TOOTH SIZE AND DENTAL ARCH DIMENSIONS IN DIFFERENT TYPES OF CROWDING IN MALAY POPULATION

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by

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TABLE OF CONTENT

Appendix A : Certifcation of particpation ,postgratuation research day 2017

APPENDIX B : Certifcation of particpation ,occupational safty and health course 2016

APPENDIX C : Certifcation of particpation systemic review and meta- analysis 2016.

APPENDIX D : Certifcation of particpation of how to speerd up thesis writing workshop.

APPENDIX E : Letter of request to use dental case from the archive of orthodontic clinic from Prof Dr ahmed Suhari Halim Director of Hospital USM.

APPENDIX F : Letter of request to use dental case from the archive of orthodontic clinic from Prof Dr Adam Husein.Dean of school dental Science

APP APPENDIX I : Certificate of complete cource Basic Life Support ENDIX G : Certificate of attendance Endnote workshop 2018 (BLS).

APPENDIX G : Certificate of attendance Endnote workshop

LIST OF TABLES

LIST OF FORMULA

Bolton Index:

Maxillary tooth material excess = Sum of maxillary 12 – (Sum of mandibular 12 ÷ 91.3) × 100…… (1)

Mandibular tooth material excess = Sum of mandibular 12 – (Sum of maxillary 12 ÷ 100) × 91.3… (2)

Overall Ratio = $\frac{\text{Sum of MD width of mandibular 1}^{st}\text{ molar of one side to 1}^{st}\text{ molar on opposite side}}{\text{Sum of MD width of maxillary 1}^{st}\text{ molar of one side to 1st molar on opposite side}}$ x100 …..(3)

Anterior ratio= $\frac{\text{Sum of MD width of mandibular anterior teeth}}{\text{Sum of MD width of maxillary anterior teeth}}$ x100 …………………… (4)

Pont's Index:

CPV = (SI x 100) / 80…………………………..………………………………… (5)

CMV = (SI x 100) / 64…………….……………………………………………… (6)

(SI=Sum of incisors).

Linder harth index arch:

Calculated premolar value, (SL × 100) / 85………….……………………………. (7)

Calculated molar value, (SL × 100) / 64 ÷ (SL × 100) / 65 …….……………..…… (8)

(SL: Sum of mesiodistal width of incisors).

Korkhaus formula = (SI/160) x100 (SI=Sum of incisors)……………………….…. (9)

Lundstrom segment analysis

(Space available – space required = negative value)……………………………... (10)

Howes Segment analysis

(PMBAW (first premolar buccal width) x 100) /TTM (total tooth material)……..

(11)

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACS	Auto Calibration Software
ANOVA	Analysis of Variance
BAR	Bolton Anterior Ratio
BL	Buccolingual
BOR	Bolton Overall Ratio
BLUCI	Buccolingual Maxillary Upper Central Incisor
BLLI	Buccolingual Maxillary Upper Lateral Central Incisor
BLUC	Buccolingual Maxillary Upper Canine
BLU1P	Buccolingual Maxillary Upper First Premolar
BLU2P	Buccolingual Maxillary Upper Second Premolar
BLUM	Buccolingual Maxillary Upper First Molar
CBCT	Cone Beam Computed Tomography
CPV	Calculated Premolar Value
CMV	Calculated Molar Value
HUSM	Hospital University of Sines Malaysian
ICC	Inter Class Correlation Coefficient
LAD	Lower Mandible Arch Depth
LCD	Lightly Soured Digital Camera
LII	Little's Irregularity Index
LRAP	Lower Mandible Left Arch Perimeter
LAICW	Lower Mandible Inter Canine Widths
LAI1PW	Lower Mandible Inter 1st Premolar Widths
LAI2PW	Lower Mandible Inter 2nd Premolar Widths

LAIMW	Lower Mandible Inter 1st Molar Width
LAP1	Lower Mandible Arch Perimeter1
LAP2	Lower Mandible Arch Perimeter2
LAP3	Lower Mandible Arch Perimeter3
LAP4	Lower Mandible Arch Perimeter4
LICW	Lower Mandible Inter Canine Widths
LI1PW	Lower Mandible Inter 1st Premolar Widths
LI2PW	Lower Mandible Inter 2nd Premolar Widths
LIMW	Lower Mandible 1st molar Width
LLAP	LAP1+LAP2 Right Mandible Arch Perimeter
MD	Mesiodistal
MDLCI	Mesiodistal Width of Mandible Lower Central Incisor
MDLLI	Mesiodistal Width of Mandible Lower lateral Central Incisor
MDLC	Mesiodistal Width of Mandible Lower Canine
MDL1P	Mesiodistal Width of Mandible Lower First Premolar
MDL2P	Mesiodistal Width of Mandible Lower Second Premolar
MDLM	Mesiodistal Width of Mandible Lower First Molar
MDUCI	Mesiodistal Width of Maxillary Upper Central Incisor
MDULI	Mesiodistal Width of Maxillary Upper Lateral Incisor
MDUC	Mesiodistal Width of Maxillary Upper Canine
MDU1P	Mesiodistal Width of Maxillary Upper First Premolar
MDU2P	Mesiodistal Width of Maxillary Upper Second Premolar
MDUM	Mesiodistal Width of Maxillary Upper First Molar
mm	Millimetre
MMV	Measurement Molar Value

