VARIATIONS IN TOOTH SIZE, DENTAL ARCH DIMENSIONS AND SHAPE AMONG MALAY SCHOOL CHILDREN

By

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Dedication

To my beloved family, for their unconditional love, support and care…

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In the name of ALLAH, the Beneficent, the Merciful …

First of all, I would to thank ALLAH for giving me the strength and courage throughout the duration of this research project. There are times when words are inadequate. I grant my grateful appreciation and thanks to all those who have contributed to this work.

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Dr. KHALID WALEED HUSSIEN

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

VARIASI SAIZ GIGI, BENTUK DAN DIMENSI LENGKUNG GIGI DI KALANGAN PELAJAR-PELAJAR MELAYU.

ABSTRAK

Nisbah saiz gigi merupakan satu cara diagnostik yang sah untuk membuat andaian tentang hasil rawatan dan ia juga dapat mengurangkan keperluan untuk membuat diagnostik untuk kes-kes yang rumit.

Diagnosis dan rawatan maloklusi dalam ortodontik memerlukan pengetahuan yang tepat mengenai dimensi gigi memandangkan oklusi yang stabil bergantung kepada ketepatan jarak antara juring gigi. Maklumat lengkung saiz gigi populasi manusia penting dalam klinikal pergigian sama seperti bidang sains lain seperti anatomi dan antropologi. Saiz gigi ditentukan oleh genetik, namun begitu, jenis dan nisbah kandungan genetik yang mengawal mungkin berbeza antara gigi, individu dan populasi. Persekitaran juga memainkan peranan dalam kepelbagian genetik untuk terus memberi variasi dalam saiz gigi.

Matlamat kajian ini adalah untuk mengukur saiz gigi mesiodistal dan dimensi lengkung gigi pelajar-pelajar Melayu Kelas I, Kelas II, dan Kelas III. Yang kedua ialah untuk membuat perbandingan saiz gigi, dimensi lengkung dan morfologi kelas maloklusi yang berlainan. Kajian ini melibatkan 150 orang subjek yang terdiri daripada 78 orang lelaki dan 72 orang perempuan, berumur antara 12-16 tahun. Setiap kumpulan maloklusi terdiri daripada 50 orang subjek. Alat "caliper" digital elektronik digunakan untuk mengukur lebar setiap gigi mesiodistal kesemua gigi kekal maksilari dan mandibular kecuali molar kedua dan ketiga. Lebar antara kanin

dan antara molar juga akan diukur menggunakan "caliper". Perimeter dan jarak lengkung gigi maksila dan mandibular diukur menggunakan prisisan "AutoCAD".

Perisian "Morphostudio" digunakan untuk menyatakan kuantiti dan mengesan dengan tepat perubahan bentuk ciri-ciri lengkung pergigian. Data dianalisis dengan ANOVA, ujian –t bebas, ujian-t berpasangan dan statistik perihalan. Didapati lebar gigi dan dimensi lengkung lebih besar bagi lelaki berbanding perempuan kecuali perimeter lengkung bawah dan lengkung atas. Keputusan menunjukkan bahawa lebar lengkung paling kecil adalah dalam kelas II berbanding oklusi normal kelas I.

Perbezaan signifikan hanya didapati dalam lebar antara molar mandibular. Tiada perbezaan signifikan dalam kedua-dua perimeter lengkung atau jarak lengkung dalam lengkung gigi maksilari dan mandibular. Pengetahuan tentang lebar lengkung dan saiz gigi yang dikaitkan dengan maloklusi dapat membantu dalam menentukan matlamat rawatan ortodontik dan rawatan susulan yang mugkin untuk maloklusi.

VARIATIONS IN TOOTH SIZE, DENTAL ARCH DIMENSIONS AND SHAPE AMONG MALAY SCHOOL CHILDREN

ABSTRACT

Tooth size ratio represents an important diagnostic tool for prediction of treatment outcomes and may also limit the necessity for diagnostic setups in complex cases. In orthodontics, the diagnosis and treatment of malocclusions require accurate knowledge of tooth dimensions as a stable occlusion is often reliant on the correct inter-cuspation of the teeth. Information concerning tooth size in human population is of importance to clinical dentistry as well as other sciences such as anthropology and anatomy. It appears that tooth size is determined principally by genetics but the proportion and type of genetic control may vary between teeth, individuals and populations. It is likely to be polygenic in nature. Environment then acts on this genetic variability to produce continuous variation in tooth size

The aims of the present study were (1) to measure mesio-distal tooth size and dental arch dimensions in Malay schoolchildren with Class I, Class II and Class III. (2) To compare tooth size and arch dimensions and morphology in different classes of malocclusion.

The current study consisted of study models of 150 subjects (78 males and 72 females), aged 12 to 16 years. Every malocclusion group consisted of fifty subjects. An electronic digital caliper was used to measure the individual mesio-distal tooth width of all maxillary and mandibular permanent teeth except second and third molars, inter-canine and inter-molar widths were also measured by the caliper. To measure maxillary and mandibular dental arch perimeter and length, AutoCAD software was used.

