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

NAZIK ABDULLAH MUSTAFA SAEED

UNIVERSITI SAINS MALAYSIA

2018
TOOTH SIZE AND DENTAL ARCH DIMENSIONS IN DIFFERENT TYPES OF CROWDING IN MALAY POPULATION

by

NAZIK ABDULLAH MUSTAFA SAEED

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

November 2018
ACKNOWLEDGEMENTS

Praises and thanks are to “Almighty Allah” who bestowed upon me the intellect and sound sense of conception for higher ideals of life.

I am extremely indebted to research guide from my supervisor, Dr Asilah Yusof, for her continuous support, guidance, suggestions and constant encouragement and patience during the entire period of the study.

My heartiest thanks to my co-supervisor, Prof. Dr Rozita Hassan, for her sympathetic support,

Constructive criticism and unutterable efforts during preparation of this thesis.

It is also a pleasure to record my thanks to all the staff of University Sains Malaysia for their support.

Finally I am indebted to my parents (may Allah rest their souls in peace), brothers, sister, my beloved kids, husband and friends for their love, encouragement, prayers and patience throughout my post graduate study at USM.
TABLE OF CONTENT

ACKNOWLEDGEMENTS ........................................................................................................ ii

TABLE OF CONTENT ......................................................................................................... iii

LIST OF TABLES ................................................................................................................ vi

LIST OF FORMULA ........................................................................................................... xi

LIST OF FIGURES ............................................................................................................. vii

LIST OF ABBREVIATION ................................................................................................... xii

ABSTRACT ........................................................................................................................ xviii

CHAPTER 1: INTRODUCTION ............................................................................................ 1

1.1 Background of the study .............................................................................................. 1

1.2 Problem Statement ..................................................................................................... 6

1.3 Justification of the study ........................................................................................... 7

1.4 Research Questions .................................................................................................. 7

1.5 Research hypotheses ................................................................................................. 7

1.6 Objectives of the study ............................................................................................ 8

1.6.1 General objective .................................................................................................... 8

1.6.2 Specific objectives .................................................................................................. 8

CHAPTER 2: LITERATURE REVIEW .............................................................................. 9

2.1 Crowding .................................................................................................................. 9

2.1.1 Prevalent of Crowding ....................................................................................... 9

2.1.2 Aetiology of Crowding ....................................................................................... 10

2.1.3 Crowding and measurements ............................................................................. 12

2.2 Tooth size ................................................................................................................ 13

2.2.1 Measurements of tooth size ............................................................................. 14
2.3 Arch size..................................................................................................................14

2.4 Space analysis........................................................................................................15

2.4.1 Bolton analysis (Tooth size discrepancy between arches)...............................15

2.4.2 Pont’s analysis (Arch width analysis) ...............................................................18

2.4.3 Linder Harth Index (Arch width analysis).........................................................20

2.4.4 Korkhaus analysis (Arch length analysis).........................................................21

2.4.5 Carey’s analysis (Arch perimeter and tooth size analysis)..............................21

2.4.6 Little’s Irregularity Index (LII) (crowding measurement)...............................22

2.4.7 Lundstrom segmental analysis (crowding measurement)...............................24

2.4.8 Howe’s analysis (crowding measurement).......................................................24

2.5. Tools of measuring the dimension of human dentition .....................................25

2.5.1 Stereomicroscope..............................................................................................26

2.5.2 CBCT, Cone beam computed tomography images .........................................26

2.5.3-Three-dimensional 3D Computer Graphics.....................................................27

CHAPTER 3: MATERIALS AND METHODS .................................................................29

3.1 Study design...........................................................................................................29

3.2 Study area..............................................................................................................29

3.3 Population and sample .........................................................................................29

3.3.1 Reference population .....................................................................................29

3.3.2 Source population ...........................................................................................29

3.4 Sampling Frame....................................................................................................29

3.4.1 Inclusion criteria ..............................................................................................30