n	Sample Size
MPV	Measurement Premolar Value
PBM	Photobiomodulation Lasers
PMBAW	First Premolar Buccal Width
RLAP	Right Lower Mandibular Arch Perimeter
RUAP	Right Upper Maxillary Arch perimeter
SD	Standard Deviation
SE	Standard Error
SI	Sum of Mesiodistal Widths of the Incisors
SM	Hirox Digital Stereomicroscope
SPSS	Statistics Package of the Social Sciences.
TLAP	Total Lower Arch Perimeter
TUAP	Total Upper Arch Perimeter
TSD	Tooth Size Discrepancy
TTM	Total Tooth Material
UAICW	Upper Maxilla Inter Canine Widths
UAI1PW	Upper Maxilla Inter 1st Premolar Widths
UAI2PW	Upper Maxilla Inter 2nd Premolar Widths
UIMW	Upper maxilla Inter 1st Molar Width
UP1+LP2	Upper maxilla Right Arch Perimeter
UP3+LP4	Upper maxilla Left Arch Perimeter
UICW	Upper maxilla Inter Canine Widths
UI1PW	Upper maxilla Inter 1st Premolar Widths
UI2PW	Upper Maxilla Inter 2nd Premolar Widths
UIMW	Upper Maxilla 1st Molar Width

UAD	Upper Maxilla Arch Depth
UAP1	Upper Maxilla Arch Perimeter 1
UAP2	Upper Maxilla Arch Perimeter 2
UAP3	Upper Maxilla Arch Perimeter 3
UAP4	Upper Maxilla Arch Perimeter4
USM	Universiti Sains Malaysia
2D	Two Dimension
3D	Three Dimension

JENIS GIGI DAN DIMENSI LENGKUNG GIGI DALAM JENIS KESESAKAN YANG BERBEZA DA LAM POPULASI MALAY

ABSTRAK

Tujuan penyelidikan ini adalah untuk membandingkan saiz gigi dan dimensi lengkung gigi antara pelbagai jenis kesesakan iaitu ringan, sederhana, dan teruk, dalam populasi Malaysia. Parameter saiz gigi yang disiasat adalah lebar mesiodistal, lebar buccolingual dan nisbah saiz gigi (Indeks Bolton) dan parameter dimensi lengkung adalah perimeter lengkung, lebar lengkung, kedalaman lengkung dan nisbah lengkung (Indeks Pont).Kajian ini dijalankan di Pusat Pengajian Sains Pergigian, Universiti Sains Malaysia (USM), dengan sampel yang melibatkan 192 model pergigian subjek lelaki dan wanita dengan umur antara 18 hingga 35 tahun dan tiada riwayat rawatan pergigian ortodontik sebelumnya yang dikumpulkan dari arkib klinik pergigian ortodontik. Pengimbasan telah dilakukan menggunakan stereomikroskop digital Hirox (SM) untuk pembuatan model digital untuk menyiasat saiz gigi dan dimensi lengkung untuk kedua-dua lengkung rahang atas dan bawah untuk setiap subjek. ANOVA digunakan untuk membandingkan saiz gigi dan dimensi lengkung serta Indeks Bolton dan Pont dalam pelbagai jenis kesesakan gigi.Terdapat hanya beberapa ukuran gigi dan dimensi lengkung yang menunjukkan perbezaan yang signifikan dalam pelbagai jenis kesesakan. Kedua-dua indeks Bolton dan Pont juga tidak menunjukkan perbezaan yang ketara.Sebagai kesimpulan, saiz gigi, dimensi lengkung, Indeks Bolton dan Indeks Pont tidak berbeza dalam pelbagai jenis kesesakan dalam penduduk Malaysia. Etiologi kesesakan tidak berkaitan dengan saiz gigi dan dimensi lengkung secara individu tetapi adalah gabungan faktor-faktor ini.

TOOTH SIZE AND DENTAL ARCH DIMENSIONS IN DIFFERENT TYPES OF CROWDING IN MALAY POPULATION

ABSTRACT

The aim of this research is compare tooth size and dental arch dimensions between different types of crowding i.e. mild, moderate, and severe crowding, in the Malaysian population. Tooth size parameters under investigation were mesiodistal widths, buccolingual widths and tooth size ratio (Bolton Indexes) and arch dimension parameters were arch perimeters, arch widths, arch depth and arch ratio (Pont's Indexes). This study was carried out at the School of Dental Sciences, Universiti Sains Malaysia (USM), on a sample involving 192 dental models of male and female subjects with the age range of 18 to 35 years old and no history of previous orthodontic treatment collected from the archive of orthodontic clinic. Scanning were done with Hirox digital stereomicroscope (SM) for the fabrication of the digital models to investigate the tooth size and arch dimensions of both maxillary and mandibular arches for each subject. ANOVA was used to compare tooth size and arch dimensions as well as the Bolton and Pont's Indexes in different types of crowding.There were only a few measurements of the tooth size and arch dimensions which showed significant difference in different types of crowding. Both Bolton's and Pont's indexes also did not show significant difference. In conclusions, tooth size, arch dimensions, Bolton Indexes and Pont's Indexes were not different in different types of crowding in Malaysian population. The aetiology of crowding were not related to individual tooth sizes and arch dimensions but rather a combination of these factors.