Morphostudio software was used to quantify and localize the shape-changes of dental arch features. Descriptive statistics, ANOVA, independent t-test and paired *t*-test were used for data analysis. Tooth width and arch dimensions were larger in males than that of females except for lower arch perimeter and upper arch length. The results also showed that the arch widths were significantly smaller in Class II, compared to Class I.

Significant difference was observed only in the mandibular inter-molar width. There were no significant differences neither in arch perimeter or arch length in the maxillary and mandibular dental arches. Knowledge of arch width and tooth size that is associated with malocclusion is helpful in determining orthodontic treatment goals and likely post-treatment sequence for the malocclusion.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Tooth size exhibits a continuous range of variation among individuals and between populations. Accumulated evidence indicates that tooth size reflects a complex interaction between a variety of genetic and environmental factors (Hattab *et al.*, 1996). Tooth size represents an important diagnostic tool that illustrates some prediction of treatment outcomes and may also limit the necessity for diagnostic managements for complex cases. A proper relationship of the total mesio-distal width of the maxillary dentition to the mesio-distal width of the mandibular dentition will favour an optimal post treatment occlusion (Santoro *et al.*, 2000).

Mesio-distal tooth width has an anthropological significance because it provides valuable information on human evolution with its technological and dietary changes (Al-Khateeb and Abu Alhaija, 2006). On a clinical level, mesio-distal tooth width is correlated to the arch alignment and large teeth are associated with crowded dental arches (Bermudez de Castro and Nicolas, 1995). Differences in tooth size have been associated with different ethnic backgrounds and malocclusions (Al-Khateeb and Abu Alhaija, 2006). The mesio-distal tooth size of the maxillary and mandibular arch must relate to each other in order to obtain an excellent occlusion at the completion of the orthodontic treatment. A determined tooth size ratio may predict the functional and aesthetic outcome of treatment of the case (Heusdens *et al.*, 2000).

A relative harmony in the mesio-distal dimension of the maxillary and mandibular teeth is major factors in coordinating posterior inter digitations, overbite, and over jet in centric occlusion. Tooth size must also be in harmony with arch size to allow proper alignment (Hashim and Al-Ghamdi, 2005). It was stated by Singh and Goyal (2006) that the task of the orthodontist is to align the teeth to improve the mastication efficiency, facial esthetics and alignment of the dental arches, which becomes difficult in the presence of tooth size discrepancies.

A significant variation in the harmony of tooth size ratio will lead to malocclusion and difficulties in obtaining an occlusion with optimal overjet, overbite and class I canine and molar relationships. The natural teeth match very well in most individuals, however some degree of discrepancy among the size of the teeth is present among individuals of any population (Hashim and Al-Ghamdi, 2005).

Analysis of maxillary to mandibular tooth-width proportions (ratios) is an important diagnostic tool for predicting the occlusal results of orthodontic treatment. Successful orthodontic treatment is based on comprehensive diagnosis and treatment planning. A few of the fundamental factors in the diagnosis are tooth spacing condition, tooth size, arch form and its dimensions, as well as the tooth-arch discrepancies (Zilberman *et al.*, 2003). An appropriate relationship of the mesio-distal widths of the maxillary and mandibular teeth favours a good post treatment occlusion (Bernabe *et al.*, 2004).

Many factors such as heredity, growth of the bone, eruption and inclination of the teeth, external influences, function, and ethnic background could affect the size and shape of the dental arches (Al-Khateeb and Abu Alhaija, 2006).

Previous studies have been trying to describe and classify the human dental arch form. It is commonly believed that the dental arch form is initially shaped according to the configuration of the supporting bone and following the eruption of the teeth, by the circum-oral musculature and intra-oral functional forces (Braun *et al.*, 1998).

The differences in arch shape and dimensions can affect the clinical treatment. In addition to that, people from different ethnic groups present with different morphological conditions, and the clinician should anticipate the differences in size and form rather than treating all cases to a single ideal (Burris and Harris, 2000). In any multicultural societies knowledge of the characteristics and distinctive features of individuals with different ethnic origins is of particular interest. At most metropolitan areas of the world, the populations are constituted of a considerable mixture of races (Zeng *et al.*, 1998).

Based on previous studies on relapse, it is generally agreed that post orthodontic occlusal stability is enhanced through maintenance of the original mandibular inter-canine width and preservation of the original arch form (Nojima *et al.*, 2001). Arch shape affects both the functional and the esthetics of the occlusion. The preservation of dental arch shape during growth is an indicator of the equilibrium of teeth between tongue and circum-oral muscle forces. Dimensional changes of dental arches might affect arch form as well (Taner *et al.*, 2004).

The identification of a suitable arch form and dimension is a key aspect of achieving a stable, functional, and esthetic arch form in orthodontic diagnosis and treatment (Banabilh *et al.*, 2006), furthermore, failure to customize the arch form creates the probability of relapse and can lead to poor prognosis. It is important in the leveling and alignment stage to select the shape that most closely matches the patient's pretreatment arch form, according to either his or her ethnicity and type of malocclusion (Kook *et al.*, 2004).

