T.C.
İSTANBUL YENİ YÜZYIL UNİVERSİTY
HEALTH SCIENCES INSTITUTE
DEPARTMENT OF ORTHODONTICS

RELIABILITY OF TANAKA AND JOHNSTON ANALYSIS IN A TURKISH SAMPLE

MASTER OF THESIS

MOHANAD M. J. ODEH

Supervisor

Dr. Hüseyin ÖZKAN

ISTANBUL

July 2019

DEDICATION

This thesis is dedicated to;

My beloved Mother for her endless love, support and encouragement,

My Father for all sacrifices he made for me,

My Sister and Brothers thank you for the support, I love you all.

ACKNOWLEDEGMENT

I would first to thank my thesis supervisor Dr. Hüseyin Özkan. The door to his office was always open whenever I had a question about my research or writing. He guided me to the right direction.

I also would like to thank all of the orthodontic staff for educating me.

A special thanks is extended to the colleagues at the Yeni Yüzyıl dental hospital who were cooperative and supportive during my data collection.

Finally, I must express my very deep appreciation to my parents Mahmoud and Reem for providing me with continuous encouragement and unfailing support throughout my years of study and through the process of researching and writing this thesis. This study would not have been possible without them. Thank you.

TABLE OF CONTENTS

DEDICATION II

ACKNOWLEDEGMENT III

TABLE OF CONTENTS IV

LIST OF TABLES VI

LIST OF FIGURES VIII

ABSTRACT IX

ÖZET X

1. INTRODUCTION 1

2. LITREATURE REVIEW 3

2.1 Determination of space available 4
2.2 Determination of space required 5
2.3 Tooth size variation 6
2.4 Determination of unerupted tooth size 7
2.5 Odontometric measurements techniques 8
2.6 Measurement of unerupted teeth on radiograph 10
2.7 Measurement of unerupted teeth using proportionality tables 12
2.8 Measurement of unerupted teeth using regression equations 14
2.9 Prediction from combination of radiograph and prediction tables 16
2.10 Comparisons of the prediction methods 18
2.11 Space analysis in different races (Black Africans, Chinese, European, Latins) 19
2.12 Gender Dimorphism 21
2.13 AIM AND OBJECTIVES 22

3. MATERIAL AND METHODS 23

3.1 Ethical Considerations 23
3.2 Study design 24
3.3 Sample selection 24
3.4 Inclusion Criteria: 24
3.5 Sampling technique 25
3.6 Impression and pouring procedures 25
3.7 Measuring technique of mesiodistal tooth width 25
3.8 Prediction of mesiodistal width of canine and premolars (Predicted tooth values) 27
3.9 Comparison between Actual and Predicted tooth measurements 27
3.10 Null Hypothesis 27
3.11 Reliability of the measurement 28

3.12 Statistical analysis 28
4. RESULTS 29
4.1 Study sample: 29
4.2 Reliability of the measurements 30
4.3 Descriptive statistics for the sample: 31
4.4 Bilateral symmetry 32
4.5 Gender comparisons of mesio-distal tooth widths 34
4.6 Comparisons of predicted and actual tooth size 35
4.7 Regression equations for the Turkish sample 38
5.DISCUSSION 44
5.1 Introduction 44
5.2 Reliability of measurements 44
5.3 Mesiodistal tooth widths 45
5.4 Gender variations 48
5.5 Bilateral symmetry 49
5.6 Comparisons of prediction method with actual values 50
5.7 Correlation coefficient (r) 54
5.8 Coefficient of determination (r^2) 54
5.9 Standard error of the mean (SEM) 55
6.CONCLUSION 56
7.REFERENCES 57
8.APPENDICES ..... **HATA! YER İŞARETİ TANIMLANMAMIŞ.**

LIST OF TABLES

TABLE 1. AGE DISTRIBUTION OF TURKISH SAMPLE..... 29

TABLE 2. REPRODUCIBILITY OF THE STUDY FINDINGS (THE DIFFERENCES BETWEEN REPEATED AND ORIGINAL MEASUREMENTS). 30

TABLE 3. MEAN, RANGE AND STANDARD DEVIATION OF MANDIBULA AND MAXILLARY TEETH FOR THE MALES, FEMALES AND BOTH SEXES COMBINED..... 31

TABLE 4. COMPARISON BETWEEN RIGHT AND LEFT MESIODISTAL TOOTH WIDTH FOR WHOLE SAMPLE. 33

TABLE 5. COMPARISON OF MESIODISTAL WIDTH OF INDIVIDUAL TEETH BETWEEN MALE AND FEMALE SUBJECTS. 34

TABLE 6. COMPARISONS OF MESIODISTAL WIDTH OF GROUP OF TEETH BETWEEN MALE AND FEMALE SUBJECTS. 35

TABLE 7. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MAXILLARY PERMANENT CANINE, FIRST AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUES FOR FEMALE SUBJECTS (N=64). 36

TABLE 8. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MANDIBULAR PERMANENT CANINE, FIRST AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUES FOR FEMALE SUBJECTS (N=64). 36

TABLE 9. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MAXILLARY PERMANENT CANINE, FIRST AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUE FOR MALE SUBJECTS (N=36). 37

TABLE 10. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MANDIBULAR PERMANENT CANINE, FIRST

AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUE FOR MALE SUBJECTS (N=36). 37

TABLE 11. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MAXILLARY PERMANENT CANINE, FIRST AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUE FOR WHOLE SAMPLE (N=100). 37

TABLE 12. COMPARISON BETWEEN THE PREDICTED VALUES OF MESIO-DISTAL WIDTHS OF MANDIBULAR PERMANENT CANINES, FIRST AND SECOND PREMOLARS USING T/J METHOD AND THE ACTUAL VALUE FOR WHOLE SAMPLE (N=100). 37

TABLE 13. REGRESSION PARAMETERS FOR PREDICTION OF THE SUMMATION OF THE MESIODISTAL WIDTH OF CANINE AND TWO PREMOLARS IN ONE QUADRANT. 38

TABLE 14. COMPARISONS OF MEAN MESIODISTAL TOOTH WIDTHS IN MILLIMETERS WITH VARIOUS OTHER STUDIES FOR MALE AND FEMALE SUBJECTS 47

TABLE 15. COMPARISONS OF SUM MESIODISTAL WIDTHS OF GROUP OF TEETH BETWEEN THE PRESENT AND OTHER STUDIES (MEAN ± SD IN MM). 48

TABLE 16 REGRESSION PARAMETERS FOR THE SUM OF CANINE PREMOLARS SEGMENT WIDTH FROM VARIOUS STUDIES. 53

LIST OF FIGURES

FIGURE 1. TOOTH MEASUREMENT PROCEDURE FOR A SELECTED CASE. 26

FIGURE 2. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MANDIBULAR CANINE AND PREMOLARS (Y) FOR THE MALE GROUP. 41

FIGURE 3. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MAXILLARY CANINE AND PREMOLARS (Y) FOR THE MALE GROUP. 41

FIGURE 4. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MANDIBULAR CANINE AND PREMOLARS (Y) FOR THE FEMALE GROUP..... 42

FIGURE 5. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MAXILLARY CANINE AND PREMOLARS (Y) FOR THE FEMALE GROUP..... 42

FIGURE 6. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MANDIBULAR CANINE AND PREMOLARS (Y) FOR THE WHOLE SAMPLE. 43

FIGURE 7. COEFFICIENT CORRELATION BETWEEN SUM OF MANDIBULAR INCISORS (X) AND SUM OF MAXILLARY CANINE AND PREMOLARS (Y) FOR THE WHOLE SAMPLE. 43

Abstract

Background: Mixed dentition space analysis is the prediction of the mesiodistal tooth width of the unerupted canine, first and second premolars to determine the discrepancy between the available and required space in each dental jaw. This is often accomplished in the mixed dentition stage after the eruption of mandibular permanent incisors. During this stage, forecasting the mesiodistal size of unerupted dentition relative to the existing arch space available is an important diagnostic process in orthodontics. The non-radiographic tooth size prediction method "Tanaka and Johnston" derived from population of Northern European descents. However, the reliability of this method in other racial groups has been questionable.

Aim: To examine the reliability of the Tanaka and Johnston equation (1974) for the prediction of the mesiodistal width of unerupted permanent canine and two premolars in sample of Turkish patients and to derive coefficient of correlation between the summation of mesiodistal width of the four mandibular permanent incisors and the summation of mesiodistal width of canine, first and second premolars of maxillary and mandibular quadrant and to arrange a new prediction equation for this particular sample if Tanaka and Johnston is not reliable.

Material and methods: A sample of 100 sets of dental models obtained from randomly selected patients (64 females, 36 male) age ranged 13-16 years old, attending Yeni Yuzyil dental college and hospital. The mesiodistal width of four mandibular incisors, mandibular and maxillary canines, and two premolars were measured using digital caliber (Wuppertal, Germany) to the nearest 0.01mm. The actual measurements were then compared with the predicted ones derived from Tanaka and Johnston equations.

Results: Obvious sexual dimorphism was erected in mesiodistal tooth size **(**$p<0.05$). Coefficient of correlation between the sum of mandibular permanent incisors and the sum of canine, first and second premolars were 0.77 for upper and 0.79 for lower in males and 0.65 and 0.63, respectively, in female subjects. Tanaka and Johnston regression equation overpredicted the mesiodistal width of permanent canine and premolars in both dental arches and for both sexes separately and for combined sexes. New linear regression equations were suggested for males and females combines as well as for separate sexes.

Conclusion: Tanaka and Johnston equations were not accurate when applied to Turkish sample. New more accurate prediction equations were proposed. It is necessary to use separate equations for females and males.

Key words: Mixed dentition analysis; Regression equations; Mesiodistal width; Tanaka and Johnston method.

ÖZET

Giriş: Karışık dişlenme döneminde yapılan yer darlığı analizlerinin amacı, her iki çenede de sürmemiş kanin, birinci premolar ve ikinci premolar dişlerin toplam meziodistal genişliklerini tahmin ederek, mevcut ve gerekli ark mesafesi arasındaki farkı tespit etmektir. Bu analizler sıklıkla karışık dişlenme döneminde, mandibular sürekli keser dişlerin sürmesinden sonra yapılır. Bu dönemde, sürmemiş dişlerin meziodistal genişliklerinin tahmin edilerek gerekli ark mesafesi ile karşılaştırılması, ortodontik tanı sürecinde önemli bir yere sahiptir. ‘’Tanaka – Johnston analizi’’ radyografik olmayan diş boyutu tahmin yöntemidir ve Kuzey Avrupa toplumundan türemiştir. Diğer yandan, diğer ırklar için bu yöntemin güvenilirliği sorgulanmaktadır.

Amaç: Türk hastalarda, sürmemiş kanin, birinci premolar ve ikinci premolar dişlerin toplam meziodistal genişliklerini tahmin etmek için kullanılan Tanaka – Johnston denkleminin (1974) güvenilirliğini araştırmak, dört mandibular daimi keser dişin meziodistal genişliklerinin toplamı ile maksiller ve mandibular yarım çenelerdeki kanin, birinci premolar ve ikinci premolar dişlerin meziodistal genişliklerinin toplamları arasında bir korelasyon katsayısı türetmek ve eğer Tanaka – Johnston denklemi güvenilir değilse, tahmin için yeni bir denklem geliştirmektir.

Metot: Yeni Yüzyıl Üniversitesi Diş Hekimliği Fakültesi Hastanesi’nde tedavi gören, 13-16 yaşları arasındaki rastgele seçilmiş 100 hastaya (64 kız, 36 erkek) ait dental modeller kullanılmıştır. Dört mandibular kesici dişin, mandibular ve maksiller kaninlerin, ve premolarların meziodistal genişlikleri dijital kalibre (Wuppertal, Germany) kullanılarak ölçülmüştür. Gerçek değerler Tanaka – Johnston denkleminden elde edilen değerlerle karşılaştırılmıştır.

Bulgular: İki cinsiyet arasında dişlerin meziodistal boyutlarında belirgin fark bulunmuştur ($p<0.05$). Mandibular daimi keserlerin meziodistal genişlikleri toplamı ile kanin, birinci premolar ve ikinci premolar dişlerin meziodistal genişlikleri toplamı arasındaki korelasyon katsayısı erkeklerde alt çene için 0.77, üst çene için 0,79 ve kızlarda alt çene için 0.65, üst çene için 0.63’ tür. Her iki cinsiyet ayrı ayrı ve birlikte değerlendirildiğinde, Tanaka – Johnston regresyon analizi her iki dental arktaki kanin ve premolarların meziodistal genişliklerinin toplamlarının gerçek değerlerinden fazlasını öngörmüştür.

Sonuç: Tanaka – Johnston denklemi Türk hastalar üzerinde uygulandığında bulunan sonuçlar hatasız değildir. Daha doğru tahminlere ulaştırabilecek denklemler önerilmiştir. Kızlar ve erkekler için farklı denklemler kullanılması önemlidir.

Anahtar kelimeler: Karışık dişlenme analizi; Tahminsel denklemler; Meziodistal genişlik; Tanaka – Johnston yöntemi

1. INTRODUCTION

Most of modern orthodontic philosophies are based on early treatment, and before any treatment, mixed dentition space analysis should be accurately calculated (Profitt and Fields, 2000). Among the conditions which need early consideration are those in which there is disharmony between the width of tooth structure and the amount of dental arch space which should be accommodated (Huckaba, 1964; Profit and Fields, 2000).

The accurate mixed dentition space analysis determines whether the treatment plan may require serial extractions, the eruption guidance, space preservation, space regaining or just periodic follow up of the patient until the emergence of the permanent dentition (Bishara and Jakobsen, 1998). Space analysis need comparison between the available space and the space required for alignment the teeth correctly (Profitt and Fields, 2000).

Orthodontic treatment planning in mixed dentition is difficult and complicated dur to the difficulty in estimating the mesiodistal widths of unerupted permanent teeth. During mixed dentition phase, a precious assisting tool is the space analysis, which is done after the emergence of the first permanent molars and the lower incisors, as most of the lower and upper jaws growth has already happened. This analysis forecasts the mesiodistal widths of the permanent canine and premolars and define the difference between the tooth widths and the available space in each dental jaw (Sillman JH, 1964).

