to larger than average. On the other hand, in the under Pont's prediction group, Australian Aborigines and Indonesian generally had relatively large teeth, whereas Caucasians had large teeth in relatively small arches.

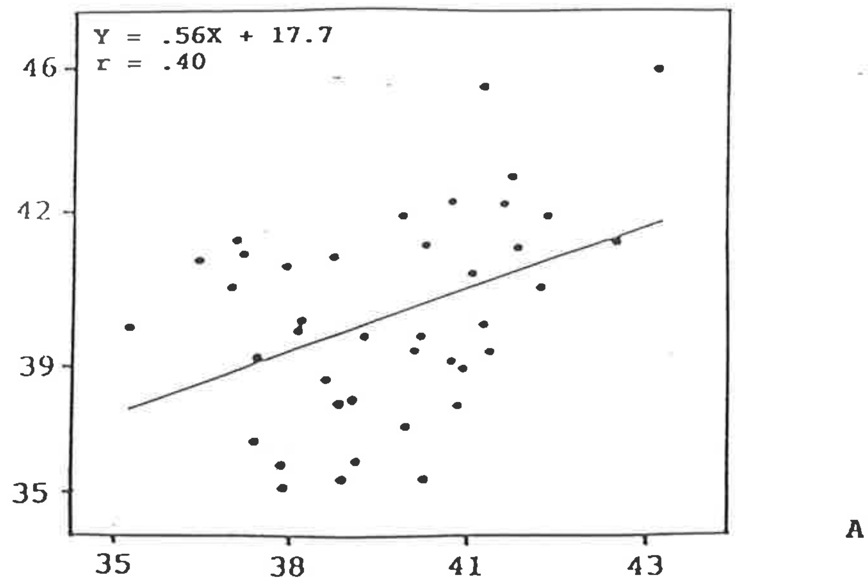
Table 10: Percentage of subjects whose observed arch widths were under Pont's predictions, grouped according to their z-scores for the sum of crown diameters (SI) and arch widths

z-score ranges	SI			arch widths		
	Abor.	Ind.	Cauc.	Abor.	Ind.	Cauc
	subjects %			subjects %		
< -3	-	-	-	-	-	-
-3 - -2	-	-	-	2.3	-	2.7
-2 - -1	3.4	-	4.7	18.2	33.3	18.9
-1 - 0	17.0	22.2	27.0	34.0	25.0	43.2
Total	20.4	22.2	31.7	54.5	58.3	64.8
0 - 1	52.8	43.1	45.3	30.7	30.6	28.4
1 - 2	23.4	25.0	18.9	12.5	11.1	5.4
2 - 3	3.4	9.7	4.1	2.3	-	1.4
>3	-	-	-	-	-	-
Total	79.6	77.8	68.3	45.5	41.7	35.2

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

where: $\bar{x}$ = mean
x = individual value
SD = standard deviation

Scatter diagrams were plotted to illustrate the associations between observed and predicted interpremolar and intermolar widths of males and females in each study population. Points were generally dispersed widely above and below the regression lines indicating low positive correlations between the observed arch widths and those predicted by Pont's Index (Figure 20 - Figure 25).



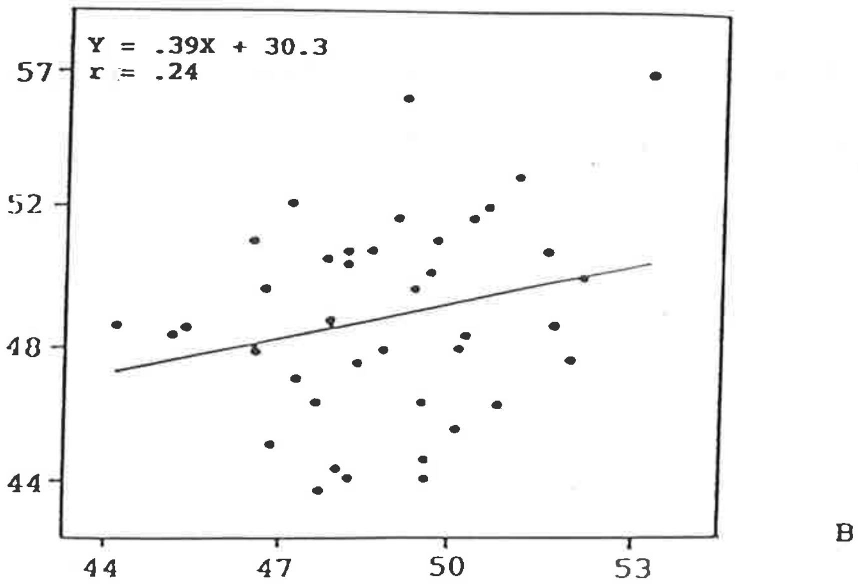


Figure 20:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Aboriginal females (N=40)

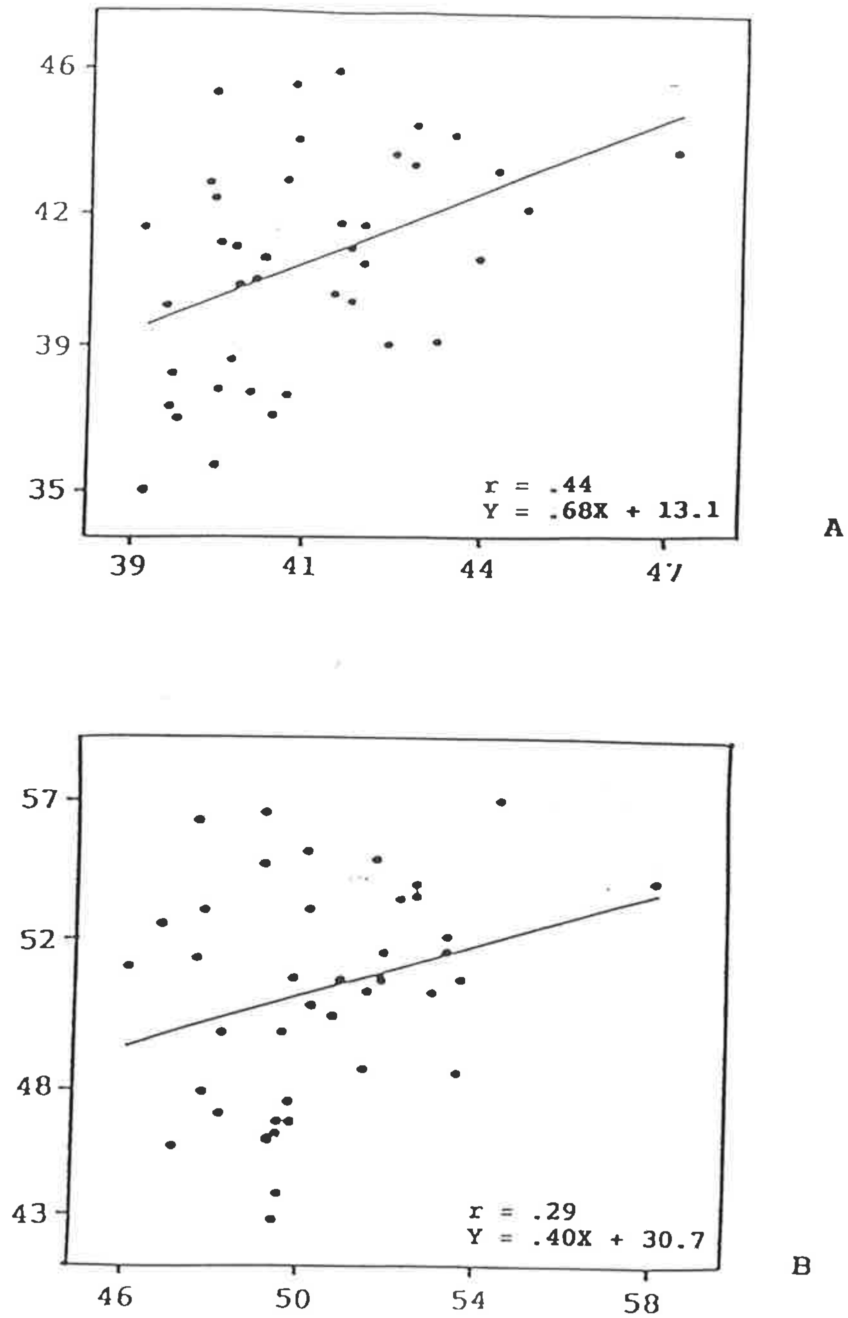
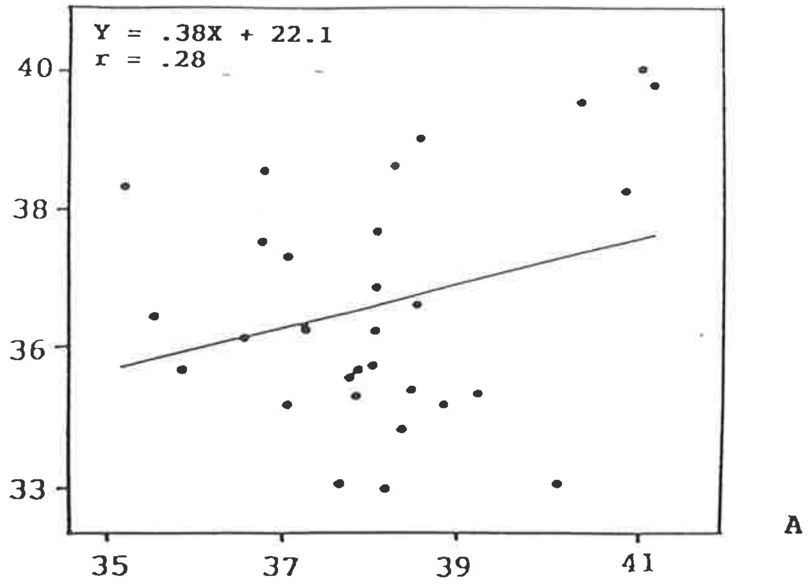