Dental casts are still considered a vital diagnostic tool in orthodontic practice. They facilitate the analysis of tooth size and shape; alignment and rotations of the teeth, arch width, length, form and symmetry and the occlusal relationship (Hashim and Al-Ghamdi, 2005). Computer technology is expanding to include more areas in various scientific fields, and orthodontics is no exception. The introduction of digital models offers the orthodontist an alternative to the plaster study models routinely used. However, plaster study models are a standard component of orthodontic records, and they are fundamental to diagnosis and treatment planning, case presentations, evaluation of treatment progress and results, and record keeping (Santoro *et al.*, 2003).

1.2 Statement of Problem

Researchers around the world had studied tooth size and dental arch dimensions of different populations. As far as we are aware, previous studies were done on cleft lip and palate patients, scant research has been done on dental cast of the Malay population to determine the clinical significance of maxillary and mandibular tooth-size measurements, dental arch dimension and morphology in orthodontic diagnosis and treatment planning.

1.3 Justification of Study

Mesio-distal crown tooth width provides significant information on human evolution, biological problems and clinical odontology. Furthermore, it provides data that is useful for comparative studies of tooth size (Hattab *et al.*, 1996). Tooth size is of great importance to the general dentist as well as to the pedodontist and orthodontist in diagnosis and treatment plan of spacing problems (Singh and Goyal, 2006).

It is important to have data concerning relevant human group for purposes of clinical diagnosis and planning of treatment. These data may also be useful in forensic dentistry (Ling and Wong, 2007). The ethnic differences in arch dimensions should be considered during treatment, especially in prosthodontics and orthodontics where arch shape can be modified appreciably (Burris and Harris, 2000).

Knowing arch dimensions helps the prosthodontist in the selection of the correct shape and size of stock impression trays and suitable molds of artificial teeth for fixed and removable prostheses (Hashim and Al-Ghamdi, 2005). In addition to that it is of great clinical value in modern orthodontic techniques, in which preformed super elastic arch wires are frequently used. Clinically, instead of one preformed arch wire, it is more reasonable to have several types of preformed arch wires available and to identify the patient's pretreatment arch form according to race and malocclusion (Kook *et al.*, 2004).

1.4 General Objectives

To study the variations in tooth size, dental arch dimension and shape among Malay school children with different classes of malocclusion in the permanent dentition.

1.5 Specific Objectives

1. To compare the mesio-distal tooth width on the dental cast, in Class I, Class II and Class III malocclusion groups.
2. To compare the dental arch dimensions on the dental cast in Class I, Class II and Class III malocclusion groups. These include:
    - Inter-canine width
    - Inter-molar width
    - Arch length
    - Arch perimeter

3. To compare the shape of dental arch in Class I, Class II and Class III malocclusion groups.

1.6 Research Hypothesis

In achieving the aims of the study, the following hypotheses were tested:

1. There are no differences in the mesio-distal crown width within different malocclusion groups.

2. There are no differences in arch dimensions and arch shape within different malocclusion groups.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tooth size

The development of teeth begins early in life and except for disturbances such as severe febrile illness, infection, trauma and pathological conditions which cause hyperplasia. The sizes of teeth remain immune to outside influences and are governed by their hereditary potential. Tooth size from different population groups around the world has been measured and published by many researchers. In a dentition with malocclusion, the impact of tooth width discrepancy may not be apparent until the final stages of orthodontic treatment. Furthermore, the maxillary and mandibular teeth have been shown to vary in size not only between the male and female but also between different racial groups (Ho and Freer, 1994).

Hattab *et al.* (1996) measured mesio-distal crown diameters of the permanent teeth of 198 Jordanians aged 13-19 years using sliding caliper. Results showed that males had significantly larger teeth than females, the maxillary lateral incisors showed the greatest variability while the first molar had the least in mesio-distal diameter. Similarly, canines displayed greater sexual dimorphism in crown size than any other tooth. The cumulative tooth widths of males were higher than females by a sum of 3.1 mm in the maxilla and 3.6 mm in the mandible, these differences were statistically significant.

McCann and Burden (1996) examined tooth size in a sample of Northern Irish people with bimaxillary dental protrusion. Plaster dental casts were obtained from 30 white subjects (14 males and 16 females), diagnosed as having an Angle's class I bimaxillary dental protrusion. A control group of 30 white subjects (14 males and 16 females) exhibiting a variety of malocclusions but without bimaxillary protrusion were randomly selected from the orthodontic department's patient records. The mean age of the bimaxillary protrusion group was 12.75 years (range 9-21 years), and the mean age of the control group was 14.3 years (range 9-28 years).The mesio-distal diameters of all permanent teeth were measured. Measurements were made directly on the dental casts by a single operator using caliper. The results revealed that, on average, tooth size for the overall maxillary and mandibular dentition was 5.7% larger in the bimaxillary group than in the control group.