It is important to assess the amount of available space in upper and lower arches, because treatment is based on the amount of space shortage and severity of crowding. These days, it's important to be able to tell the parents that their child will have crowding in their teeth, and when the more favorable time for intervention (Orla Carty et al., 2015).

Mixed dentition stage is both primary and permanent dentition are found which is between 6-12 year of age. Throughout this stage clinicians can create proper and correct forecasting for space in the dental arch in permanent dentition (Hunter WS, 1978). During treatment planning in orthodontics, it is essential to forecast the room required and available for non-emerged teeth in each arch and this assessment for tooth width should be accomplished before emergence of canine and two premolars by using different approaches of space analysis.

Typically, there are four main approaches by that analyze space in the orthodontic patient in the mixed dentition, to forecast mesiodistal size of non-emerged permanent canine and premolar:

a. Measuring the unerupted teeth by using radiograph (Nance, 1947; Bull, 1959; Huckaba, 1964).
b. Proportionality charts, based on comparing and make relations between the width of different teeth within the jaw (Seipel, 1946; Moyer, 1973).
c. Regression equations which try to predict the required space by the permanent canine and premolars (Ballarad and Willie, 1947; Tanaka and Johnston, 1974).
d. A mixed of both proportionality charts and radiographs (Hixon and Oldfather, 1958; Stalley and kreber, 1980).

The Hixon forecasting technique is considered the most precise estimation of the mesiodistal size of non-emerged canine and premolars that can be accomplished by measuring size of these teeth on radiograph combined with measuring the size of the erupted lower permanent teeth on dental cast (Gardner RB, 1979; Irwin et al., 1995; Abu Alhaija et al., 2006). The precision of the approach, however, is greatly influenced by the condition of

the available x-ray (Abu Alhaija et al., 2006).

Tanaka and Johnston (Tanaka MM, Johnston LE, 1974) have regulated formulas for each jaw that are depended on simple linear regressions. Because of their simplicity, Tanaka and Johnston method is most frequently used. The researchers used erupted lower incisors to forecast the MD width of canines and premolars in 506 Northern European teenage. There was good relation between MD width of emerged lower incisors and the non-emerged canines and two premolars found (Huckaba, 1964); However, researches have presented variation in some dental characteristics among different races (Bailit HL, 1975). A lot of available data illustrates the shortage of Tanaka and Johnston approach when used between different descents other than European descent (Lee-Chan et al., 1998; Abu Alhaija, 2006). African population, for example, have larger MD tooth size than European population (Doris JM, 1981).

2. LITREATURE REVIEW

Orthodontic treatment in the early age is generally depends on an exact space analysis. It is important to evaluate the amount of available space for adjusting the dentition within the jaws because treatment varies depending on whether the space is adequate, insufficient, or excessive. In adolescents and adults, the amount of available space and the amount needed to align all the teeth can be measured directly in mouth or on dental cast, but in the mixed dentition there is a difference between the apparent crowding at one point in time and the true eventual crowding after the move from the primary and permanent to the permanent dentition. (Proffit and Fields, 2000).

Space analysis requires a comparison between the available space and the space required for alignment the teeth correctly (Proffit and Fields, 2000).

Several methods have been invented either to estimate the space available (Huckaba, 1964) or space required (Nance, 1947; Hixon and Oldfather, 1958; Staley and Kerber, 1980; Moyers, 1973; Tanaka MM and Johnston LE, 1974) for space analysis in mixed dentition phase.

2.1 Determination of space available

This is carried out by:

measuring arch circumference from the mesial of one 1st molar to the other, over the contact points of posterior teeth and the incisal edge of the anteriors;

1) Either by dividing each jaw into parts that can be measure each part separately as straight-line approximations of the jaw length (Huckaba, 1964).
2) Or by bring a wire to the line of occlusion and then leveling it out for calculation (Proffit and Fields, 2000).

3) Or computerized methods based on the previous principles. (Proffit and Fields, 2000).

2.2 Determination of space required

This is accomplished by measuring the size of each emerged tooth from contact point to contact point, assessing the MD size of non-emerged permanent dentition, and then calculating the MD sizes of the individual teeth (Proffit and Fields, 2000).

If the sum of calculated width of permanent dentition is more than the available space. There is insufficient space and crowding would be expected. But if the sum of calculated width of permanent dentition is less than the available space, gaps and spaces between the teeth would occur (Proffit and Fields, 2000).

Space analysis carried out in this way is based on three important assumptions:

1) The incisors accurately positioned anteriopostriorly (i.e., the anterior teeth are neither retruded nor protruded) (Proffit and Fields, 2000).

2) The available space will not alter due to the growth and dental compensatory tipping (Proffit and Fields, 2000).

3) All the teeth are found and reasonably normal in size (Proffit and Fields, 2000)., and it doesn't forecast the quantity of normal decline in circumference in the dental ach during transition from primary to permanent teeth (Moyers, 1988).

❖ None of these assumptions can be taken for granted. All of them must be kept in mind when space analysis is done.

2.3 Tooth size variation

Teeth can supply proof about the nature and extent of variation between human populations (Keiser J, 1990) and diversities in dental crown size have been stated between different races (Moorrees C et al., 1957). Various factors can contribute to variation in tooth size and these may be described mostly as genetic, epigenetic and environmental influences (Townsend G et al., 2008). A strong genetic contribution to variation in tooth size has been shown but environmental factors (e.g. nutrition and disease) may also play a role (Townsend G, 1978) For example, low birth weight has been associated to a reduction in the MD size of primary dentition (Fearne J, 1993).

Bailit found that there is variation in size of permanent teeth among different races. For instance, population of Asian heritage have larger maxillary lateral incisors compared to their central incisors. This feature is not appeared in the other races (Bailit H L, 1975).

In South Africa, a study of One Hundred randomly selected dental cast of black patients concluded that the tooth width of permanent canine, 1st and 2nd premolar were wider than those of white subjects (Schirmer UR, Wiltshire WA, 1997).

A study on Dominican Americans, it was found that the mesiodistal size of the teeth of Dominican Americans was larger than that of North white American sample (Santoro M, Ayoub ME et al., 2000).

Alvesalo has presented that there are sexual differences presented in the teeth, with males tending to have bigger teeth than females, indicating X

chromosome linkage with the Y chromosome also having an effect (Alvesalo L, 1971). Garn found that there was 4% difference in mesiodistal teeth sizes between two sexes. The biggest difference was in the upper canine and lowest one was for incisors (Garn et al., 1964; Moyers, 1988).

A few researchers have noted a secular trend towards an increase in dentition width with following generations (Garn et al., 1968). In addition, the size of dental arch and the size of teeth is subject to independent control systems (Garn, 1977). Crown morphogenesis is assumed to be determined by interaction of polygenic and environmental factors (Garn, 1977).

A comparative study conducted on Norwegian sample born in 1960s and 1980s, and a sample of Norwegian skulls belong to 14^{th} to 19^{th} century revealed that the permanent dentition width was larger in the modern subjects compared with the skulls. Developed nutrition is considered the major factor for this difference (Lindsten R, 2003).

2.4 Determination of unerupted tooth size

Forecasting the width of the non-emerged canines and premolars relative to the existing arch space available is an important diagnostic process in orthodontics. Prediction approaches depended on that the crown formation is done and the dentition are less vulnerable to adjusting factors (Bishara et al., 1986; Moyers, 1988).

Because of tooth size variability between races, methods based on specific racial sample may be not applicable to another races so it is not universal, we can't apply it on another races, Therefore, their reliability and

precision is varied and doubtful in different ethnic samples (LeeChan et al., 1998). Determination the amount of space within the dental arch is important in mixed dentition phase and play important role in treatment plan's decision. So, it will be useful for orthodontists to use a precise approach to forecast the size of non-emerged teeth in a particular racial group (Wangpichit et al., 2001).

Different groups of dentitions have been used as predictor for the predicting of MD width of unerupted canine and premolars in mixed dentition space analysis. Sum of mesiodistal width of four permanent mandibular incisors has been widely used to develop regression equations to accurately predict size of unerupted teeth specific to their own population by many authors (Al-Khadra BH, 1993; Digane F, 2004; Abu Alhaija, 2006);

The use of numerous factors in multiple linear regressions may elevate the prediction, but they may be very difficult for dental use. But, if a proper factor is used for simple regression analysis, precision can still be satisfied (Staley et al., 1984; Van der Merwe, 1991).

2.5 Odontometric measurements techniques

Measuring the mesiodistal width of the teeth can be done on the dental cast and/or on radiograph, or directly in the mouth to evaluate either erupted and unerupted teeth. However, Both the radiograph and the dental cast should be high quality.

Hunter and Priest (1960) reported that measuring the teeth on dental cast were slightly larger than those measured directly in mouth. Because of alginate initial expansion and the gypsum setting expansion, the reproduction

of teeth by stone tend to be slightly greater than original teeth size (Philips R.W., 1973). Hunter and Priest also compared the soaped and non-soaped models, they found the soaped models are to be slightly larger in overall dimensions, probably simple by the addition of a slight film. However, the size of this increase is insignificant as far as individual teeth are concerned.

There is a general consensus is that measuring the mesiodistal width of teeth from dental cast are more consistent thus, more accurate than measurements taken directly from mouth, especially in posterior segments where measurements become difficult to take (Axelsson and Kirveskari, 1983).

There are basically two techniques for measuring the teeth:

a. Sliding caliper with a vernier scale and a graded gauge.

b. A conjunction of divider with a millimetric rule.

Hunter and Priest (1960) stated that the sliding caliper to be more exact, while the divider gave frequently higher mean readings. Presently most of odontometric studies apply the former method, which is also available with a digital micrometer (Zilberman et al ,2003). The caliper should be held parallel to the occlusal surface and perpendicular to the long axis of the tooth according to the method described by Seipel and Moorrees in 1965, This is to measure the greatest mesiodistal width of the tooth at the contact points. Furthermore, Wangpichit et al. (2001) stated that when the tooth is rotated or malposed, the measurements should be taken between the points on the approximate surface of the tooth, where it is judged that the normal contact should be with the adjacent tooth.

Many other researchers have confirmed that the measure of mesiodistal width tooth size is a highly repeatable measure (Doris et al., 1981). Zilberman et al (2003) reported that measurement with digital calipers on dental casts produced the most accurate and duplicable values and digital caliper seem to be a most suitable instrument for scientific work.

Orthodontists routinely use and maintain pre and post-treatment plaster models, for reasons of convenience and storage they started to use computerized digital models. Santoro et al. (2003) did a study comparing measurements made on plaster and digital models. He concluded that the tooth width made on plaster and computerized models presented statistically pronounced discrepency; however, these differences do not look to be clinically important.

2.6 Measurement of unerupted teeth on radiograph

The approach of computing emerged teeth on x-ray has been used clinically for some time. Different approaches for assessing the accurate width of unerupted dentition from x-rays have been recommended by many authors.

Previously, clinicians depended mainly on the averages of the mesiodistal tooth widths (Black GV, 1902). However, the use of those averages could not be validated with the evidence of tooth size variations within individuals and different populations (Ngesa JL, 2005).

Nance et al compared the primary canine and molars mesiodistal widths on dental cast and the unerupted canine and premolars mesiodistal widths on periapical radiograph, by using paralleling technique (Nance HN, 1947). Paralleling periapical x-ray is recommended to use in this analysis and better than panoramic x-ray. Because paralleling periapical has less distortion, wide focus margin, more focus and less elongation than panoramic x-ray. Paralleling periapical radiograph is more accurate especially in canine area. Radiograph is essential to evaluate space in both upper and lower arches in all racial groups, with accuracy can reach to good grade (Irwin RD et al., 1995). But it can be complicated to provide an undisoriented look of the canine. teeth can be rotated which give false measurements. Nance et al reported that space analysis by using radiographs can maximize the predicted length of arch by 3mm, that has the possible there is no need for extraction of teeth (Nance HN, 1947). It is also not easy to adjust the proper dose of radiation that is needed for full series of periapicals in the growing patients (Sonick M, Abrahams, 1994).

Cohen tried to explain a method to calculate the correction factor of elongation of x-ray (Cohen ME, 1959). This factor is calculated by measuring the mesiodistal width of primary erupted teeth in patient mouth by digital calipers and then divided it on the mesiodistal width of the same teeth in radiograph. The result is called correction factor and it is become applicable for use to measure the width of unerupted teeth. But little evidence is available about the accuracy of this method (Cohen ME, 1959).

In summary**;** The accuracy of radiographic prediction methods is largely influenced by the quality of the radiograph and the technique with which the films are taken; overexposure, underexposure, distortions of x-rays are certain disadvantages. Also, high quality films and a meticulous radiographic technique are essential for minimal error. Even if these variables are

controlled, the teeth can be rotated in their crypts, giving false measurements. Hence these disadvantages can only be overcome with prediction tables or equations (Bherwani and Fida, 2011).

2.7 Measurement of unerupted teeth using proportionality tables

The methods that use prediction tables depend on the higher linear correlation between different combination of teeth. They use the mesiodistal width of erupted teeth to forecast the width of unerupted ones (Hunter WS and Priest WR, 1960).

Seipel published the first study in this field (Seipel CM, 1946). Further Carey was the first who found strong connection between the mesiodistal width of lower incisors and the mesiodistal width of non-emerged canine and premolars (Carey CW, 1946). Proportionality tables try to establish a correlation between the erupted teeth and the unerupted teeth. At first, these were attempts to put a linear connection between primary and unerupted permanent teeth. Because the results showed no obvious correlation, Further researches tried to find correlation between non-emerged permanent teeth with the erupted first permanent molars, but this also gave poor correlation.

Singh and Nanda in a study of Indian children in 1972 concluded that there is a strong relationship between sum of mesiodistal width of lower permanent incisors and width of unerupted canine and premolars (Singh M and Nanda RS, 1972).

