DETERMINATION OF TOOTH SIZE AND ARCH DIMENSION IN A PAKISTANI POPULATION: A NOVEL APPROACH UTILIZING DIGITAL MODEL

By

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Alhamdulillah, praise is only to Allah for his endless mercy and blessings that we can still breathe the fresh air and survive in this world for gratis. Allah says in Holy Quran: “Your Lord is best aware of you. If He will, He will have mercy on you, or if He will, He will punish you” (Holy Quran 17:54).

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AL	Arch length
ANOVA	Analysis of variance
BAR	Bolton anterior ratio
BL	Buccolingual crown diameter
BOR	Bolton overall ratio
C	Canine
CAR	Circumferential anterior tooth size ratio
CBCT	Cone beam computed tomography
CDP	Canine disto palatal
CDs	Compact disc
CFT	Circumferential tooth size
CI	Confidence interval
CIn	Central incisor
CInMP	Central incisor mesio palatal
CInDP	Central incisor disto palatal
CMP	Canine mesio palatal
COR	Circumferential overall tooth size ratio
CPU	Central processing unit
DBML	Distobuccal to the mesiolingual
DC	Digital caliper
DD	Diagonal crown diameters
FDI	Fédération dentaire internationale (international dental federation)
ICC	Intra-class correlation coefficient
ICD	Inter canine distance
IM	1st molar
IMD	Inter molar distance
IMDP	1st molar disto palatal
IMMP	1st molar mesio palatal
IMTSD	Intermaxillary tooth size discrepancy
IPM	1st premolar
LI	Lateral incisor
LIC	Lower inter canine width
LICh	Lower inter canine width hirox
LIDP	Lateral incisor disto palatal
LIM	Lower inter molar width
LIM	Lower inter molar width
LIMh	Lower inter molar width hirox
LIMP	Lateral incisor mesio palatal
LIP1	Lower inter first premolar width
LIP1h	Lower inter first premolar width hirox
LIP2	Lower inter second premolar width
LIP2h	Lower inter second premolar width hirox
MBDL	Mesiobuccal to distolingual
MD	Mean differences
MxDDP	Maxillary diagonal distopalatal diameter
MxDMP	Maxillary diagonal mesiopalatal diameter
SD	Standard deviation

SM	Hirox digital stereomicroscope
STROBE	Strengthening the reporting of Observational studies in epidemiology
UIC	Upper inter canine width
UICh	Upper inter canine width hirox
UIM	Upper inter molar width
UIMh	Upper inter molar width Hirox
UIP1	Upper inter first premolar width
UIP1h	Upper inter first premolar width hirox
UIP2	Upper inter second premolar width
UIP2h	Upper inter second premolar width hirox
USM	Universiti Sains Malaysia
X	X axis
Y	Y axis
1PMDP	1st premolar disto palatal
1PMMP	1st premolar mesio palatal
2D	Two-dimensional
2M	2nd molar
2MDP	2nd molar disto palatal
2MMP	2nd molar mesio palatal
2PM	2nd premolar
2PMDP	2nd premolar disto palatal
2PMMP	2nd premolar mesio palatal
3D	Three-dimensional

PENENTUAN SAIZ GIGI DAN DIMENSI ARKUS PERGIGIAN DALAM KALANGAN PENDUDUK PAKISTAN: KAJIAN MODEL DIGITAL

ABSTRAK

Tujuan utama tesis ini ialah untuk membangunkan norma saiz gigi, nisbah saiz gigi (Indeks Bolton), dimensi arkus dan panjang arkus dan ukurlilit arkus pada subjek mempunyai oklusi Angle Kelas I dalam populasi Pakistan. Tesis ini menerangkan kesahan dan keutuhan ukuran model digital, norma geomorfometrik saiz gigi dan analisis dimensi arkus menggunakan stereomikroskop digital, ukuran untuk siasatan nisbah saiz gigi Bolton (perbezaan intermaksilari), saiz gigi dan perbezaan saiz gigi intermaksilari menggunakan ukuran saiz ukurlilit gigi.

Dalam usaha untuk mewujudkan norma standard untuk penduduk Pakistan, kami menyiasat saiz gigi dan dimensi arkus menggunakan angkup digital konvensional (DC) dan stereomikroskop digital (SM). Sampel kajian terdiri daripada 128 subjek yang berusia antara 18 hingga 24 tahun. Model gigi setiap subjek untuk arkus rahang atas dan bawah telah diimbas menggunakan Hirox stereomikroskop digital untuk menghasilkan dan menggunakan model digital, dan saiz serta arkus dimensi gigi model digital diukur melalui SM. Perbezaan jantina dan perubahan yang berkaitan dengan kaedah ukuran telah dinilai, dan saling-hubungan antara pemboleh ubah yang berbeza telah diterokai dalam kumpulan kajian. Bagi data yang diperolehi oleh teknik SM, lelaki mempunyai norma dimensi arkus dan geomorfometrik saiz gigi lebih besar secara statistik yang signifikan daripada wanita ($p<0.05$).

Bagi penyiasatan nisbah saiz gigi Bolton (perbezaan saiz gigi intermaksilari), jumlah saiz gigi anterior dan saiz gigi keseluruhan menunjukkan perbezaan seksual yang

signifikan secara statistik ($p<0.05$) melalui kaedah SM. Tiada perbezaan seksual yang signifikan bagi nisbah Bolton anterior (BAR) dan keseluruhan nisbah Bolton (BOR) telah diperhatikan.

Kajian ini telah mewujudkan satu pangkalan data rujukan baru saiz gigi dan dimensi arkus menggunakan SM untuk pertama kalinya untuk penduduk Pakistan. Norma data ini akan membantu untuk merancang rawatan klinikal dalam bidang pergigian dan pergigian forensik.