Otuyemi and Noar (1996) compared the mesio-distal and bucco-lingual crown dimensions of the permanent teeth in Nigerian and British populations. The study sample consisted 30 pairs of study models of randomly-selected Nigerian children (15 boys and 15 girls) residing in Nigeria. Their mean age was 12.5±1.4 years. The British sample was also obtained from study models of 15 boys and 15 girls enrolled for orthodontic treatment at the Department of Orthodontics, Mount Vernon Hospital, UK. Their mean age was 12.9 ± 1.2 years. All mesio-distal measurements were carried out on the plaster study models using a digital caliper. The results indicated that the mesio-distal crown diameters were significantly larger in the Nigerian sample. There were no statistically significant differences in bucco-lingual crown diameters in the two populations, except for the mandibular central incisors and maxillary canines.

Yuen *et al.* (1996) studied the relations between the mesio-distal crown diameters of the primary and permanent teeth of Hong Kong Chinese. The study was performed on serial dental casts of 112 Hong Kong Chinese (61 males, 51 females) taken at mean ages of 5.68 for the primary dentition and 12.31 years for the permanent. The mesio-distal crown diameters of both primary and permanent teeth were measured by one operator using digital calipers. For size differences, results revealed that the incisors and canines were larger in the permanent dentition in both arches. Premolars were smaller than their primary predecessors except for the upper first premolar. The second premolar-second primary molar differences were the greatest while those between the first premolar-first primary molar were the smallest. When tooth groups were assessed, the permanent teeth were larger than their predecessors in the anterior segments but smaller in the posterior segments. The leeway space was larger in the mandibular arch than in the maxillary arch.

Becker *et al.* (2002) investigated the relation between the palatally displaced canine and the existence of a reduction in the size of the other teeth in the maxilla. The sample included 58 patients with maxillary canine anomaly (37 females, 21 males) aged 11-15 years, and compared these with a control group of 40 subjects (20 females, 20 females) with normally erupted maxillary canines. Caliper was used to measure the mesio-distal and bucco-lingual of the teeth directly on the plaster dental casts of both groups. The results indicted that the teeth of males with palatally displaced canine are reduced in size and similar to those palatally displaced canine females, in contrast to general population, where males have larger teeth. Among males only, there was a distinct trend towards mesio-distal narrower teeth in the palatally displaced canine group when compared with the control males. They stated that in general, the mesio-distal width of teeth in females with bilateral palatally displaced canine was smaller than the mesio-distal width in females with unilateral palatally displaced canine. The reverse was true for the bilateral palatally displaced canine males, where a larger mesio-distal width was seen, compared with the unilateral palatally displaced canine males.

Santoro *et al.* (2003) performed a study to compare the accuracy of measurements made by the OrthoCAD system on digital models with measurements made by hand on traditional plaster models. The study sample consisted of 76 randomly selected pre-treatment patients. Tooth width was measured using an orthodontic-style Boley gauge. Overbite and overjet were measured with a graduated, calibrated periodontal probe on both upper and lowers casts. The results were then statistically evaluated. Tooth size was measured on the digital models with the analysis tools provided by OrthoCAD, as well as for measuring the overjet and overbite. The results showed a statistically significant difference between the 2 groups for tooth size and overbite, with the digital measurements being smaller than the manual measurements. However, the magnitude of these differences ranged from 0.16 mm to 0.49 mm and can be considered not relevant clinically. No difference was found between the 2 groups in the measurement of overjet. Inter-examiner reliability was consistent for both the plaster and the digital models.

In Turkey, Saglam *et al.* (2004) compared the mesio-distal crown dimensions of the permanent teeth between subjects with and without fluorosis. The study included 25 pairs of dental casts for each group and the mean ages were 13.9 ± 1.6 and 13.9 ± 1.4 years, respectively. A vernier caliper was used to record the maximum mesio-distal tooth width. The results indicated that the mesio-distal crown dimensions were larger in subjects with non-fluorotic permanent teeth. On the other hand there was no difference in the mandibular mesio-distal crown diameters for any of the measurements except for the mandibular first premolars.

Khalaf *et al.* (2005) performed a study to compare tooth size measurements between patients with supernumerary teeth and a control group. The supernumerary group consisted of 56 subjects and the control group of 40 subjects. All available permanent teeth on the dental casts were imaged and measured from both buccal and occlusal views using an image analysis system. Mesio-distal, bucco-lingual or occluso-gingival dimensions, area and perimeter were measured from each view. Results showed that supernumerary tooth patients tended to have larger tooth size measurements for almost all variables compared to controls. They stated that there is some evidence of a local effect with greater differences in tooth dimension adjacent to the site of the supernumeraries.

Paschos *et al.* (2005) investigated the differences in mesio-distal and labio-lingual crown sizes of naturally, fully-erupted permanent maxillary teeth between patients with and without palatal canine displacement. 115 Caucasian patients (mean age: 14 years 10 months; females: 77 males: 38) treated in the Department of Orthodontics, University of Munich were included in the study. 65 of the patients showed at least one palatally-displaced canine. The mesio-distal and labio-lingual width of each maxillary tooth were measured using a dial caliper on each dental cast. An analysis of available space was made by evaluating the pre-treatment dental casts of all patients included in the study. Comparing the tooth widths of patients with unilateral canine displacement with the corresponding contra-lateral quadrants, the central and lateral incisors and the canines of the affected side were narrower than those of the non-affected side in the same patient. Moreover, the displaced upper canines showed an increase in vestibulo-oral dimension. Overall tooth width (including all tooth groups) in patients with palatally displaced canines were significantly less than that in the control group. However, when comparing the crown diameters of unilaterally- and bilaterally-affected patients, no differences in tooth-size were observed. The space-analysis showed excessive dental-arch space in patients with a palatally-displaced canine.