Figure 21:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Aboriginal males (N=40)



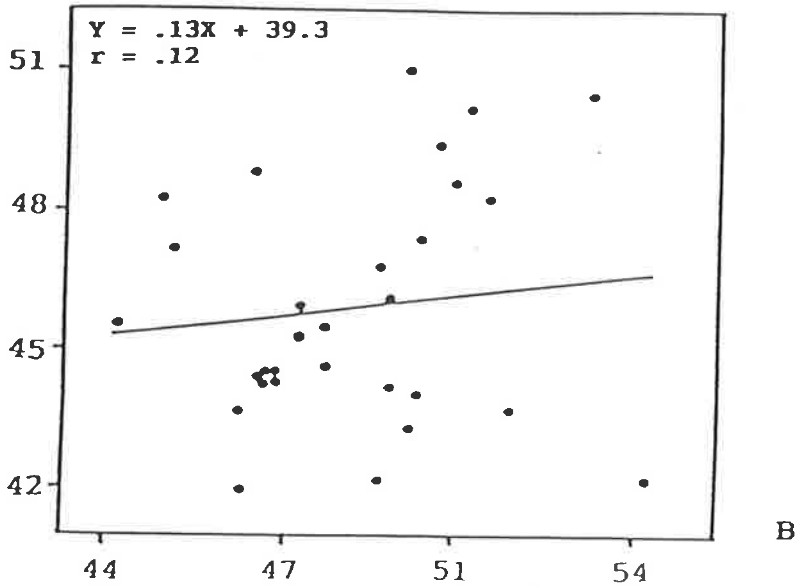


Figure 22:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Indonesian females (N=30)

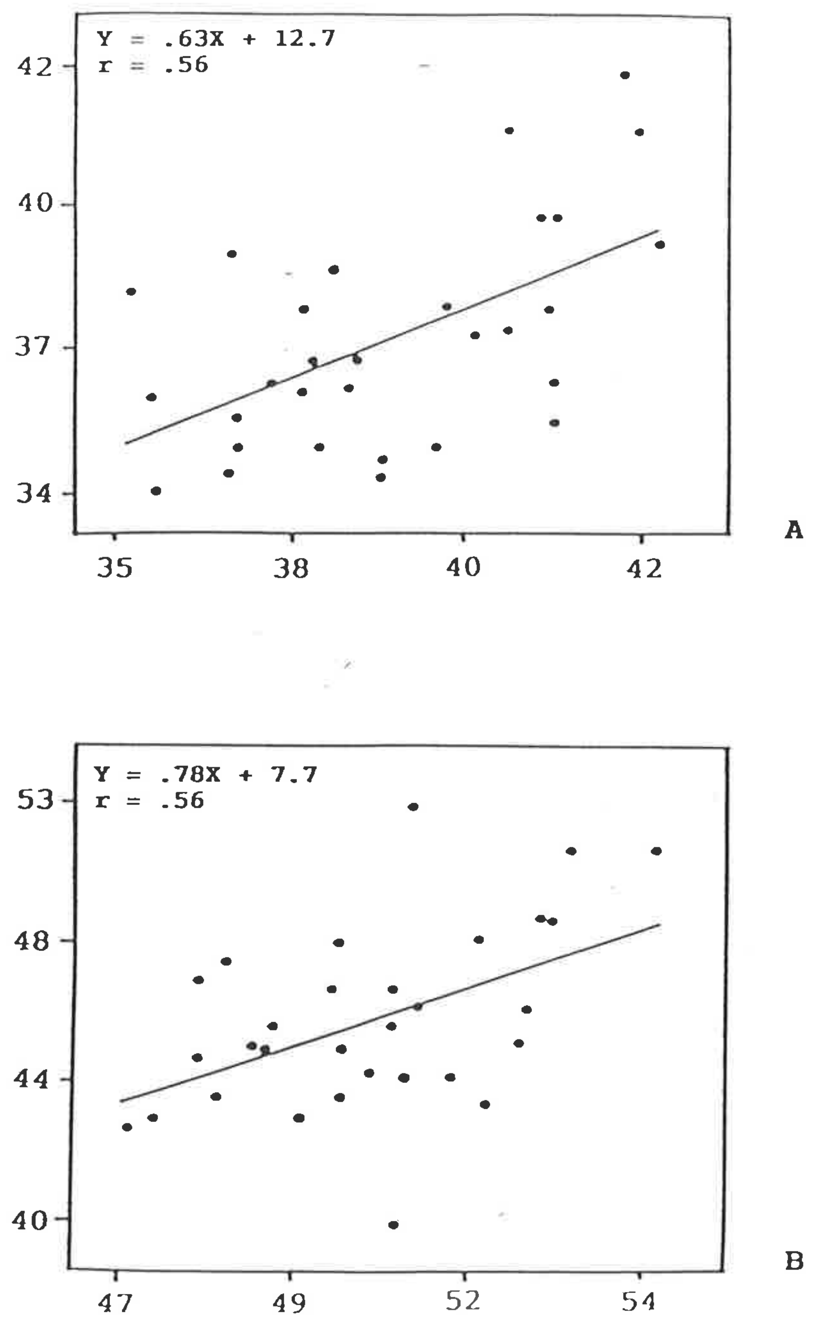
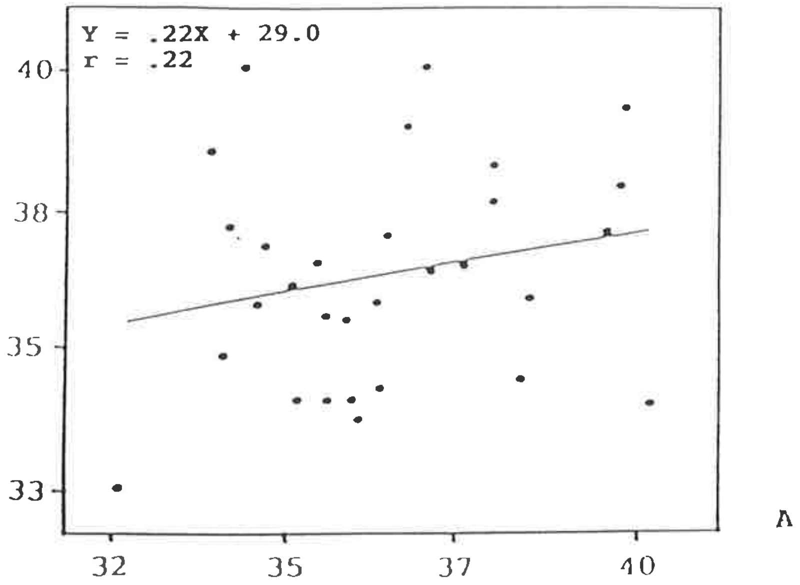


Figure 23:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Indonesian males (N=30)



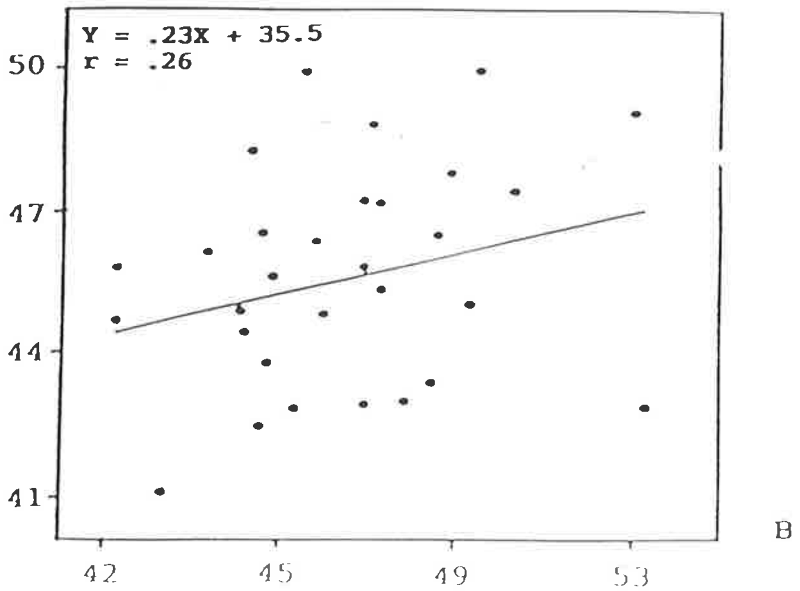
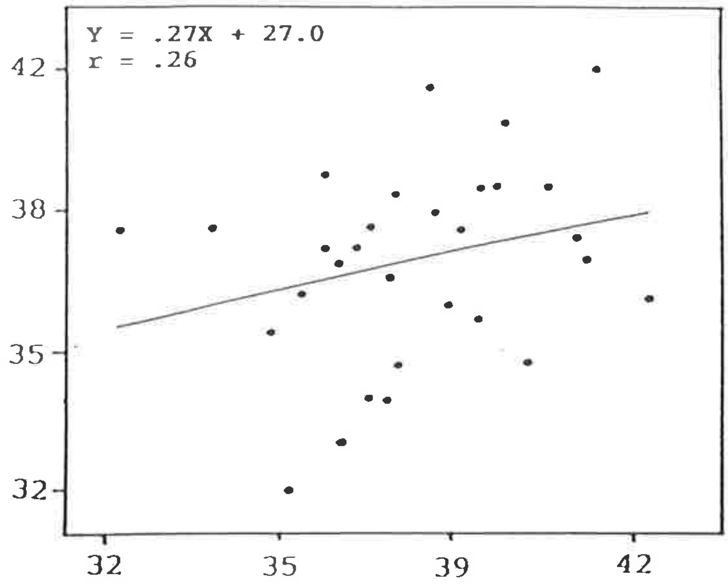
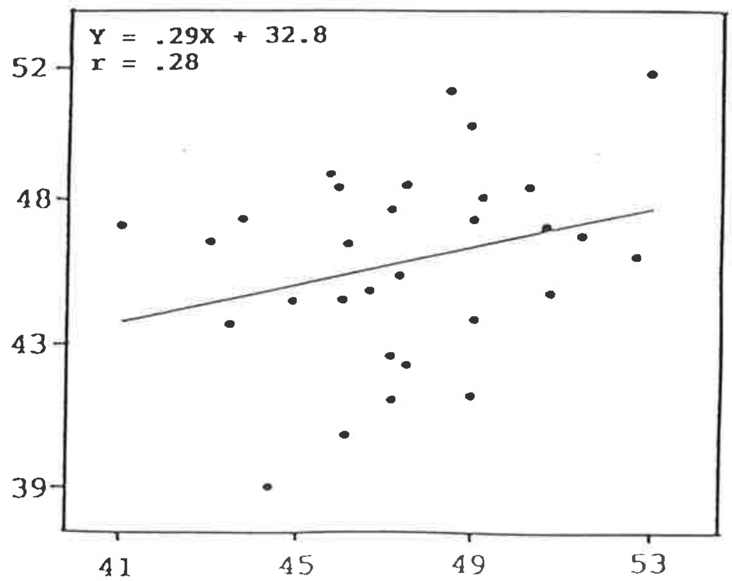