DETERMINATION OF TOOTH SIZE AND ARCH DIMENSION IN A PAKISTANI POPULATION: A NOVEL APPROACH UTILIZING DIGITAL MODEL

ABSTRACT

The prime aim of this thesis is to develop the norms for tooth size, tooth size ratio (Bolton index), arch dimension, arch length and arch perimeter on subjects of Angle's class I (normal) occlusion in Pakistani population. This thesis describes the validity and reliability of digital model measurements, geomorphometrics norms of tooth size and arch dimension analysis by conventional digital caliper and digital stereomicroscope, measurement for Bolton' tooth size ratio (intermaxillary tooth size discrepancy) investigation, tooth size and intermaxillary tooth size discrepancy via circumferential tooth size measurements.

In order to establish standard norms for the Pakistani population, we investigated the tooth size and arch dimension using conventional digital caliper (DC) and digital stereomicroscope (SM). The sample consisted of 128 subjects ranging in age from 18 to 24 years. Dental models of each subject for maxillary and mandibular arches were scanned via Hirox digital stereomicroscope for the fabrication of the digital models, and the tooth size and arch dimensions were measured via SM scanned digital models. Sex differences were assessed, and interrelationships between different variables were explored within the study group. For the data obtained by SM techniques, the men had statistically significant larger arch dimensions and geomorphometrics norms of tooth size than the women ($p<0.05$).

For the Bolton' tooth size ratio (intermaxillary tooth size discrepancy), the sum of anterior tooth size and overall tooth size via SM methods showed statistically significant result in relation sexual disparities ($p<0.05$). No significant sexual disparities for Bolton's anterior ratios (BAR) and Bolton's overall ratios (BOR) were observed.

This study has established a new reference database of tooth size and arch dimensions via SM for first time on Pakistani population. These norms for tooth size and tooth size ratio will be helpful for clinical treatment planning in dentistry and forensic dentistry.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Malocclusion is a very common problem in all populations, frequency of which is well-known in modern countries (Bishara *et al.*, 1989). Although the nature of malocclusion varies in different population but tooth size arch length discrepancy (TSALD) is considered to be an important etiologic factor (Shahid *et al.*, 2015). If tooth size and arch dimension are accurately predicted before the occurrence of malocclusion then the estimation can be used to prevent or reduce the severity of malocclusions either by guidance of eruption, serial extraction, space maintenance, space gaining or periodic observation of patient for orthodontic treatment (Anwar and Fida, 2010).

Pre-treatment investigation of dental arch form is very important in clinical orthodontics, these investigation used to predict the future arch form and shape (Nojima *et al.*, 2001). For the stability of the arch form after treatment, the patient's existing arch form appear to be the best guide because of the tendency to relapse to its original shape (de la Cruz *et al.*, 1995).

In orthodontic treatment the arch form and shape are usually modified to achieve the treatment goals. It is customized by the various forms of wires used in the treatment course; these dimensional changes affect the arch form and its dimensions (Anwar and Fida, 2010).Lavelle *et al.* (1971) investigated the dental arches of four major ethnic groups: Caucasoid, Mongoloid, Negroid, and Australoid. They concluded that there were some basic differences in dental arch size and shape between the different racial groups (Lavelle *et al.*, 1971). The dental arch size and shape has population's variations (Burris and Harris, 2000). Studies of other populations have further supported these findings (Hussein *et al.*, 2009; Leifert *et al.*, 2009). For orthodontic treatment planning and diagnosis of dental arches, their dimensions have great importance for the position of teeth, smile, esthetics, and stability of teeth.

For tooth size and arch dimension analysis direct measurement methods including hand-held calipers, graphs and scale were used on dental casts (Zilberman *et al.*, 2003). Recent development in technology has made it possible that the dental cast can be produced in digital models (Bell *et al.*, 2003). These digital model studies provide more accurate and reliable tools for obtaining measurements and carrying out dental analysis (Leifert *et al.*, 2009). Furthermore, they have supplementary profits, such as accessibility of the images produced, reduction in storage costs and the ability to analyze images by using sophisticated software (Stevens *et al.*, 2006; Leifert *et al.*, 2009).

There is obvious population variation in the pattern and magnitude of sexual dimorphism (Yuen *et al.*, 1997; Ling and Wong, 2007; Acharya and Mainali, 2008). Teeth in relation to sexual dimorphism have been of prodigious importance to anthropologists and forensic odontologists as well as the focus of many studies for gender assessment (Lund and Mörnstad, 1999; İşcan and Kedici, 2003).

1.2 Geomorphometrics of Tooth Size and Arch Dimension

Nature has given an ideal balance between the maxillary and mandibular teeth size that should be attained for the ideal occlusion and aesthetics, especially in relation to the finishing phase in orthodontics (Bolton, 1958; Bolton, 1962; Alam and Iida, 2013).

Conventional caliper was used by researchers to investigate sexual disparities through mesiodistal (Ateş *et al.*, 2006; Acharya and Mainali, 2007; Alam and Iida, 2013; Khamis *et al.*, 2014), buccolingual (İşcan and Kedici, 2003; Ateş *et al.*, 2006; Acharya and Mainali, 2007; Khamis *et al.*, 2014) and diagonal crown (Karaman, 2006) diameters of teeth. Geomorphometrics is the quantitative approach that refers to the morphology of an entity depending on landmarks which provide the core information on morphology of the object. This technique resolves numerous problems accompanying with out-of-date methods of measurements (Zelditch *et al.*, 2012).