In the study conducted by Singh and Goyal (2006) on 110 North Indian children 12-18 years old, the mesio-distal crown dimension of the teeth was measured on the plaster casts by a sliding caliper. The results revealed that the mesio-distal crown dimensions of teeth of males were larger than those of females in both arches. The maxillary first premolars were larger than the second premolars, whereas the mandibular second premolars were larger than the first premolars. The first molars were larger than the second molars in both maxillary and mandibular arches in both sexes.

Ling and Wong (2007) measured the mesio-distal, bucco-lingual, and clinical crown height dimensions of 12-year-old children from Hong Kong using a sliding dial calipers. Sexual dimorphism was evident in all tooth dimensions with the exception of the mesio-distal dimension of mandibular central incisors. The Chinese male tooth dimensions were larger than Chinese females in nearly all characters.

A study of tooth size was carried out by Puri *et al*. (2007) using a digital caliper to examine the extent of tooth size that contributes to dental crowding or spacing. A sample of 240 orthodontic study casts was selected. The sample was divided into crowded, spaced, and normal dentition groups with 80 casts in each group. Results revealed that the mesio-distal crown dimensions of individual teeth, the sum of the incisors, and the sum of the canines and the premolars were uniformly larger in crowded arches than in normal and spaced dentition groups. Mesio-distal crown dimensions of individual teeth were smaller in the spaced arches compared with normal dental arches, but the difference was significant only in the combined mesio-distal crown dimensions of the mandibular incisors.

Clinch (2007) measured the mesio-distal crown diameters of the deciduous teeth and their permanent successors on plaster models of 65 children (34 boys and 31 girls) using sliding calipers. Correlation analyses were calculated which showed some correlation between the two dentitions. These correlations were stronger in girls than in boys. On the average the sum of the permanent teeth exceeds that of the deciduous teeth in mesio-distal crown diameter but there is considerable individual variation.

2.2 Tooth size discrepancy

The Bolton analysis, based on the ratios between the mesio-distal tooth diameter sums of the mandibular and the maxillary dentitions, remains the most recognized and widely used method for detecting inter-arch tooth size discrepancies (Smith *et al.*, 2000). Bolton developed his overall and anterior ratios based on 55 patients with excellent Class I occlusions, in addition, introduced mathematical tooth size ratios (Heusdens *et al.*, 2000).

Although Bolton's analysis has proven extremely useful in the clinical setting to guide the orthodontist in cases with extreme tooth size discrepancies, it is not without limitations. First, Bolton's estimates of variation were underestimated because his sample was derived from perfect Class I occlusions. Secondly, and perhaps more importantly, the population and gender composition of Bolton's sample were not specified, which implies potential selection bias (Smith *et al.*, 2000). A high prevalence of tooth size discrepancies in an orthodontic patient population and the statistically significant correlation of these dental characteristics suggest that the measurement of inter-arch tooth size ratios might be clinically beneficial for treatment outcomes (Akyalcin *et al.*, 2006)

A study by Nie and Lin (1999) performed to determine the prevalent tendency for inter-maxillary tooth size discrepancies among different malocclusion groups of Chinese. Measurements were performed on the models of normal occlusion and pre-treatment models of patients by the three dimension measuring machine (This sort of machine is used extensively in the precision machine tool industry). The study consisted of 60 subjects who served as the normal occlusion group and 300 patients divided into Class I, Class II and Class III malocclusion groups and they were between 13 and 17 years old except for Class III patient they were from 17-23 years old. The results showed significant difference in the tooth-size ratios between the groups, the ratios showing that Class III > Class I > Class II. It demonstrated that inter-maxillary tooth size discrepancy may be one of the important factors in the cause of malocclusions, especially in Class II and Class III malocclusions. Thus this study proved the fact that Bolton analysis should be taken into consideration during orthodontic diagnosis and therapy.

Heusdens et al. (2000) compared the anterior and overall tooth size ratios reported by Bolton to values reported in epidemiologic studies. They investigated the effect of generalized tooth size discrepancy on occlusion and assessed the accuracy of tooth size discrepancy measurements. The measurements for the study were taken from one dental cast of a male patient with an ideal occlusion achieved following a non-extraction orthodontic treatment. Sliding calipers were used to determine the largest mesio-distal diameter of the teeth from first molar to first molar, measured perpendicularly to the occlusal surface. The total mesio-distal size of the maxillary and mandibular teeth was calculated by needle point dividers with the points of the dividers parallel to the occlusal plane. They concluded that the effect of generalized tooth size discrepancy appears to be limited on occlusion. Extraction therapy only slightly affects the final occlusion. Only in severe situations of tooth-size discrepancy (TSD) which is evaluated on the dental setup, the outcome of the final occlusion will be affected to some extent.