3.4.2 Exclusion criteria.............................................................................................30

3.5 Sample size calculation........................................................................................30

3.5.1 Objective 1 ........................................................................................................30
3.5.2 Objective 2 .............................................................. 31
3.5.3 Objective 3 .............................................................. 31
3.5.4 Objective 4 .............................................................. 31
3.6 Sampling method ........................................................ 31
3.7 Variables and tool ...................................................... 32
3.7.1 Research tool ........................................................ 32
3.7.2 Variables ............................................................ 32
   3.7.2(a) Independent Variables .................................... 32
   3.7.2(b) Dependent Variables ....................................... 32
3.8 Data collection ........................................................ 33
3.8.1 Scanning procedures ............................................. 33
3.9 Classification of type of the crowding ............................ 36
   3.9.1 Measurements of mesiodistal crown width ............. 38
   3.9.2 Measurements of buccolingual crown diameters ....... 40
   3.9.3 Measurements of maxillary and mandibular arch ... 42
      3.9.3(a) Measurements of arch perimeter .................. 42
         3.9.3(a)(i) Arch perimeter 1 .......................... 42
         3.9.3(a)(ii) Arch perimeter 2 ......................... 42
         3.9.3(a)(iii) Arch perimeter 3 ....................... 43
         3.9.3(a)(iv) Arch perimeter 4 ....................... 43
         3.9.3(a)(v) Right Arch perimeter ..................... 43
         3.9.3(a)(vi) Lift arch perimeter ....................... 43
         3.9.3(a)(vii) Total arch perimeter 4 .................. 43
5.9.3(a). Measurements of arch Widths ........................... 46
      3.9.3(a) Measurements of arch depth ...................... 48
3.10 Bolton indexes (Tooth size ratio) .......................................................... 50
3.11 Pont’s indexes (calculated arch values).................................................. 52
3.12 Statistical analyses................................................................................. 54
3.13 Error study.............................................................................................. 54
3.14 Ethic Approve ....................................................................................... 54
3.15 Flow chart of the study........................................................................... 55

CHAPTER 4: RESULTS................................................................................. 56
4.1 Sample distribution .................................................................................. 56
4.2 Reliability results .................................................................................... 56
4.3 Mesiodistal tooth width in a different type of crowding.......................... 63
4.4. Buccolingual tooth width in different type of crowding ....................... 70
4.5 Bolton indexes in a different type of crowding....................................... 77
4.6. Dental arch perimeter in a different type of crowding.......................... 78
4.7. Pont’s Indexes in a different type of crowding....................................... 84

CHAPTER 5: DISCUSSION......................................................................... 85
5.1 Tooth size (mesiodistal width)............................................................... 85
5.2 Buccolingual width.................................................................................. 88
5.3 Arch width.............................................................................................. 88
5.4 Bolton index ........................................................................................... 90
5.5 Pont’s index............................................................................................ 93

CHAPTER 6: CONCLUSIONS.................................................................. 95
6.1 Conclusions............................................................................................ 95
6.2 Limitation............................................................................................... 95

REFERENCES............................................................................................ 97

APPENDICES
Appendix A: Certification of participation, postgraduate research day 2017

APPENDIX B: Certification of participation, occupational safety and health course 2016

APPENDIX C: Certification of participation, systemic review and meta-analysis 2016.

APPENDIX D: Certification of participation of how to speed 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

APPENDIX I: Certificate of complete course Basic Life Support


APPENDIX G: Certificate of attendance Endnote workshop
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1</td>
<td>Little’s Irregularity Index</td>
<td>23</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Inter-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>57</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Inter-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>58</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Inter-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>59</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Intra-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>60</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Intra-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>61</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Intra-examiner reliability analysed using (ICC) analysis (continued)</td>
<td>62</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Comparison of mesiodistal width of the right maxillary teeth in different type of crowding</td>
<td>64</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Comparison of mesiodistal width of the left maxillary teeth in different type of crowding</td>
<td>65</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>Comparison of mesiodistal width of the right mandibular teeth in different type of crowding</td>
<td>66</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Comparison of mesiodistal width of the left mandibular teeth in different type of crowding</td>
<td>67</td>
</tr>
<tr>
<td>Table 4.7</td>
<td>Comparison of mesiodistal width of the right and left maxillary teeth in different type of crowding</td>
<td>77</td>
</tr>
<tr>
<td>Table 4.8</td>
<td>Comparison of mesiodistal width of the right and left mandibular teeth in different type of crowding</td>
<td>69</td>
</tr>
</tbody>
</table>
Table 4.9  
Comparison of the buccolingual width of the right maxillary teeth in different type of crowding  

