Mixed dentition space analysis among a sample of a high secondary school Sudanese students: an odontometric study

By

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Dedication

To the soul of my father

To my beloved Mother

To my family, friends & colleagues
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Abbreviations

CPM: permanent canines and first and second premolars.

UCPM: upper permanent canines and first and second premolars.

LCPM: lower permanent canines and first and second premolars.

T/J: Tanaka and Johnston.

MPI: mandibular permanent incisors.

r: coefficient of correlation.

r²: coefficient of determination.

mm: millimeter.

MLRE: multiple linear regression equation.

SLRE: simple linear regression equation.

ANOVA: analysis of variance.

t-test: Student t-test.

P: P-value.

SD: standard deviation.

SEM: standard error of the mean.

t: t-value.

df: degree of freedom.

M: males.

F: females.

a: y-intercept, in millimeters.
\( b \): slope of the regression line.

\( Y \): predicted value of the sum of the unerupted permanent canines, first and second premolars in one quadrant.

\( X \): the sum of the mesiodistal widths of the lower permanent incisors.

\( n \): sample size.
Abstract

**Background:** Mixed dentition analysis is the prediction of the tooth size of the unerupted permanent canine, first and second premolars (CPM) to determine the discrepancy between the available and required space in each dental arch. This is often done in the mixed dentition stage after the eruption of mandibular permanent incisors (MPI). It is an important step in the diagnosis and treatment planning. The two most widely used non-radiographic tooth size prediction methods were derived from populations of Northern European ancestry. However, the applicability of these methods in other ethnic groups has been varied and questionable.

**Design:** Descriptive, cross-sectional study.

**Settings:** A sample of 250 female and male students, aged from 13 to 19 years was randomly selected from two public high secondary schools of Khartoum Locality. The mesiodistal widths of the upper and lower CPM as well as the MPI were measured manually on the dental casts using a digital caliper (Mitutoyo™, Japan). The predicted values of the mesiodistal widths were statistically compared with the respective actual sum of the canine and premolars of the same quadrant.

**Objectives:** To test the applicability of the T/J equation for the prediction of the mesiodistal width of the unerupted permanent teeth in a sample of Sudanese students and to develop a new prediction equation for this specific sample.
**Results:** Moderate correlation coefficients between the sum of the mesiodistal width of the MPI and the sum of the CPM were 0.618 (for lower) and 0.626 (for upper) in male subjects and 0.726 and 0.680, respectively, in female subjects. Further, a lower coefficient of determination was recorded (0.45 and 0.48) with high standard error of estimate of 0.87 in both jaws for combined genders. Furthermore, the Tanaka and Johnston equations overestimated the actual mesiodistal width of CPM in both arches for both genders separately and for the combined genders. Finally, new prediction equations with more accurate regression parameters were proposed for males and females combined as well as for separate genders.

**Conclusion:** The new proposed equations for the prediction of the mesiodistal width of permanent canine, first and second premolars in both jaws give better and accurate estimate among this Sudanese sample. Therefore, one can recommend, with caution, the use of this proposed equation among Sudanese population with the intention of conducting future studies using a more representative sample from the different parts of the Sudan.
منصص الدراسة

مقدمة: يمكن بواسطة تحليل الأسنان المختلطة التنبؤ محصلة العرض الإنسني الوحشي للأسنان في مناطق الأنياب والأضاحك غير البازغة وذلك تحديد الاختلافات في المساحات الموجودة والمطلوبة في القوس السني. يُنتج هذا التحليل عادة في مرحلة الأسنان المختلطة بعد نزول القواطع السفليّة الدائمة ويعتبر من الخطوات المهمة في التشخيص وتخطيط العلاج. أكثر الطرق غير الإشعاعية شيوعاً للتنبؤ بحجم الأسنان مشتقة من تحليل سلالات أوروبا الشمالية.

التصميم: دراسة مستعرضة وصفية.

الإعدادات: شملت الدراسة عينة مؤلفة من 250 طالباً وطالبة (أعمارهم من 13-19 سنة) تم اختيارهم عشوائياً من مدرستين ثانويتين حكوميتين محلية الخرطوم. استخدم مقياس رقمي لقياس العرض الإنسني الوحشي للأنياب الدائمة والأضاحك العلوية (Mitutoyo™, Japan) والسفليّة وكذلك القواطع السفليّة الدائمة. أجريت مقارنة بين القيمة التنابوية للعرض الإنسني الوحشي وبين القيم الفعلية لنفس جزء الأنياب والأضاحك.

الأهداف: اختبار تطبيق معادلة تاناكو وجونستون للتنبؤ بالعرض الإنسني الوحشي للأنياب الدائمة والأضاحك غير البازغة عند عينة من الطلبة السودانيين بهدف تطوير معادلة تنبؤ جديدة لهذه البيئة الخاصة.