CHAPTER 1
INTRODUCTION

1.1 Background of the study

Dental crowding can be defined as the disparity in the relationship between the tooth size and jaw size, which may result in imbrications, dislocated eruption, delayed eruption and rotation of teeth (Arif *et al.*, 2014). Dental crowding occurs when the space required for the correct alignment of teeth exceeds the space available in the dental arch (van der Linden, 1974). The cause of crowding was proposed as hereditary by Brash in1965, while other investigators suggested that crowding was caused by environmental factors, such as soft diet and loss of arch length due to dental caries (Radnzic, 1988).

Information of dental crowding was investigated in many populations. In Peru, crowding of the upper arch was found as follows; moderate crowding in 18% (36/200), mild crowding in 43% (86/200) and no crowding in 39% (78/200) of the population. Crowding on the lower arch was found to be 17% (34/200), 41% (82/200), and 42% (84/ 200) with moderate, mild, and no crowding respectively (Bernabé and Flores-Mir, 2006).

High prevalence (81.7%) of incisor crowding was found in young Saudi population (Togoo *et al.* (2012) whereas lower prevalence (12.9%) was found in Nigerian population (Isiekwe, 1983). Investigators also found that mandibular incisor crowding to be of higher prevalence than the maxillary (Al-Balkhi and Al-Zahrani, 1994; Al-Emran *et al.*, 1990; Little, 1975).

Crowding should be corrected because not only it affects aesthetic but also reduces the proper functions of the dentitions such as mastication and speech. It can also prevent adequate cleaning of teeth surfaces and in the long term may cause dental caries, increase the chances of periodontal disease and further compromise the proper functions of the dentitions (Alam *et al.*, 2014b; Sadeghian *et al.*, 2015).

Factors to consider during treatment planning for crowding include the degree of crowding calculated in millimetres per arch, the severity of malocclusions, the position, presence, and prognosis of the remaining permanent teeth, patient's age and the likelihood of the crowding increasing or reducing with patient's growth (Mitchell, 2013). One of the methods to measure the severity of crowding is by measuring the mesiodistal width of misaligned teeth in relation to the available space in the arch. It was proposed that the severity of crowding can be classified as mild crowding (<4mm per arch), moderate crowding (4 −8mm per arch) and severe crowding (>8mm per arch) (Mitchell, 2013).

Another method of crowding is Little Irregularity Index 1975 which measured the presence of crowding by taking the sum of linear distances of five anatomic contacts from the mesial aspect of one mandibular canine to the mesial aspect of the contralateral canine which is then further classified into ideal (0 – 0.9 mm), minimal (1− 3.9 mm), moderate (4− 6.9 mm), severe (7 – 9.9 mm), and extremely severe crowding i.e. more than 10 mm (Little, 1975).

Tooth size can be measured in many different dimensions. However, this study focused on the mesiodistal and buccolingual dimensions. The mesiodistal crown dimension of a tooth is determined as the distance between its mesial and distal surfaces of the tooth which is the more commonly used measure. Buccolingual crown diameters were recorded as the highest distance between buccal and lingual or labial and lingual surfaces perpendicular to the occlusal plane (Shahid *et al.*, 2015).

Various study of tooth size from mesiodistal tooth dimension has been published in the literature, they show the prevalence of tooth size in the different population done earlier with different studies to determine mesiodistal tooth size width of upper and lower arch in a normal occlusion and malocclusion groups such as Northern Ireland, Jordan and Panghaladish (Alam *et al.*, 2013; Crosby and Alexander, 1989)

Tooth size measurements can then be utilised to study the discrepancy between the maxillary and mandibular arches. One of the space analyses of this discrepancy was introduced as the Bolton's Indexes and has since become a well-defined means of assessing dental crowding and space analyses (Bolton, 1958; Bolton, 1962).

(Bolton, 1958) suggested an anterior ratio of 77.2% and the overall ratio of 91.3%. These were known as Bolton's Indexes where the anterior ratio refers to the greatest mesiodistal widths of each tooth from canine to canine and the overall ratio defined as the greatest mesiodistal widths of each tooth from the first molar on one side to the molar on the opposite side (six to six) (Bolton, 1958). These indexes were used worldwide for comparison of maxillary and mandible arch discrepancy. In Malaysian population, the anterior ratio was reported as 77.7% (2.89%) and the overall ratio as 91.6% (2.20%) (Othman *et al.*, 2008a).

Additionally, arch size dimensions which include the perimeter, the width, and the depth measurements, are also the highlight of this study. Tooth size and arch length discrepancies may contribute to crowding or spacing in dental arches. Large teeth relative to the size of the jaws are associated with crowded dental arches and small teeth relative to the size of the jaws are associated with spaced dental arch (Al-sharafa, 2012).

Pont's index was used to predict the width of the maxillary arch at the premolar and molar region by measuring the mesiodistal widths of the four permanent incisors. Measured Premolar Value (MPV) and Measured Molar Value (MMV) can be calculated using Sum of Incisal Widths (S.I) by applying specific formula (Purmal *et al.*, 2013; Singh and Goyal, 2006). Pont suggested that the study helps to determine if the dental arch is narrow or normal, and if expansion is possible or not.

Various methods of measuring the dimensions of the human dentition were defined in the literatures. Each of these methods was associated with advantages and disadvantages. Direct measurement methods using callipers were used traditionally prior to the development of the more advanced methods. Some researchers have utilizes callipers and brass wire for tooth measurements on the skulls (Begg, 1954; Mack, 2016). While others directly performed measurements in the mouth (Correia *et al.*, 2014). These methods were succeeded by measurements on dental casts after which impressions of the dentition were obtained (Vego, 1962).