Smith *et al.* (2000) evaluated Bolton's inter-arch ratios in three populations of blacks, Hispanics, and whites. 180 persons with age range between 12 and 38 years. They reported significant differences in the overall, anterior, and posterior inter-arch ratios between these groups. White people displayed the lowest overall ratio (92.3%), followed by Hispanics (93.1%), and blacks (93.4%).

Ta *et al* (2001) compared anterior and overall ratios among different occlusion groups of southern 12 years old Chinese children (50 subjects with Class I occlusion, 30 with Class II malocclusion, and 30 with Class III malocclusion). A TESA Digit-Cal SM caliper with Liquid Crystal Display and digital output was used to measure the casts. For the anterior ratio, a statistically significant difference was observed between the Bolton standard and the Class III occlusion group. For the overall ratio, statistically significant differences were found between the Bolton standard and the Class II occlusion group, and between the Class II and the Class III occlusion groups.

Araujo and Souki (2003) investigated the correlation between anterior tooth size discrepancies and Angle’s Class I, II, and III malocclusions, as well as their prevalence in the Brazilian population from Belo Horizonte. The mesio-distal width of six anterior teeth in 300 patients was measured using a digital caliper. Analysis of variance (ANOVA) was used to compare the mean Bolton anterior tooth size ratios as a function of Angle classification as well as gender. Results showed that significant discrepancies were found in 22.7% of the sample. A significant difference in mean anterior Bolton ratio among the malocclusion groups was found.

However, gender alone or in combination with Angle classification was not statistically significant.

In Turkey, Basaran *et al* (2004) using a digital caliper conducted a study to determine whether there is a prevalent tendency for inter-maxillary tooth size discrepancies among different malocclusion groups. This study involved 60 subjects who served as the normal occlusion group and 300 patients divided into five malocclusion groups (i.e., Class I, Class II, Class II division 1, Class II division 2, and Class III) the sample age was 13 and 19 years. Tooth size measurements were performed on the models of the normal occlusion group and the pre-treatment models of the patients. The tooth size ratios and the one-way analysis of variance test showed no sexual dimorphism for these ratios in each of five groups, so the sexes were combined for each group. Then, these ratios were compared among different malocclusion groups. The results showed no significant difference between subcategories of malocclusion, so these groups were combined as Class I, Class II, and Class III. No significant difference was found for all the ratios between the groups.

Bernabe *et al*. (2004) conducted a study to determine maxillary to mandibular tooth-size ratios among 200 Peruvian children with complete permanent dentition. The dental casts were measured with a sliding caliper and a Vernier scale. No significant differences were found in anterior tooth-size sums according to sex, but there was difference in the total tooth-width ratio and there were significant tooth-size discrepancies in almost one third of the sample.

Uysal and Sari (2005) conducted a study to determine the size of individual permanent teeth, tooth size ratios for the maxillary and mandibular dentitions and sex differences in 150 Turkish subjects with age range 21-25 years old with normal occlusions. A digital caliper was used to measure the dental cast. Results showed greater variability in the mesio-distal dimensions of the maxillary teeth than the mandibular teeth. In addition, significant sex difference was also found.

Akyalcin *et al* (2006) using a digital caliper with a LCD digital output, investigated the frequency and association of Bolton tooth size discrepancies with dental discrepancies on study casts ages of 12 and 15 years. The study included 45 skeletal Class I, 60 Class II, and 44 Class III subjects with similar skeletal characteristics. Analysis of variance was performed to compare the mean ratios of Bolton analysis as a function of the Angle classification and sex. Chi-square tests were performed to determine the prevalence of tooth size imbalances among the three groups of occlusions and the two sexes. To determine the correlation of tooth size imbalances with certain dental characteristics, Pearson's correlation coefficients were calculated. No statistically significant differences were determined for the prevalence of tooth size discrepancies and the mean values of Bolton's anterior and overall ratios among the occlusal groups and sexes. Bolton's anterior ratio discrepancies had significant correlations with midline shifts in Angle Class I cases. Bolton discrepancies related to overall ratio had significant correlations with overjet in Class I cases and overbite in Class II cases.

Baidas and Hashim (2005) conducted a study to compare the anterior tooth size width in patients with congenitally missing maxillary lateral incisors using the Bolton Index and divine proportion. The sample of the study consisted of 30 pairs of orthodontic models with unilateral (12 patients; 7 females, 5 males) and bilateral (18 patients; 13 females, 5 males) absence of maxillary lateral incisors. The mean ages of the selected cases were 17.7 and 17.5 years, respectively. An electronic digital caliper was used for measuring the greatest mesio-distal width of each anterior tooth. The result showed the mean of the Bolton Index in cases with bilateral absence was closer to the Bolton mean than in cases with unilateral absence. In the unilateral absence cases the width of the existing lateral incisor (5.5 mm) was an average of 1.00 mm less compared to the standard mean (6.5 mm). The divine proportion showed the maxillary central incisors were small in width as indicated by the adjusted value or they were slightly larger in width than the mandibular central incisors.