النتائج: بلغ معامل الارتباط بين محصلة العرض الإنسني الوحشي القواطع السفليّة الدائمة ومحصلة الأنياب والأضاحك 0.618 (لفلك السفلي) و0.626 (لفلك الطرف) عند الذكور و0.680 و0.726 على التوالي بالنسبة للإناث. تراوح معامل التحديد بين 0.45 و0.48 مع خطأ تقييمي 0.87 في الفكين لكلا الجنسين. بالغت معادلات تاناكو وجونستون في تقدير العرض الإنسني الوحشي للأنياب والأضاحك في القوسين عند كلا الجنسين. تم صياغة معادلات تنابوية بمعايير إرتدادية أكثر دقة بالنسبة للذكور والإناث معاً أو منفصلين.

الاستنتاج: المعادلات الجديدة المقترحة للتنبؤ بالعرض الإنسني الوحشي للأنياب الدائمة والاضاحك غير البازغة في الفكين تعتبر أكثر دقة بين هذه العينة السودانية، ولذلك يوصي، مع الحذر، باستعمال هذه المعادلات المقترحة بين السودانيين مع الأخذ بعين الإعتبار إجراء دراسات مستقبلية تستخدم عينة أكبر تمت مقابلة مناطق السودان.
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1.1 Introduction

The ideal time to commence orthodontic treatment in the growing patient is a controversial issue in the profession. Timing of treatment to begin in the permanent dentition involves several problems such as ectopic eruption of teeth. This problem, and probably others, can be reduced by careful assessment of the teeth in the mixed dentition stage.

Mixed dentition analysis is the prediction of the tooth size of unerupted permanent canine, first and second premolars to determine the discrepancy between the available and required space in each dental arch. Such a determination is often made prior to eruption of the permanent canines, first and second premolars (CPM). It is an important criterion in determining whether the orthodontic treatment plan will involve serial extraction, space maintenance, space regaining, or just observe the patients periodically.

There are three basic methods of predicting mesiodistal width of the CPM: direct measurements from the radiographs, correlation-statistical methods, and combination of radiographs and correlation-statistical methods.
Because of their simplicity, correlation-statistical methods are most frequently used. The most common one is the Tanaka and Johnston\textsuperscript{9} method. However, a lot of available data illustrates the limitation of the Tanaka and Johnston\textsuperscript{9} method when applied among populations other than European descent.\textsuperscript{3,10} However, when searching the literature, no relevant study was carried among the Sudanese population.
1.2 Literature Review

1.2.1 Tooth size variation

Tooth size varies significantly between different populations and races. Variation in tooth size is influenced by genetic and, to a less extent, by environmental factors (e.g. nutrition and disease) which may affect the dentition during the prenatal period.\textsuperscript{11}

It was concluded that tooth size was determined to a large extent by genetic factors.\textsuperscript{12} Various degrees of admixture within a population could result in a new genetic pool that needs to be investigated. From an orthodontic point of view, it is important to determine the dental traits as well as the dentofacial relationships that result from this admixture.\textsuperscript{13}

A study on Saudi Arabian population showed that the Saudis had smaller tooth size than a sample population of Northern European descent,\textsuperscript{14} whereas a comparative study between Jordanians, Iraqi, Yemenis, and Caucasians reported that the Jordanians and Iraqis had larger mesiodistal teeth size.\textsuperscript{15}

In South Africa, a study of 100 randomly selected study models of black patients concluded that the mesiodistal tooth size of CPM were larger than those of white subjects.\textsuperscript{16}
It was found that the crown width of the teeth of Dominican Americans was consistently larger than that of the North American white sample.\textsuperscript{17}

Some investigators found that there was some evidence of secular trends of changing dimensions of the teeth, which may require progressive modifications of mixed dentition space analysis for different populations.\textsuperscript{18}

A comparative study conducted on Norwegian children born in the 1960s and 1980s, Swedish children born in the 1960s and 1980s, Norwegian Sami children born in the 1980s, and a sample of Norwegian skulls dating from the 14\textsuperscript{th} to the 19\textsuperscript{th} century showed that the permanent tooth size was smaller in the skulls compared with the modern groups. Improved nutrition is considered to be the main reason for the difference.\textsuperscript{19}

\subsection*{1.2.2 Prediction of the size of the unerupted dentition}

Prediction of the size of the unerupted teeth presents a great challenge to both dentists and orthodontists. Prediction methods are based on the fact that once crown morphogenesis is complete; the teeth are less susceptible to postnatal modifying factors.\textsuperscript{1,20}
A review of the literature regarding space analysis in the mixed dentition stage showed that there were three main methods of prediction being used:

1. Direct measurements of unerupted tooth sizes on radiographs.\textsuperscript{6,7}
2. Calculations from prediction equations and tables.\textsuperscript{1,9, 21-23}
3. Combination of radiographic and prediction table.\textsuperscript{2}