Moyers and Jenkins reached to better results with strong correlation when tried to found a connection between unerupted canines, premolars and incisors (Moyer RE, 1988). The correlation coefficient was 75% which means there is a strong correlation, 75 out of 100 cases measured can be forecasted

correctly (Moyer RE, 1988). The Moyer's prediction chart is used by measuring the mesiodistal width of mandibular central and laterals. This width is then compared to proportionality charts to forecast the MD size of upper and lower non-emerged canine and premolars. Moyer prediction is based on lower incisors not the uppers, because there is an obvious variation in width of upper lateral incisors, Besides the lower incisors erupt before the upper incisors which allow earlier prediction. Further to that, there is no need to radiograph to estimate the widths of the non-emerged permanent teeth. Many researchers have found a trend toward increase in tooth size in sequent descent, which means that the values found in the chart tends to minimize the width of the non-emerged teeth in contemporary communities. Due to the biological differences in the progression from primary to permanent dentition, so should use the table by caution. There is also variation in mesial movement of permanent 1st molars between individuals due to the loss of the primary teeth. Another disadvantage of this method was the sample was taken from white North American. The applicability of Moyer analysis is reasonable when apply it on North European white children. However, when apply it on other races is not reliable. So, race specific is one of the limitations for Moyer analysis.

Due to the variation in tooth size between races, Singh & Nanda found that sample collected from specific race for means of space analysis would not be applicable to another racial group (Singh M and Nanda RS, 1972).

Multiple studies were done on several racial groups to regulate a specific correlation table for each group. Although the results that we gained from these studies were useful and reliable, but unfortunately none of these studies were validated. So, there is a doubt about data's accuracy. So, more studies should be done on different racial group to make more reliable proportionality table

2.8 Measurement of unerupted teeth using regression equations

All regression equations depended on statistical linear correlation between the total mesiodistal width of lower incisors and the total mesiodistal width of unerupted canine and two premolars (Ballard & Wyile, 1947; Tanaka & Johnston, 1974). Ballard & Wyile (1947) formulated the first forecasting equation. Ballard & Wylie established this equation despite it has a low coefficient of correlation (r= 0.64).

⟹ $Y=9.41 + 0.527X$;

Where Y indicates to the total of the MD widths of the unerupted canine and premolars for each quadrant, and X indicates to the total of the mesiodistal width of four permanent lower incisors.

Ballard and Wylie found that their equation had less error of mean (0.6 millimeter) than using X-rays approach only (2.2 millimeter). As a result, they advised to use their equation as a addition to Nance's approach (1947).

Tanaka and Johnston (1974) based on a European sample (506 subject) – used the sum of mesiodistal widths of mandibular incisors to establish regression equation to predict the width of unerupted canines and premolars. They formulated a linear regression table similar to Moyer's table but were able to develop a newer equation which reached the 75% probability level. The unerupted canine and premolars can be predicted by talking one half the width of the mandibular incisors and adding 10.5 mm for mandibular teeth and 11.0 mm for maxillary teeth, the result equals the predicted size of the canine and premolar in one side of the jaw. In this method, radiographs and tables are not required. Just simple equation to be memorized. This approach is arguably the easiest and quickest of all methods of mixed dentition space analysis. The correlation coefficient (r) which achieved by Tanaka & Johnston regression equation are (r = 0.625) for upper dentition and (r = 0.648) for lower dentition. There were obvious differences in the coefficient of correlation in different populations (Lee-Chan et al., 1998; Al-Khadra, 1993; Jaroontham and Godfrey, 2000).

Although these low to moderate correlations some benefits found in their clinical use. The lower incisors appear early in the mixed stage and have small variation in size and shape (Moyer, 1988). Furthermore, the location of permanent lower incisors in the middle of the space management problems not only provide one of the advantages in their use in predicting the unerupted tooth sizes of the canines and premolars but also provide easy accessibility for exact measurement both in the mouth and on the casts (Moyer, 1988). Sillman (1964) reported that with the eruption of the first permanent molars and mandibular incisors, most of expected growth in mandibular arch has been attained.

Regression equations used for predicting the size of unerupted teeth are based on genetic inheritance of tooth size. The size of permanent teeth is varied between different ethnic populations (Bailit, 1975; Bishara et al., 1986). So, Tanaka & Johnston's equation has also been done on a specific racial group, the analysis based on white ethnic population sample.

Al Khadra stated that Tanaka and Johnston equation overestimated the size of unerupted canine and premolars in a Saudi population. The data illustrated the limitation of the method when applied to a sample population of other than European origin (Al-Khadra BH, 1993). Another study proved that Tanaka and Johnston prediction equation was not accurate in a sample of Hong Kong population and new regression equations were introduced (Yuen KK et al., 1998).

In a study of Jordanian children in 2006, Abu Al Haija and Qudeimat tested the reliability of Tanaka and Johnston approach on a Jordanian community, and aimed to regulate a modified equation to be accurate on Jordanian population if Tanaka and Johnston's method is not reliable. They found that Tanaka and Johnston method of prediction overestimated the mesiodistal width of both upper and lower canine and premolars when compared with measurements on dental casts using digital calipers (Abu Al-Haija and Qudeimat, 2006).

Dasgupta and Zahir in 2012 tested the reliability of Tanaka and Johnston on Bengali children. They found that the Tanaka and Johnston equation for space analysis is not applicable for Bengali children and for North European descent. So, they formulated in their study a new equation to allow more accurate and reliable space analysis for Bengali population (Dasgupta B, Zahir, 2012).

In a study of Nepalese Brahmins children in 2017, Gyawali et al reported that the prediction of Tanaka and Johnston did not accurately predict the mesiodistal dimension of unerupted canine and premolars in Nepalese children as it was for those of north European descent. In this study Gyawali et al formulated a new regression equation that accurately predict the mesiodistal width of maxillary and mandibular permanent canines and premolars in Nepalese Brahmins (Rajesh Gyawali et al., 2017).

Recently many researches have been done to evaluate the reliability of Tanaka and Johnston (1974) method in different ethnical groups: Lee-Chan et al (1998) for Asian Americans, Ferguson et al (1978) for black Americans, Schirmer and Wiltshire (1997) for black south Africans, Al-Khadra et al (1993) for Saudi Arabians, Nourallah et al (2002) for Syrians, Diagne et al (2003) for Senegalese.

2.9 Prediction from combination of radiograph and prediction tables

Many approaches have used a multiple of measurements from emerged teeth and radiographs of non-emerged teeth to assess the space needed comparative to the room existed. The two approaches of analysis were mixed as it was thought at this would supply a more exact account of tooth size consistently (Ballard & Wylie, 1947). This combines the best characteristics of both methods in an effort to upgrade predictability. The condition of periapical x-rays will be the determinant to prefer this method over the others. The prediction approaches which depend on regression equations are more precise than using low quality x-rays While high quality x-rays are preferred than regression equations (Foster and Wylie, 1958).

Hixon and Oldfather in 1958, published a method to forecast the mesiodistal width of mandibular canines and two premolars. Data from Iowa facial growth study was used to supply an equation to forecast the unerupted canine and premolars width. In joining measurements from radiograph and cast, Hixon and Oldfather joined the width of permanent mandibular central and lateral incisors with those of unerupted premolars measured on periapical x-ray. The total value is named "measured value" which is utilized to decide the "estimated value" from forecasting graph. The forecasting graph compensates for magnification in radiograph and are accurate only for measurements captured from radiographs from a long cone (16 inch) radiograph unit. Some limitations of this method include that they only considered information collected from the lower teeth. Also, the space was analyzed individually side by side rather than as a whole arch. Commonly nowadays, it is accepted this technique routinely underpredict the mesiodistal size of canine and two premolars. Furthermore, the amount of the sample was small and the population was not well presented (Moyer, 1973; Gardner, 1979). It's obvious that their technique didn't spread wide between clinicians although the low standard error of estimation (0.6mm) that was appeared.

Staley and Kreber in 1980 modified the original Hixon and Oldfather's (1958) method to improve its predictive value by gaining data from clearly defined population type and increase the size of the sample. They also took measurements from both sides of the arch, where the original Hixon and Oldfather's method had only gained data from the left side of the mouth. The use of calipers allowed for measurements to the nearest 0.05 mm, making the data more precise than those gained with Boley gauge which used by Hixon and Oldfather. Furthermore, Staley and Kreber had the chance to use computer technology to analyze data and chose to exclude teeth which were rotated. The newly adjusted equation emerged in a little standard error of estimation as related to the initial regression equation (Staley and Kreber, 1980).

This method is considered to be the most accurate ones due to the lowest standard error of estimate. On the other hand, it is complex and may give only marginal improvement over simpler methods, discouraging its use by

orthodontists, and many found it difficult to use (Gardner, 1979; Irwin RD et al., 1995).

2.10 Comparisons of the prediction methods

Several studies comparing different techniques of mixed dentition analysis were done. Zilberman et al (1977), Kaplan et al (1978), Gardner (1979), Staley and Hoag (1978), De Paula (1995) were few of them who compared many mixed dentition analyses to find their reliability on different populations. Most of these studies have reported that the measuring the unerupted teeth on radiograph were more accurate for determining their true mesiodistal sizes.

Foster and Wylie (1958) compared the predicted mesiodistal sizes of the unerupted permanent canines, 1st and 2nd premolars from Ballard & Wylie (1947) prediction equation and x-ray approach with same teeth after eruption, both approaches revealed inaccuracies in a sample of 14 children. These inaccuracies extended from overprediction of 3.9 mm and 4.0 mm by Ballard and Wylie equation (1947) and underprediction of 5.7 mm and 1.6 mm by radiographic approaches.

Cohen et al. (1959) concluded that the prediction tables and regression equations work well when applied to target population from which they were derived. If the patient is from North European descent, the predictions based on the combined dental cast-radiographic approach have the least variable overall validity. This makes Staley-Kreber technique the most precise followed by Tanaka and Johnston and then that of Moyers. In the case of the patient who does not belong to the target population from which the correlation is based, radiographic estimation is the best method.

Kaplan made a comparison between three mixed dentition analyses; Moyer, Tanaka & Johnston, and Hixon and Oldfather. He found that Hixon and Oldfather was the most precise one because it used radiograph and the erupted teeth to forecast the unerupted ones. He made modification for Hixon

and Oldfather approach and included Lower lateral incisors which was not included in the original approach (Kaplan et al., 1977). The modified approach was more accurate than Tanaka & Johnston and Moyer with higher correlation and lower standard error of estimation between the predicted and the actual measurements.

Staley (1979) stated that in non-radiographic analyses which differentiate between the sexes are more precise than those analyses which use same variables for males and females. However, The Hixon and Oldfather approach (1958) didn't affect by sexes.

Gardner (1979) reported that Nance technique (1947), Moyer tables (1973), Tanaka and Johnston regression equation (1974) bear to maximized the unerupted teeth 1-3 millimeter but Hixon and Oldfather's approach (1958) minimized the unerupted teeth about 0.5 millimeter.

A newly study in (2017) they compared and correlated radiographic and non-radiographic methods of predicting unerupted canine and premolars in children of Himachal Pradesh in India. They reached to conclusion the correlation and determination coefficients for non-radiographic techniques are low as compared to radiographic techniques. Thereby concluding that, estimation of unerupted tooth width in early mixed dentition is best made by means of radiographs. The non-radiographic methods as given by Moyers and Tanaka and Johnston give reasonable approximation for forecasting of unerupted canine and premolars when it's impossible to obtain good quality image (Kahol et al., 2017).

2.11 Space analysis in different races (Black Africans, Chinese, European, Latins)

In a randomly selected sample of One hundred thirty-one Kenyan patient attending to the Kenyatta National Hospital, the mean sum of the four mandibular incisors was used to determine the sum of the canine and premolars in one quadrant. The predicted values of the mesiodistal tooth widths were compared statistically with their respective actual sum of the canine and premolars of the same quadrant. Tanaka and Johnston method did not show any statistically obvious differences for separate males and females or combined genders at 95% confidence level. However, it was observed that

Tanaka and Johnston method was the most accurate among the non-radiographic prediction approaches in the mixed dentition analysis in the Kenyan sample (Ngesa JL ,2005).

In a study carried Italy, 150 dental model of permanent dentition (68 males, 82 female) were collected from the department of Orthodontics at University of Catania. The width of canine and premolars as a group and mandibular incisors were taken by means of a bow-compass and sliding digital caliper. The results explained that the total of mesiodistal tooth size of canine and premolars was larger in males than in females. Furthermore, the results suggested that the North-American predictions overpredicted the tooth size of Canine and premolars in both genders (Verzi P et al., 2002).

Yuen KK et al tested the reliability of regression equations on Chinese group and he developed a new equation which were more precise than that for Tanaka & Johnston to precisely forecast the size of unerupted canine and two premolars (Yuen KK et al., 1998).

Melgaço (2007) tested the reliability of the methods of Moyers, Tanaka and Johnston, and Flores-Mir in Brazilian sample. Statistically significant differences were found, although the differences were not clinically relevant. He formulated a new regression equation using mandibular permanent incisors as a predictor for the sum of the widths of the lower canine and premolars (Melgaco CA et al., 2007).

In a study carried out in Jordan on 226 teenage patients with fully erupted teeth, they tested the reliability of the regression equation which done by Tanaka & Johnston. They found that Tanaka & Johnston minimized the size of unerupted teeth (canine and two premolars) in both females and males except in the upper arch in male patients which was maximized. Thus, new equation was formulated for the Jordanian population to improve the prediction (Abu Alhaija ESJ and Qudeimat, 2006).

2.12 Gender Dimorphism

Gender dimorphism does exist in most of odontometric studies of mesiodistal width of permanent teeth;

Legovic et al (2003) stated that it was important to determine whether or not that the sizes of teeth in male and female vary and reported a statistically obvious difference between male and female (Legovic M, 2003).

A study carried out on a sample of Black Kenyan descent found that the average mesiodistal teeth size of male patients were wider than female in both maxillary and mandibular arch. The differences were statistically significant ($p<0.05$). The most statistically significant differences were noticed in the upper central incisors and both upper and lower canines, while the smallest differences were observed in the first and second premolars in the upper arch and for the incisors in the lower arch (Ngesa JL, 2005).

Digane F et al in an odontometric study on Moroccan sample, they measured the greatest mesiodistal width of all mandibular and maxillary canine and premolars and mandibular incisors with digital orthodontic caliper. Significant gender dimorphism was found in tooth sizes ($p<0.001$) (Digane F et al., 2004).