The type of callipers used also varies, for example, sliding callipers with a vernier scale and engineer dividers used in conjunction with a millimetre ruler which was found to be more accurate (Grünheid *et al.,* 2014; Mack, 2016). Others have employed Boley gauge, also known as vernier calliper and needlepoint dividers to measure mesiodistal width of the tooth to calculate the Bolton’s ratio on dental models (Shellhart *et al.*, 1995).

Many variations of measurements utilising dental model such as OrthoCAD which employs digital callipers have been investigated over the years (Zilberman *et al.*, 2003). These showed as being highly valid and reproducible for both tooth size and arch width measurements. Other researchers used photocopy images of dental models to measure mesiodistal tooth width. However, it was reported that photocopied images of the dental models did not produce accurate and reliable measurements compared to manual measurements done directly on the models (Nalcaci *et al.,* 2013).

One of the disadvantages of using dental models is that they need ample storage area. The development of digital dental model has overcome the problem of storage. Some of the methods that can capture images of plaster models and change them into three-dimensional (3D) digital models are traveling microscope (Bhatia and Harrison, 1987), holographic system (Mrtensson and Rydén, 1992), stereo photogrammetry and digital 3D scanner (Correia *et al.*, 2014; Freeman *et al.*, 1996).

Digital stereomicroscope is one of the more advanced methods where it can be used to scan dental models of the maxillary and mandibular arches prior to fabrication of digital models. With the aid of computer software and the advanced easy to use auto control technology function, images can be captured, viewed, and analysed even though measurements are still two-dimensional (2D). Advantages of digital models include no risk of damage to the plaster model, easy storage, quick repossession, and ease as well as time saving computer analysis.

Digital stereomicroscope (HIROX stereomicroscope) is available at the School of Dental Sciences and was used for the fabrication of digital models in this study. This machine has digital camera, lens axis, magnification lens of 50 to 400x, adapter for 50% magnification reduction, fixed base for dental model placement, ruler with bubble spirit and lightly sourced LCD monitor. Tooth size, arch size, dental crowding as well as other measurements can be measured on these digital images using its Auto Calibration Software (ACS). This machine has been proven to be valid and reliable for dental measurements with the accuracy of $0.1\text{x}10^{-6}$mm (Shahid *et al.*, 2014).

1.2 Problem Statement

The dental crowding, tooth size, and dental arch dimensions have been studied around the globe on different ethnic groups of various populations. Based on the literature search there is no study made on tooth size and dental arch dimensions in different types of crowding in Malay adult population. Previous studies in Malays reported the tooth size and arch dimensions without relation or indication to the different types of crowding (HUSSEIN, 2008; Othman *et al.*, 2008b).

1.3 Justification of the study

Information on the relationship of dental crowding with tooth size and dental arch dimension is not only of research interest but also of clinical importance. This information may assist in diagnosis and treatment planning of patients undergoing orthodontic treatment procedures, maxillofacial, orthognathic, and reconstructive and plastic surgeries to achieve desirable and aesthetically accepted results. Therefore, these information is important for the purpose of clinical diagnostic and planning of treatment. Additionally, these data may also be helpful in forensic dentistry (Ling and Wong, 2007).

1.4 Research Questions

1. Is there any difference in mesiodistal and buccolingual tooth widths between different types of crowding?
2. Is there any difference in tooth size ratio (Bolton's Index) between different types of crowding?
3. Is there any difference in dental arch perimeter, width, and depth between different types of crowding?
4. Is there any difference in the dental arch ratio (Pont's Index) between different types of crowding?

1.5 Research hypotheses

1. There are differences in mesiodistal and buccolingual tooth widths between different types of crowding.

2. There are differences in tooth size ratio (Bolton's Index) between different types of crowding.
3. There are differences in dental arch perimeter, width, and depth between different types of crowding.
4. There are differences in dental arch ratio (Pont's index) between different types of crowding.

1.6 Objectives of the study

1.6.1 General objective

To determine the type of dental arch crowding and to compare tooth size, tooth size ratio (Bolton's index), dental arch dimensions and dental arch ratio (Pont's Index) between different types of crowding in Malay adult population.

1.6.2 Specific objectives

The specific objectives of this study are:

1. To determine and compare the mesiodistal and buccolingual tooth widths between different types of crowding.
2. To determine and compare tooth size ratio (Bolton's Index) between different types of crowding.
3. To determine and compare dental arch perimeter, width, and depth, between different types of crowding.
4. To determine and compare dental arch ratio (Pont's Index) between different types of crowding.

CHAPTER 2
LITERATURE REVIEW

2.1 Crowding

Dental crowding is the most common dental malocclusion, with the major leading factor to this occurrence is due to the lack of coordination between the size of the tooth and the arch dimension. Consequently, positions of teeth with relations to each other in a dental arch are highly influenced. In other words, when there is space deficiency for alignment of teeth in the dental arch, the teeth would rotate, or dislocated or be delayed to erupt hence resulted in crowding (Sadeghian *et al.*, 2015).

2.1.1 Prevalence of crowding

In Saudi (Jeddah) population, the prevalence of crowding was considerably highest in the mandible than the maxilla and in males than females with the left and right mandibular lateral incisors being the most common teeth involved in crowding. Specifically, crowding occurred 5.4% in maxilla, 13.4% in mandible, and 4.0% in both maxilla and mandible (Shigenobu *et al.*, 2007).