Figure 24:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Caucasian females (N=30)



A



B

Figure 25:
Scatter diagrams of the associations between observed and predicted interpremolar (A) and intermolar (B) widths according to Pont's Index in Caucasian males (N=30)

Longitudinal Study

Arch widths were described in terms of mean values, standard deviations and coefficients of variations in both Stage I and Stage II of the longitudinal study for both Aboriginal males and females. Maxillary incisor crown diameters were described in the same manner for Stage II (Tables 11 and 12).

Changes in arch widths from stage I to stage II were also computed (Tables 13 and 14). No significant changes were found in mandibular intercanine or maxillary interpremolar arch widths. However, significant increases were noted in the maxillary intercanine and intermolar regions and in the mandibular interpremolar and intermolar regions.

Correlation coefficients between observed and predicted arch widths according to Premolar and Molar Indices were computed for both stage I and stage II, values ranging from .13 to .51 (Table 15).

Table 11: Tooth size and dental arch width (in mm) in 19 males Australian Aborigines, in stage I (mixed dentition) and stage II (permanent dentition)

Variables	Stage I			Stage II		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Crown diameters						
right I2	-	-	-	7.1	0.32	4.5
right I1	-	-	-	8.9	0.47	5.3
left I1	-	-	-	8.9	0.59	6.6
left I2	-	-	-	7.1	0.47	6.6
Arch widths						
Maxilla						
C-C / 3-3	37.3	1.70	4.6	38.5	2.07	5.4
D-D / 4-4	41.0	1.80	4.4	40.9	2.15	5.3
6-6 / 6-6	49.1	1.77	3.6	51.4	2.06	4.0
mandible						
C-C / 3-3	28.7	1.66	5.9	29.1	1.79	6.1
D-D / 4-4	33.6	1.64	4.9	35.7	1.96	5.5
6-6 / 6-6	49.1	2.02	4.1	51.4	1.89	3.7

Table 12: Tooth size and dental arch width (in mm) in 14 females Australian Aborigines, in stage I (mixed dentition) and stage II (permanent dentition)

Variables	Stage I			Stage II		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Crown diameters						
right I2	-	-	-	7.0	0.55	7.8
right I1	-	-	-	8.9	0.50	6.0
left I1	-	-	-	8.8	0.43	4.9
left I2	-	-	-	7.0	0.46	6.5
Arch widths						
Maxilla						
C-C / 3-3	37.1	2.18	5.9	38.0	2.00	5.1
D-D / 4-4	39.7	1.66	4.2	39.4	1.87	4.8
6-6 / 6-6	46.9	1.99	4.3	48.7	2.13	4.4
mandible						
C-C / 3-3	28.6	1.86	6.5	28.7	1.37	4.8
D-D / 4-4	32.4	2.24	6.9	34.6	1.64	4.7
6-6 / 6-6	47.7	2.20	4.6	49.8	2.05	4.1

Table 13: Arch width differences (in mm) between stage I (mixed dentition) and stage II (permanent dentition) in Australian Aborigines (male, n = 19)

Variables		$\bar{d}$	$SE_{\bar{d}}$	t
Stage I	Stage II			
Maxilla				
C - C	3 - 3	1.2	0.31	3.99*
D - D	4 - 4	-0.1	0.41	-0.18
6 - 6	6 - 6	2.3	0.27	8.67*
Mandible				
C - C	3 - 3	0.4	0.37	1.09
D - D	4 - 4	2.1	0.37	5.49*
6 - 6	6 - 6	2.3	0.28	8.19*

critical t value with 18 degrees of freedom 2.10

* significant at $p < 0.05$

Table 14: Arch width differences (in mm) between stage I (mixed dentition) and stage II (permanent dentition) in Australian Aborigines (female, n = 14)

Variables: Stage I	Stage II	$\bar{d}$	$SE_{\bar{d}}$	t
Maxilla				
C - C	3 - 3	0.9	0.27	3.54*
D - D	4 - 4	-0.3	0.26	-1.30
6 - 6	6 - 6	1.8	0.32	5.68*
Mandible				
C - C	3 - 3	0.1	0.37	0.23
D - D	4 - 4	2.2	0.53	4.14*
6 - 6	6 - 6	2.1	0.37	5.94*

critical t value with 13 degrees of freedom 2.16

* significant at $p < 0.05$

Table 15: Correlation coefficients (r) and coefficients of determination (r^2) between observed and predicted arch widths in stage I (mixed dentition) and stage II (permanent dentition) in Australian Aborigines (n = 33)

Indices		Stage I	Stage II
Premolar Index	r	.51*	.47*
	r^2	.27	.22
Molar Index	r	.13	.23
	r^2	.02	.05

* "r" values differ significantly from zero at $p < 0.05$

Twin Study

Mean values, standard deviations, and coefficients of variations were computed for all variables, for male and female twin data separately (Tables 16 and 17). Correction factors, which were calculated as the differences between mean values of males and females, were then added to all females values. In addition, intraclass correlations between pairs of monozygous and dizygous twins were calculated for all variables.

Significant differences in mean values of mesiodistal diameters of maxillary central incisors were detected between MZ and DZ twins (Table 18). These differences invalidated further genetic analyses or calculations of heritability estimates for these variables (Christian, 1979).

Table 19 presents intraclass correlations for tooth size and arch width between monozygotic and dizygotic twins. The "r" values for the maxillary central and lateral incisors ranged from .78 to .79 for MZ twins and .34 to .48 for DZ twins. A stronger correlation was noted for the sum of mesiodistal diameters of the incisors in MZ twins (.89), with a value of .48 for DZ twins. The arch widths of MZ twins showed higher "r" values (ranging from .55 to .83) than DZ twins (.00 to .28)

Table 16: Tooth size and dental arch width in Caucasian twin males (in mm)

Variables	n	$\bar{x}$	SD	CV
Crown diameters				
right I2	154	6.6	0.53	8.1
right I1	154	8.7	0.57	6.6
left I1	156	8.7	0.57	6.6
left I2	156	6.5	0.53	8.2
Arch widths				
Maxilla				
3-3 (cusp tip)	48	34.8	2.21	6.4
4-4 (dist pit)	49	37.7	2.09	5.5
4-4 (bu cusp)	49	42.7	2.35	5.5
4-4 (pal cusp)	49	31.9	2.13	6.7
6-6 (cen fossa)	45	48.6	1.99	4.1
6-6 (mespal cusp)	45	42.9	2.15	5.0
mandible				
3-3 (cusp tip)	46	26.3	1.88	7.2
4-4 (dist fossa)	47	33.6	1.77	5.3
6-6 (distbu cusp)	46	48.7	2.17	4.5

Table 17: Tooth size and dental arch width in Caucasian twin females (in mm)

Variables	n	$\bar{x}$	SD	CV
Crown diameters				
right I2	189	6.3	0.60	9.5
right I1	195	8.3	0.52	6.3
left I1	194	8.3	0.55	6.6
left I2	193	6.3	0.59	9.4
Arch widths				
Maxilla				
3-3 (cusp tip)	61	33.2	1.76	5.3
4-4 (dist pit)	65	35.2	1.86	5.3
4-4 (bu cusp)	61	40.2	1.96	4.9
4-4 (pal cusp)	61	29.8	1.80	6.0
6-6 (cen fossa)	48	45.5	2.16	4.7
6-6 (mespal cusp)	49	40.3	2.22	5.3
Mandible				
3-3 (cusp tip)	46	25.1	1.20	4.8
4-4 (dist fossa)	48	31.3	1.46	4.7
6-6 (distbu cusp)	45	45.8	1.92	4.2

Table 18: Comparisons of mean values for tooth size and arch width between monozygotic (MZ) and dizygotic (DZ) Caucasian twins (in mm)