Ling JY and Wong RW in an odontometric study on a sample of Southern Chinese in Hong Kong found that in both dental arches the males had larger absolute mesiodistal tooth dimension in all teeth (incisors, canines, premolars and molars). The absolute inter-gender differences of the size ranged from 0.05 mm (mandibular central incisor) to 0.42 mm (mandibular canines). All the teeth sizes were significantly different ($P \leq 0.05$) between the two sexes, with the exception of the lower central incisors. It was concluded that, separate prediction equations are needed for the females and males (Ling JY, Wong RW, 2000).

Muzzafer Ateş et al (2006) in a study carried out on a sample of Turkish students (50 male and 50 female) found that the mean mesiodistal and buccolingual teeth size for males were bigger than females in maxillary and mandibular jaws. The biggest differences were noticed in both lower and upper canines and upper lateral incisors, while the smallest one was in lower incisors (Muzzafer Ateş et al., 2006).

2.13 AIM AND OBJECTIVES

The aims of this study were to test the reliability of Tanaka and Johnston equation (1974) of predicting the size of permanent canine and premolars in Turkish sample, and to derive coefficients of correlation between the combined mesiodistal widths of four permanent mandibular incisors and the combined widths of the maxillary and mandibular canine and premolars.

Objectives

a) To calculate the mesiodistal widths of permanent canines and premolars from Tanaka and Johnston equation (Predicted value) in the Turkish sample.

b) To compare the predicted values of mesiodistal width of permanent canine and premolars with the measured mesiodistal width of canine and premolars (Actual value).

c) To derive coefficient of correlation between the width mandibular incisors with the maxillary and mandibular canine and premolars.

d) To formulate new equations If Tanaka & Johnston is not precise.

3. Material and Methods

3.1 Ethical Considerations

Ethical confirmation for the research was attained from the Head of orthodontic department, Dean of dental college, and from Ethics and Research Committee at university of Istanbul Yeni yüzyıl (Appendix 1 & 3).

The parents of the participating patients were informed and gave informed consent by signing the consent form (Appendix 2). Only patients with informed consent were entered into the study.

3.2 Study design

The present study is a hospital-based, cross sectional one.

3.3 Sample selection

The sample for this cross sectional study consists of pretreatment study models for 100 patients, which include 36 male and 64 female with the age group of 13-16 years old who presented with complete eruption of the permanent teeth from 1st molar to 1st molar randomly selected from the records of patients, reporting to the department of orthodontics at Yeni Yuzyil dental college and hospital, Istanbul, Turkey.

Mixed dentition space analysis is used in the treatment planning for mixed dentition stage where not all the permanent canines and premolars are present in the mouth. However, in this study included only dental casts with presence of permanent teeth (Canine and two premolars) in order to test the reliability of Tanaka and Johnston equation (1974) of prediction.

The effect of attrition and erosion are minimized significantly in the present study because only the teeth of adolescent (13-16 years old) were measured (Newly erupted teeth).

3.4 Inclusion Criteria:

1. Patients had to be native Turkish.
2. All teeth must be present and fully erupted permanent incisors, permanent canines and premolars.
3. Intact dentition with no restorations, fractures, proximal caries or age-related attrition.
4. Absence of dental anomalies in tooth morphology (abnormal sized or shaped teeth).
5. No missing or supernumerary teeth.
6. No previous orthodontic treatment.
7. Mild crowding up to 3 mm.
8. High quality dental models free from any distortion.

3.5 Sampling technique

Stratified random sampling technique.

3.6 Impression and pouring procedures

Dental impressions were taken with alginate impression material (Blueprint cremix). A mix of alginate impression material was placed into the standard orthodontic trays. The standard techniques for the mixing of alginate, impression disinfection, and storing the impression. Within one hour the impression were poured with dental stone to avoid any dimensional change. The dental casts were trimmed in a standard manner. The dental casts were non-soaped or waxed.

3.7 Measuring technique of mesiodistal tooth width

The mesiodistal size of the teeth was measured by electronic digital vernier caliper (150mm Erbschloe-Wuppertal, Germany), which had accuracy of ±0.01 mm. The tips of the caliper were accurately engineered to facilitate the greatest degree of accuracy. All teeth from right second premolar to the left second premolar were measured. The mesiodistal dimension of the teeth were measured at contact points (Highest width of the teeth) as illustrated by Hunter & Priest (1960). The caliper was held parallel to the occlusal surface and perpendicular to the long axis of the tooth according to the approach described by Seipel and Moorrees in 1965 (figure 1). The measurements were recorded to 0.01mm, and entered to excel spread sheet.

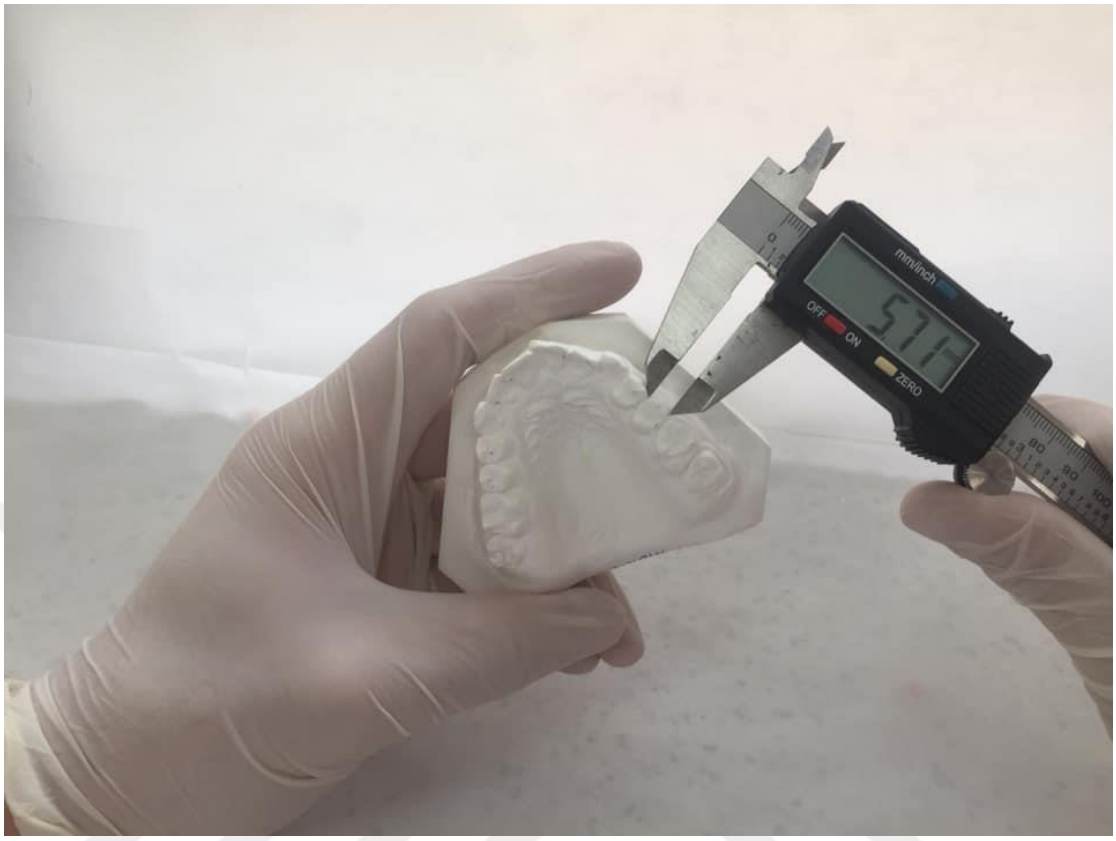


Figure 1. Measuring the mesiodistal tooth width for randomly selected case.

The total of the four lower incisors was determined for each dental cast. Because of high bilateral symmetry in the MD size of canines and premolars has been documented in the literature (Dahlberg G, 1940; Digane et al., 2004), The values which obtained from the right and left posterior segment were averaged so that would be one value for the maxillary canine and premolars and one value for the mandibular canine and premolars.

The sum of the following groups of teeth were pooled and the mean MD tooth width calculated for each sex, and for the whole sample:

a) Mandibular permanent central and lateral incisors.
b) Maxillary permanent canines and premolars.
c) Mandibular permanent canines and premolars.

3.8 Prediction of mesiodistal size of canine and two premolars (Predicted tooth values)

The prediction of permanent canine, first & second premolars in both arches were made with sum of four mandibular incisors using Tanaka and Johnston equation (1974);

In Tanaka and Johnston prediction equation, the sum of the mesiodistal width of the four mandibular incisors are correlated with the sum of the mesiodistal diameters of the maxillary and mandibular canines and premolars of both arches separately;

Tanaka and Johnston equations are as follow;

Y= 10.5 + 0.5X (predicted width of lower canine and premolars in one quadrant).

Y= 11 + 0.5X (predicted width of upper canine and premolars in one quadrant).

Where, Y indicates the total width of permanent canine and two premolars in one side and X indicates the total mesiodistal size of permanent lower incisors.

3.9 Comparison between Actual and Predicted tooth measurements

Actual tooth measurements which obtained from the sample (measured ones) were compared with the predicted values derived from Tanaka and Johnston equations (1974).

3.10 Null Hypothesis

There is no difference between the sums of measured mesiodistal widths of permanent canine, first and second premolars in one quadrant of either mandibular or maxillary arch, and their predicted values which obtained from Tanaka and Johnston regression equation (1974).

3.11 Reliability of the measurement

All dental models were high quality, free of distortion and non-soaped. Measurements of teeth were taken by one operator (M. Odeh) under natural day light and neon light within one-week interval.

To test the reliability of the measurements, 20 dental model, randomly selected, were measured and remeasured within 7 days interval by the same examiner. The reproducibility of the double measurements was expressed using Dahlberg formula (Dahlberg G, 1948) to examine the method of error:

$$ME=\sqrt{\Sigma d^2/2n}$$

Where ME = the method error, d = the differences between the repeated and the original values, and n = the total number of double determinations. The error values of mesiodistal teeth widths ranged from 0.05-0.25 mm. The values were considered clinically acceptable.

3.12 Statistical analysis

Computer software, program SPSS (Version 23.0) was used to analyse the statistical data achieved from this study. Two-tailed paired t-test were used and statistically significant differences were achieved only if the P-value was less than 0.05;

- Kolmogorow-Smirnov test ($p>0.05$) to examine the normal distribution of the data.
- Two-tailed paired t-tests were done to evaluate bilateral symmetry of mesiodistal widths of all measured individual teeth and combined mesiodistal width of canine, first and second premolars of each dental arch.
- To evaluate the correlation between the groups of teeth were used Pearson product-moment Coefficients.
- Independent t-test was done to compare the results between females and males.
- Paired t-test were used to examine the significance of the differences between the predicted and the measured values.

- ❖ A simple regression analysis of the dependent values "Y"= (the mean sum of the mesiodistal width of canine, first and second premolars) was done with independent values "X"= (mean sum of mandibular permanent incisors) to formulate a regression possible equation for Turkish sample.

4. Results

4.1 Study sample:

A total of 100 sets of dental casts were obtained from 64 female and 36 male participants. The mean age of the females and males was 14.5 years (SD; 1.004 years) and 14.52 years (SD; 1.05 years) respectively.

Table 1. Age distribution of Turkish sample.

Sex	Mean (years)	Range (years)
Male (36)	14.52	13.1-16.3
Female (64)	14.5	13-16.5

	N	Range	Minimum	Maximum	Mean	Std. Deviation
ffff	64	3.50	13.00	16.50	14.5038	1.00355
Valid N (listwise)	64					

	N	Range	Minimum	Maximum	Mean	Std. Deviation
male	36	3.20	13.10	16.30	14.5239	1.04570
Valid N (listwise)	36					

4.2 Reliability of the measurements

Dahlberg method error showed the differences between repeated and original measurements;

The errors that appeared when repeat the measurements varied between (0.05) millimeters and (0.25) millimeters with average of (0.104) millimeters in the maxillary arches and (0.114) millimeters in mandibular arches which are less than 1 mm; indicating that the measurement is reliable. These values of method error were acceptable for odontometric studies.

Table 2. Reproducibility of the study Findings (The differences between repeated and original measurements).

Tooth#	Upper teeth (mm)	Lower teeth (mm)
RCi	0.055	0.064
LCi	0.084	0.077
RLi	0.250	0.137
LLi	0.145	0.069
RCa	0.061	0.191
LCa	0.093	0.150
R1st Pm	0.075	0.050
L1st Pm	0.126	0.183
R2nd Pm	0.062	0.075

L2nd Pm	0.088	0.143
Mean	**0.104**	**0.114**

- RCi: Right central incisor, LCi: Left central incisor, RLi: Right lateral incisor, LLi: Left Lateral incisor, RCa: Right Canine, LCa: Left canine, R1stPm: Right 1st premolar, L1stPm: Left 1st premolar, R2ndPm: Right 2nd premolar, L2ndPm: Left 2nd premolar.

4.3 Descriptive statistics for the sample:

Table (3) below shows the means of the mesio-distal widths of the teeth, its ranges and standard deviations are presented for the female, male subjects and the combined sexes. For female subjects, there were less variability in mesiodistal size of the lower incisors than the upper incisors. But in the other teeth as the second Premolars there were variability in the mandibular teeth more than in the upper teeth. A similar thing was also noticed in the male subjects as well as for the combined sexes. This variability is described by the SD of their mesiodistal size of dentition.

- The values obtained from right and left side were averaged so that would be one value for each tooth.

Table 3. Mean, Range and standard deviation of mandibula and maxillary teeth for the males, females and both sexes combined.