Mockers *et al.* (2004) found that crowding occurred in adult's prehistoric population of Roaix, France which is localised to the lower central and lateral incisors and canine. When compared to crowding in the historic population of the 19^{th} century, it has been pointed out that crowding is increasing in the modern population. Additionally, Little (1975) reported that the mandibular incisor irregularity is often the precursor of maxillary crowding.

In another Saudi study (Al-Hummayani (2004), which determined the prevalence of incisor crowding in maxillary and mandibular arches of adults females, the researcher found that crowding decreases with age in the upper and lower arches with mandibular incisor crowding to be more prevalent than the maxillary.

Bernabé and Flores-Mir (2006) studied the causes of different types of dental arch crowding and classified them as moderate, mild, and non-crowding. They found that the mesiodistal (MD) tooth size and crown proportion contributed to crowding but not the buccolingual (BL) tooth sizes.

Moreover, Arif *et al.* (2014) found that arch length contributed to dental crowding in Iraqi population. Golwalkar and Msitry (2008) showed that the crowded group to have smaller dental arch dimensions than the non-crowded group.

2.1.2 Aetiology of Crowding

Crowding is associated with several conditions such as:

1- Disproportion between arch size and tooth size, or arch length. Puri *et al.* (2007) stated that significant determinants of crowding or spacing in dental arches were due to discrepancy between the size of teeth and the bony bases. Nevertheless, crowding is more common in persons whose teeth with large MD dimensions than in those with smaller teeth (Richardson, 1994).

2- Late mandibular growth, which resulted in increased pressure in the front of the mouth which in turn may cause reduction in arch length and depth, hence resulted in crowding. The researchers also added that lower jaw grows forward more than the upper jaw and the growth of lower basal bone to be more than alveolar bone. It is possible that the restraining influence of the upper arch may have controlled the mandibular incisors from moving forward, thus the probability of them to be retroclined with high possibility of crowding (Richardson and Malhotra, 1975). In spite of that, there is no direct relationship between the increase in crowding and the change in incisor inclination (Richardson, 1994). Young adults aged between 18 and 21 years old were proposed to have remarkable stability of the lower arch regardless of third molar status and continuing growth; indicating that the increase in lower arch crowding (which may occur in later life), is due to different aetiological factors (which occur in the immediate post-adolescent years) (Richardson, 1994). On the contrary, tertiary crowding or late crowding has been reported to occur during the adolescent and post-adolescent period after the eruption of the third molars (Proffit *et al.*, 2006).

3- Delayed eruption of permanent teeth due to congenital absence of permanent tooth.
4- Premature loss of deciduous tooth leading to formation of bone over the erupting permanent teeth.
5- Forward mandibular rotation which significantly correlated with increase in lower incisor crowding (Suri *et al.* (2004).

6- Presence of supernumerary teeth where the erupted supplemental teeth most often cause crowding (Manuja *et al.*, 2011). In a study, supplemental lateral incisor may cause crowding in the upper anterior region (Barry *et al.*, 1999).

7- Congenital characteristics of malocclusion, which includes genetic trait inherited from the parents, may contribute to the development of malocclusion.

Besides, since the offspring is a product of parents with similar heredities, traits may be inherited from both parents resulting with abnormalities. Not only that, these genetic traits can be further influenced by prenatal or postnatal environmental factors (Phulari, 2011). Furthermore, studies have shown that the incidence of jaw size discrepancies and occlusal disharmonies are greater in populations where there has been a mixture of racial and ethnic strain (Cobourne and DiBiase, 2015; Phulari, 2011).

8- Environmental influences and habits such as thumb sucking and mouth breathing. Thumb sucking also alters the tongue-lip-cheek equilibrium, resulted in the mandible which may be rotated downward and backward, which lead to teeth crowding in posterior segment (Proffit *et* al., 2006).

2.1.3 Crowding and measurements

According to (Mitchell, 2013) the amount of crowding can be calculated by measuring the MD width of any misaligned teeth in relation to the available space in the arch. Then, the amount of crowding can be classified into mild crowding (<4mm per arch), moderate crowding (4-8mm per arch), and severe crowding (>8mm per arch). This procedure is repeated for all misaligned teeth in the arch to give the total amount of crowding. If two adjacent teeth are displaced, then assessment of crowding can be undertaken by measuring the MD width of each tooth and determine the combined space available.

On the other hand, Bernabé and Flores-Mir (2006) proposed a different method of defining crowding which is the difference in millimetres between the arch perimeters and the sum of MD tooth size. In detail, crowding are classified as moderate (-5.1mm or more of discrepancy), mild (-0.1 and -5mm of discrepancy) and no crowding (zero or a positive discrepancy). Finally, Little's Irregularity Index establishes a classification of crowding by distinguishing the ideal alignment, which are: ideal (0 – 0.9mm), minimal (1 − 3.9mm), moderate (4 − 6.9 mm), severe (7 – 9.9mm) and extremely severe of more than 10mm (Little, 1975).

In a North American population, the MD dimension of the maxillary teeth were determined as 8.49 mm for central incisor, 6.59 mm for lateral incisor, 7.72 mm for canine, 6.90 mm for the first premolar and 6.67 mm for the second premolar; and the MD dimension of the mandibular teeth were determined as 5.16 mm for central incisor, 5.75mm for lateral incisor, 6.70 mm for canine, 6.92 mm for first premolar and 7.08 mm for second premolar (Doris *et al.*, 1981).