Table 4.10  
Comparison of the buccolingual width of the left maxillary teeth in different type of crowding  

Table 4.11  
Comparison of the buccolingual width of the right mandible teeth in different type of crowding  

Table 4.12  
Comparison of the buccolingual width of the left mandibular teeth in different type of crowding  

Table 4.13  
Comparison of the buccolingual width of the right and right maxillary teeth in different type of crowding  

Table 4.14  
Comparison of the buccolingual width of the right and right mandibular teeth in different type of crowding  

Table 4.15  
Comparison of Bolton anterior (BAR) and overall ratio (BOR) ratio in a different type of crowding  

Table 4.16  
Comparison of the arch perimeter right and left of the maxillary arch in a different type of crowding  

Table 4.17  
Comparison of the arch perimeter of the mandibular arch in a different type of crowding  

Table 4.18  
Comparison of right and left arch perimeter of the maxillary and mandibular arches in a different type of crowding  

Table 4.19  
Comparison of the arch width and depth of the maxillary arch in a different type of crowding  

Table 4.20  
Comparison of arch width and depth of the mandibular arch in different types of crowding  

Table 4.21  
Comprising of Pont’s Indexes in different types of crowding.
LIST OF FORMULA

Bolton Index:

Maxillary tooth material excess = \( \text{Sum of maxillary 12} - (\text{Sum of mandibular 12} \times 91.3) \times 100 \) …… (1)

Mandibular tooth material excess = \( \text{Sum of mandibular 12} - (\text{Sum of maxillary 12} \div 100) \times 91.3 \) … (2)

Overall Ratio = \( \frac{\text{Sum of MD width of mandibular 1st molar of one side to 1st molar on opposite side} \times 100}{\text{Sum of MD width of maxillary 1st molar of one side to 1st molar on opposite side}} \) … (3)

Anterior ratio = \( \frac{\text{Sum of MD width of mandibular anterior teeth}}{\text{Sum of MD width of maxillary anterior teeth}} \times 100 \) ………… (4)

Pont’s Index:

CPV = \( \frac{(SI \times 100)}{80} \) ……………………………………………………………………………… (5)

CMV = \( \frac{(SI \times 100)}{64} \) ……………………………………………………………………………… (6)

(SI=Sum of incisors).

Linder harth index arch:

Calculated premolar value, \( \frac{(SL \times 100)}{85} \) ………………………………………………………… (7)

Calculated molar value, \( \frac{(SL \times 100)}{64} \div \frac{(SI \times 100)}{65} \) ………………………………… (8)

(SL: Sum of mesiodistal width of incisors).

Korkhaus formula = \( \frac{(SI/160) \times 100}{\text{(SI=Sum of incisors)}} \) ……………………… (9)

Lundstrom segment analysis

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

Howes Segment analysis

(PMBAW (first premolar buccal width) \times 100) / TTM (total tooth material) …… (11)
LIST OF FIGURES

Figure 3.1 Hirox KH 7700 digital stereomicroscope system with built in evaluation monitor and software

Figure 3.2 Digital dental model fabrication with the aid of built in software of Hirox KH7700 digital stereomicroscope

Figure 3.3 Measurement of type of crowding determined as the size of misaligned teeth (Red line) mines space available (green line) which equal space required

Figure 3.4 Measurement of mesiodistal tooth width

Figure 3.5 Measurement of buccolingual tooth size

Figure 3.6 Measurement of arch perimeter

Figure 3.7 Measurement of arch width

Figure 3.8 Measurement of arch depth (red line)

Figure 3.9 Bolton indexes consist of Anterior Ratio (BAR)