Tooth		Mandibular			Maxillary		
	Gender	Mean	Range	SD	Mean	Range	SD
2ndPm	M	7.4439	6.15-8.40	0.49656	6.8986	5.79-7.80	0.45099
	F	7.0986	6.20-7.95	0.42528	6.6237	5.73-7.56	0.42399
	M+F	7.2229	6.15-8.40	0.47959	6.7227	5.73-7.80	0.45153
1STPm	M	7.3128	6.30-8.28	0.46615	7.1578	6.26-8.12	0.45269
	F	7.1069	6.29-8.25	0.40790	7.0061	5.91-7.95	0.46683
	M+F	7.1810	6.29-8.28	0.43882	7.0607	5.91-8.12	0.46528
Ca	M	7.2603	6.01-8.33	0.49001	8.2447	7.35-9.12	0.43592
	F	6.6984	5.83-7.73	0.44479	7.7556	6.81-8.98	0.47923
	M+F	6.9007	5.83-8.33	0.53315	7.9317	6.81-9.12	0.51865
Li	M	6.1961	5.26-7.54	0.47166	7.0369	5.83-8.52	0.62386
	F	5.9470	5.22-6.54	0.31854	6.7383	5.53-7.82	0.50446
	M+F	6.0367	5.22-7.54	0.39706	6.8458	5.53-8.52	0.56595
Ci	M	5.6219	4.75-6.66	0.41292	9.0256	7.24-10.94	0.74654
	F	5.4456	4.89-6.00	0.26642	8.6631	7.65-9.80	0.45565
	M+F	5.5091	4.75-6.66	0.33568	8.7936	7.24-10.94	0.59977

❖ M: Male; F: Female; SD: Standard deviation; 2ndPm: Second Premolar; 1stPm: First Premolar; Ca: Canine; Li: Lateral Incisor; Ci: Central incisor

4.4 Bilateral symmetry

The comparison between the right and left individual mesiodistal tooth width differences for the whole sample (N=100) was done by paired t-test, because normal distribution of the data was confirmed by Kolmogorow-Smirnov test (p>0.05). In addition, Pallant in 2003 stated that with a sample size greater than 30, violation of assumption of normality is unlikely to cause any problems. The mean differences between the left and right mesiodistal sizes of any single tooth extended from 0.14 to 0.35 millimetresas showed in table(4) below. Only mandibular lateral incisors exhibited statistically obvious bilateral differences of 0.35 millimetres ($p < 0.05$) with standard deviations of 0.397 millimetres and mandibular central incisors showed statistically significant bilateral differences of 0.311 millimetres ($p < 0.05$) with standard deviations of 0.33568 millimetres . But, when Bonferroni correction was applied ($p<0.005$), no statistically significant bilateral differences between them were observed (Table 4).

Table 4. Comparison between Right and left mesiodistal tooth width for whole sample.

	Mandibular					Maxillary				
	Mean	SD*	t*	df*	P	Mean*	SD*	t*	df*	P
2nd Pm	0.168	.47959	1.67	100	.007	.169	.45153	1.688	100	.007
1st Pm	0.216	.43882	2.16	100	.00	.157	.46528	1.570	100	.014
Ca	0.222	.53315	2.22	100	.00	.148	.51865	1.484	100	.024
Li	0.350	.39706	3.50	100	.00	.228	.56595	2.278	100	.00
Ci	0.311	.33568	3.11	100	.00	.294	.59977	2.943	100	.00

- 2nd Pm: 2nd premolars; 1st Pm: first premolar; Ca: canines; Li: lateral incisors; Ci: central incisors . Mean represents absolute mean (without positive or negative sign); SD:standard deviation; df: degree of freedom.
- P value, P<0.05; Significance level with Bonferroni correction, P< 0.005.

4.5 Gender comparisons of mesio-distal tooth widths

In the following tables (table 5 and 6) the data was based on the average mesiodistal width of teeth on the right and left side.

The results of independent t-tests presented in Table 5 below show obvious gender differences. The mean mesiodistal tooth widths of the female sample were smaller than male subjects in both maxillary and mandibular jaws. All mean differences were statistically significant at $p< 0.05$ for upper and lower teeth, except upper first premolars ($p=0.118$). The most noticeable differences were appeared by both lower (0.56±0.096 mm) and upper (0.48±0.097 mm) canines, but upper first premolars (0.15±0.096 mm) and lower central incisors (0.17±0.068 mm) showed the least differences.

Table 5. Comparison of mesiodistal width of individual teeth between male and female subjects.

	sex	N	mean	SD	T	P	Mean diff	Std errorDD
	Mandible							
2nd Pm	m	36	7.44	0.49	3.66	0.00	0.34	0.094
	f	64	7.09	0.42				
1st Pm	m	36	7.31	0.46	2.3	0.024	0.20	0.089
	f	64	7.10	0.40				
Ca	m	36	7.26	0.49	5.84	0.00	0.56	0.096
	f	64	6.69	0.44				
Li	m	36	6.19	0.47	3.14	0.002	0.24	0.079
	f	64	5.94	0.31				
Ci	m	36	5.62	0.41	2.59	0.011	0.17	0.068
	f	64	5.44	0.26				
	Maxilla							
2nd Pm	m	36	6.89	0.45	3.04	0.003	0.27	0.090

	f	64	6.62	0.42				
1stPm	m	36	7.15	0.45	1.57	0.118	0.15	0.096
	f	64	7.00	0.46				
Ca	m	36	8.24	0.43	5.05	0.000	0.48	0.097
	f	64	7.15	0.47				
Li	m	36	7.03	0.62	2.60	0.011	0.29	0.114
	f	64	6.73	0.50				
Ci	m	36	9.02	0.74	3.01	0.003	0.36	0.120
	f	64	8.66	0.45				

Table 6 show obvious gender differences between the means of the sum of mesiodistal widths of lower permanent incisors, and the total of canine and two premolars of both jaws indicating that male subjects had greater mesiodistal tooth size than females in all groups.

Table 6. Comparisons of mesiodistal width of group of teeth between male and female subjects.

Sum of teeth	Gender	mean	Sd	Mean diff±SEM	t	P
Mandibular Incisors	M	23.63	1.71	0.83±.28	2.9	0.004*
	F	22.80	1.09			
Mandibular Canine and premolars	M	22.01	1.32	1.09±.23	4.5	0.00*
	F	20.92	1.04			
Maxillary Canine and premolars	M	22.30	1.16	0.92±.24	3.6	0.00*
	F	21.38	1.21			

4.6 Comparisons between the predicted and the actual tooth size

Two tailed t-test was used to compare the differences between the actual (measured) mesiodistal width value of the mean of sum canine and premolars and the predicted values of the same group of teeth using Tanaka and Johnston equation (1974). High statistically significant differences (p=0.000) were observed between the predicted and measured values. The Tanaka and Johnston prediction equation overpredicted the actual measurements in males and females and for both dental arches.

In the following tables (From table 7 to table 12) Comparison between the predicted values of mesiodistal widths of CPM, using Tanaka and Johnston equation (1974), and their actual values in both dental arches for the males and females separately and for whole sample.

Table 7. Comparison between the predicted values of mesiodistal diameter of maxillary permanent canine, first and second premolars using T/J method and the actual values for female subjects (N=64).

	Mean diff. (Y-X)	SD	T	Df	P value
T/J	1.009	1.36	5.93	63	0.00*

Table 8. Comparison between the predicted values of mesiodistal diameter of mandibular permanent canine, first and second premolars using T/J method and the actual values for female subjects (N=64).

	Mean diff. (Y-X)	SD	T	Df	P value
T/J	0.96	0.81	9.44	63	0.00*

Table 9. Comparison between the predicted values of mesiodistal diameter of maxillary permanent canine, first and second premolars using T/J method and the actual value for male subjects (N=36).

	Mean diff. (Y-X)	SD	T	Df	P value
T/J	0.544	1.45	2.24	35	0.031*

Table 10. Comparison between the predicted values of mesiodistal diameter of mandibular permanent canine, first and second premolars using T/J method and the actual value for male subjects (N=36).

	Mean diff. (y-x)	SD	t	Df	P value
T/J	0.33	0.89	2.20	35	0.034*

Table 11. Comparison between the predicted values of mesiodistal diameter of maxillary permanent canine, first and second premolars using T/J method and the actual value for whole sample (N=100).

	Mean diff. (Y-X)	SD	t	df	P
T/J	0.842	1.40	5.98	99	0.00*

Table 12. Comparison between the predicted values of mesiodistal diameter of mandibular permanent canines, first and second premolars using T/J method and the actual value for whole sample (N=100).

	Mean diff. (Y-X)	SD	t	df	P
T/J	0.734	0.895	8.2	99	0.00*

- CPM: permanent canine, first and second premolar.
  Prediction method T/J: Tanaka and Johnston.
  Mean difference; where y= the predicted value and x= the measured (actual) value of ΣCPM.

Significance at P<0.05, df: degree of freedom, SD: Standard deviation.

4.7 Regression equations for the Turkish sample

The regression characteristics of the obtained prediction equations for the Turkish sample were presented in table 13.

Table 13. Regression components for prediction of the summation of the mesiodistal width of canine and two premolars.

Gender	ΣCPM	Coefficient correlation (R)	Coefficient of determination R^2	constants		SEM
				A	B	
Male	Maxilla	0.77	0.59	9.871	0.526	0.755
	Mandible	0.79	0.62	7.527	0.613	0.819
Female	Maxilla	0.65	0.42	5.186	0.711	0.929
	Mandible	0.63	0.39	7.415	0.593	0.818
Combined Male & Female	Maxilla	0.72	0.52	6.801	0.646	0.891
	Mandible	0.74	0.55	6.043	0.662	0.852

- ΣCPM: sum of permanent canine and two premolars in one quadrant, SEM: standard error of the mean.

The Pearson product correlation coefficients (r) ranged from 0.63 (mandibular arch of females) to 0.79 (mandibular arch of males). The accuracy of the prediction is often expressed as the standard error of the mean (SEM) for the prediction equation. In this study SEM ranged from 0.755 (maxillary arch of males) to 0.929 (maxillary arch of female).

The new regression equations take the form:

Y = a + b (x) where:

Y = the estimate of the sum of the mesiodistal width of the unerupted permanent canine and premolars in one quadrant in millimeters.

X = the sum of the mesiodistal width of the four permanent mandibular incisors in millimeters.

a = the y-intercept, in mm (regression constant).

b = the slope of the regression line (regression coefficient).

By using the values of coefficients, a and b listed in table 13, six equations for the prediction of the upper and lower combined canine-premolar mesiodistal width for each sex and for both sexes combined were done as follow:

Males

1) Mandibular canine and two premolars:

Y=7.527+0.613X

2) Maxillary canine and two premolars:

Y=9.871+0.526X

Females

3) Mandibular canine and two premolars:

Y=7.415+0.593X

4) Maxillary canine and two premolars:

Y=5.186+0.711X

Combined M+F

5) Mandibular canine and two premolars:

Y=6.043+0.662X

6) Maxillary canine and two premolars:

Y=6.801+0.646X

The Coefficient correlation (r) between the permanent mandibular incisors and the actual canine premolars segment (measured) for Turkish sample for each gender and for both genders combined are presented graphically (figures 1-6).

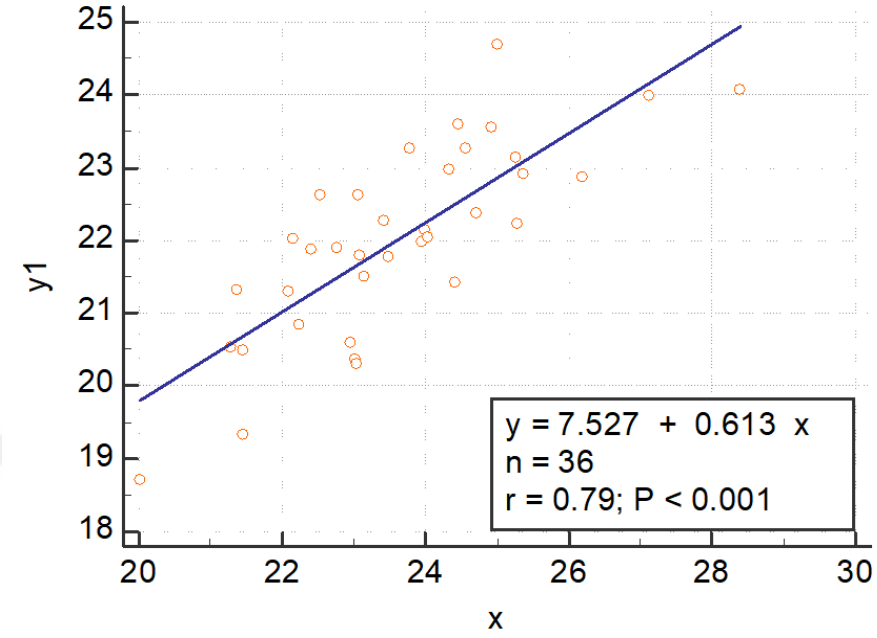


Figure 2. Coefficient correlation between sum of mandibular incisors (X) and sum of mandibular canine and premolars (Y) for the male group.

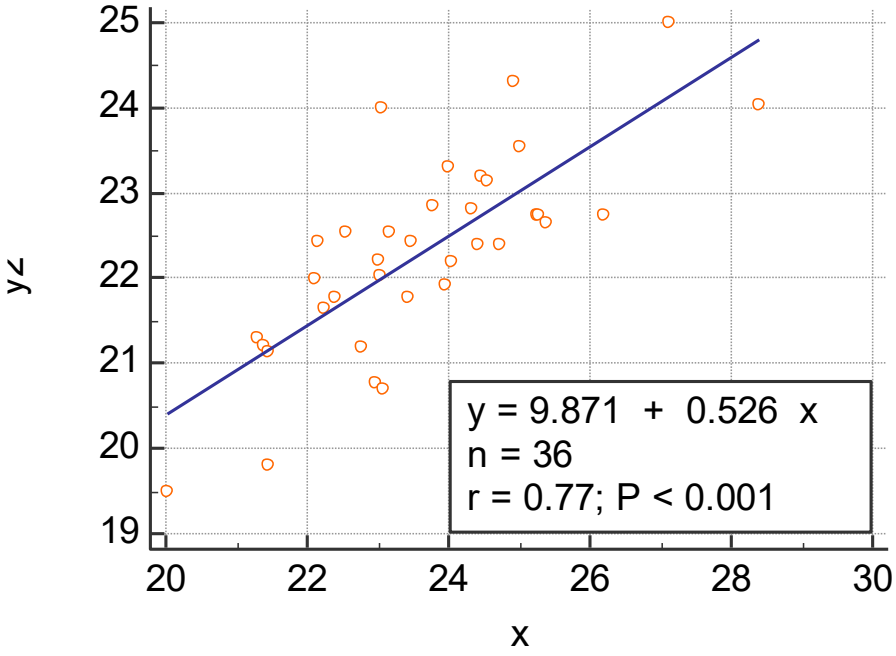


Figure 3. Coefficient correlation between sum of mandibular incisors (X) and sum of maxillary canine and premolars (Y) for the male group.