2.2 Tooth size

Correct tooth size relationship between maxillary and mandibular teeth is an important factor to achieve a proper occlusal interdigitation. For a good occlusion, the teeth must be proportional in size. Tooth size discrepancy, defined as disproportion in the size of the tooth between the maxillary and mandibular arches where large teeth relative to the jaws are associated with crowded dental arches and small teeth with spaced dental arches associated with spacing (Ismail and Abuaffan, 2015).

2.2.1 Measurements of tooth size

Most traditional morphometric studies utilised direct techniques to measure tooth size, such as the MD and BL widths, while others used indices to represent size (Kieser *et al.*, 1985). Tooth size differs according to sex, in that males have slightly larger teeth than females. When the MD and BL tooth diameters are measured, major sex difference in tooth shape will appear, with males are more inclined towards nearly square dimensions than females. They concluded that tooth size, along with other factors such as arch width and arch perimeter showed a great range in variability between samples of more and less crowded arches. On the other hand, it was suggested that one of the important factors determining whether or not a dental arch will be crowded is the absolute size of teeth in that arch (Doris *et al.*, 1981).

In a Malaysian study (HUSSEIN, 2008) compared the MD tooth sizes and dental arch dimensions in Malay boys and girls with Class I, Class II and Class III malocclusions. Dental casts of 150 subjects (78 boys, 72 girls), between 12 and 16 years old, were measured using electronic digital calliper. The researcher found that the boys had significantly wider teeth than girls, except for the left lower second premolar. The boys also had larger upper and lower intermolar widths and lower intercanine width compared to the girls. Additionally, there were no remarkable differences between the boys and girls in the arch perimeters or arch lengths in all three malocclusions.

2.3 Arch size

Moorrees (1957) stated that crowding was defined as the lack of space for a tooth in the dental arch to be well aligned. Alignment of teeth in the dental arch is partially dependent on the ratio between the size of the teeth and the size of the dental arch. The method used in this study leads to a clearer evaluation of the roles of tooth size and arch size as the foundation of analysis of spacing and crowding.

Most of the permanent teeth erupted during the mixed dentition stage, in which the first group of teeth is the first molars and incisors, and they normally erupt from the age of 6−8 years old. Add the second group is canaine and premolares . The third group, the second permanent molars would erupt at the end of the mixed dentition stage, which is at 12 years old and during this stage, crowding can develop due to insufficient space available for the eruption of the rest of permanent teeth, especially permanent canines and premolars in addition to the dimensional changes that occur in arches. During the permanent dentition stage, although an established occlusion has been achieved, many changes will still occur in dental arches (Moorrees, 1957). Crowding of mandibular incisors are commonly developed around the age of 14 years old or later, either due to eruption of the third molars or due to a decline in arch breadth, especially in mandibular incisor region.

2.4 Space analysis

In dental treatment particularly orthodontic disciplines, space analysis is important in order to fulfil the treatment aims and to decide if the planned treatment are feasible. Assessment is made between the amount of space available for the alignment of the teeth and the amount of space required to align them properly (Mitchell, 2013).

2.4.1 Bolton analysis (Tooth size discrepancy between arches)

The Bolton tooth size analysis is commonly used as a diagnostic tool in orthodontics. Tomassetti *et al.* (2001) reported that based on a sample of orthodontists, 91% of them confessed of using only Bolton analysis when measuring tooth size. Bolton used 55 dental models of Caucasians and measured the MD width of 12 maxillary teeth from the first right permanent molar to the first left permanent molar. Then, he compared them with the sum derived by the same procedure carried out on the 12 mandibular teeth. He showed this measurement as the ratio between the mandibular arch length and the maxillary arch length which is also known as the overall ratio. The formula for the overall ratio is as follows:

$$\text{Overall Ratio} = \frac{\text{Sum of MD width of mandibular 1}^{st}\text{ molar of one side to 1}^{st}\text{ molar on opposite side}}{\text{Sum of MD width of maxillary 1}^{st}\text{ molar of one side to 1}^{st}\text{ molar on opposite side}} \times 100 \ldots\ldots\ldots\ldots (1)$$

The normal values of the overall Bolton ratios are as follows (Bolton, 1958):

Mean = 91.3%
Within 1SD = 89.39-91.29 & 91.31-93.21%
Between 1SD and 2SD = 87.48-89.38 & 93.22-95.12
Within 2SD = <87.47 & > 95.13%

Bolton (1958) used the same method to set up the ratio between the maxillary and mandibular anterior teeth known as the anterior ratio. This ratio is a percentage relationship between the width of mandibular anterior teeth and the width of maxillary anterior teeth. The formula for the anterior ratio is as follows:

$$\text{Anterior ratio} = \frac{\text{Sum of MD width of mandibular anterior teeth}}{\text{Sum of MD width of maxillary anterior teeth}} \times 100 \ldots\ldots\ldots(2)$$

The normal values of the Bolton anterior ratios are as follows:

Mean = 77.2 %

Within 1SD = 75.55-77.19 & 77.21-78.85%

Between 1SD and 2SD =73.90-75.54 & 78.86-80.50%

Within 2 *SD* = <73.89 & >80.15%

Both the overall and anterior ratios are also known as the Bolton Indices. Using overall Bolton ratio as a reference, it was inferenced that if the value is greater than 91.3%, there is an excess on the overall mandibular teeth sizes. Values that are less than 91.3%

indicated an overall excess of maxillary teeth sizes (Bernabé *et al.*, 2005; Othman *et al.*, 2008b). It is then possible to quantify the total tooth material excess by using the following formula:

Maxillary tooth material excess = Sum of maxillary 12 – (Sum of mandibular 12 ÷ 91.3) × 100…(2)

Mandibular tooth material excess = Sum of mandibular 12 – (Sum of maxillary 12 ÷ 100) × 91..(3)

Bolton indices were widely used for studies conducted on various populations. For instance, Batool *et al.* (2008) evaluated the tooth size discrepancy in different malocclusion groups in the Pakistani population, which included 200 dental casts. The MD widths of the teeth were measured by using a manual calliper. The readings were then used to compute the anterior and overall Bolton ratios. Significantly higher mean anterior tooth ratios were found in Class II ($p<0.01$) patients. All other ratios were within a close range of Bolton’s norms.