1.3 Intermaxillary tooth size discrepancy

Comprehensive diagnosis and treatment planning are essential in a successful orthodontic practice. Dental model analysis plays a vital role in diagnosis and subsequent treatment planning. An intermaxillary tooth size discrepancy (IMTSD) is a disproportion among the sizes of the individual teeth (Bolton, 1958). IMTSD evaluation is an important factor to be considered for orthodontic diagnosis and treatment planning (Alam and Iida, 2013). For ideal occlusion, absence of IMTSD is considered as “seventh key of occlusion” (McLaughlin, 2002). Patient with significant values for IMSTD inhibit ideal occlusion at the finishing stage of the orthodontic treatment. Bolton did IMTSD ratio evaluation on fifty-five dental models. The upper and lower arch anterior ratio (BAR) from canine to canine (3 to 3) and total ratio (BOR) from first molar to first molar (6 to 6) were revealed by Bolton. A BAR 77.2% and BOR 91.3% is required to achieve the good occlusion with ideal overjet, overbite and coinciding midline (Bolton, 1958; Bolton, 1962). The mesiodistal tooth size of the maxillary and mandibular arch must relate to each other in order to obtain an excellent occlusion at the completion of the orthodontic treatment. Thus BAR and BOR were the norms values obtained by Bolton in percentage for the evaluation of IMSTD. He proposed the following formula to calculate the IMTSD ratios-

$$\text{BAR} = \frac{\text{sum of the mandibular 3 to 3}}{\text{sum of the maxillary 3 to 3}} \times 100 \quad \text{BOR} = \frac{\text{sum of the mandibular 6 to 6}}{\text{sum of the maxillary 6 to 6}} \times 100$$

Variations in tooth size and tooth size proportion have been associated with different ethnic background and malocclusion groups (Lavelle, 1972; Smith *et al.*, 2000; Ta *et al.*, 2001; Araujo and Souki, 2003). IMTSD is not occasional in numerous populations (Crosby and Alexander, 1989; Freeman *et al.,* 1996; Alam and Iida, 2013). From a clinical perspective, perfect equivalence should exist between the mesiodistal tooth sizes of the maxillary and mandibular arches for the surety of ideal interdigitation, overbite and overjet at the culmination of orthodontic treatment (Al-Tamimi and Hashim, 2004; Othman and Harradine, 2006; Othman and Harradine, 2007a; Alam *et al.,* 2014a).

More orthodontists are using digital dental models for diagnostic records and assessment of patients' orthodontic conditions. This trend will probably accelerate and become more common as digital models alleviate or solve many problems and difficulties associated with storage, retrieval, reproduction, communication, and breakage of conventional plaster casts (Paredes *et al.*, 2006). The various types of digital dental models were used for the investigation of IMSTD on various populations (Alam *et al.*, 2014a).

1.4 Statement of problem

The tooth size and dental arch dimension have been studied around the globe on the different ethnic groups of various populations. Little research however has been done on the dental cast of the Pakistani population, for the tooth size, dental arch dimension and tooth morphology in the orthodontic diagnosis and treatment planning, and for forensic application. There is no study on the tooth size and arch dimension by this novel method of 2D KH7700 HIROX (Japan) stereomicroscope and digital models. Until now no study has been conducted for the tooth size, arch size, arch dimensions, intermaxillary tooth size discrepancy, sexual disparities in the crown dimension of Pakistani population via digital dental models.

1.5 Justification of the study

To accomplish the good occlusion with proper inter-digitations, vertical and horizontal relation, there must be specific relationships between the tooth dimensions to seat in good occlusion.

Discrepancy in the tooth size needs to be measured in orthodontic practice before starting the orthodontic treatment. The crown size of the tooth presents important information on individual development, biological problems and clinical odontology. Moreover, it presents the data for the comparative study of tooth size (Hattab *et al.*, 1996). Natural teeth proportion of most of the individual's match very well, but some degree of disproportion in the teeth size may be observed in 5% of the population (Bishara *et al.*, 1989). IMTSD is common in many populations (Crosby and Alexander, 1989; Freeman *et al.*, 1996). For the management of the space and crowding in the field of dentistry, tooth size is of enormous significance to general dentists, pedodontists and orthodontists (Singh and Goyal, 2006). It is significant to have information (data) about related human population for reason of clinical diagnosis and planning of treatment. These informative data may also be helpful in forensic dentistry (Ling and Wong, 2007).

Arch dimension has a profound effect in the orthodontic diagnosis and treatment planning such as for the tooth size arch discrepancy, dental aesthetics and the stability of the occlusion after treatment (Lee, 1999). The arch dimension is affected by many factors such as hereditary, growth of the jaws, eruption and inclination of the teeth, racial background, function and pressure of the muscles (Bjork *et al.*, 1984; Lee, 1999; Hassanali and Odhiambo, 2000). The arch dimension is clinically important in the contemporary orthodontic procedures. The prefabricated orthodontic wires are frequently used for the arch modification. Clinically, to use preformed arch wire, it is more genuine to have several types of preformed arch wires accessible and to recognize the patient's arch form, according to race and malocclusion (Hussein *et al.*, 2009). Therefore, populations' variability in the arch dimension and shape should be kept in consideration (Burris and Harris, 2000).

1.6 Objectives of the study

1.6.1 General objective

To develop the norms for tooth size, tooth size ratio (Bolton index), arch dimension, arch length and arch perimeter on subjects of Angle’s class I (normal) occlusion in Pakistani population through novel method utilizing 2D HIROX KH7700 stereomicroscope (Japan).