Variables	MZ			DZ			p
	n	$\bar{x}$	SD	n	$\bar{x}$	SD	
Crown diameters							
right I2	98	6.4	0.53	70	6.5	0.60	0.42
right I1	101	8.4	0.51	73	8.6	0.56	<0.01**
left I1	101	8.4	0.53	73	8.6	0.58	<0.01**
left I2	101	6.4	0.56	72	6.4	0.57	0.90
Arch widths Maxilla							
3-3 (cusp tip)	32	33.8	1.96	22	34.1	1.99	0.48
4-4 (dist pit)	35	36.2	1.83	22	36.5	2.14	0.53
4-4 (bu cusp)	33	41.3	1.86	22	41.3	2.49	0.98
4-4 (pal cusp)	33	30.7	1.80	22	30.9	2.14	0.75
6-6 (cen fossa)	30	46.6	1.86	16	47.7	2.37	0.14
6-6 (mespal cusp)	29	41.3	2.00	18	41.9	2.27	0.31
Mandible							
3-3 (cusp tip)	28	25.7	1.65	17	25.7	1.46	0.98
4-4 (dist fossa)	30	32.3	1.60	17	32.6	1.62	0.64
6-6 (distbu cusp)	29	47.1	1.81	15	47.7	2.45	0.37

** Mean values differ significantly at p <0.01

Table 19: Intraclass correlations "r" for tooth size and arch width in monozygotic (MZ) and dizygotic (DZ) Caucasian twins

Variables	MZ			DZ		
	n	r	p	n	r	p
Crown diameters						
right I2	98	.78	<0.01	70	.48	<0.01
right I1	101	.78	<0.01	73	.43	<0.01
left I1	101	.79	<0.01	73	.35	<0.01
left I2	101	.78	<0.01	72	.34	<0.01
sum of inc	96	.89	<0.01	68	.48	<0.01
Arch widths						
Maxilla						
3-3 (cusp tip)	32	.72	<0.01	22	.10	0.33
4-4 (dist pit)	35	.64	<0.01	22	.28	0.10
4-4 (bu cusp)	33	.56	<0.01	22	.18	0.21
4-4 (pal cusp)	33	.55	<0.01	22	.18	0.20
6-6 (cen fossa)	30	.70	<0.01	16	.25	0.16
6-6(mespal cusp)	29	.76	<0.01	18	.19	0.21
Mandible						
3-3 (cusp tip)	28	.83	<0.01	17	.14	0.27
4-4 (dist fossa)	30	.55	<0.01	17	.00	0.50
6-6 (distbu cusp)	29	.69	<0.01	15	.18	0.25

Table 20 presents heritability estimates for tooth size and arch width in MZ and DZ Caucasian twins. Heritability estimates were not computed for the maxillary central incisors as the mean values of these variables in MZ twins differed significantly from the mean values in DZ twins. Among-component estimates (h^2_{ac}) were used instead of within-pair estimates (h^2_{wp}) for the following variables: the maxillary right lateral incisor, maxillary interpremolar popoarch width measured at the buccal cusp, intermolar arch width measured at central fossa, and mandibular intermolar arch width. Estimates of heritability for the maxillary lateral incisors ranged from .29 to .87, while for maxillary and mandibular arch widths they ranged from .35 to 1.30.

Table 20: Heritability estimates (h^2) for tooth size and arch width in monozygotic (MZ) and dizygotic (DZ) Caucasian twins

Variables	h^2_{ac}	h^2_{wp}	h^2_H	h^2_r
Crown diameters				
right I2	.29	-	.58	.60
right I1	no estimate			
left I1	no estimate			
left I2	-	.46	.66	.87
sum of inc	-	.46	.78	.82
Arch widths				
Maxilla				
3-3 (cusp tip)	-	.64	.69	1.25
4-4 (dist pit)	-	.53	.50	.71
4-4 (bu cusp)	.35	-	.46	.76
4-4 (pal cusp)	-	.58	.45	.74
6-6 (cen fossa)	.45	-	.60	.89
6-6 (mespal cusp)	-	.69	.70	1.12
Mandible				
3-3 (cusp tip)	-	.51	.76	1.30
4-4 (dist fossa)	-	.56	.55	1.11
6-6 (distbu cusp)	.51	-	.62	1.02

Among-component estimates (h^2_{ac}) were used instead of within-pair estimates (h^2_{wp}), if the F' test yielded a value <0.2 Calculations of h^2_{ac}, h^2_{wp}, h^2_H, and h^2_r were presented in Chapter III.

CHAPTER V: DISCUSSION

CHAPTER V: DISCUSSION

Over the years, various dental indices have been developed which provide population dependent average values that can be used as references and guides in treatment planning, with a view to achieving "normal" occlusion.

As orthodontic problems commonly result from disharmony between tooth size and dental arch size, the indices have often related to either one or both of these variables. For example, Bolton (1962) analysed the ratio between maxillary and mandibular tooth size, and Peck and Peck (1972) described an index for assessing deviation in tooth shape. The relationship between tooth size and the size of the supporting structures has also been addressed by Howes (1947), while Moyers (1958) developed an index to predict available space for the permanent dentition from an analysis performed during the mixed dentition period.

Not many of the indices have provided useful clinical applications. For example, interproximal stripping of mandibular incisors based on the tooth shape ratio developed by Peck and Peck (1972) has been questioned by Smith et al. (1982). Pont's Index, which was originally developed by Pont in 1909, is one of the indices that still raises debate with regard to its clinical value. Its simplicity and apparent practicality have been very attractive to some dentists. It is still believed by some that Pont's Index can be used to determine the genetic potential of dental arch width despite many studies providing scientific evidence that it is not clinically reliable (Worms et al., 1969; Joondeph et al., 1970; Marshall, 1987).

Numerous studies of tooth size in different populations exist in the dental literature. Many of them relate to the dentition of Caucasians (for example, Moorrees et al., 1957; Moyers et al., 1976), although some researchers have studied tooth size in other populations such as Australian Aborigines (Barrett et al., 1963); Caucasoid, Negroid and Mongoloid (Lavelle, 1972); Japanese (Yamada et al., 1986). In the present study, the mesiodistal diameters of the maxillary central and lateral incisors of Australian Aborigines, Indonesians and Caucasians were measured in an attempt to assess the validity of the relationship between tooth size and arch width according to Pont's Index.

Maxillary incisor crown diameters of Australian Aborigines were found to be the largest among the three study populations. This finding was similar to the results of Barrett et al., (1963) and Townsend (1976) who found that Australian Aborigines had the largest tooth size compared to other observed populations. However, no significant difference in tooth size between Indonesian and Caucasian samples has been found in the present study. Bailit (1975) suggested that populations of Asian ancestry display maxillary lateral incisors that are relatively large compared with central incisors. This view was confirmed in the present study where the ratio of maxillary lateral incisor crown size to central incisors was greater in Indonesians than in Caucasians. Interestingly, the ratio was also higher in Aboriginals than in Caucasians.

Compared to other studies on mesiodistal diameters of incisors in Caucasians (Moorrees et al., 1957; Lavelle, 1972; Moyers et al., 1976; Doris et al., 1981; Lysell and Myrberg, 1982; Howe et al., 1983), the mesiodistal diameters of the maxillary central and lateral incisors in Caucasian males and females in the present study were generally smaller. A similar finding was noted in Australian Aborigines in which the mean mesiodistal diameters of maxillary central and lateral incisors were about 0.25 mm smaller than those reported in previous studies (Townsend, 1976; Townsend and Brown, 1979).

Several possible explanations can be provided for these measurement differences. The number of subjects included in the present study was considerably smaller than previous studies described above. This could have led to some bias and distortion of the results. Differences between measuring instrumentation and technique also need to be taken into account. Furthermore, the samples in the present study were selected according to strict criteria of good occlusion and good alignment of teeth which could bias the sample towards smaller tooth size. However, all measurements were made by the same investigator in the present study, thereby eliminating the problem of inter-observer error. The results of the replicability studies confirmed that any intra-observer errors were small in magnitude and unlikely to bias the analysis.

Australian Aboriginal males in the present study showed reasonably high correlation coefficients between mesiodistal crown diameters of left and right maxillary central and lateral incisors ranging from .66 to .72, whereas females showed moderate values (.47 to .56). Indonesian males and females generally showed moderate values .51 to .64 except for the correlation between maxillary left lateral and right central incisors (.37). Caucasians showed low to moderate values (.36 to .63) except that between maxillary left lateral and left central incisors (.76). These findings were similar to the reported associations between tooth crown size in Caucasians (Moorrees and Reed, 1964) and a larger sample of Australian Aborigines (Townsend, 1976).

Variability in tooth size was also quantified using coefficients of variation. The maxillary lateral incisors were generally more variable than the central incisors in the three study populations. Variability of tooth size in Indonesians was slightly greater than for Japanese as reported by Yamada et al. (1986). Even though Japanese and Indonesians are generally grouped together within the Mongoloid ethnic group, the difference could reflect subtle population differences. Similar values were found in comparing variability in tooth size of Aboriginals in the present study to the previous study of Townsend and Brown (1979).

These findings are consistent with the Field Theory originally described by Butler (1939), who postulated that the mammalian dentition could be divided into three morphogenetic fields corresponding to incisor, canine and molar groups. Dahlberg (1945) subsequently applied this field concept to human dentition, identifying four fields in each jaw: incisor, canine, premolar and molar. Each field has its "key" tooth which is considered to be more stable developmentally than the remaining teeth. One of these fields is the maxillary incisor field in which central incisors should be more stable than the lateral incisors, and this was confirmed in each of the three study groups.