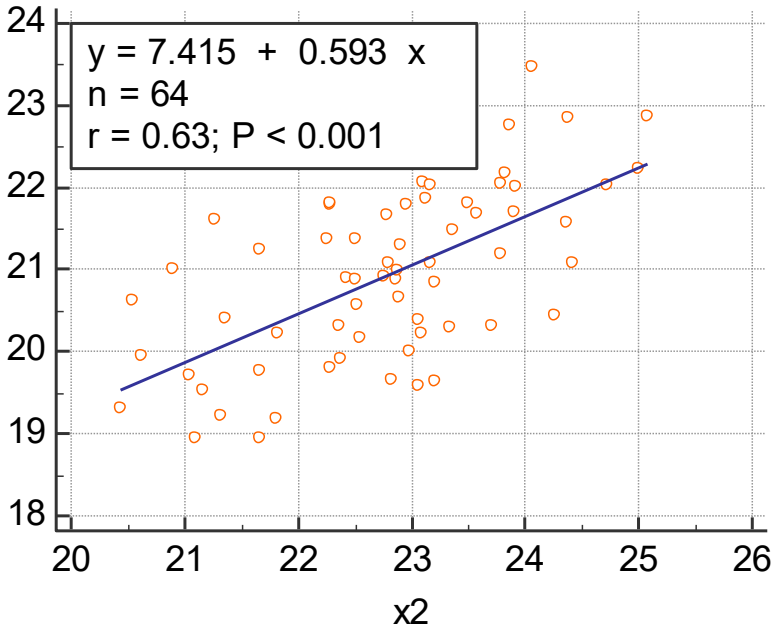


Figure 4. Coefficient correlation between sum of mandibular incisors (X) and sum of mandibular canine and premolars (Y) for the female group.

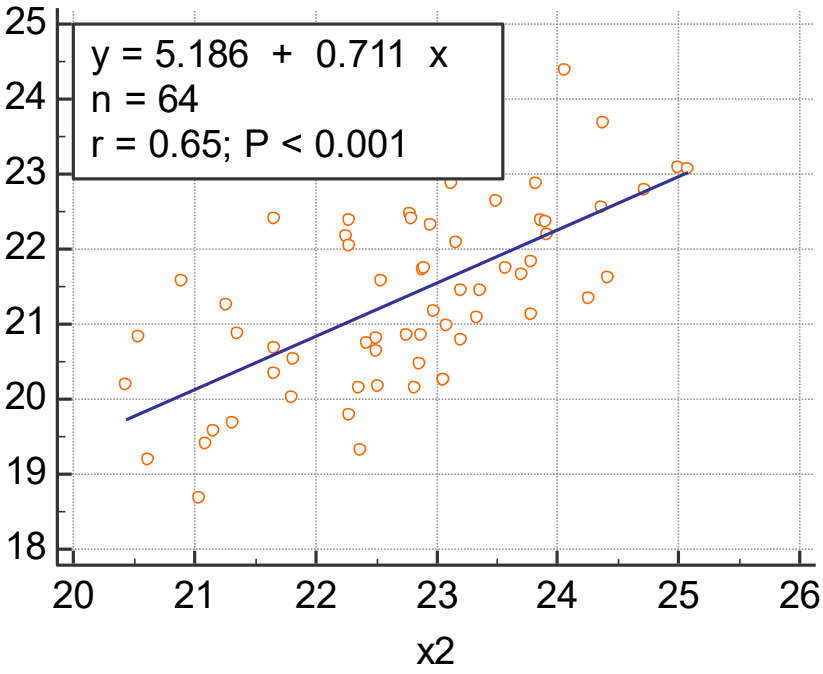


Figure 5. Coefficient correlation between sum of mandibular incisors (X) and sum of maxillary canine and premolars (Y) for the female group.

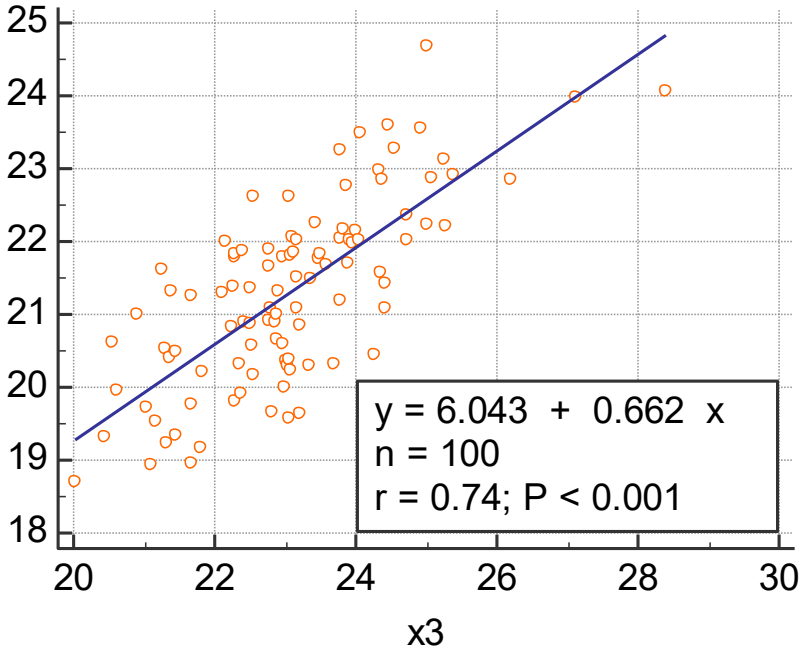


Figure 6. Coefficient correlation between sum of mandibular incisors (X) and sum of mandibular canine and premolars (Y) for the whole sample.

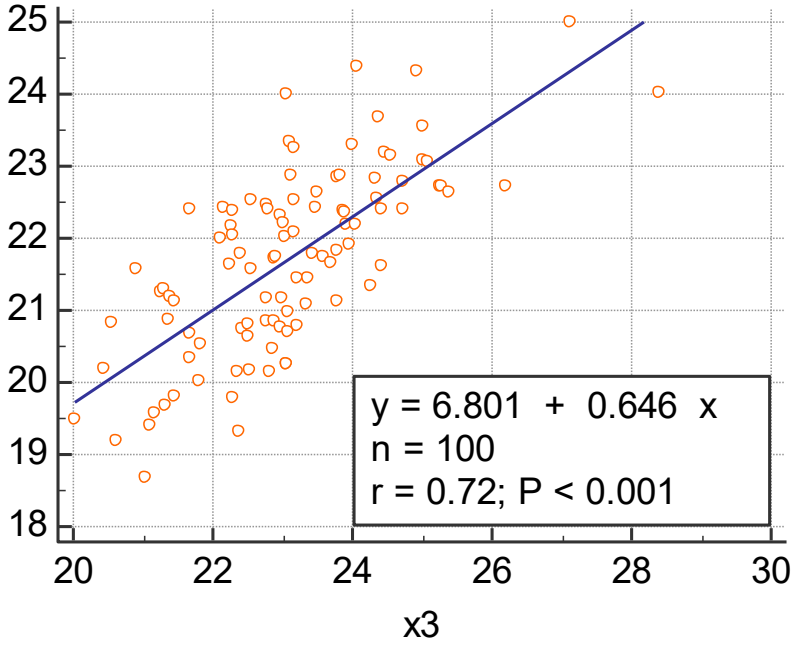


Figure 7.
Coefficient correlation between sum of mandibular incisors (X) and sum of maxillary canine and premolars (Y) for the whole sample.

5.Discussion

5.1 Introduction

An important aspect of diagnosis in the mixed dentition stage is the determination of the tooth size-arch length relation. Such a determination is often preceding the eruption of permanent canine and premolars. The determination of tooth size arch length discrepancy in the mixed dentition need an exact estimation of the mesiodistal widths of the unerupted teeth.

Each diagnostic analysis utilizing tooth size data is designed to provide at least one of these purposes:

- Predicting the mesiodistal width of unerupted premolars and canine.
- Quantifying the amount of crowding within the arches.
- Assessment of tooth size compatibility between two arches.

All of the prediction approaches have one unit in common that is, the data about the size of sum of individual erupted teeth. Without these data about the size of the individual teeth and groups of teeth, it is difficult for clinicians to make an accurate diagnosis and treatment plan.

The purpose of the present study was to examine the reliability of Tanaka and Johnston method of prediction in a sample of Turkish population and to develop a new prediction method for this specific population if it is not reliable.

5.2 Reliability of measurements

The reliability of the measurements is an important feature of tooth size researches. In making attempt to enhance the reliableness of measurements in our study the subsequent procedures were applied:

- High quality models were used from dental stones (Type 3, Zhermack™, Italy) (Zilberman ,2003).
- Using caliper with digital screen (Erbschloe, Germany) that could facilitate to decrease the eye fatigue & therefore the chance of error will decrease (Zilberman ,2003).

- Dahlberg's formula was used in assessing the intra-examiner reliability (Dahlberg G ,1940).

The present study showed that the differences between duplicate measurements ranged from 0.14 millimeters to 0.35 millimeters with average 0f 0.25 millimeters and 0.19 millimeters in the mandibular and maxillary arch respectively;

Yuen KK et al (1997) stated that values of this range were satisfactory for the study of tooth sizes. Other investigators reported similar values to those of the present study (Kaplan RG ,1977; Keene HJ, 1979; Moorrees CF, 1957). However, these values were even better than those reported by other investigators. Buschang et al. (1988) obtained a method error of 0.14 millimeter as the highest value and 0.06 millimeter as the lowest one using the same method.

Yuen KK et al (1996) found that the highest value was 0.11 millimeter and the lowest one was 0.04 millimeter with a mean of 0.07 millimeter which were considerable acceptable. Referring to the previous studies, the measurements achieved in the present study were considered reliable and within acceptable range.

5.3 Mesiodistal tooth widths

The mean mesiodistal tooth sizes are bestowed within this research to supply odontometric information about the Turkish sample and this information are compared with those of different ethnic groups. However, these values had some limitations. Only the mean values of the mesiodistal tooth diameters, and not the individualized left & right mesiodistal tooth diameters, were included. Furthermore, the sample size may not be representative of the Turkish population.

The most common mesiodistal width analysis of tooth size is carried out by using average of the teeth from the left and right sides, or, alternatively, by using teeth on one side of the jaw (Bishara SE, 1998; Seipel CM, 1946; Moorrees CFA, 1964). Therefore, the averaged values of right and left sides of every jaw were utilized in this study. The same way was done by Lee-Chan (1998), Jaroontham and Godfrey (2000).

Most of odontometric studies have found mesiodistal tooth widths to be generally smaller in Caucasian population than in black ones (Richardson and Malhotra, 1975; Macko et al., 1979; Merz et al., 1991; Otuyemi and Noar, 1996). Comparisons of mean mesiodistal tooth widths in the present study and in other Caucasian population groups (Moorrees et al., 1957; Moyer et al., 1976) to those in black populations (Richardson and Malhotra, 1975; Kieser and Groeneveld, 1988) have confirmed that the Caucasian population have generally smaller teeth for all tooth types for both genders (Table 14). The present sample and North American Caucasian sample (Moyer et al, 1976) tend to have smaller combined mesiodistal tooth widths in both sexes than the black south African (Schirmer and Wiltshire, 1997) and Senegalese population (Digane et al., 2003) (Table 15). The differences could be attributed to the methodology, sample selection, ethnic and racial variations.

These mesiodistal width averages of teeth in this study may be useful and serve as a diagnostic tool in Turkish population. Mesiodistal tooth size prediction for an individual would be relatively more accurate and reliable in the organizing of orthodontic treatment plan and accomplishing the treatment.

Table 14. Comparisons of mean mesiodistal tooth widths in millimeters with various other studies for male and female subjects

Tooth Number	North American Caucasians (Moorrees et al., 1957)	North American Caucasians (Moyers et al., 1976)	African Americans (Richardson and Malhotra, 1975)	Black South Africans (Kieser & Groeneveld 1988)	Turkish (Present study)
Male					
Max 2nd Premolar	6.82	6.67	7.25	7.39	6.89
Max 1st Premolar	7.01	6.76	7.66	7.68	7.15
Max Canine	7.95	7.99	8.19	8.12	8.24
Max Lateral Incisor	6.64	6.88	7.26	7.56	7.03
Max Central Incisor	8.78	8.91	9.12	9.28	9.02
Man 2nd Premolar	7.29	7.22	7.85	7.90	7.44
Man 1st Premolar	7.07	6.89	7.76	7.86	7.31
Man Canine	6.96	6.96	7.37	7.57	7.26
Man Lateral Incisor	5.95	6.04	6.13	6.43	6.19
Man Central Incisor	5.42	5.54	5.53	5.61	5.62
Female					
Max 2nd Premolar	6.62	6.50	6.94	7.10	6.62
Max 1st Premolar	6.85	6.60	7.37	7.55	7.00
Max Canine	7.53	7.49	7.74	7.90	7.15
Max Lateral Incisor	6.47	6.78	7.08	6.94	6.73
Max Central Incisor	8.40	8.67	7.72	8.72	8.66
Man 2nd Premolar	7.02	7.07	7.61	7.77	7.09
Man 1st Premolar	6.87	6.78	7.41	7.62	7.10
Man Canine	6.47	6.58	6.86	7.27	6.69
Man Lateral Incisor	5.78	5.92	5.99	6.11	5.94
Man Central Incisor	5.25	5.46	5.38	5.42	5.44

Table 15. Comparisons of sum mesiodistal widths of group of teeth between the present and other studies (Mean ± SD in mm).