Figure 3.10 Bolton index consist of Overall Ratio

Figure 3.11 Pont’s index (calculate arch values)
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
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Sample Size</td>
</tr>
<tr>
<td>MPV</td>
<td>Measurement Premolar Value</td>
</tr>
<tr>
<td>PBM</td>
<td>Photobiomodulation Lasers</td>
</tr>
<tr>
<td>PMBAW</td>
<td>First Premolar Buccal Width</td>
</tr>
<tr>
<td>RLAP</td>
<td>Right Lower Mandibular Arch Perimeter</td>
</tr>
<tr>
<td>RUAP</td>
<td>Right Upper Maxillary Arch perimeter</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>SI</td>
<td>Sum of Mesiodistal Widths of the Incisors</td>
</tr>
<tr>
<td>SM</td>
<td>Hirox Digital Stereomicroscope</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistics Package of the Social Sciences.</td>
</tr>
<tr>
<td>TLAP</td>
<td>Total Lower Arch Perimeter</td>
</tr>
<tr>
<td>TUAP</td>
<td>Total Upper Arch Perimeter</td>
</tr>
<tr>
<td>TSD</td>
<td>Tooth Size Discrepancy</td>
</tr>
<tr>
<td>TTM</td>
<td>Total Tooth Material</td>
</tr>
<tr>
<td>UAICW</td>
<td>Upper Maxilla Inter Canine Widths</td>
</tr>
<tr>
<td>UAI1PW</td>
<td>Upper Maxilla Inter 1st Premolar Widths</td>
</tr>
<tr>
<td>UAI2PW</td>
<td>Upper Maxilla Inter 2nd Premolar Widths</td>
</tr>
<tr>
<td>UIMW</td>
<td>Upper maxilla Inter 1st Molar Width</td>
</tr>
<tr>
<td>UP1+LP2</td>
<td>Upper maxilla Right Arch Perimeter</td>
</tr>
<tr>
<td>UP3+LP4</td>
<td>Upper maxilla Left Arch Perimeter</td>
</tr>
<tr>
<td>UICW</td>
<td>Upper maxilla Inter Canine Widths</td>
</tr>
<tr>
<td>UI1PW</td>
<td>Upper maxilla Inter 1st Premolar Widths</td>
</tr>
<tr>
<td>UI2PW</td>
<td>Upper Maxilla Inter 2nd Premolar Widths</td>
</tr>
<tr>
<td>UIMW</td>
<td>Upper Maxilla 1st Molar Width</td>
</tr>
</tbody>
</table>
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 Perimeter 4
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 buccolingu al 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 to 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 in 1965, while other investigators suggested that crowding was caused by environmental factors, such as soft diet and loss of arch length due to dental caries (Radnizc, 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 (<4 mm per arch), moderate crowding (4 – 8 mm per arch) and severe crowding (>8 mm 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 repossesion, 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 0.1x10^-6mm (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 19th 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 ($0 - 0.9\text{mm}$), minimal ($1 - 3.9\text{mm}$), moderate ($4 - 6.9\text{mm}$), severe ($7 - 9.9\text{mm}$) and extremely severe of more than $10\text{mm}$ (Little, 1975).

In a North American population, the MD dimension of the maxillary teeth were determined as $8.49\text{ mm}$ for central incisor, $6.59\text{ mm}$ for lateral incisor, $7.72\text{ mm}$ for canine, $6.90\text{ mm}$ for the first premolar and $6.67\text{ mm}$ for the second premolar; and the MD dimension of the mandibular teeth were determined as $5.16\text{ mm}$ for central incisor, $5.75\text{ mm}$ for lateral incisor, $6.70\text{ mm}$ for canine, $6.92\text{ mm}$ for first premolar and $7.08\text{ mm}$ 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:

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

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:

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

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 2SD = <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:

\[
\text{Maxillary tooth material excess} = \text{Sum of maxillary 12} - (\text{Sum of mandibular 12 ÷ 91.3}) \times 100 \ldots (2)
\]

\[
\text{Mandibular tooth material excess} = \text{Sum of mandibular 12} - (\text{Sum of maxillary 12 ÷ 100}) \times 91.3 \ldots (3)
\]

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):

$$CPV = \frac{(SI \times 100)}{80}$$  
(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.

Purnal 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 = \( \frac{SI \times 100}{85} \) ………………………………………… (5)

Calculated molar value = \( \frac{SI \times 100}{64} \div \frac{SI \times 100}{65} \) ……………… (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 = \( \frac{SI}{160} \times 100 \) …………………………………………………. (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).**

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1,2,3</th>
<th>4,5,6</th>
<th>7,8,9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect Alignment</td>
<td>Perfect Alignment</td>
<td>Minimum Irregularity</td>
<td>Moderate Irregularity</td>
<td>Severe Irregularity</td>
<td>Very Severe Irregularity</td>
</tr>
</tbody>
</table>

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).

\[ \text{Space available} - \text{space required} = \text{negative value (crowding)} \]  

(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