\textbf{1.2.2.1 Direct radiographic measurements}

Previously, clinicians relied mainly on the averages of the mesio-distal tooth widths.\textsuperscript{24} However, the use of those averages could not be justified with the evidence of tooth size variations within individuals and population groups.\textsuperscript{25}

Nance\textsuperscript{6} proposed one of the first analyses to measure unerupted mesiodistal tooth size from intraoral radiographs. This method was recommended by other investigators.\textsuperscript{26,27}

The direct radiographic measurement requires undistorted radiographic image. Even with individual films, it is often difficult to obtain undistorted views, which inevitably reduces the accuracy. Moreover, with any type of radiographs, it is necessary to compensate for enlargement of the image. In spite of this, accuracy of this technique is fair to good depending
on the quality of the radiographs. In addition to that, the technique can be used in both dental arches for all ethnic groups.\textsuperscript{28}

### 1.2.2.2 Calculations from prediction equations and tables

The methods that use prediction equations and tables are based on the high linear correlation between relevant groups of teeth. The common factor in this category is the possibility of predicting the sizes of unerupted teeth by using the widths of other fully erupted permanent teeth.\textsuperscript{29} Seiple\textsuperscript{30} published the first study in this field. Further Carey\textsuperscript{31} was the first who proved the existence of a strong linear correlation between the size of the permanent lower incisors and the size of the CPM. Furthermore, Ballard and Wylie\textsuperscript{21} examined more closely Carey's study and established the first regression equation.

Moyers\textsuperscript{1} proposed a table for prediction of the mesiodistal diameter of CPM based on the sum of the widths of the permanent four lower incisors. Moyers\textsuperscript{1} analysis was reassessed by Tanaka and Johnston\textsuperscript{9} and a simple equation to predict the widths of unerupted CPM for both jaws and genders using the size of the four MPI was established. Tanaka and Johnston\textsuperscript{9} method is simple, flexible, relatively accurate, easily remembered, and non-invasive applied regression equation.
In spite of the tendency to overestimate the size of the unerupted teeth, the accuracy of Moyers\textsuperscript{1} and Tanaka and Johnston\textsuperscript{9} methods is fairly good for the northern European white children.

1.2.2.3. Combination of radiographic and prediction tables

This method is considered to be the most accurate ones due to the lowest standard of error of estimate. On the other hand, it is complex and may give only marginal improvement over simpler methods, discouraging its use by clinicians, and many found it difficult to use.\textsuperscript{32,33}

A regression equation was established where the sizes of unerupted mandibular CPM could be predicted after measuring the mandibular canines and premolars on radiograph.\textsuperscript{2} It was modified by including the sizes of MPI.\textsuperscript{34} Later, another study on the tooth size prediction found that the predicted mesiodistal widths of the teeth to be significantly smaller than their actual widths.\textsuperscript{26} The same conclusion was reached by other investigators.\textsuperscript{32,35} This finding led to the revision of the prediction equations which significantly improved the predictive capability of the old methods.\textsuperscript{36}

In a study conducted in Brazil, the reliability of using the 45° oblique teleradiography, after correcting the magnification, can be used in predicting the unerupted lower canine and premolar widths in the Brazilian children.\textsuperscript{27}
In a recent study, a new regression equation was determined and its accuracy was tested. It was found that correlations between the width of the lower first premolar in the 45° oblique teleradiographs and the actual sum widths of lower CPM showed adequacy for space analysis in mixed dentition.37

1.2.3 Tanaka and Johnston Method

Tanaka and Johnston9 studied a sample of 506 North American orthodontic patients using the sum of the mesiodistal widths of the mandibular permanent central and lateral incisors to develop regression equations in predicting the sizes of the unerupted CPM. The results showed that the mesiodistal widths of CPM at the seventy-fifth percentile level can be predicted by taking one half of the width of mandibular permanent incisors and adding 10.5 mm for the mandibular teeth and 11.0 mm for the maxillary teeth. Tanaka and Johnston9 method is quick, easy and practical one, because no radiographs were required, and no reference tables must be consulted. However, several authors have pointed out that the predicted values obtained by Tanaka and Johnston9 equations are overestimated.3, 11, 38

A Saudi Arabian study stated that the Tanaka and Johnston9 equations overestimated the size of buccal segment in a Saudi population. The data
illustrated the limitation of the method when applied to a sample population of other than European descent. Another study proved that the Tanaka and Johnston prediction equation was not accurate in a sample of Hong Kong population and new prediction equations were introduced.

1.2.4 Predictors used in the regression equations

- Mandibular permanent incisor.
- Mandibular permanent central incisors and the maxillary permanent first molars.
- The mesiodistal diameter and the vestibulo-oral diameter of the crowns of the mandibular and maxillary permanent incisors and the first permanent molars.
- The combination of mandibular and maxillary permanent central incisors and maxillary permanent first molars.
- Maxillary permanent central incisors and mandibular permanent first molars.