Fattahi *et al* (2006) designed a study to compare tooth size discrepancies among subjects with different skeletal malocclusions in an orthodontic population. The study employed the pre-treatment models of 200 patients (100 males, 100 females, aged from 14 to 20 years) selected from the records of the Orthodontic Department, Shiraz Dental School. The subjects were from four malocclusion groups, Class I, Class II division 1, Class II division 2, and Class III. Each group comprised 50 healthy individuals (25 males, 25 females). The mesio-distal dimensions of teeth were measured using digital electronic calipers and the Bolton indices were determined. The data were statistically analysed using analysis of variance and Duncan's multiple range tests. The results revealed that the mean anterior ratio was 79.01 for the whole sample and statistically significantly different from Bolton's 77.2 but no significant difference was found for the overall ratio. The posterior and overall ratios of the Class III malocclusion group were statistically greater than the other malocclusion groups. The mean anterior ratio of the Class III group was greater than that of the Class II group. However, there was no difference when compared with the Class I malocclusion group. The two types of Class II malocclusion, no significant ratio differences were observed.

Mirzakouchaki *et al.* (2007) performed a study on a sample of 50 plaster models (25 male subjects, 25 female subjects) of Iranian-Azari subjects aged 20-28 years old. The mesio-distal widths of all teeth were obtained and the Bolton anterior ratio and overall ratio were calculated by using a digital Boley gauge with a Vernier scale. The mean values for the anterior and overall ratios for male and female subjects were very similar and did not differ significantly The comparison with the original data from Bolton indicated higher ranges for anterior and overall ratios with mean values being very similar.

Paredes *et al.* (2006) used a digital method for measuring tooth sizes and calculating the Anterior Bolton Index (ABI) and the Overall Bolton Index (OBI) then compared it with the traditional method. 100 sets of study dental casts of the permanent dentition in a Spanish sample were included in the study (30 females and 70 males with a mean age of 14.8 years old). For the traditional method calipers were used to measure the mesio-distal size of the teeth on the dental cast.

The ABI and OBI of these mesio-distal sizes were calculated by totalling the sizes of the teeth and determining the corresponding index. For the digital method the casts were scanned, digitization was carried out by placing the stone dental casts on a scanner surrounded by a sheet of squared paper in order to enable the calibration calculation. Software program (Department of Orthodontics, University of Valencia) that include different measurement options was used to calculate the mesio-distal width of the teeth on the scanned images. A statistical package by SPSS was used to analyse the comparison of paired measurement means and the correlation between variables calculated by the analysis of linear regression and correlation coefficients. The proportion comparison test was also used to validate statistically the ratio of correct predictions. The results demonstrated that the digital method provided results comparable with those of the traditional technique, since the regression parameters for each index showed that the correlation coefficients of the two methods were very high and similar to each other. The results also showed more discrepancies in the ABI than in the OBI using both methods in this sample.

2.3 Arch dimensions

The size and form of the dental arches can have considerable implications in orthodontic diagnosis and treatment planning, affecting the space available, dental esthetics, and stability of the dentition (Lee, 1999).

The growth changes of arch widths in normal occlusion subjects and a comparison of arch widths in normal occlusion and different malocclusion samples have been studied extensively (Uysal *et al.*, 2005).

Filho *et al.* (2008) conducted a study to calculate the difference in the dimensions of the upper and lower dental arches in Class II division 1 malocclusion with a mandibular deficiency compared to normal Class I occlusion dental arches. Dental arches of 48 patients exhibiting Class II division 1 malocclusion with mandibular deficiency and of 51 individuals with normal occlusion were compared. Images of the occlusal surface of the dental casts were obtained using a photocopy machine (PRO 40; Xerox, Hertfordshire, UK). The images of the models were measured with a digital caliper. All 99 individuals were in the permanent dentition. The ages of the subjects ranged from 11 years 4 months to 20 years (mean age = 12 years 5 months). The upper dental arches of the Class II division 1 patients presented reduced transverse dimensions and longer sagittal dimensions while the lower arches were less influenced, when compared to subjects with normal occlusion.

Poosti and Jalali (2007) used calipers and AutoCAD software (Autodesk, Inc., San Rafael, CA, USA) to examine the contribution of arch dimension and tooth size to dental crowding. Two groups of dental casts were selected. Each group consisted of 30 pairs of dental casts including equal male and female samples. The first group had Class I malocclusions without crowding or spacing. The second group exhibited Class I malocclusions with severe dental crowding. The following parameters were measured and used to compare the two groups: individual and collective mesio-distal tooth diameters, dental arch length, as well as buccal and lingual dental arch widths in the canine and molar regions. Statistically significant differences in both tooth diameters and transverse arch dimensions were found between the two groups. The group with crowded teeth was found to have a significantly smaller maxillary arch width and larger tooth size when compared with the non-crowded teeth group.