1.6.2 Specific objective

The specific objectives for this study are to-

1. determine and compare the mesiodistal and buccolingual tooth width, tooth perimeter, crown height and diagonal crown dimensions of the maxillary and mandibular arch between male and female in Pakistani population.
2. determine and compare the mesiodistal and buccolingual tooth width, tooth perimeter, crown height and diagonal crown dimensions of the maxillary and mandibular arch between right and left side in Pakistani population.
3. determine and compare the tooth size ratio (Bolton’s Index) between male and female in Pakistani population.
4. determine and compare the circumferential tooth size discrepancy in Pakistani population.
5. determine and compare the arch size between male and female in Pakistani population.

1.6.3 Null hypothesis

1. There is no significance significant difference between the mesiodistal and buccolingual tooth width, tooth perimeter, crown height and diagonal crown dimensions of the maxillary and mandibular arch between male and female in Pakistani population.

2. There is no significance significant difference between the mesiodistal and buccolingual tooth width, tooth perimeter, crown height and diagonal crown dimensions of the maxillary and mandibular arch between right and left side in Pakistani population

3. There is no significance significant difference between the tooth size ratio (Bolton's Index) between male and female in Pakistani population.

4. There is no significance significant difference in circumferential tooth size discrepancy between male and female in in Pakistani population

5. There is no significance significant difference in the arch size between male and female in Pakistani population.

CHAPTER 2

LITERATURE REVIEW

2.1 Tooth size

Natural teeth proportion for most of the individual's match very well but some degree of disproportion in the teeth size may be observed in 5% of the population (Bishara *et al.*, 1989). Inter maxillary tooth size discrepancy is not infrequent in many populations (Crosby and Alexander, 1989; Freeman *et al.*, 1996).

2.2 Measurement of tooth size

Most traditional morphometric utilize linear techniques for measurements such as mesiodistal dimension, buccolingual dimension and occlusogingival dimension, while others use indices to represent size (Kieser *et al.*, 1985). Many orthodontists practise some form of odontometry as part of diagnosis (Peck and Peck, 1975). Metrical and non-metrical variations are usually differentiated in studies investigating tooth morphology. All aspects that are measured directly are known as metrical (i.e., the mesiodistal, buccolingual, crown height and diagonal crown diameters of teeth), while non-metrical variations involve scoring or describing the presence, absence and degree of development or form visually (Hillson, 1996). Complexity of non-metric is related mainly to difficulty in assessment due to its subjectivity. Non-metric features are scored visually in terms of presence, absence, degree of development, or form. Non-metric features are quite complex and their assessment requires uniform standards. This has been accomplished with the use of cast plaster plaques, a process initiated by Dahlberg (Dahlberg, 1940).

Although model analysis is time consuming procedure, yet it is considered pivotal in orthodontics diagnosis and treatment planning. Previously, orthodontists judged the models subjectively without applying the analytical tests (Binder and Cohen, 1998). After introduction of digital calipers it became easy to measure the tooth size, avoiding adding up mistakes in contrast to analysis that necessitate dividers, scale and calculators (Ho and Freer, 1999).

2.2.1 Mesiodistal dimension

Mesiodistal width of tooth is measured from anatomical contact of one tooth to other from the buccal side of the tooth or from the occlusal side for a rotated tooth (Bishara *et al.*, 1989). Conventional technique for the measurement of mesiodistal width on the dental models was by using either sharp pointed dividers, sliding calipers or Boley's gauge (Shellhart *et al.*, 1995).

Plenteous terms are used to refer to the mesiodistal diameter of the crown such as tooth width (Othman and Harradine, 2007b), mesiodistal width (Bolton, 1958), and mesiodistal crown diameter (Lavelle, 1968). Moorrees and colleagues (1957) defined mesiodistal dimension as the greatest distance between the contact points while holding calipers placed parallel to both the occlusal and vestibular surfaces, while Kieser *et al*. (1985) defined it as the maximum distance between the contact points of a tooth in normo-occlusion. Difficulties can arise in the case of rotation or displacement of teeth. Other researchers defined the mesiodistal dimension by measuring a line between the mesial and distal contact points of each crown when the teeth are in the normal occlusion (Scott and Turner, 1988). Interestingly, the majority of researchers have stated that the mesiodistal dimension line is the maximum distance between contact points or points where contact happens (Lavelle, 1972; Potter *et al.*, 1981; Axelsson and Kirveskari, 1983). However, teeth with marked proximal and occlusal attrition may be excluded (Kieser, 1990). Others consider the mesiodistal line to be the largest distance between the normal contact points on the proximal regions of the tooth crown, measured parallel to the occlusal plane (Lavelle, 1971). Holding calipers parallel to the occlusal and buccal surfaces has been suggested as a way of obtaining a more accurate measurement of the mesiodistal line (Potter *et al.*, 1981; Axelsson and Kirveskari, 1983).

2.2.2 Buccolingual dimension

Buccolingual dimension is also known as buccolingual crown diameter (Lavelle, 1968), or breadth (Kieser *et al.*, 1985). The maximum buccolingual dimension of the tooth as taken perpendicular to the mesiodistal dimension has been considered as the reference for their measurement (Moorrees et al., 1957; Lavelle, 1971; Potter *et al.*, 1981; Axelsson and Kirveskari, 1983). According to Lavelle (1972), this was the greatest distance between the buccal and lingual crown convexities, measured at right angles to the mesiodistal crown diameter.

2.2.3 Crown height (Occlusogingival dimension)

The occlusogingival line is infrequently referred in the dental literature. Bolton (1958) used the term ‘incisogingival height’ to explain this length. It has also been called crown height (Lavelle, 1968; Volchansky *et al.*, 1981) and is usually taken from the buccal surface. Lavelle (1968) used this dimension in premolars, canines and incisors, from the point on the upper surface of the crown above the lowest point of the cementoenamel junction or free gingival margin. In molars, on the other hand, the measurement was taken from between the tip of the mesiolingual cusp to the lowest point on the cementoenamel junction or free gingival margin. However, the crown height was explained as distance between the occlusal line and cemento-enamel junction (Volchansky *et al.*, 1981).