Groups of teeth	Sex	North Americans Caucasians (Moyers et al. ,1976)	Black South Africans (Schirmer and Wiltshire, 1997)	Senegalese (Diagne et al., 2003)	Turkish (Present Study)
∑ MPI	M	23.16±1.80	23.92±1.90	23.71±1.25	23.63±1.71
	F	22.76±1.67	23.66±1.59	22.86±1.12	22.80±1.09
∑ LCPM	M	21.07±1.65	23.22±1.11	22.70±1.01	22.01±1.32
	F	20.43±1.53	22.28±1.26	21.87±0.77	20.92±1.04
∑ UCPM	M	21.42±1.34	23.45±1.37	22.60±1.22	22.30±1.16
	F	20.59±1.25	22.20±1.24	21.64±0.99	21.38±1.21

5.4 Gender variations

In the present study, the mean mesiodistal tooth width of male subjects were found to be consistently larger than females in both maxillary and mandibular dental arches; consequently, the mean of the summation of the mandibular permanent incisors, maxillary and mandibular canine and premolars width was greater in males than females, and the differences were statistically significant ($p<0.05$). Most tooth size studies also discovered that male teeth are bigger than female teeth in any racial group (Garn et al. ,1964; Richardson and Malhotra, 1975; Bishara et al., 1986; D Paula et al., 1995).

The results of our study is similar to the study done by Jaroontham and Godfrey (2000) in Thai children showed that the mesiodistal tooth width of mandibular incisors, maxillary and mandibular canine and premolar segments were greater in male than in females and studies done by Digane et al (2003) in black Senegalese population also shows the similar results, and also study done by Ling JY, Wong RW. (2006), where the sexual dimorphism was noticeable between southern Chinese male and female. This may be attributed to genetic and environmental factors.

The most noticeable statistically significant differences were presented by both mandibular and maxillary canines and maxillary central incisors, while smallest differences appeared in first premolar of maxillary arch, and in central and lateral incisors of mandibular arch. However, with Bonferroni correction ($p<0.005$) the mean mesiodistal widths of maxillary teeth failed to show any statistically significant gender differences except those of maxillary first premolar ($p=0.118$) and lateral incisor ($p=0.011$). The most significant differences were shown by both mandibular (0.56±0.96 mm) and maxillary canines (0.48±0.097 mm) and maxillary central incisor (0.36±0.12 mm), while the smallest differences was by maxillary first premolar (0.15±0.096 mm).

Considering these differences, we have regulated new regression equations for mandible and maxilla in both females and males of Turkish population. We feel our equations would be more appropriate than Tanaka and Johnston equation for this population.

5.5 Bilateral symmetry

There were no statistically significant variations in mesiodistal tooth size widths between right and left sides (Garn et al., 1966; Moyers et al., 1976; Alavi DG et al., 1988; Otuyemi OD et al., 1996). Therefore, the averaged values of left and right side for combined canine and premolars as a group of each jaw were used in the statistical analysis. Bishara et al. (1986) stated that there were very small and clinically insignificant absolute mean differences in the mesiodistal size of lower teeth between the right and left side.

Odontometric researches of mesiodistal teeth size in Caucasian Americans have discovered high bilateral symmetry between the right and the left side (Moorrees and Reed, 1964; Staley and Hoag, 1978). The same was reported by Hashim HA et al. (2005) for Saudi population and Hattab et al. (1996) for Jordanians. These investigations have also been noted in many other racial populations (Macko et al., 1979; Noss JF et al.,1983; Bishara et al., 1989). Hashim HA et al. (1997) in a study on Sudanese population found that the differences in individual tooth widths between the two sides of dental arch was statistically insignificant and the measurement from one side could be considered as a truly representative. Bishara and Jakobsen (1998) reported that the teeth on one or both sides of dental arch could be used to analyze mesiodistal teeth width.

5.6 Comparisons of prediction method with actual values

Different groups of teeth have been used as a predictor for the estimation of the mesiodistal width of unerupted teeth in mixed dentition space analysis. The total of the mesiodistal width of lower incisors was commonly used by researchers to formulate regression equations to forecast exactly the size of canine and two premolars (Carey, 1949; Tanaka and Johnston, 1973; Moyers, 1973; Motokawa et al., 1987).

Since many clinical benefits of using permanent mandibular incisors in prediction equations have been mentioned before, in our study also used permanent mandibular incisors as the independent variable. One of the advantages include the ease of measuring of mandibular incisors in mouth (Motokawa et al., 1987) and on dental cast (Hunter and priest, 1960; Moyers, 1973).

Although the other predictors have a moderate correlation (Melgaco CA et al., 2007) their usage in predicting are limited due to some complicating factors. These include morphological defects as in when combination of four maxillary permanent incisors due to malformation of maxillary lateral incisor (Nourallah et al., 2002; Legovic et al.,2003); or late eruption or distal gingival

coverage as in use of a combination of four lower incisors and two lower first molars (Melgaco CA et al., 2007).

The aim of our study is to test the ability of the predictor (mandibular permanent incisors) to reproduce the values of the mesiodistal width of permanent canine and premolars in one quadrant. The mean differences between the predicted and actual (measured) values can be used to determine the error of the prediction. The squared value of the absolute mean difference (between predicted and actual values) provide a measure how good the prediction is. when the predictions are close to the measured values, the absolute mean differences or the squared errors are insignificant.

When we applied T&J (1974) equations on whole Turkish sample, it was found that Tanaka and Johnston overpredicted the actual values of mesiodistal width of the canine and two premolars in maxillary and mandibular arch. There was obvious variation between the predicted values of those teeth and their actual (measured) ones. Tanaka and Johnston (1974) prediction method overpredicted the actual value of canine and two premolars by 0.98 mm in the female subjects and in the male subjects, Tanaka and Johnston overpredicted the actual measurements by 0.43mm.

Several investigators found that Tanaka and Johnston prediction equations (1974) overestimated the actual values of the unerupted canine and premolars (Al-Khadra, 1993; Digane et al., 2003; Hashim HA et al., 2003). On the other hand, some studies observed that Tanaka and Johnston (1974) prediction equation minimized all the values of unerupted canine and premolars (Lee Chan, 1998; Yuen et al., 1998; Abu Alhaija and Qudeimat, 2006). Janthroom and Godfrey (2000) found predictions from Tanaka and Johnston (1974) to be close to the actual mesiodistal measurements of permanent canine and premolars of Thai population.

White (1978) stated that permanent teeth may be either wrongly extracted or retained on the basis of an unreliable tooth size prediction.

Overestimation of mesiodistal tooth width tends to magnify space requirements and leads to unnecessary extractions, while underestimation would result in a more conservative clinical approach. Due to the inadequacy of Tanaka and Johnston regression equation and it is overpredicted the unerupted canine premolar segment in Turkish people, new prediction equations were formulated specifically for the Turkish sample was proposed with different prediction constants for female and male separately and combined for each jaw. The new equations produced a more accurate prediction for canine premolar segment.

Table 16 shows regression parameters, including the correlation coefficients (r), correlation of determination (r^2), constants of regression equation (a and b) and the standard error of the mean (SEM), for the sum of canine premolars segment width, for the present study as well as from different other studies.

Table 16 Regression parameters for the sum of canine premolars segment width from various studies.

Study	Gender	Dental Arch	R	Constants		r^2	SEM (mm)
				A	B		
Frankel & Benz (1986) Black Americans	M	Mandible	0.66	5.97	0.72	0.51	0.91
		Maxilla	0.72	9.15	0.58	0.62	0.92
	F	Mandible	0.66	10.34	0.49	0.37	0.71
		Maxilla	0.61	12.83	0.39	0.43	0.67
	M + F	Mandible	0.70	8.30	0.64	0.42	0.95
		Maxilla	0.65	10.18	0.52	0.49	0.87
Yuen et al. (1998) Hong Kong	M	Mandible	0.77	8.82	0.58	0.60	0.61
		Maxilla	0.79	7.97	0.66	0.62	0.68
	F	Mandible	0.69	6.66	0.64	0.47	0.82
		Maxilla	0.65	8.30	0.61	0.42	0.81
Jaroontham & Godfrey (2000) Thailand	M	Mandible	0.58	11.92	0.43	0.34	0.85
		Maxilla	0.54	13.36	0.41	0.29	0.88
	F	Mandible	0.65	9.49	0.53	0.42	0.78
		Maxilla	0.62	11.16	0.49	0.39	0.78
	M + F	Mandible	0.64	10.30	0.50	0.41	0.82
		Maxilla	0.60	11.87	0.47	0.36	0.84
Abu Alhaija & Qudeimat (2006) Jordan	M	Mandible	0.60	9.80	0.54	0.36	0.92
		Maxilla	0.51	12.80	0.43	0.26	0.92
	F	Mandible	0.59	9.79	0.56	0.35	1.00
		Maxilla	0.64	8.31	0.64	0.41	0.98
	M + F	Mandible	0.59	9.41	0.56	0.35	0.99
		Maxilla	0.57	10.55	0.53	0.32	0.99
Tanaka and Johnston (1974) Northern Americans	M + F	Mandible	0.65	9.18	0.54	0.42	0.85
		Maxilla	0.63	10.41	0.51	0.40	0.86
Present study (2019) Turkish	M	Mandible	0.79	7.53	0.61	0.62	0.81
		Maxilla	0.77	9.87	0.53	0.59	0.75
	F	Mandible	0.63	7.42	0.59	0.39	0.82
		Maxilla	0.65	5.19	0.71	0.42	0.93
	M + F	Mandible	0.74	6.04	0.66	0.55	0.85
		Maxilla	0.72	6.8	0.65	0.52	0.89

5.7 Correlation coefficient (r)

In the present study, the correlation coefficient "r" between the sum of mesiodistal width of four mandibular incisors and the permanent canine and premolars in the maxillary and mandibular arches ranged from 0.63 to 0.79 (table 13), which is stronger than that obtained by Tanaka and Johnston (1974) which is 0.63-0.65. These correlations are comparable to published researches and considered high (Ferguson Fs et al., 1978; Al-Khadra BH, 1993; Schirmer and Wiltshire, 1997; Yuen et al., 1998; Jaroontham and Godfrey, 2000; Nourallah et al., 2002; Abu Alhaija and Qudeimat, 2006). However, the moderately high degree of linear correlation that was established in this study made it possible to measure the total width of mandibular permanent incisors to forecast more accurately the mesiodistal size of unerupted canine and two premolars.

5.8 Coefficient of determination (r^2)

The coefficient of determination values are indicators of the predictive accuracy of the regression equation for the sum of mesiodistal width of unerupted canine and premolars (Y) based on values of mesiodistal size of lower incisors (X), that means, the proportion of the difference of (Y), which is determined then value of (X) for each regression.

In the present study the coefficient of determination was found to be 0.52 and 0.55 for the combined males and females in maxillary and mandibular arches respectively (Table 13). This means that 52% and 55% of the total variance for sum of unerupted mandibular and maxillary canine and premolars segment (Y) were accounted by knowing the sum of mesiodistal width of mandibular permanent incisors (X).

In the present study, the male subjects showed higher coefficient of determination values (0.62 for mandibular teeth and 0.59 for maxillary teeth) than the female subjects (0.39 and 0.42, respectively). This finding was consistent with that of Yuen et al. (1998) on Hong Kong population, where the coefficient of determination value for the males (0.60 for mandibular arch and 0.62 for maxillary arch) was higher than females (0.47 and 0.42, respectively). In contrast to this, coefficient of determination value for the female subjects was higher than that for males in Kenyan (Ngesa JL, 2005) and Thai group (Jaroontham and Godfrey, 2000).

5.9 Standard error of the mean (SEM)

It is also known standard error of estimate, the precision of the forecasting commonly revealed as the standard error of the mean for the regression equation (Johnston, 2002), indicates the error using the prediction equation. The smaller values are better, it illustrate that the investigations are closer to the regression line (Johnston, 2002).

The standard error of the mean (SEM) are shown in table 13 extended from 0.76mm to 0.93mm for male, female and combined groups, which was found to slightly higher than that of Tanaka and Johnston regression equation (SEM=0.85 and 0.86, for mandibular and maxillary arches, respectively).

Ngesa JL, (2005) in Kenyan sample showed higher standard error of the mean (SEM=1.14) for males in maxillary arch. Abu Alhaija and Qudeimat (2006) obtained a high SEM (SEM= 0.99 for both sexes) and even higher error in mandibular jaw for the females (SEM= 1.00).

The magnitude of the SEM is inversely proportional to the number of subjects (that is, the larger sample size the smaller the SEM). Therefore, it may not reasonable to compare the Turkish prediction equations with those of other researches because of differences in the sample size.

6.Conclusion

1. Mesiodistal teeth widths shows statistically significant differences between two genders, with male teeth consistently being larger. Thus, Turkish subjects should be divided according to gender prior to perform a mixed dentition analysis and the analogous equation applied.

2. The correlation coefficient between the sum of four mandibular permanent incisors and the sum of canine and two premolars in this study was found in the range 0.63-0.79 which is considered moderate high positive.

3. The commonly used Tanaka and Johnston (1974) prediction equation were not accurate when applied to our sample of Turkish population since it tends to overpredict the actual measurements in both arches.

4. New regression equations for Turkish the population were developed for predicting the mesiodistal width of canine and premolars segment. For both genders, the following regression equations were formulated:
   a. In maxilla: Y=6.801+0.646X
   b. In mandible: Y=6.043+0.662X

   Where, Y= Mesiodistal width of unerupted canine and two premolars.
   X= Sum of mesiodistal width of four mandibular incisors.

5. This study shows the necessity of determining distinctive regression equations for different populations.

7.References

1. Abu Alhaija ES, Qudeimat MA. Mixed dentition space analysis in a Jordanian population: comparison of two methods. Int J Pediatric Dent. 2006 Mar; 16(2): 104-10.

2. Al-Khadra BH. Prediction of the size of unerupted canines and premolars in a Saudi Arab population. American Journal of Orthodontics and Dentofacial Orthopedics 1993; 104: 369–372.

3. Alavi, DG, BeGole, EA, Schneider, BJ. Facial and dental arch asymmetries in Class II subdivision malocclusion. AM J ORTHOD DENTOFAC ORTHOP. 1988; 93:38–46.

4. Alvesalo L. The influence of sex-chromosome genes on tooth size in man. Proc Finn Dent Soc 1971; 67:3–54.

5. Ateş M. Sexual differences in Turkish dentition. 2006 Available online 5 October 2006.Available form URL: https://doi.org/10.1016/j.legalmed.2006.06.003 .