1.2.5 Odontometric studies in Sudan

No study was done in mixed dentition space analysis in Sudan. The only odontometric study was conducted by Hashim et al. on a Sudanese sample of 30 participants from the University of Khartoum, aged 20-25
years. The results revealed that the mean values of tooth widths in the right side of the upper arch were relatively greater than on the left side while the opposite was observed in the lower arch. However, this difference was insignificant. Supporting previous reports, it was concluded that measurements from one side could be considered as truly representative when the corresponding measurements of the other side were unobtainable.

1.2.6 Space analysis in Arab population

Bishara et al.\textsuperscript{44} studied a sample from three different populations: 57 subjects from Iowa City, USA; 54 subjects from Alexandria, Egypt; and 60 subjects from Chihuahua, Mexico. Comparisons of single teeth, as well as sum of groups of teeth were performed between boys and girls within and between the three populations. The result showed that the prediction equations used for space analysis in the mixed dentition to determine tooth size-arch length discrepancies in the Iowa population can also be used for subjects from Egypt and the Northern part of Mexican Republic, with some suggested modifications.

Al-Khadra\textsuperscript{14} selected randomly 100 pretreatment dental casts of patients attending orthodontic clinic in the Department of Orthodontics at King Saud University, Saudi Arabia. The patients were all native Saudis of
age less than 20 years old. All teeth selected for measurements had to be fully erupted, free of visible fractures, caries, and restorations. The patients who fulfilled criteria of selection were 34. After performing the required measurements and analysis, the result revealed that both the Moyers\textsuperscript{1} charts at the 75\textsuperscript{th} percentile confidence level and the Tanaka and Johnston\textsuperscript{9} equations of prediction overestimated the size of the buccal segments. Further, Al-Khadra\textsuperscript{14} stated that the different results obtained could be attributed to the small sample size that could have biased the results, and to the differences in the ethnic origins of the samples. Zilberman et al.\textsuperscript{45} reported similar results when applied the Moyers\textsuperscript{1} method to another sample of Middle East population. AL-Khadra\textsuperscript{14} result indicated that the Saudi sample has smaller teeth than a sample population of Northern European descent and also indicated that the currently popular prediction methods were not accurate when applied on Saudi population.

Hashim and Al-Shalan\textsuperscript{46} conducted an Odontometric study in pretreatment orthodontic casts of 65 Saudi subjects (18-25 years old). The mesiodistal widths of all permanent teeth mesial to the first permanent molar of both dental arches were measured. The result showed that the Tanaka and Johnston\textsuperscript{9} prediction equations overestimated the widths of the CPM, which was in agreement with the results obtained by Al-Khadra.\textsuperscript{14}
A recent study was carried in Syria in order to validate the Tanaka and Johnston\textsuperscript{9} analysis. A sample of 600 Syrian patients aged 14-22 years was selected. New and more accurate prediction tables as well as new regression equations were presented. The analyses was based on teeth that erupted earlier than those used by Tanaka and Johnston.\textsuperscript{9} Equations were developed to allow easier prediction of the size of the unerupted maxillary CPM by adding 6 mm to the half-widths of teeth 31, 41, 16, and 26. The analogous prediction of the size of the unerupted mandibular CPM was obtained by adding 5.5 mm to the half-widths of the same teeth 31, 41, 16, and 26.\textsuperscript{39}

Jordanian subjects aged from 14-16 years old had been studied by Abu Alhaija and Qudeimat\textsuperscript{10} using 226 dental casts (130 males and 96 females) with complete permanent dentition. The actual teeth measurements were then compared with the predicted values derived from the Tanaka and Johnston\textsuperscript{9} equations. The results showed that except for the maxillary arch in male subjects, Tanaka and Johnston\textsuperscript{9} regression equations underestimated the mesiodistal widths of CPM. Hence, new regression equations were formulated for the Jordanian population.
1.2.7 Space analysis in black population

Few odontometric data was available in the literature for African children.\textsuperscript{30} Significant differences in mesiodistal tooth diameters in Kenyan and Irish populations were reported.\textsuperscript{47} Other researchers reported that the mean mesiodistal tooth sizes for all the teeth were significantly larger in Nigerians than in their British counterpart.\textsuperscript{48}

A comparative study between black and white patients revealed that the mean mesiodistal tooth sizes for the lower CPM and the first molar were significantly larger in the black patients than that of the white ones.\textsuperscript{49}

Another study collected 100 study models of black patients, randomly, at a major university orthodontic clinic in Pretoria, South Africa, to formulate the relevant probability tables that would be more applicable to black subjects. The proposed equations and the predicted values were compared with those of Moyers\textsuperscript{\textsuperscript{22}} probability tables. Significant differences were found and new probability tables for black subjects were formulated. It was concluded that these new tables were more accurate for black population of African ancestry.\textsuperscript{16}

Diagne et al.\textsuperscript{50} carried out a study on fifty black university Senegalese students. Significant gender dimorphism was found in tooth sizes. The Tanaka and Johnston\textsuperscript{9} equations and the Moyers\textsuperscript{22} chart at 50% confidence
level did not accurately predict the tooth size of the unerupted CPM in Senegalese children. Therefore, the prediction tables formulated were suggested to be more accurate when applied to local children, despite the ethnic variety in Senegal.