For the achievement of pleasant smile and proper interdigitation, the preadjusted fixed orthodontic brackets should be ideally positioned. Thus the crown height is of extreme value in orthodontic bonding. The teeth crown height has significant relation to facial stature, both can be swayed by orthodontic treatment (Purohit *et al.*, 2012) Therefore, during orthodontic planning to design a smile the macro, mini and micro-esthetics should be deliberated afore (Sterrett *et al.*, 1999; Djeu *et al.*, 2002; Bergman *et al.*, 2013). The crown height of incisors has tremendous effect on the smile of a patient, and leads an imperative part in facial charm (Owens *et al.*, 2001; Hasanreisoglu *et al.*, 2005).

2.2.4 Circumferential tooth size measurement

Up to our knowledge and extensive literature search using Medline, PubMed data base, and Google Scholar search engine, there is no publication on circumferential tooth measurements.

The closest publication which utilized similar methods was Kondo and Townsend (2006). They measured the cusp areas in human permanent maxillary first molars from both mesiodistal and buccolingual approaches and concluded that the molar cusp areas and the areas of Carabelli cusps were larger in males on average than in females.

2.3 Methods of determination of tooth dimensions

Various methods of measuring the dimensions of the human dentition are described in the literature. Each of these methods has advantages and disadvantages. The subjective procedural problem is always associated with measurement: e.g., caliper placement on crowded teeth.

The techniques involve either direct (digital calipers) or indirect measurement (laser scanning, radiographs, photographs). Indirect measurements can be in the form of 2D/3D and in-printed or digital format. However, the direct measurements use the manual techniques i.e. dividers, sliding, vernier or dial calipers, or a Boley's gauge, allows only linear measurements. Thus the type of measuring instrument plays an important role in accuracy of measurements (Bolton, 1958; Hunter and Priest, 1960; Garn and Lewis, 1970; Lavelle, 1970; Richardson and Malhotra, 1975).

The digital formats have advantages like- can be kept in digital format and also eliminating the storage problem with study models in dental clinics.

Digital images can be showed to patients in order to motivate them in their treatments. Measurements can be made on digital casts in an easy, accurate and automatic way (Santoro et al., 2003; Quimby et al., 2004). Digital dental models and their measurements can be accessed at any time and at any distance for diagnostic, clinical and information purposes (Hajeer et al., 2004). Conversely, the digital dental model has several disadvantages. Digitalizing dental casts is a laborious process and requires expensive 3D scanners.

2.4 Intermaxillary tooth size discrepancy (IMTSD)

Bolton used fifty five dental models for the investigation of tooth size analysis. He totalled the tooth size ratio in percentage involving the upper and lower arch teeth. He suggested BAR from both canine to canine (3 to 3) and BOR from first molar to first molar (6 to 6). To achieve the good occlusion with ideal overjet, good overbite and proper midline, he proposed the norms tooth size ratio of 77.2% for BAR and 91.3% for BOR (Bolton, 1958).

The BOR can be deliberated by dividing the sum of mandibular arch teeth (from first molar to first molar) with the sum of maxillary arch teeth (from first molar to first molar) as shown in Figure 2.1. BAR were analysed by dividing the sum of lower arch six anterior teeth (right canine to left canine) with upper arch six anterior teeth (canine to canine) (Figure 2.2) (Bolton, 1962).

$$\text{BOR} = \frac{\text{sum of the mandibular 6 to 6}}{\text{sum of the maxillary 6 to 6}} \times 100 \qquad \text{BAR} = \frac{\text{sum of the mandibular 3 to 3}}{\text{sum of the maxillary 3 to 3}} \times 100$$