6. Axelsson G, Kirveskari P. Crown size of permanent teeth in Icelanders. Acta Odontologica. 1983;41(3):181–6.

7. Bailit H L. Dental variation among populations. Dent Clin North Am 1975; 19:125-39.

8. Ballard ML, Wylie WL. Mixed dentition case analyses – estimating size of unerupted teeth. Am J Orthod 1947; 33:754-9.

9. Bherwani AK, Fida M. Development of a prediction equation for the mixed dentition in a Pakistani sample. Am J Orthod Dentofacial Orthop. 2011 Nov; 140(5): 626-32.

10. Bishara SE, Jakobsen JR. Comparison of two non-radiographic methods of predicting permanent tooth size in the mixed dentition. Am J Orthod Dentofacial Orthop. 1998;114(5):573–6.

11. Bishara SE, Jakobsen JR, Abdallah EM, Fernandez Garcia A. Comparisons of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico, and the United States. American Journal of Orthodontics and Dentofacial Orthopedics 1989; 96: 416–422.

12. Bishara SE, Garcia AF, Jakobsen JR, Fahl JA. Mesiodistal crown dimensions in Mexico and the United States. Angle Orthod. 1986;56(4):315–23

13. Black, G.V. Description anatomy of the human teeth ed.4, Philadelphia.S. S White dental Mfg.co;1897, P16.

14. Bull R L. Radiographic method to estimate the mesiodistal dimension of unerupted teeth. Am J Orthod 1959; 45:711-712.

15. Buschang PH, Demirjian A, Cadotte L. Permanent mesiodistal tooth size of French-Canadians. J Can Dent Assoc 1988;54(6): 441-444.

16. Carey CW. Linear arch dimension and tooth size. Am J Orthod 1946; 35:762-775.

17. Carty O et al. A manual for space analysis in the mixed dentition. 2015 Published Online:18 Jul 2017.Available form: URL: https://doi.org/10.12968/ortu.2015.8.4.118

18. Cohen MI. Recognition of the developing malocclusion. Dent Clin North Am. 1959; 6: 299-311.

19. Dahlberg G. Statistical Methods for Medical and Biological Students. New York: Interscience Publications; 1940.

20. Dasgupta B, Zahir S. Comparison of two non-radiographic techniques of mixed dentition space analysis and evaluation of their reliability for Bengali population. Contemp Clin Dent. 2012;3(6):146–50.

21. De Paula S, De Oliveira Almeida MA, Lee PCF. Prediction of mesio-distal diameter of unerupted lower canines and premolars using 45º Cephalometric radiography. Am J Orthod Dentofacial Orthop. 1995; 107: 309-14.

22. Diagne, F, Diop-Ba K, Ngom P I, Mbow K. Mixed dentition analysis in a Senegalese population: Elaboration of prediction tables. Am J Orthod Dentofacial Orthop 2003; 124: 178-183.

23. Doris JM, Bernard BW, Kuftinec MM, Stom D. A biometric study of tooth size and dental crowding. Am J Orthod. 1981;79(3):326–36

24. Fearne J, Brook A. Small primary tooth-crown size in low birth weight children. Early Hum Develop 1993;33(2): 81–90.

25. Ferguson FS, Macko DJ, Sonnenberg EM, Shakun ML. The use of regression constants in estimating tooth size in a Negro population. American Journal of Orthodontics 1978; 73: 68– 72.

26. Foneseca C. Predicting of mesiodistal crown width of the canine premolars segment in maxillary dental arches. Memphis, Tenn: University of Tennessee School of Dentistry; 1961.

27. Foster, H.R., and Wylie, W.L. Arch length deficiency in the mixed dentition. Am J Orthod 44:464 Ju n e 1958.

28. Frankel HH, Benz EM. Mixed dentition analysis for black Americans. Pediatric Dent. 1986;8(3):226–230.

29. Gardner RB. A comparison of four methods of predicting arch length. American Journal of Orthodontics 1979; 75: 387–398.

30. Garn, S. M., Lewis, A. B., Kerewsky, R. S. (1964). Sex difference in tooth size. J Dent Res. 43: 306.

31. Garn, S.M.; Lew is, A. B.; and Walenga, A. Evidence for a secular trend in tooth size over two generations. J Dent R e s 47: 503 M ay-June 1968.

32. Garn, S. M., Kerewsky, R. S. & Swindler, D. R. Canine ‘field’ in sexual dimorphism of tooth size. Nature 1966, 212, 1501-1502

33. Hashim HA, Suliman A, Bello L, Saikh H. Tooth width among Sudanese population sample. Egypt Dent J 1997; 43:2209-2216.

34. Hashim HA, Al-Shalan TA. Prediction of the size of un-erupted permanent cuspids and bicuspids in a Saudi sample. J Contemp Dent Pract 2003;4(4):40-53.

35. Hattab FN, al-Khateeb S, Sultan I. Mesiodistal crown diameters of permanent teeth in Jordanians. Archives of Oral Biology 1996; 41: 641–645.

36. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod. 1958; 28: 236-40.

37. Huckaba GH. Arch size analysis and tooth size prediction. Dent Clin North Am 1964; 11:431-40.

38. Hunter WS, Priest WR. Errors and discrepancies in measurements of tooth size. J Dent Res. 1960; 39:405–414.

39. Hunter WS. Application of analysis of crowding and spacing of the teeth. Dent Clin North Am. 1978 Oct; 22(4): 563-77.

40. Ibrahim IA, Elkateb MA, Wahba NA, El Harouny NM. A digital method to predict the mesiodistal widths of canines and premolars in an Egyptian sample. J Clin Pediatric Dent. 2011 Summer; 35(4): 421-27.

41. Ingervall B, Lennartson B. Prediction of breadths of permanent canines and premolars in the mixed dentition. Angle Orthodontist 1978; 48:62-69.

42. Irwin RD, Herold JS, Richardson A. Mixed dentition analysis: a review of methods and their accuracy. International Journal of Pediatric Dentistry 1995; 5: 137–142.

43. Jaroontham J, Godfrey K. Mixed dentition space analysis in a Thai population. Euro J Orthod 2000; 22: 127-134.

44. Johnston LE. Regression: Is your guess as good as mine? Semin Orthod. 2002;8(2):87–91.

45. Kaplan R G, Smith CC, Kanarek P H. An analysis of three mixed dentition analyses. J Dent Res 1978; 56:1337-43.

46. Keene HJ. Mesiodistal crown diameters of permanent teeth in male Americans negroes. Am J Orthod 1979; 76:95-9.

47. Keiser JA. Human Adult Odontometric: The Study of Variation in Adult Tooth Size. Cambridge, UK: Cambridge University Press; 1990;15–28.

48. Keiser, J.A., Groeneveld, H.T. (1988). Patterns of variability in the South African Negro dentition. J Dent South Afr. 43: 105-10.

49. Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian American. Am J Orthod Dentofacial Orthop 1998; 113:293-9

50. Legovic M, Novosel A, Legovic A. Regression equations for determining mesiodistal crown diameters of canines and premolars. Angle Orthod 2003;73(3):314-318.

51. Lindsten R. Secular changes in tooth size and dental arch dimensions in the mixed dentition. Swed Dent J Suppl 2003(157):1-89.

52. Ling JY, Wong RW. Tanaka-Johnston mixed dentition analysis for southern Chinese in Hong Kong. Angle Orthod 2006;76(4):632-636.

53. Lysell L, Myrberg N. Mesio-distal tooth size in the deciduous and permanent dentitions. Eur J Orthod. 1982; 4:113–22.

54. Macko, D. J., Ferguson, F. S., Sonnenberg, E. M. (1979). Mesio-distal crown dimensions of permanent teeth of black Americans. J Dent Child, 46: 314- 18.

55. Melgaco CA., et al. “Applicability of three tooth size prediction methods for white Brazilians”. Angle Orthodontist 76.4 (2006): 644- 649.

56. Merz, M. L., Isaacson, R. J., Germane, N., Rubenstein, L. K. (1991). Tooth diameters and arch perimeters in a black and a white population. Am J Orthod Dentofacial Orthop. 100: 53-8.

57. Moyers RE. Handbook of orthodontics. 3rd ed. Chicago: Year Book Medical Publishers; 1988.

58. MOYERS, R.E.: Handbook of Orthodontics for the Student and General Practitioner (3rd ed), Chicago: Year Book Medical Publishers, 1973, p 369.

59. Moyers, R. E., van der Linden, F. P. G. M., Riolo, M. L. & McNamara Jr., J. A. Standards of human occlusal development Monograph Number 5, Craniofacial growth series, Center for Human Growth and Development, The University of Michigan, Michigan 1976.

60. Moorrees CF, Reed RB. Correlations among Crown Diameters of Human Teeth. Arch Oral Biol. 1964 Nov-Dec; 9: 685-97.

61. Motokawa W, Ozaki M, Soejima Y, Yoshida Y. A method of mixed dentition analysis in the mandible. J Dent for Children. 1987; 54:114–8.

62. Moorrees, C. F.A., and others. Mesiodistal crow n diameters of the d e c id u o u s and perm anent teeth in individuals. J Dent R e s 36:39 Feb 1957.

63. Nance HN. Limitation of orthodontic treatment. I. Mixed dentition diagnosis and treatment. Am J Orthod Oral Surg. 1947; 33: 177- 223.

64. Ngesa JL. Applicability of tooth size predictions in the mixed dentition analysis in a Kenyan sample: University of the Western cape. 2005.

65. Noss JF, Scott GR, Potter RH, Dahlberg AA. Fluctuating asymmetry in molar dimensions and discrete morphological traits in Pima Indians. American journal of physical anthropology.1983 Aug;61(4):437-45.

66. Nourallah AW, Gesch D, Khordaji MN, Splieth C. New regression equations for predicting the size of unerupted canines and premolars in a contemporary population. Angle Orthod 2002;72(3):216-221.

67. Otuyemi OD, Noar JH. A comparison of crown size dimensions of the permanent teeth in a Nigerian and a British population. Eur J Orthod. 1996;18(6):623–628.

68. Paredes V, Gandia JL, Cibrian R. A new, accurate and fast digital method to predict unerupted tooth size. Angle Orthod. 2006 Jan; 76(1): 14-9.

69. Phillips, R. W. Skinner's Science of Dental Materials, 7th ed. W. B. Saunders Co., Philadelphia 1973.

70. Profitt W R, Fields H W. Contemporary Orthodontics. 3rd edition. St. Louis: Mosby Inc., 2000:165-70.

71. Richardson ER, Malhotra SK. Mesiodistal crown dimension of the permanent dentition of American Negroes. Am J Orthod. 1975;68(2):157–64.

72. Santoro M, Glkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003; 124:101-105.

73. Santoro M, Ayoub ME, Pardi VA, Cangialosi TJ. Mesiodistal crown dimensions and tooth discrepancy of the permanent dentition of Dominican Americans. Angle Orthod 2000; 70:303-307.

74. Schirmer UR, Wiltshire WA. Orthodontic probability tables for black patients of African descent: mixed dentition analysis. Am J Orthod Dentofacial Orthop 1997;112(5):545-551.

75. Seipel C. Variation in tooth position: a metric study of variation and adaptation in the deciduous and permanent dentitions. Swed Dent J. 1946; 39:1–176.

76. Sillman JH. Dimensional changes of the dental arches: longitudinal study from birth to 25 years. Am J Orthod 1964; 50:824-41.

77. Singh M, Nanda RS. Prediction of tooth size and its clinical application. J Ind Dent Assoc 1972; 44(5): 95−98.

78. Sonick M, Abrahams J, Faiella RA. Comparison of the accuracy of periapical, panoramic, and computerized tomographic radiographs in locating the mandibular canal. Quintessence Pub Co 1994; 9(4): 455−460.

79. Staley R N, Kerber R E. A revision of the Hixon and Oldfather Mixed-Dentition prediction method. Am J Orthod.1980; 78: 296- 302.

80. Staley R N, Shelly T H, Martin J F. Prediction of lower canine and premolar widths in the mixed dentition. Am J Orthod Dentofacial Orthop 1979; 76: 300-309.

81. Staley R N, Hoag J F. Prediction of the mesiodistal widths of maxillary permanent canines and premolars. Am. J. Orthod. 1978; 73:169-77.

82. Staley RN, O'Gorman TW, Hoag JF, Shelly TH. Prediction of the widths of unerupted canines and premolars. J Am Dent Assoc 1984;108(2):185-190.

83. Tanaka MM, Johnston LE. The prediction of the size of unerupted canine and premolars in a contemporary orthodontic population. J Am Dent Assoc 1974; 88:798-1.

84. Townsend G, Brown T. Heritability of permanent tooth size. Am J Phys Anthropol 1978; 49:497–504.

85. Townsend G, Brook A. Genetic, epigenetic and environmental influences on dental development. Ortho Tribune 2008; 3:3–6

86. van der Merwe SW, Rossouw P, van Wyk Kotze TJ, Trutero H. An adaptation of the Moyers mixed dentition space analysis for a Western Cape Caucasian population. J Dent Assoc S Afr. 1991 Sep; 46(9): 475-79.

87. Verzi P, Leonardi M, Palermo F. Mixed dentition space analysis in an eastern Sicilian population. Minerva Stomatol 2002;51(7-8):327-339.

88. Wangpichit, K., Huntington, N. L., Kapala, J. T. (2001). Comparison of three methods of mixed dentition analysis in cleft lip and patients. Pediatric Dent. 23: 478-80.

89. White LW. Individualized ideal arches. J Clin Orthod. 1978; 12: 779-787.

90. Yuen KK, Tang EL, So LL. Mixed dentition analysis for Hong Kong Chinese. Angle Orthod. 1998;68(1):21–28.

91. Yuen KK, So LL, Tang EL. Mesiodistal crown diameters of the primary and permanent teeth in southern Chinese–a longitudinal study. Eur J Orthod. 1997;19(6):721–31

92. Yuen KK, Tang EL, So LL. Relations between the mesio-distal crown diameters of the primary and permanent teeth of Hong Kong Chinese. Archs Oral Biol. 1996; 41: 1-7

93. Zilberman O, Huggare JV, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod. 2003; 73:301–6

94. Zilberman Y, Kaye EK, Vardimon A. Estimation of mesiodistal width of permanent canines and premolars in early mixed dentition. J Dent Res 1977; 56:911-5.