In a randomly selected sample of 131 Kenyans patients attending the Kenyatta National Hospital, the mean sum of the four MPI was used to determine the sum of the CPM in one quadrant. The predicted values of the mesio-distal widths were compared statistically with their respective actual sum of the CPM of the same quadrants. Tanaka and Johnston\textsuperscript{9} method failed to show any statistically significant differences for either gender or combined genders at 95% confidence level. However, it was observed that the Tanaka and Johnston\textsuperscript{9} was the most accurate among the non-radiographic prediction methods in the mixed dentition analysis in the Kenyan sample.\textsuperscript{25}

1.2.8 Space analysis in other populations

Bishara and Jakobsen\textsuperscript{4} compared two mixed dentition prediction methods that do not require the use of periapical radiographs of the unerupted permanent teeth. Records of 33 male and 22 female subjects who participated in the Iowa Longitudinal Growth Study were also used in that study. The two methods compared were the Tanaka and Johnston\textsuperscript{9} and the
Boston University prediction methods. The findings indicated that, on the average, the Tanaka and Johnston\textsuperscript{9} method slightly overestimated the tooth size of the unerupted teeth. On the other hand, the Boston University approach slightly underestimated the tooth size of the unerupted teeth.

In a study carried in the city of Salvador, the Tanaka and Johnston\textsuperscript{9} method of prediction was evaluated, with the objective of verifying its effectiveness for the white, light mulatto, medium mulatto, dark mulatto and black races. The obtained results were statistically compared with the real values. It was concluded that the Tanaka and Johnston\textsuperscript{9} method, could be used for the prediction of the mesiodistal diameter of CPM in the different races evaluated in that study.\textsuperscript{51}

One hundred and fifty plaster casts of permanent dentition (82 females and 68 males) were collected from the School of Orthodontics at the University of Catania, Italy. The width of CPM and MPI were taken by means of a bow-compass and a sliding digital caliper. The results indicated that the sum of the mesio-distal crown diameters of CPM was smaller in females than in males. Also the results suggested that the North-American predictions overestimated the tooth size of CPM in both genders.\textsuperscript{52}

Flores-Mir et al.\textsuperscript{53} compared the predicted tooth width measurements of CPM using Tanaka and Johnston\textsuperscript{9} regression equations with that of the \textit{in}}
*situ* measurements in a sample of Peruvian adolescents in Peru (248 dental casts), and found that Tanaka and Johnston\(^9\) regression equations were not precise, except for the upper arch in the male sample. It was concluded that using tooth width prediction methods from other races could under- or over-estimate of the real combined canine and premolars tooth width, although their clinical significance is disputable.

One year later, it was concluded that it was important not only to evaluate the statistical need for specific simple linear regression equation (SLRE) in different populations, but also to state the clinical significance of their differences against commonly used SLRE.\(^{54}\) Looking for better predictors, a study on 150 Peruvian children with complete permanent dentition was conducted. The combination of the sum of the permanent upper and lower central incisors and the upper first molars was found to be the best predictors for the sum of the unerupted canine and premolars. A multiple linear regression equation (MLRE) was calculated including the gender and the arch (maxilla/mandible) as an additional predictor variables. The newly formulated MLRE underestimated the actual mesiodistal width of the unerupted CPM by less than 1 mm in 7% of the cases (on the basis of a validation sample).\(^{41}\)
A study in Spain was conducted in order to develop a new, fast and accurate computerized method to predict the tooth size of unerupted CPM, and to determine which reference tooth or combination of reference teeth was the best predictor. It was found that the combination of the sum of the permanent upper central incisors and the lower first molars was the best predictor. Moreover, the result showed that the proposed method was very accurate.42

Melgaço55 evaluated the applicability of the methods of Moyers,22 Tanaka and Johnston,9 and Bernabé and Flores-Mir53 in Brazilian individuals. Statistically significant differences were found, although the differences were not clinically relevant. He proposed new regression equations using the MPI as a predictor for the sum of the widths of the lower CPM.

Another study on a Hong Kong Chinese sample was done to generate prediction equations for the combined mesiodistal crown diameters of CPM based on the size of MPI. Significant gender differences were found for the combined diameters of the canine-premolar segments. The prediction equations were different from those of Tanaka and Johnston.9 Thus, the accuracy in the mixed dentition analysis for that sample would be improved by applying them instead.38
Lee-Chan et al.³ conducted a study in a sample of Asia-Pacific-American to test the accuracy of the Tanaka and Johnston⁹ method in different ethnic groups. The actual measurements were compared with the predicted values derived from the Tanaka and Johnston⁹ equations. Significant differences were found. The data illustrated the limitation of the Tanaka and Johnston⁹ method when applied to races other than European descent.