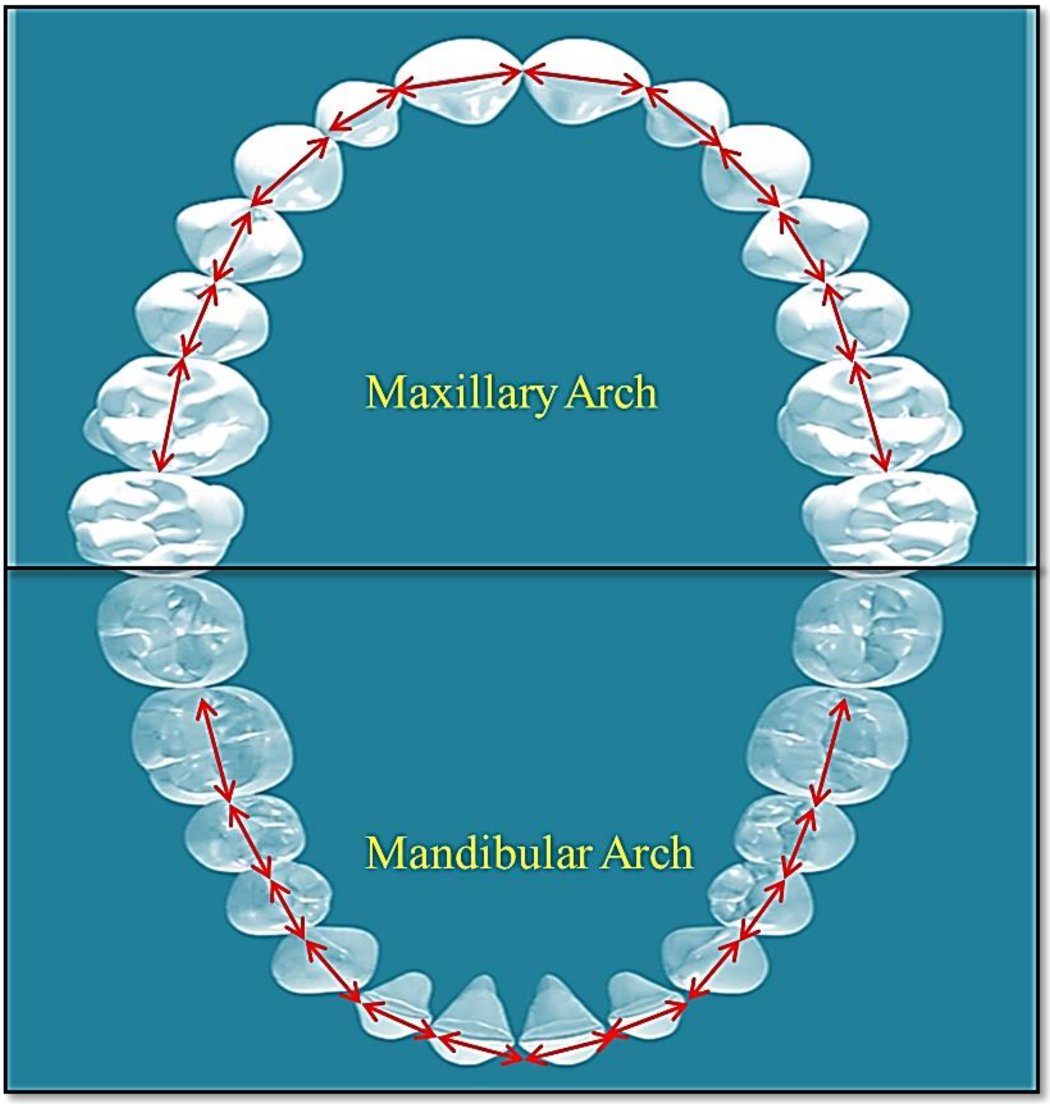

Figure 2. 1 Sum of maxillary and mandibular teeth (6-6) for BOR.