The present study indicated that only maxillary right lateral and left central incisors in Australian Aborigines differed significantly in size between males and females. Sexual dimorphism was found to be low in magnitude for the three study populations ranging from 1.2% to 4.7% in which Aboriginal and Indonesian maxillary right lateral incisors showed values of 4.3% and 4.7% respectively. Townsend and Brown (1979) previously found significant differences in tooth size between males and females, with dimorphism scores of about 4.3% for central incisors and 4.4% for lateral incisors. The number of subjects included and the selection criteria applied to the subjects are again likely to limit general interpretations relating to sexual dimorphism from the present findings.

Maxillary intercanine and interpremolar widths and mandibular intercanine and intermolar widths were significantly larger in Australian Aborigines, whereas no significant differences were found between maxillary intermolar widths of Aboriginal and Indonesian males. Similar patterns were found in females. Variability in arch size tended to be slightly greater in Caucasians, while Australian Aborigines and Indonesian showed similar values. Variability in arch width in Aboriginal males and females was of similar magnitude to that reported by Barrett et al. (1965).

Aboriginal maxillary intermolar arch widths in the present study were in agreement with those reported by Barrett et al. (1965), whereas mandibular intermolar widths in the present study showed higher values, both in males and females. The similar values in the maxilla were not unexpected given the similarity in landmarks used. In the mandible, although similar landmarks were also used, difficulty in locating the cusp tips of the distobuccal cusps of the mandibular first molars may have contributed to the differences in measurement results. Compared to the study of Burgess (1989), all arch width measurements in the present study were slightly higher probably because of the application of different measurement methods and the use of different landmarks.

Compared to the study of Johnson et al. (1978), Indonesian maxillary intermolar widths in males and females in the present study were generally smaller, again resulting from the use of dissimilar landmarks. Johnson used the disto-buccal cusps of the maxillary first molars. Mandibular intermolar widths in the present study were similar to those reported by Johnson and colleagues, reflecting the use of similar landmarks. Furthermore, they pointed out that Indonesian dental arch widths were slightly larger than those in an English group which is in accord with the present study in which maxillary and mandibular intermolar widths in Indonesians were significantly larger than those in Caucasians.

In the present study, low to moderate "r" values (ranging from .09 to .56) were found between observed and predicted arch widths according to Pont's, W and P Indices. Joondeph et al. (1970) found "r" values of .23 and .20 between observed and predicted interpremolar and intermolar arch widths in individuals who had received orthodontic treatment and were ten years post-retention. Marshall (1987), found correlation values ranging from .23 to .58 between observed and predicted arch width according to Pont's, W and P Indices in American children. They both concluded that Pont's Index was unreliable in predicting dental arch width. On the other hand, Gupta et al. (1979) presented similar values (.46 and .49) for the correlations between the sum of the mesiodistal diameters of the four maxillary incisors and interpremolar and intermolar arch widths, and proposed a variation of Pont's Index to be used for the North Indian populations. Despite different interpretations of the usefulness of Pont's Index, consistently low correlations between observed and predicted arch width have confirmed the poor predictive capacities of Pont's Index and its corresponding Indices. This fact was reinforced by the calculation of coefficients of determination which revealed that only 1% to 32% of the variations in observed arch widths could be explained by the variations in predicted arch widths.

Pont (1909) in describing arch form according to his index allowed an additional 1 to 2 mm in anticipation of relapse and repositioning of the incisors according to the form of the face. As interpremolar and intermolar widths are estimated entirely by the sum of mesiodistal diameters of the four maxillary incisors, the possibility of arch form variation depends upon the arch length between the centre of the occlusal surfaces of the maxillary first premolars and molars and differences in axial inclination of the incisors, in addition to 1 or 2 mm variation in arch width.

No specific arch form has been accepted as representing the ideal arch shape, although extensive studies have been performed utilizing computerized mathematical formulae. Rudge (1981), in a thorough review of different studies of arch form, concluded that there may be considerable variability in arch shape between individuals without any detriment to function. Any specific arch form could be suitable for a particular individual, a finding confirmed by the present study.

Australian Aborigines and Caucasians generally showed a uniform divergence of arch shape in the maxillary and mandibular buccal segments while Indonesians tended to have broad maxillary and mandibular arches in the molar regions. These differences in shape of the dental arches reflect the considerable variation in arch form that occurs between human populations which in turn can affect the accuracy of any predictive index. In addition, as Pont's Index depends on the measurement of dental crown diameters, variations in tooth size within and between populations will also influence predictions.

The variations in dental arch shape in the premolar and molar regions can be tested with calculation of the E Index as was proposed by Wiebrecht (quoted by Bastien, 1983). According to the E Index, the distance between the buccal cusps of the first premolars should coincide with the distance between the mesiopalatal cusps of the first molars. If this was indeed the case, every "normal" dental arch should theoretically show a similar arch width in these regions. No such result could be found in the present study. Indeed, comparisons between the observed and predicted E Index showed that the values of correlations between arch widths in those two regions were generally lower than those between the predicted values, highlighting considerable variability in dental arch form.

Individual variations affected the direction of the relationship between tooth size and arch width. Some individuals were "over Pont's prediction", which meant that their observed arch widths were larger than those predicted by Pont's Index. On the other hand, some individuals were "under Pont's prediction" indicating that their observed arch widths were less than expected according to Pont's Index. Since only 20.6% of Aboriginal, 30.8% of Caucasian and 17.5% of Indonesian arch widths demonstrated differences between -1 mm to +1 mm of Pont's Index, it was clear that Pont's Index did not predict dental arch width in individuals with any degree of accuracy. Most of the arch widths were either "over" or "under" the predictions. Appendices 8 to 10 illustrate dental arch forms of individuals who showed differences from Pont's predictions ranging from -8.9 mm to 12.7 mm. Appendices 11 to 13 show the variability of dental arch forms in individuals whose arch widths were within 1 mm of those predicted by Pont's Index.

As all of the subjects were carefully selected according to the criteria of normal occlusion, arch form and alignment, any trend in the nature of the distribution of subjects either over or under Pont's prediction between the study populations provided some insight into ethnic differences within the dentition. The fact that Australian

Aborigines have large teeth in large arches and Caucasians have smaller teeth in small arches seemed to result in a fairly uniform distribution of subjects who were either "over" or "under" Pont's prediction. The findings of the present study for Caucasians differed from those of Marshall (1987) who found that the observed arch widths in his Caucasian sample were generally smaller than Pont's predictions. Even though Marshall did not give descriptive statistics for the mesiodistal diameters of incisors in his sample, the cause of this discrepancy could relate to differences in tooth size between study groups.

Most of the dental arch widths of Indonesians (77.5%) were over Pont's predictions reflecting the presence of small teeth and large dental arches. However, as the Indonesians represented several tribes who show some differences in dentofacial morphology, and the number of subjects included was small, this finding should be treated cautiously.

Further analysis of z-scores for all tooth size and arch width measurements revealed that, of those Australian Aborigines whose arch widths were over Pont's prediction, 81.3% of subjects showed smaller tooth size (negative z-scores) compared to their corresponding group mean values, although no such trend was evident in their arch widths. On the other hand, 79.6% of the "under Pont's prediction" individuals showed larger tooth size (positive z-scores) compared to their mean values. Similar findings were noted in Indonesians, in which small tooth size was found in 73.7% of individuals whose arch widths were over Pont's prediction while 77.8 % of individuals in the "under Pont's prediction" group had larger than average tooth size. As tooth sizes varied independently of arch width variation, these findings highlighted the fact that in Australian Aborigines and Indonesians, subjects tended to be over Pont's predictions because they had relatively small tooth size rather than having larger than average arch widths.

Caucasians showed a different trend from the other two populations. In individuals whose arch widths were over Pont's prediction, 70.7% showed smaller tooth size and 60.9% displayed larger than average arch widths, while 68.3% of individuals in the under prediction group showed larger tooth size and 64.8% showed smaller arch widths than average. It is likely that in Caucasians both tooth size and dental arch width influenced the results of the predictions using Pont's Index.

The reason for the different pattern of results in Caucasians is not clear. Doris et al. (1981) concluded that tooth size along with other factors such as arch width and arch perimeter, were important determinants of crowding in the dental arch. Furthermore, Doris and colleagues found that in the maxilla, lateral incisors and second premolars showed the greatest potential for influencing dental arch dimensions. On the other hand, Howe et al. (1988) felt that arch width was the most important factor in determining whether dental crowding would occur or not, while Radnzig (1988) concluded that tooth size coud not be ruled out as an important contributory factor in dento-alveolar disproportion, although they did not believe it was the main factor.

In the Aboriginal females, correlations between the size of maxillary lateral incisors and intermolar widths were low (.15 and .19). Furthermore, low correlations were also noted between the sum of mesiodistal diameters of the four maxillary incisors and intermolar arch width (.24). An interesting finding in Indonesian females was that the correlation between maxillary left lateral incisor and intermolar arch width was much lower (.01) than for the right lateral incisor. The clinical implications of this finding are unclear at present, although further studies based on larger sample size would be worthwhile.

Some authors such as Moorrees et al. (1969), Grewe (1970), Knott (1972) and Marshall (1987) have found that growth in mandibular intercanine width generally ceases after about 8 years of age. The results of the longitudinal study in Australian Aboriginal males and females support these earlier findings, with no significant changes in mandibular intercanine width being noted from Stage I (8.99 years and 8.21 years for boys and girls respectively) to Stage II (14.42 years and 13.81 years for males and females respectively).