The mesiodistal crown diameters of dentition of a Chinese sample were measured to study the relationship between MPI and CPM. This was performed in order to provide the most accurate equation in orthodontic diagnosis and treatment planning for Chinese people. The mesiodistal crown diameters of the teeth were assessed and investigated separately for males and females. The result showed a significant gender dimorphism. It was also found that the total mesiodistal crown diameter of MPI was closely correlated with the total mesiodistal crown diameter of CPM.⁵⁶

In a comparative study by Ling and Wong⁵⁷ to compare the unerupted permanent canine and premolars using a comparable sample size of southern Chinese population with that of Tanaka and Johnston.⁹ A Chinese mixed dentition analysis based on the Tanaka and Johnston⁹ method was constructed with linear regression equations for prediction of the mesiodistal
widths of unerupted CPM. For simplicity and easy memorization when performing mixed dentition analysis, the constants for male and female southern Chinese were approximated. The result of this study showed that gender dimorphism in tooth size was evident between southern Chinese males and females in incisors, canines, and premolars.

A sample of 430 Thai students, representing the population of the region, was selected. The total population of that region was 20.8 millions. It was found that males had significantly larger teeth than females. The regression equations produced predictions of mesiodistal width summations for maxillary and mandibular canine and premolars arch segment that were slightly different from other reported Asian studies.58

1.2.9 Space analysis in cleft lip and palate cases

Three non-radiographic methods of mixed dentition analysis in cleft lip and palate patients were compared. It was concluded that the type of cleft had no effect on the size of the mandibular CPM. Besides, the application of mixed dentition analyses in cleft lip and palate patients did not differ from non-cleft patients.59
1.2.10 Gender Dimorphism

Gender dimorphism does exist in most of the odontometric studies of mesio-distal widths of permanent teeth:

Legovic et al.\textsuperscript{40} stated that it was important to determine in advance whether or not that the dimensions of teeth in boys and girls vary and reported a statistically significant difference between boys and girls.

Fifty dental casts of Moroccan students were used to perform measurements of the greatest mesiodistal widths of all mandibular and maxillary CPM and MPI with an orthodontic caliper. Significant gender dimorphism was found in tooth sizes (P<0.001).\textsuperscript{60}

Ngesa\textsuperscript{25} found that the mean mesiodistal tooth widths of male subjects were consistently larger than females in both mandibular and maxillary dental arches. The differences were statistically significant (p<0.05). The most statistically significant differences were noticed in both maxillary and mandibular canines and maxillary central incisors, while the smallest differences were observed in the incisors in the mandibular arch and for the first and second premolars in the maxillary arch.

A study carried out on a sample of Southern Chinese in Hong Kong found that in both arches the males had larger absolute mesiodistal tooth dimensions in all tooth types (incisors, canines, premolars and molars). The
absolute inter-gender difference of the size ranged from 0.05 mm (mandibular central incisor) to 0.42 mm (mandibular canines). All the teeth size were significantly different ($P \leq 0.05$) between the two genders, with the exception of the lower lateral incisors. It was concluded that, separate prediction equations are needed for the males and the females.$^{57}$

Al-Khateeb and Abu Alhaija$^{61}$ in an odontometric study on a Jordanian sample, found that there were differences in tooth size between the right and the left sides confirming the presence of asymmetry between the two sides. Moreover, females showed a tendency of having smaller teeth than males.

1.2.11 Methods of odontometric measurements

Mesiodistal measurements of teeth can be done directly in the mouth, on the dental casts and/or on radiographs in order to determine the tooth sizes of either erupted teeth and/or unerupted teeth. However, both dental casts and the radiographs need to be of high quality. Hunter and Priest$^{29}$ reported that the cast measurements were slightly larger than the direct measurements made in the mouth. Comparing the soaped and un-soaped models, it was found that the measurements made on the former were slightly larger. Measurements made from dental casts were more consistent
and therefore more accurate than direct measurements taken from the mouth, particularly in the posterior segments where measuring became difficult because of the accessibility.

For reasons of convenience and economy, orthodontists routinely use and maintain pre- and post treatment plaster casts, started to use computer-based digital models. Santoro et al. did a study comparing measurements made on digital and plaster models. He concluded that the tooth width and overbite measurements made on plaster and digital models showed statistically significant differences; however, these differences do not appear to be clinically relevant.

Many investigators compared the linear dental anatomic measurements obtained from plaster and digital models, whereas others, used Bolton analyses on plaster and digital models. The former investigators found statistically significant difference between plaster and digital model linear measurements but they concluded that the average difference was clinically insignificant. On the other hand, the opposite was observed by Tomassetti et al. Further, Quimby et al. concluded that the measurements made from computer-based models appear to be generally accurate and reliable as measurements made from plaster models. Furthermore, Rheude et al. stated that plaster casts of the dentition remain
a recognized tool for orthodontic diagnosis and treatment planning, although in most instances, digital models can be successfully used in orthodontic records.