Huth *et al.*, (2007) conducted a study to compare arch widths in adults with Class II division 2 (II-2), Class II division 1 (II-1), Class I normal occlusions, gender dimorphism, differences between maxillary and mandibular arch widths and to develop adult norms for arch widths. Subjects were white Americans with no history of orthodontic treatment and the age was 16-22 years old. Arch width dimensions (inter-canine and inter-molar) were measured using dial calipers. Analysis of variance (ANOVA) and Duncan's test were used to compare between the groups. They concluded that the II-2 group had maxillary arch widths significantly smaller than the normal occlusions and significantly larger than the II-1 group. All groups had similar mandibular inter-canine and alveolar widths. The II-2 and II-1 groups had similar mandibular inter-molar widths, both significantly smaller than normal occlusions. The II-2 group had a maxillary/mandibular inter-molar difference significantly smaller than the normal occlusions, and significantly less negative than the II-1 group. Gender comparisons in two of six widths showed normal and II-2 male subjects were similar, and in six of six widths normal and II-2 female subjects were similar; in five of six widths II-2 and II-1 male and female subjects were similar. Gender dimorphism occurred in five of six widths in normal occlusions, four of six widths in II-2, and one of six widths in II-1.

Baccetti *et al.* (1997) evaluated transverse discrepancy in 25 subjects with Class II malocclusion (13 males and 12 females) and compared it with a control group of 22 subjects with ideal occlusion from deciduous to mixed dentition stage. They reported that transverse inter-arch discrepancy determined in Class II malocclusion in deciduous dentition persisted into the mixed dentition, and treatment to correct Class II problem could be initiated in all three planes of space, such as rapid maxillary expansion (RME), extra oral traction, and functional jaw orthopedics.

140 orthodontic models of school children aged 13–15 years were included in the study of Al-Khateeb and Abu Alhaija (2006) to determine mesio-distal tooth width of the dentition, Bolton anterior and overall ratios, arch length, and arch width in the different malocclusions in a Jordanian sample. The results showed that females have smaller teeth than males, Class III malocclusion showed larger teeth than the rest of the other occlusal categories, however no statistically significant differences were found in Bolton ratios between the different malocclusions. Class II division 1 showed the narrowest maxillary arch compared with the other types of malocclusion. All the measurements were done by using a vernier caliper.

To establish tooth width and arch dimensions in normal and malocclusion samples and to compare tooth width and arch dimensions between males and females in normal and malocclusion samples, Hashim and Al-Ghamdi (2005) using an electronic digital caliper, measured tooth width and arch dimensions of 120 pairs of orthodontic study casts. Significant differences were found in tooth width between normal and malocclusion samples. However, no significant difference was observed in arch dimensions. Furthermore, there was statistical significant difference in tooth width between males and females where the males showed highest mean values. The same was true when arch dimensions were compared.

Tollaro *et al.* (1996) compared arch widths of 60 Class II, division 1 patients (26 males and 34 females) with 70 Class I subjects (25 males and 35 females) in the mixed dentition. Class II, division 1 subjects were grouped according to the presence of the posterior transverse inter-arch discrepancy (PTID). They reported that Class II, division 1 patients with PTID had narrower maxillary inter-molar widths than Class II, division 1 patients without PTID and Class I subjects. Mandibular inter-molar widths did not differ between the three groups. They also suggested that Class II patients with PTID needed a preliminary expansion of the maxillary arch.

Uysal *et al.* (2005) performed a study to compare the transverse dimensions of the dental arches and alveolar widths of Class III malocclusion group with a group of untreated normal occlusion subjects. Measurements were done on dental casts of 150 normal occlusion (mean age, 21.6 ± 2.6 years) and 100 Class III malocclusion (mean age, 15.4 ± 2.2 years) subjects using a dial caliper. Results revealed that maxillary inter-premolar, inter-molar widths and all maxillary alveolar width measurements were narrowest in the Class III group, the mandibular inter-canine and inter-molar alveolar widths were largest in the Class III group and the lower canine and premolar alveolar width measurements were larger in the normal occlusion group when compared with the Class III malocclusion group.

Sayin and Turkkahraman (2004) evaluated dental arch and alveolar widths of Turkish patients with Class II, division 1 malocclusion. Thirty females with Class II, division 1 malocclusion were compared with 30 females with Class I ideal occlusion and the mean age was 16-21 years old. Dental cast measurements were performed by a dial caliper. They stated that inter-molar widths were narrower in the Class II, division 1 group while mandibular inter-canine widths were narrower in the Class I group. Inter-alveolar widths showed no difference between the groups. These results suggest that the transverse discrepancy in Class II, division 1 patients originated from upper posterior teeth and not from the maxillary alveolar base.

Warren and Bishara (2001) performed a study to describe secular changes that might have occurred in tooth sizes and tooth size-arch length relationships in the same groups of contemporary and historical North American white children in the primary dentition. The two samples were similar in terms of geographic location, racial and ethnic backgrounds, and socioeconomic status. Mesio-distal tooth sizes for all deciduous teeth, as well as arch lengths were measured directly from the casts by a single examiner with digital calipers. The results indicated that tooth sizes were generally similar in the 2 cohorts but slightly larger in contemporary children. Crowding was found to be common in the mandibular arch for contemporary children in the deciduous dentition of both boys and girls. Moreover, crowding was much more common and severe in contemporary children compared with children in the historical cohort. They recommended that further research is needed to determine whether the increase in mandibular crowding in the deciduous dentition will continue to be observed in the mixed and permanent dentitions.