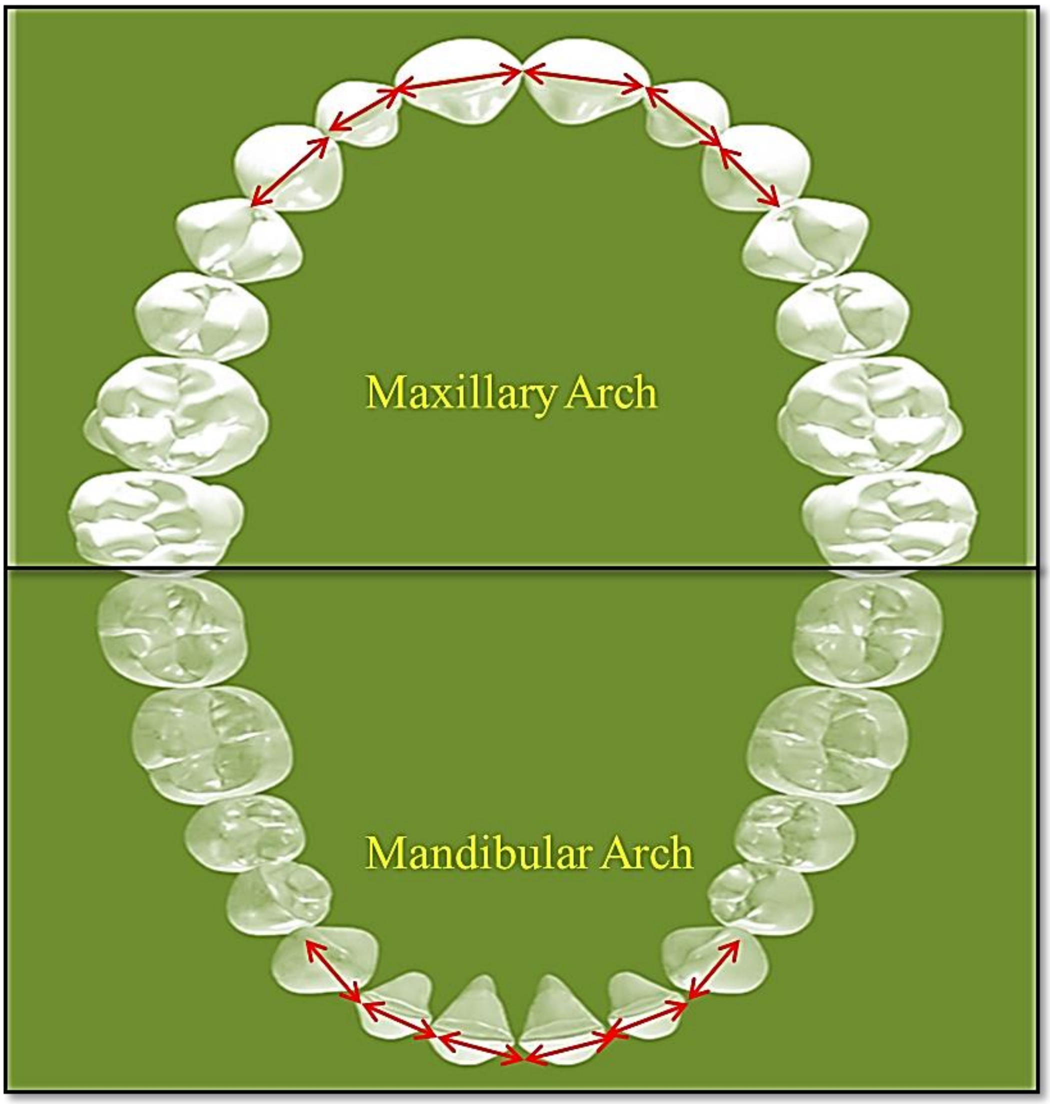

Figure 2. 2 Sum of maxillary and mandibular anterior teeth (3-3) for BAR

Al-Khateeb *et al*. (2006) found the dissimilarity in tooth size between right and left sides of the arches which verify the occurrence of unevenness among the two sides. Females demonstrate a trend to have smaller mesiodistal width than males. In the different classes of angle's malocclusion, the class III has the tendency of larger tooth size. No statistically significant dissimilarity was established in the Bolton ratios for the six anterior teeth and the twelve teeth within the different malocclusions (Al-Khateeb and Abu Alhaija, 2006).

Tooth size discrepancy in the dental arches such as the peg-shaped lateral teeth; require space management for the final restoration of normal occlusion. Larger discrepancy in the tooth size can also affect the extraction choice in orthodontic treatment planning (Batool *et al.*, 2008). Tooth size discrepancy determination is the seventh key to ideal occlusion (McLaughlin, 2002). Therefore, a good equilibrium should be present between the mesiodistal tooth sizes of both arches to guarantee the ideal orthodontic treatment.

2.4.1 Bolton study on the various population and their results

Researchers performed the investigation for the IMTSD around the globe. Variations were observed amongst different populations. Studies conducted on IMTSD on various populations are shown in **Table 2.1**.

Table 2. 1 Bolton study on various populations

Author,Year,	**Population**	**Subjects**	**Results**
(Bernabe *et al.*, 2004).	Peruvian	200	Significant BAR and BOR discrepancies were observed in approximately one third of the sample.
(Crosby and Alexander, 1989).	Orthodontic Practice	30 class I malocclusion 30 class II div 1 malocclusion	The means for BAR and BOR ratios in this study were similar to those of Bolton's.
(Sperry *et al.*, 1977).		30 class III malocclusion 26 Class I malocclusion subjects. 20 class II malocclusion subjects.	The Bolton ratios for groups of Class I, Class II, and Class III cases. Male and female subjects were not differentiated. The BAR showed a mandibular tooth size excess for the Class III patients.
(Araujo and Souki, 2003).	Belo Horizonte, Brazil	300	Individuals with Class I and Class III showed significantly greater prevalence of tooth size discrepancies than individuals with Class II for BOR and BAR. Mean BAR discrepancy for Angle Class III subjects was significantly greater than for Class I and Class II subjects.
(Nourallah *et al.*, 2005).	Syrian	55 (35 male and 20 female)	The mean value for BAR and BOR were similar to Bolton's.
(Santoro *et al.*, 2000).	Dominican-Americans orthodontic patients	54 (36 men and 18 women)	The overall tooth size ratio was equivalent to the original Bolton overall ratio, but the anterior tooth size ratio was larger than the Bolton anterior ratio. The difference was statistically significant and suggests the need for more specific standards for

			the Dominican.
(Uysal and Sari, 2005a).	Turkish	150 class I normal occlusion	Bolton’s original data do not represent Turkish people. A discrepancy in the BOR was found in 18% of Turkish subjects with Bolton’s ratio and anterior ratios outside 2 SD from the Bolton mean were found in 21.3% of Turkish population.
(Richardson and Malhotra, 1975).	American Negroes	162	The ratio of the mandibular dentition maxillary dentition was 94 % (BOR) in both sexes. The ratio of the sum of the widths of the canines and incisors of the mandibular dentition to those of the maxillary dentition was 77 % (BAR).
(Jaiswal *et al.*, 2009).	Nepalese		The BAR 79.46% and BOR 92.42% were revealed. Thus Nepalese requires specific tooth size discrepancy analysis.
(Othman *et al.*, 2008)	Malaysian	40 subjects (12 male and 28 female)	The 45 % and 10% variation were found for BAR and BOR from the Bolton norms, respectively.
(Rahman and Othman, 2012)	Malaysian Chinese Malaysian Indians Malaysian Malays	30 each group (15 male and 15 female)	The Chinese and Indians have no difference with original Bolton values however, there were significant difference observed for the Malaysian Malays.
(Quraishi *et al.*, 2011)	Pakistani	150	They found the 14.7 % of subjects have BAR and 9.1% had BOR greater than Bolton’s proposed values.

2.5 Arch size

Arch dimensions include the arch length, arch width and depth. In orthodontic treatment the arch form and shape are usually modified to achieve the treatment goals by the various forms of wires used in the treatment course (Anwar and Fida, 2010). The patient's existing arch form appears to be the best guide for the stability of the arch form after treatment (de la Cruz *et al.*, 1995).

Before any clinical intervention to patient, the analysis of dental arch profile and its dimension is vital in clinical orthodontics either to achieve or maintain its original arch structure (Nojima *et al.*, 2001). The arch size and shape are of meticulous importance to orthodontists. Thus a diversity of diagnostic and analytical indices had been anticipated to help and forecast dental arch development and help out through treatment planning (Nimkarn *et al.*, 1995). For the relieving of crowding and adjustment of arch length, the dental arch expansion is one of the methods to solve the problem by non-extraction orthodontic treatment. After dental arch expansion, to avoid the relapse is most controversial (Smith *et al.*, 2000).