In the past, the tools of measuring tooth size were carried out with either of two basic instruments: the sliding calipers with a vernier scale or a pair of engineer dividers used in conjunction with a millimeter ruler. With the latter, holes are punched on a card and the distances are then measured with the millimeter ruler. Others found that the sliding calipers to be more accurate, whereas the dividers gave a consistently higher mean reading. More recently, it was demonstrated that the measurements with the digital calipers on plaster models produced the most accurate and reproducible results and recommended it as the most suitable instrument for scientific work.

Moorrees and Reed pioneered the effort to standardize the location of measurement on the models. It was stated that the best method appeared is to employ the sliding calipers with a vernier scale to the nearest 0.1 mm. This is to measure the greatest mesiodistal diameter at the contact point parallel to the occlusal surface of the teeth and also parallel to the vestibular surface of the model. In addition, Wangpichit et al. stated that when a tooth
is rotated or malposed in relation to the dental arch, the measurement should
be taken between the points on the approximate surface of the crown, where
it is judged that the normal contact should have occurred with the
neighbouring tooth.

1.2.12 Tooth size correlations in different studies

The widely used methods to predict the sum of the unerupted CPM
depend upon the statistical correlation of the sum of the MPI and the sum of
the CPM.\textsuperscript{1,9,21-23,27} The location of the MPI allows easy accessibility for
accurate measurement both in the mouth and on the dental casts.\textsuperscript{1} Further,
the MPI erupt early in the mixed dentition and have very low variability in
shape and size.\textsuperscript{1} In a longitudinal study done by Sillman\textsuperscript{71} it was found that
with the eruption of the first permanent molars and mandibular incisors,
most of the expected growth in the mandibular arch has been accomplished.

Ballard and Wylie\textsuperscript{21} established the first regression equations used to
predict the size of unerupted CPM and developed a formula despite the low
correlation (r= 0.64) between MPI and CPM \( \{Y=9.41+0.527X, \) where \( Y \) is
equal to the sum of the CPM, while X is equal to the sum of the mesiodistal widths of the MPI).

Tanaka and Johnston\textsuperscript{9} used the sum of the mesio-distal widths of the MPI to develop regression equations in predicting the sizes of the unerupted CPM. The correlation coefficient obtained by Tanaka and Johnston\textsuperscript{9} were $r=0.648$ for mandibular and $r=0.625$ for maxillary teeth. However, the standard errors of estimates for the correlations were rather high (0.86 mm for the maxillary and 0.85 mm for the mandibular teeth). Despite these low to moderate correlations an advantage existed in their clinical use.

More recently, other investigators found higher correlation between the two mandibular permanent central incisors, the two maxillary permanent first molars and the maxillary and mandibular canines and premolars. A new and more accurate prediction tables and regression equations were proposed for the Syrian population.\textsuperscript{40}

Recent several studies have been conducted to evaluate the applicability of the Tanaka and Johnston\textsuperscript{9} and Moyers\textsuperscript{1} methods in Caucasian groups. Only few of these studies have been performed for the Arabs and Africans. No study was done in the Sudan. Therefore, thorough
studies are still needed to evaluate the applicability of these prediction methods in such populations.
1.3 Aims and Objectives

General objectives

To improve the aspects of diagnosis and treatment planning in the mixed dentition stage by determining the tooth size-arch length relationship in a sample of young Sudanese students.

Specific Objectives

1. To establish odontometric database for a sample of Sudanese students.
2. To test if there is a correlation between the sums of the mandibular permanent incisors and the combined mesiodistal crown diameters of the maxillary and mandibular permanent canines, first and second premolars in this sample.
3. To test the applicability of the Tanaka and Johnston method for prediction of the unerupted permanent canines, first and second premolars in the Sudanese samples.
4. To develop a new prediction equations for this Sudanese sample and to compare it with the Tanaka and Johnston method if it is not applicable.
2. Materials and Methods

2.1 Study design

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

2.2 Study Area

Randomly selected public high secondary schools from Al-‘Amarat and Burri, Khartoum Locality.

2.3 Study population

The study was performed on students from Al-Khartoum Algadeema female high secondary school (325 students) and Burri male high secondary school (285 students). The total participants to be found suitable for the study were 250.

2.3.1 Criteria for selection

1. Participants should be native Sudanese.

2. The permanent teeth to be measured should be fully erupted and with no attrition, fractures, restorations or obvious proximal caries, and also with no gross dental abnormalities.
3. Normal class 1 molar, canine and incisor relationship, with 0-3 mm overbite and overjet and mild spacing or crowding (≤ 2 mm).