However, trends in maxillary interpremolar width in males and females in the present study differred from those of Burgess (1989), who found a continuous increase in maxillary interpremolar width from 8 years to 15 years of age in Australian Aboriginals. The differences have probably resulted from the use of different landmarks in the two studies. Burgess (1989) used the mid-point of contact areas to determine arch width, whereas the distal pit of the maxillary first premolars and distal fossa of the maxillary deciduous first molars were used as landmarks in the present study. Consequently, the position of the landmarks on the maxillary deciduous first molars were located more posteriorly than the landmarks on the maxillary premolars, as the mesiodistal diameters of premolars were smaller than the mesiodistal diameters of deciduous molars. In contrast, these differences did not affect the results for mandibular interpremolar widths.

Significant increases ($p<0.05$) in mandibular interpremolar and intermolar widths were found from stage I to stage II, in agreement with Burgess (1989). Marshall (1987) did not find any increase in these measurements in Caucasians, although Knott (1961) noted an increase in intermolar arch width between nine years and 15 years of age, with 60% increase over the first two to five years. Differences between these studies may be due to the differences in sample size between the studies and differences in measurement techniques, but they may reflect real differences between the groups.

Although twin studies provide a useful means of determining the importance of genetic contributions to phenotypic variability, they have some limitations. For example, because twins may be similar for certain traits due to their common environment, both pre- and postnatally, they only provide data leading to "broad" estimates of heritability. In contrast, half-siblings, for example, who have the same father but different mothers, provide the opportunity to estimate the relative contribution of additive genetic effects to total phenotypic variability, thereby enabling so-called "narrow" estimates of heritability to be derived. Ideally in attempting to quantify the role of genetic factors on different traits, information from a variety of types of related individuals such as twins, siblings, half-siblings, as well as parents and offspring should be assessed (Vogel and Motulsky, 1986).

Genetic influence for tooth size was apparently high, with values of intraclass correlations ("r") ranging from .78 to .79 for MZ twins and .34 to .48 for DZ twins. Furthermore, "r" values between twins for the sum of the width of incisors were slightly higher than those for individual teeth. This finding is in agreement with Lundström (1977) who found that total genetic variation of the incisors and canine was twice that for individual teeth, and also conformed to Harzer (1987) who concluded that genetic control over the size of tooth groups was greater than that over individual teeth.

While genetic factors are obviously important in determining variations in incisor crown size, non-genetic factors are also likely to play a role. For example, Sofaer et al. (1971) have reported compensatory increases in the size of central incisors adjacent to missing lateral incisors, indicating that local environmental conditions may play a role in determining absolute and relative tooth size, with adjacent teeth possibly interacting for available space.

Values of intraclass correlations between MZ and DZ twins were generally lower for arch widths than those for tooth size. For example, the "r" values in MZ and DZ twins for the sum of the mesiodistal diameters of maxillary incisors were .89 and .48 respectively, whereas "r" values for arch widths ranged from .55 to .83 for MZ twins and .00 to .28 for DZ twins. A further study including a larger sample size is required to clarify these findings, especially as there was evidence of heterogeneity of total variance in intermolar widths which meant that environmental factors were probably unequal between MZ and DZ twins for this particular trait.

In the present study, significant differences were found between mean values of the mesiodistal crown diameters of maxillary central incisors in monozygotic and dizygotic twins, a finding similar to that of Rogers (1990). This suggests that there may be biological differences between zygosities for this particular trait (Christian and Norton, 1977). What these biological differences might be is unclear and further analyses based on larger sample sizes are required to clarify whether this was merely a result of sampling. In this study, heritability estimates for maxillary central incisors were not presented as they would have been biased.

As stated above, there was evidence of heterogeneity of total variance between zygosities for the size of the maxillary right lateral incisor and some arch widths. In these instances, among-component heritabilities were calculated instead of the within-pair heritabilities providing more conservative estimates (Christian et al., 1974).

Heritability estimates for the size of maxillary lateral incisors and the sum of mesiodistal diameters of the four maxillary incisors ranged from .29 to .87, with estimates for combined tooth size being greater than estimates for individual teeth. Heritability estimates for the size of the maxillary lateral incisors were similar to those reported by Rogers (1990). For dental arch widths, higher heritability estimates were found for intercanine and intermolar widths than for interpremolar widths.

Compared to the findings of Townsend and Brown (1978), the present study gave slightly higher estimates of heritability for tooth size, but these findings are not directly comparable as the present study yielded only broad heritability estimates based on the twin data, whereas the former study provided narrow heritability estimates based on half-sibling data.

The present study showed several deficiencies in Pont's Index as a predictor for orthodontic treatment. Pont did not clearly describe the procedure used in developing his Index, for example with regard to the number of subjects, the nature of their occlusions or the manner in which he calculated the constant values. This uncontrolled procedure produced an index unable to cope with variabilities between individuals.

There was a small positive correlation noted between the sum of mesiodistal crown diameters of the four maxillary incisors and the interpremolar and intermolar arch widths and this is not unexpected as the combined incisors crown width contributes to anterior dental arch width. However, this relationship should not be used as a single direct determinant for dental arch size and shape, as so many factors may influence the dental arches such as the form of the apical base, the complexity of dentofacial relationships and neuromuscular activities of the jaws and facial region.

From a clinical point of view, Pont's Index can not provide reliable predictions in individual orthodontic treatment planning. Since Pont's Index was originally based on the mean value of a French population, individual variations and population differences were not covered. The tendency of dental arch lengths and widths to vary with age (Little, 1987), together with unpredictable relapse of expansions noted by Lutz and Poulton (1985) provide further clinical evidence for the unreliability of performing expansion treatment indicated by Pont's Index.

The addition of W and P indices to determine mandibular arch widths by Wiebrecht (quoted by Bastien, 1983) and the claims that Pont's Index can be used to determine the "genetic potential" of arch width have tended to provide an air of scientific respectability to Pont's Index without clear definition of the words "genetic potential" being provided by its proponents. The assumption that the teeth express their full genetic potential which can then be reflected in dental arch width and hence be used as a guide in influencing the dental arches would appear to have no scientific basis.

The genetic influences operating on tooth size and arch width are complex. Garn et al. (1966) found that genetic factors seemed to outweight pre- and post- natal environment in controlling tooth size within any one of the four quadrants. This conclusion was contrary to Bailit (1975) who believed that the environment played more important role in the determination of tooth size. Lundström (1977) stated that the association between tooth size and crowding/spacing was difficult to explain as a consequence of secondary gene effect and believed that the greater variation existing between dizygotic twins compared to monozygotics twin was primarily due to gene differences. Opposing views can again be seen from the studies of Harris and Smith (1980) who emphasized intrafamilial environment as a major contributor to occlusal variability, and Goose and Lee (1973) who concluded that a strong environmental component influenced parent-offspring relationships in tooth size in immigrant populations.

CONCLUSIONS

CONCLUSIONS

1. Low correlations have been found between observed and predicted arch widths according to Pont's Index and its corresponding Indices. Considerable variability in the dental arches between individuals was noted, although no change in mandibular intercanine width appeared to occur within individuals after about 8 years of age.

2. Low correlations between tooth size and arch width were noted in all three study populations.

3. Heritability estimates for tooth size were generally higher than those for arch width, while heritability estimates for interpremolar widths were lower than those for either intercanine or intermolar arch widths.

4. Various factors influence the relationships between tooth size and arch width. The complexity of dentofacial relationships, the effects of surrounding tissues on the occlusion, and the variability of individual arch forms should be taken into account in determining dental arch arrangement. The complexity of the inherent genetic component should not be simplified in

determining the association between tooth size and arch width. As Pont's Index does not address the above aspects, it is apparent that Pont's Index and its corresponding Indices are unlikely to be useful as true predictors of dental arch width.

5. Further studies are required to clarify the associations between tooth size and arch width in relation to the dentofacial complex, and also to quantify the genetic influences that affect all of its components.

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APPENDICES

1. THE PONT'S INDEX
2. MEASUREMENT LANDMARKS IN THE PERMANENT DENTITION
3. MEASUREMENT LANDMARKS IN THE DECIDUOUS DENTITION
4. THE DATA SHEET