In Malaysian population, Othman *et al.* (2008a) investigated the tooth size discrepancy among dental students from Universiti Malaya consisting of 40 pre-treatment study models from 12 male and 28 female subjects. The MD diameter of tooth sizes were measured manually using a Minutolo digital calliper accurate to 0.01 mm and the Bolton ratios were calculated. This study discovered that 47.5% of the samples had anterior ratio, and about 10% had overall ratio greater than 2 standard deviations from Bolton's mean.

Another prominent study with regards to the Malaysian population was carried out by Rehmani and Fida (2012). Interestingly, they specifically picked out the three major ethnics in Malaysia, which are the Malays, Chinese, and Indians in order to compare the tooth size discrepancy by using the Bolton Indices. The sample consisted of pre-orthodontic dental casts of 30 males and 30 females from each ethnicity. Digital callipers were used to measure the teeth and the Bolton Indices were calculated. It was revealed that there is significant difference of the Bolton Indices of the Malays compared to Bolton's norms but no significant difference was established for the Chinese and Indians compared to the Bolton values.

2.4.2 Pont's analysis (Arch width analysis)

In 1909, Pont presented a system whereby the measurement of four maxillary incisors can be used to establish the width of the arch in the premolar and molar regions. The greatest width of the incisors was measured with callipers, recorded in a line, and their sums were recorded in millimetres. This was termed as sum of incisors (SI). The distance between the upper right first premolar and the upper left first premolar was recorded as Measured Premolar Value (MPV) (Joondeph *et al.*, 1970). Additionally, the distance between the upper right first molar and the upper left first molar was recorded and was termed as Measured Molar Value (MMV). This analysis was also used for the mandible with the distobuccally cusps of the first permanent molars were utilized for MMV.

Pont postulated that the SI can be used to establish the width of the arch in the premolar and molar regions. These are the Calculated Premolar Value (CPV), the expected arch width in the premolar region and Calculated Molar Value (CMV), the expected arch width in the molar region. Calculations of CPV and CMV are as follows (Joondeph *et al.*, 1970; Singh and Goyal, 2006):

CPV= (SI x 100) / 80……………………………………………………… (3)

CMV = (SI x 100) / 64…………………………………..………………… (4)

(SI=Sum of incisors)

The differences between the measured and calculated values determine the need for arch expansion. If the measured values are less, expansion is required. Pont's index gives an approximate indication on the degree of narrowness of the dental arch, in a case of malocclusion and the amount of lateral expansion required for the arch to be in the sufficient size to accommodate the teeth in a perfect alignment (Joondeph *et al.*, 1970; Singh and Goyal, 2006). To further explore Pont's Index, numerous experiments were carried out in different countries, on various ethnicities. Surprisingly, some of the researchers were in consummate disagreement with Pont's Index as their data came out differently comparison was made.

Celebi *et al.* (2012) evaluated the applicability of Pont's Index to a Turkish population which comprised of 64 male and 78 female subjects, aged from 14 to 15 years old. The measured arch width values calculated according to Pont's Index were low in all cases, thus it was decided that Pont's Index should not be used to determine ideal arch width values in Turkish individuals. Even though males had significantly bigger values for incisor widths, there was no significant difference between incisor tooth size in males and females. Also, nearly all of the arch width measurements in males did not differ significantly from females

Purmal *et al.* (2013) evaluated dental casts of 87 Malays with mean cephalic index of 86.4%. Dental arch measurements, as predicted by the indices, were significantly greater that those measured. Correlation coefficient between bizygomatic width and interpremolar distance was also not significant and thus they disagree with Pont’s in their study.

Al-Sarraf *et al.* (2006b) evaluated Pont’s index of the Iraqi population, on the dental casts for Class I malocclusion of 22 male and 21 female subjects with their sample aged from 14-16 years and measurements were done using sliding calliper gauge accurate up to 0.1mm. Their results showed that the interpremolar and intermolar arch widths estimated by Pont's formula were generally less than the true interpremolar and intermolar arch widths measured.

Thu *et al.* (2005) evaluated dental casts of 119 Koreans. Only 45% predicted cases were within 1mm range of observed interpremolar width. Pont’s formula tended to overestimate the interpremolar width (premolar index = 81.96) but matched the intermolar width (molar index = 62.55).

Nonetheless, a study conducted by Agnihotri and Gulati (2008) on 100 Northern Indians showed an agreement with Pont’s values. They described a significant correlation between the widths of four maxillary incisors and arch width of Northern Indian population, showing parallelism with Pont's values which were 81 and 65 for premolar and molar indices respectively.