Numerous researchers put together the indices and techniques using tooth size to calculate the perfect interpremolar and intermolar arch width to get an ideal expansion of arches in order to avoid relapse and to alleviate the crowding. Criteria for the correlation of mesiodistal width of the maxillary incisors and arch width was analysed by Ponts analysis, Linder's analysis, Khorkhous's analysis, Schmuth method, Cha's method, Schwarz analysis, McNamara rule of thumb. Pont's method gained revival in interest for ascertaining dental arch growth (Agnihotri and Gulati, 2008).

2.6 Orthodontic Records in the Digital Age

Orthodontic treatment planning poses significant challenges for clinicians with respect to their ability to provide the most predictable results for patients in a safe, effective and efficient manner. While clinicians regard the clinical exam as the gold standard for viewing real time dental occlusion, maxilla-mandibular relationships and soft tissue conditions, orthodontic records provide invaluable information. Along with examination of oral conditions, the necessary components for orthodontic diagnosis and treatment planning include dental and skeletal radiographs, analysis of the lateral cephalogram, accurate dental study models and photographs (Graber *et al*., 2011). Medico-legally, patient record plays the most vital role in providing evidence to eliminate doubt of any breach of standards of care, and should reflect the history of the patient-doctor relationship honestly (Jerrold, 2003). Orthodontists most commonly employ diagnostic dental casts for various areas of clinical practice, clinical research and medico-legal documentation (Marcel, 2001).

Han *et al.* (1991) demonstrated that study models independently provided adequate amount of information for consistent treatment planning among multiple practitioners 55% of the time. Dental casts, therefore, seemed to have more benefit when employed with intraoral and extraoral photographs, panoramic radiographs, cephalograms and their tracings, all of which effectively and usefully demonstrate their various characteristics of a patient's malocclusion (Han *et al*., 1991).

Recently, technological advances have created a new source of practical issues in data collection for diagnosis and treatment planning. Many orthodontists still use traditional records, such as conventional film photographs plain film radiographs traced on acetate sheets for cephalometric analysis and poured plaster casts. In contrast, others have begun to integrate less proven and/or mainstream media such as digital photographs, computer-based models and digital radiography as a mean to collect, share, store and evaluate the data collected in their offices. They also use computer software when generating treatment plans and for communication with other professionals (Berman, 2010).

Dentists and dental specialists continue to integrate paperless charts and various types of digital technology into their practices. The advantages of digital archives most frequently cited include ease of record duplication, low financial and time expense, space saving benefits, portability, speed and ease of access of records, and ease of information sharing (Abelson, 1995). Software to integrate photographs, digital radiographs and digital casts, sometimes in a three dimensional manner, have become a new available technology for application in a computer-based treatment record (Marcel, 2001).

2.6.1 Computer-Based Dental Study Models

The study models maintain their vital tradition as an essential part of the orthodontic process of diagnosis, treatment planning and outcome appraisal. For many years, the only medium to provide the positive representation of impressions made in any material has been either a plaster or stone cast. They provide a measurable three-dimensional record of the original malocclusion that observers can manipulate and view from multiple angles. Progress models allow evaluation and further treatment planning at any stage during active treatment, and post-treatment models act as a major contributor to treatment outcome assessment (Berman, 2010).

Despite the indispensable role stone/plaster casts play in diagnosis, treatment planning, progress and treatment outcome evaluation, they have several practical disadvantages. Space considerations in an office make storage of stone or plaster casts problematic, and difficulty in their recovery from the storage sites can occur as well, particularly if a clinician uses an off-site storage facility. Furthermore, the bulk of traditional casts also makes them difficult to transport and/or transfer for review by insurance companies or to other members of the patients' health care team.

The introduction of computer-based study models has made another stride toward a fully electronic orthodontic patient record. Record to be better understood previous attempts at digitizing casts had poor success. Some involved digitally photographing the models from five vantage points (frontal, right and left buccal, upper occlusal and lower occlusal) (Berman, 2010)

Researchers have also attempted to develop three-dimensional models through laser scanning technology or generation of holographic images (Rossouw *et al.*, 1991; Martensson and Ryden, 1992). These technologies, however, require complex equipment and have significant cost. Furthermore, the laser technology has limitations in capturing overlapping interproximal areas.

In contrast, since its introduction in the mid- 1990s, scanning technology has improved over the past several years from advances in software development (Zilberman *et al.*, 2003). Several companies, including GeoDigm (GeoDigm Corp., Chanhassen, Minn) and OrthoCAD (CADENT, Ind., Fairview, NJ), have dramatically refined this approach. These advances have made the capture of scanned images a commercially viable enterprise and OrthoCAD utilizes the computer-aided design technology (CAD) for generation of its digital study models.

As computer software technology continues to progress, advances may provide for a single piece of imaging equipment, such as a cone beam computed tomography, to provide the full complement of information on hard and soft tissue to analyze them three dimensionally (Nakasima *et al.*, 2005).

2.6.2 Various types of digital models

Plaster and digital study models have utmost importance for various investigations, diagnosis and treatment plan in dentistry. Current scientific developments have permitted the generation of digital dental models that can be stored and seen on workstations. These new digital models solve many problems encountered with conventional plaster study models. Recent technological breakthroughs have enhanced the process of cast fabrication and manipulation for plaster cast (Peluso *et al.*, 2004).These digital models have benefits like, no physical damage, no dust or other mess and require low storage space. The digital information for each case can be stored on an office workstation’s hard drive, on portable storage devices or online drive et cetcra.

Digital models reclamation is speedy, with a single click on computers, because the models are usually stored by the patient name and identity numbers. Additional benefit is that it is possible to view digital models at multiple locations from any office computer linked to the practice. Also, allowing patients to be treated at multiple sites with ease of access to their digital records (Redmond *et al.*, 2000).