5 a-c. DOUBLE DETERMINATIONS OF CROWN DIAMETERS AND ARCH WIDTHS IN THE THREE STUDY POPULATIONS

6 a-c. DAHLBERG STATISTICS OF CROWN DIAMETERS AND ARCH WIDTHS IN THE THREE STUDY POPULATIONS

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8. ABORIGINAL DENTAL ARCHES WHICH ARE OVER- AND UNDER-PONT'S PREDICTIONS
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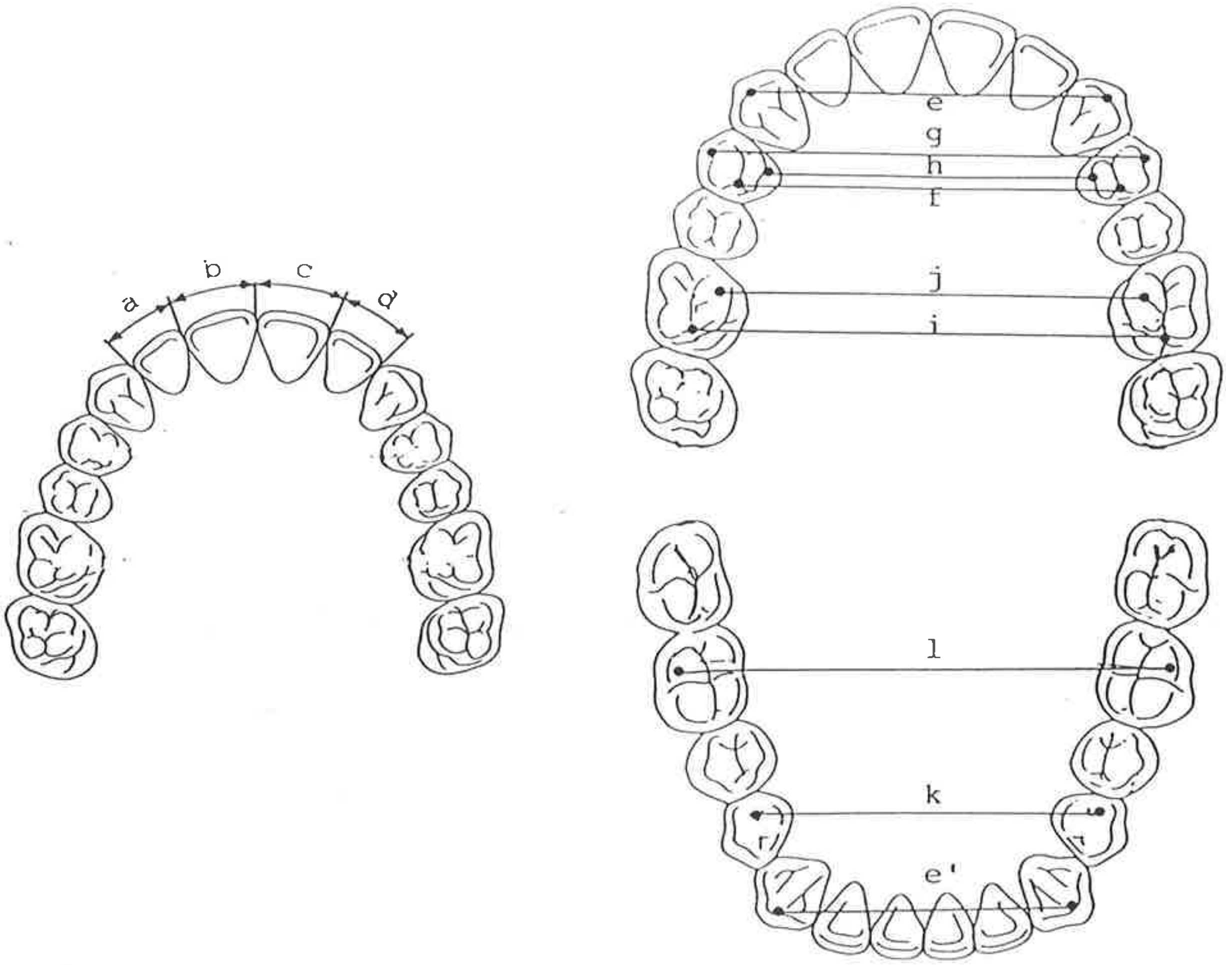
Appendix 1: The Pont's Index (Pont, 1909)

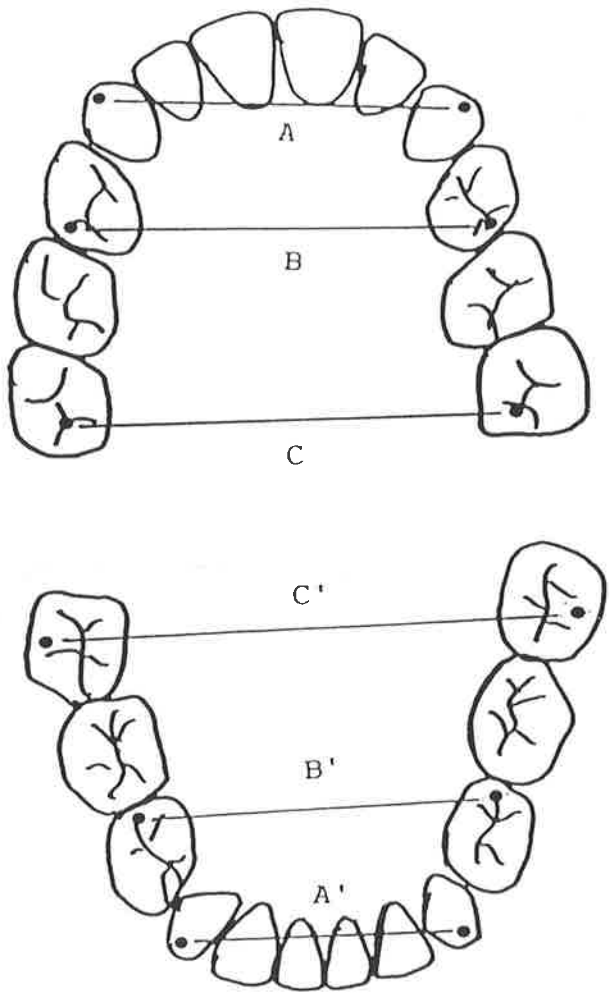
P Index 80, M Index 64 — Sum of mesiodistal diameters of four maxillary incisors	Interpremolar width	Intermolar width
25	31	39
25.5	32	39.8
26	32.5	40.9
26.5	33	41.5
27	33.5	42.5
27.5	34	42.96
28	35	44
28.5	35.5	44.5
29	36	45.3
29.5	37	46
30	37.5	46.87
30.5	38	47.6
31	39	48.4
31.5	39.5	49.2
32	40	50
32.5	40.5	50.80
33	41	51.5
33.5	42	52.3
34	43	53
34.5	43.5	53.9
35	44	54.5

Appendix 2: Measurement landmarks in the permanent dentition



a, b, c, d	:	mesiodistal crown diameters of the incisors
e and e'	:	maxillary and mandibular intercanine widths
f	:	maxillary interpremolar width (dist pit)
g	:	maxillary interpremolar width (bu cusp)
h	:	maxillary interpremolar width (pal cusp)
i	:	maxillary intermolar width (cen fossa)
j	:	maxillary intermolar width (mespal cusp)
k	:	mandibular interpremolar width (dist fossa)
l	:	mandibular intermolar width (distbu cusp)

Appendix 3 : Measurement landmarks in the deciduous dentition



A and A': Maxillary and mandibular intercanine widths

B and B': Maxillary and mandibular interpremolar widths

C and C': Maxillary and mandibular intermolar widths

Appendix 4: Data sheet.

Population :

Subject No : ....

Sex : F / M

Age : I... II...

Crown Diameters

right I2

right I1

Left I1

Left I2

Arch Widths

Maxilla

C - C (cusp tip)

D - D (dist fossa)

3 - 3 (cusp tip)

4 - 4 (dist pit)

4 - 4 (bu cusp)

4 - 4 (pal cusp)

6 - 6 (cen fossa)

6 - 6 (mespal cusp)

Mandible

C - C (cusp tip)

D - D (dist fossa)

3 - 3 (cusp tip)

4 - 4 (dist fossa)

6 - 6 (distbu cusp)

Appendix 5a. Double determination of crown diameters and arch widths in Australian Aborigines (n=30)

Variables	$\bar{d}$	$SE_{\bar{d}}$	t
crown diameters			
right I2	.097	.030	3.23*
right I1	.097	.026	3.73*
left I1	.070	.028	2.50*
left I2	.103	.028	3.68*
arch widths			
maxilla			
3 - 3 (cusp tip)	-.047	.067	0.70
4 - 4 (dist pit)	.073	.067	1.09
4 - 4 (bu cusp)	.047	.062	0.76
4 - 4 (pal cusp)	.153	.063	2.43*
6 - 6 (cen fossa)	.057	.060	0 95
6 - 6 (mespal cusp)	.160	.125	1.28
mandible			
3 - 3 (cusp tip)	-.167	.075	2.23*
4 - 4 (dist fossa)	-.030	.120	0.25
6 - 6 (distbu cusp)	.213	.083	2.57*

Critical t value with 29 degrees of freedom = 2.045
* significant at $p < 0.05$

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

Appendix 5b. Double determination of crown diameters and arch widths in Indonesians (n=30)

Variables	$\bar{d}$	$SE_{\bar{d}}$	t
crown diameters			
right I2	.003	.021	0.14
right I1	.007	.023	0.30
left I1	-.020	.017	-1.18
left I2	-.020	.022	-0.91
arch widths			
maxilla			
3 - 3 (cusp tip)	.143	.046	3.11*
4 - 4 (dist pit)	.040	.037	-1.08
4 - 4 (bu cusp)	.127	.043	2.95*
4 - 4 (pal cusp)	-.033	.058	-0.57
6 - 6 (cen fossa)	-.123	.048	-2.56*
6 - 6 (mespal cusp)	-.163	.058	2.81
mandible			
3 - 3 (cusp tip)	-.057	.046	1.24
4 - 4 (dist fossa)	-.553	.097	5.70*
6 - 6 (distbu cusp)	.030	.059	0.51*

Critical t value with 29 degrees of freedom = 2.045
* significant at $p < 0.05$

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

Appendix 5c. Double determination of crown diameters and arch widths in Caucasians (n=30)

Variables	$\bar{d}$	$SE_{\bar{d}}$	t
crown diameters			
right I2	.003	.024	0.13
right I1	.017	.017	1.00
left I1	.020	.022	0.90
left I2	-.037	.037	1.00
arch widths			
maxilla			
3 - 3 (cusp tip)	.150	.049	3.06*
4 - 4 (dist pit)	.033	.057	0.58
4 - 4 (bu cusp)	.190	.065	2.93*
4 - 4 (pal cusp)	.173	.069	2.50*
6 - 6 (cen fossa)	.103	.059	1 75
6 - 6 (mespal cusp)	.103	.066	1.56
mandible			
3 - 3 (cusp tip)	.100	.050	2.00
4 - 4 (dist fossa)	.267	.077	3.47*
6 - 6 (distbu cusp)	.173	.063	2.75*