2.4.3 Linder Harth Index (Arch width analysis)

Linder Harth proposed an analysis similar to Pont’s index. However, he made a modification in the formula to determine the calculated premolar and molar values. The following formula was used to generate calculated premolar and molar values (Doris *et al.*, 1981; Peck and Peck, 1972; Phulari, 2011).

Calculated premolar value = (SI × 100) / 85……………………………..…….. (5)

Calculated molar value = (SI × 100) / 64 ÷ (SI × 100) / 65 …………………..… (6)

(SI: Sum of MD width of incisors).

2.4.4 Korkhaus analysis (Arch length analysis)

This analysis reveals the anterior posterior malpositioning of maxillary incisor by calculating its anterior arch length. The Korkhaus analysis for calculated maxillary anterior arch length also utilised the sum of MD widths of maxillary incisor teeth and is represented by the following formula (Phulari, 2011):

Korkhaus formula = (SI/160) x100)………………………………………..…….. (7)

(SI=Sum of MD width of incisors)

The measured anterior arch length was quantified via measuring the distance between the line extending from the most anterior labial surface of maxillary incisors to the line connecting the distal surface of maxillary second premolar (inter second premolar line).

2.4.5 Carey's analysis (Arch perimeter and tooth size discrepancy)

Carey's analysis calculated the discrepancy between arch perimeter and tooth material. The total tooth material was determined as the sum of the mesiodistal widths of all teeth from the first permanent molar on one side to the first permanent molar on another side. (Phulari, 2011).

Arch perimeter was determined using a soft brass wire, measured in a manner whereby the wire was placed touching the distal aspect of the first permanent molar, then passed along the buccal cusp of premolars, incisal edges of the anterior and finally, the same way up to the distal of the first molar of the opposite side (Singh and Goyal, 2006). The brass wire was passed along the cingulum of anterior teeth, if they are proclined and along the labial surface of the anterior teeth, if they are not proclined. The difference between the arch perimeter and the measured tooth material gives the discrepancy. If arch discrepancy is 0 – 2.5 mm, proximal stripping can be carried out to reduce the minimal tooth material excess; if it is 2.5 – 5 mm, extraction of second premolar is indicated; and if it is greater than 5 mm, extraction of first premolar is usually required (Singh and Goyal, 2006).

2.4.6 Little's Irregularity Index (LII) (crowding measurement)

Little's Irregularity Index (LII) is an index used in the field of orthodontics to measure the crowding of mandibular anterior region. This index takes into account the anatomical contact points of anterior incisors in mandibular crowding, teeth are often rotated or displaced, either palatally or buccally (Little, 1975).

To explain this index, it is sufficed to say that the Little's Irregularity Index measures the horizontal linear displacement of anatomic contact points of each mandibular incisor from the adjacent anatomic point, and it sums the five displacements together, which represented the relative severity of anterior irregularity (Little, 1975). Once summed, perfect alignment from canine to canine will yield a score of zero on the Irregularity Index. As the severity of crowding increases, the score will also increase.

Little used dial callipers (with accuracy to tenths of millimetre) in his study to measure the distances on a plaster model taken of mandibular arches. It is important to note that the vertical discrepancy between the contact points does not play a role in the index. The scale of the index is simplified in Table 2.1 (Little, 1975).

Table 2.1 Little's Irregularity Index (mm).

0	1,2,3	4,5,6	7,8,9	10
Perfect Alignment	Minimum Irregularity	Moderate Irregularity	Severe Irregularity	Very Severe Irregularity

Joondeph *et al.* (1970) studied 200 dental casts of permanent dentitions which excluded the third molars to evaluate the diagnostic capability of LII in order to estimate the arch length discrepancy. They concluded that LII could potentially be used in epidemiological surveys as a valid and less time consuming measurement of crowding compared to arch length dimensions.

Macauley *et al.* (2012) however found that LII to be of limited accuracy and precision as their study aimed to examine the repeatability and the accuracy of LII measurements of four independent examiners on orthodontic patients failed to produce the reproducibility of individual contact point of displacement measurements. This implies that the use of LII by the orthodontic community to predictably determine the outcome of orthodontic treatment modalities in clinical practice cannot be advocated.

2.4.7 Lundstrom segmental analysis (crowding measurement)

Lundstrom segmental analysis divided the dental arch into six straight-line segments, comprising two teeth per segment, starting from the distal aspect of permanent first molar to the distal aspect of the first molar on the opposite side. The sum of individual segments is defined as the space available. The MD widths of the twelve teeth were also recorded and the sum of the MD tooth widths from the right first molar to the left first molar is termed as the space required. Crowding is indicated when there is a negative difference from the calculation of space available minus space required (Singh and Goyal, 2006).

Space available – space required = negative value (crowding)………………. (8)

2.4.8 Howe's analysis (crowding measurement)

Howe's believed that the results of crowding are due to the deficiency in arch width rather than arch length and eventually established the relationship between the total width of twelve teeth anterior to the second molar and the width of the dental arch in the first premolar region (Howes, 1952)

He proposed that a relationship exists between the sums of the MD width of teeth, from central incisor to first molar and the width of the dental arch in the first premolar region. Crowding is the result of reduced dental arch width in the first premolar region (Singh and Goyal, 2006). He used the term Total Tooth Material (TTM) which is the sum of the MD width of all the teeth in the arch from the first molar on one side to the first molar on the other side. The arch width in the first premolar region also termed as the first premolar buccal width (PMBAW) is measured from the buccal aspect of the