Critical t value with 29 degrees of freedom = 2.045
* significant at $p < 0.05$

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

Appendix 6 a. Dahlberg statistic of crown diameters and arch widths in Australian Aborigines (n=30)

Variables	d	S_E^2	S_E
crown diameters			
right I2	.036	.018	0.13
right I1	.029	.015	0.12
left I1	.028	.014	0.12
left I2	.033	.017	0.13
arch widths			
maxilla			
3 - 3 (cusp tip)	.131	.066	0.26
4 - 4 (dist pit)	.137	.069	0.26
4 - 4 (bu cusp)	.112	.056	0.24
4 - 4 (pal cusp)	.138	.069	0.26
6 - 6 (cen fossa)	.103	.055	0.24
6 - 6 (mespal cusp)	.480	.240	0.49
mandible			
3 - 3 (cusp tip)	.193	.097	0.31
4 - 4 (dist fossa)	.417	.209	0.46
6 - 6 (distbu cusp)	.243	.122	0.35

$$S_E = \sqrt{\frac{\Sigma d^2}{2n}}$$ (Dahlberg, 1940)

Appendix 6b. Dahlberg statistic of crown diameters and arch widths in Indonesians (n=30)

Variables	d	S_E^2	S_E
crown diameters			
right I2	.012	.006	0.08
right I1	.015	.008	0.09
left I1	.009	.005	0.07
left I2	.014	.007	0.08
arch widths			
maxilla			
3 - 3 (cusp tip)	.082	.041	0.20
4 - 4 (dist pit)	.041	.022	0.15
4 - 4 (bu cusp)	.071	.036	0.19
4 - 4 (pal cusp)	.097	.049	0.22
6 - 6 (cen fossa)	.082	.041	0.20
6 - 6 (mespal cusp)	.124	.062	0.25
mandible			
3 - 3 (cusp tip)	.065	.033	0.18
4 - 4 (dist fossa)	.558	.279	0.53
6 - 6 (distbu cusp)	.101	.052	0.23

$$S_E = \sqrt{\frac{\Sigma\ d^2}{2n}} \quad \text{(Dahlberg, 1940)}$$

Appendix 6c. Dahlberg statistic of crown diameters and arch widths in Caucasians (n=30)

Variables	d	S_E^2	S_E
crown diameters			
right I2	.016	.086	0.09
right I1	.008	.004	0.06
left I1	.014	.007	0.08
left I2	.042	.021	0.14
arch widths			
maxilla			
3 - 3 (cusp tip)	.092	.046	0.21
4 - 4 (dist pit)	.094	.047	0.22
4 - 4 (bu cusp)	.160	.080	0.28
4 - 4 (pal cusp)	.169	.085	0.29
6 - 6 (cen fossa)	.110	.055	0.23
6 - 6 (mespal cusp)	.136	.068	0.26
mandible			
3 - 3 (cusp tip)	.082	.041	0.20
4 - 4 (dist fossa)	.242	.121	0.35
6 - 6 (distbu cusp)	.147	.734	0.86

$$S_E = \sqrt{\frac{\Sigma d^2}{2n}}$$ (Dahlberg, 1940)

Appendix 7a. Error variances of crown diameters and arch widths in Australian Aborigines (n=30)

Variables	Se^2	So^2	St^2	St^2/So^2
crown diameters				
right I2	.018	.361	.343	95.0
right I1	.015	.359	.344	95.8
left I1	.014	.370	.356	96.2
left I2	.017	.386	.369	95.6
arch widths				
maxilla				
3 - 3 (cusp tip)	.066	4.061	3.061	98.4
4 - 4 (dis pit)	.069	3.498	3.429	98.0
4 - 4 (bu cusp)	.056	3.930	3.874	98.6
4 - 4 (pal cusp)	.069	3.318	3.249	97.9
6 - 6 (cen fossa)	.055	5.112	5.057	98.9
6 - 6 (mespal cusp)	.240	5.111	4.871	95.3
mandible				
3 - 3 (cusp tip)	.097	3.152	3.055	96.9
4 - 4 (dist fossa)	.209	3.776	3.567	94.5
6 - 6 (distbu cusp)	.122	5.030	4.908	97.6

So^2 Observed variance calculated as weighted average of variances for all males and females

St^2 Estimate of true sample variance

Reliability = $(St^2 / So^2) \times 100\%$

Appendix 7b. Error variances of crown diameters and arch widths in Indonesians (n=30)

Variables	Se^2	So^2	St^2	St^2/So^2
crown diameters				
right I2	.006	.270	.264	97.8
right I1	.008	.234	.226	96.6
left I1	.005	.224	.219	97.8
left I2	.007	.243	.236	97.1
arch widths				
maxilla				
3 - 3 (cusp tip)	.041	2.817	2.776	98.5
4 - 4 (dist pit)	.022	3.005	2.983	99.3
4 - 4 (bu cusp)	.036	3.745	3.709	99.0
4 - 4 (pal cusp)	.049	2.581	2.532	98.1
6 - 6 (cen fossa)	.041	4.806	4.765	99.1
6 - 6 (mespal cusp)	.062	4.716	4.654	98.7
mandible				
3 - 3 (cusp tip)	.033	2.000	1.967	98.4
4 - 4 (dist fossa)	.279	3.063	2.784	90.9
6 - 6 (distbu cusp)	.052	5.200	5.148	90.0

So^2 Observed variance calculated as weighted average of variances for all males and females

St^2 Estimate of true sample variance

Reliability = $(St^2 / So^2) \times 100\%$

Appendix 7c. Error variances of crown diameters and arch widths in Caucasians (n=30)

Variables	Se^2	So^2	St^2	St^2/So^2
crown diameters				
right I2	.008	.302	.294	97.4
right I1	.004	.199	.195	98.0
left I1	.007	.230	.223	97.0
left I2	.021	.294	.273	93.0
arch widths				
maxilla				
3 - 3 (cusp tip)	.046	4.250	4.204	98.9
4 - 4 (dist pit)	.047	5.138	5.091	99.1
4 - 4 (bu cusp)	.080	6.733	6.653	98.8
4 - 4 (pal cusp	.085	5.453	5.368	98.4
6 - 6 (cen foss)	.055	9.254	9.199	99.4
6 - 6 (mespal cusp)	.068	8.756	8.688	99.2
mandible				
3 - 3 (cusp tip)	.041	2.795	2.754	98.5
4 - 4 (dist fossa)	.121	6.540	6.419	98.2
6 - 6 (distbu cusp)	.734	10.115	9.381	92.7

So^2 Observed variance calculated as weighted average of variances for all males and females

St^2 Estimate of true sample variance

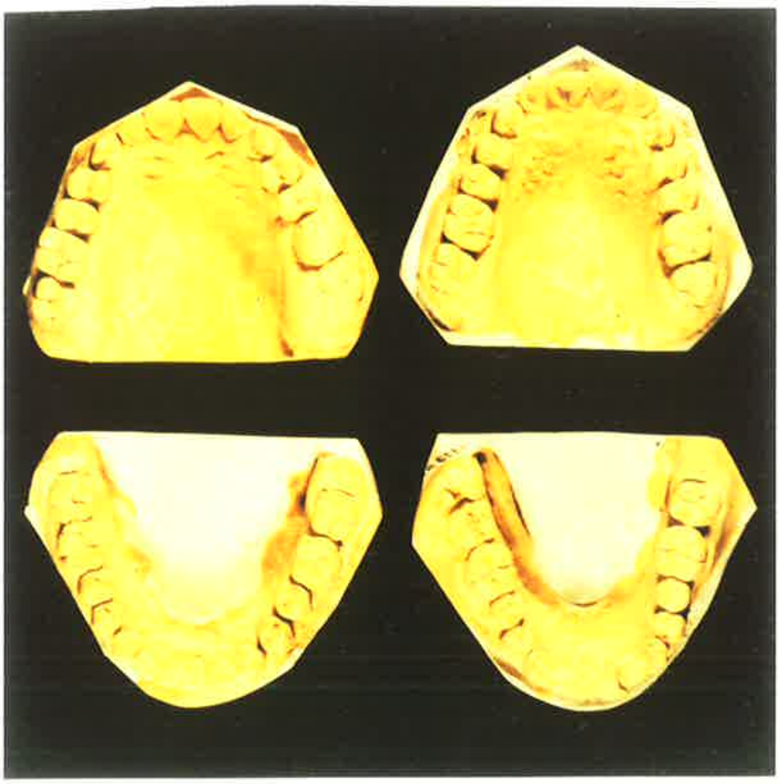
Reliability = $(St^2 / So^2) \times 100\%$

Appendix 8: Dental arch form in Australian Aborigines

left; observed dental arch width 6.0 mm over Pont's prediction

right; observed dental arch width 8.9 mm under Pont's prediction

Appendix 9: Dental arch form in Indonesians
left; observed dental arch width 12.7 mm over Pont's prediction
right; observed dental arch width 3.8 mm under Pont's prediction



Appendix 10: Dental arch form in Caucasians

left; observed dental arch width 10.0 mm over Pont's prediction

right; observed dental arch width 6.0 mm under Pont's prediction

Appendix 11: Dental arch form in Australian Aborigines with observed arch width within 1 mm of Pont's prediction

left; female dental arches

right; male dental arches

Appendix 12: Dental arch form in Indonesians with observed arch width within 1 mm of Pont's prediction

left; female dental arches

right; male dental arches

Appendix 13: Dental arch form in Caucasians with observed arch width within 1 mm of Pont's prediction
left; female dental arches
right; male dental arches