4. No previous orthodontic treatment.

5. No apparent facial disharmony.

2.3.2 Sample size

It was calculated using the following equation:

\[ n = \frac{z^2 \cdot pq}{d^2} \]

where: 
- \( z \) = the standard deviation (1.96) correspond to 95% confidence level.
- \( p \) = the proportion in the target population (estimated from a pilot study to be 25% of the total population).
- \( q \) = the probability of failure; equals to 1 - \( p \).
- \( d \) = the degree of accuracy desired: 20% of \( p \); i.e. 0.05

Therefore, \( q = 1 - 0.25 = 0.75 \)

Therefore, \( n = (1.96)^2 \cdot 0.25 \times 0.75 / (0.05)^2 = 288.1 \)

Therefore, according to this equation, the sample size should be 288.
2.4 Ethical considerations

Ethical approval was obtained from the Faculty Research Committee. The Headmaster of each secondary school was informed beforehand. Informed consent was signed by the participants. (Appendix 2, 3)

2.5 Sampling technique

Stratified random sampling technique

2.6 Materials and Instruments

1. Water
2. Hydrocolloid alginate impression material (Zhermack™, Italy)
3. Disinfectant (Cidex™)
4. Cotton (Jaycot Industries, Hyderabad, India)
5. Plastic bags
6. Examination gloves (Razymed, Indonesia)
7. Dental stone (Zhermack™, Italy)
8. Digital caliper (Mitutoyo™, Japan)
9. Plastic stock trays (Nixon, Pakistan)
10. Rubber bowls (Zhermack™, Italy)
11. Plastic spatulas (Zhermack™, Italy)
12. Dental mirrors (Nixon, Pakistan)
13. Sharp explorers (Nixon, Pakistan)
14. Wooden tongue depressor (China)
15. Markers (Staedtler, Germany)
16. Trimming machine (Buffalo Dental, USA)
17. Pencils (Flamingo™ Gold, No 2 HB, China)
18. Erasers (Penguin™, China)

2.7 Methodology

The total number of students in the public high secondary schools in Khartoum Locality was 16749. The number of male students was 9502 (56.7%), in 28 schools, whereas female students were 7247 (43.3%), in 23 schools (Ministry of Education, 2005). One public high secondary school of each gender was selected randomly; Al-Khartoum Algadeema Female High Secondary School (325 students) and Burri Male High Secondary School (285 students). The total number of the students of both schools was 610. All of them were examined but only those who fulfilled the criteria of selection were included. The examination was performed by the investigator (A. Alzubir) and two well trained dentists in the period from 26/11-3/12/2005. A consent form was given to all participants who fulfill the criteria of selection.

Clinical data was obtained by clinical examination in day light, using dental probes, wooden tongue depressors and dental mirrors. All materials used intra-orally were either sterilizable or disposable. Standard, different sized orthodontic trays were used for impression taking. Alginate impression
material (Hydrogum, Zhermack™, Italy) was mixed according to the manufacturer’s instructions, placed into the trays, and the impressions were taken. The impressions were rinsed thoroughly in water, and disinfected using a chemical disinfectant (Cidex™: Activated Glutaraldehyde Solution, Johnson and Johnson Medical Limited, United Kingdom). The impressions were rinsed again to wash the disinfectant. The impressions were poured immediately in dental stone (Type III, Zhermack™, Italy). Dental casts were checked for quality, trimmed, coded and packed, in order to be ready for data measurement.

The sum of the MPI was used to predict the combined sizes of the permanent unerupted CPM using Tanaka and Johnston⁹ method. The mesiodistal widths of the relevant maxillary and mandibular teeth (the study variables) were measured manually, using a vernier gauge calibrated with digital micrometer (Digimatic Caliper 207 Series No. 500, Mitutoyo™, Corporation, Japan - providing measurements to the nearest 0.01 mm). Measurements of the teeth were made directly on dental casts. Mesiodistal width is measured between two anatomical contact points of each tooth. The caliper peaks were inserted and held occlusally and parallel to the long axis of the tooth. Then the beaks were closed until gentle contact with the tooth
was felt. (Appendix 4) All the measurements were recorded and entered into an excel spreadsheet.

2.8 Data analysis

2.8.1 Reliability of the measurements

All dental casts were of high quality, un-soaped, and free of distortion. Measurements were taken by one operator (A. Alzubir) under natural daylight and neon light.

To standardize the readings and assess the reliability of the examiner, 56 casts were measured and re-measured within seven days interval between the two readings. Dahlberg formula was used to test the method error.

\[
\text{ME} = \sqrt{\left(\sum \frac{d^2}{2n}\right)},
\]

where ME = the method error, \(d\) = the difference between the two measurement values, and \(n\) = the total number of double determinations.

Two-tailed paired t-tests were used and statistical significant differences were achieved only if the P-value was less than 0.05.

Because of the high bilateral symmetry in the mesiodistal width of canines and premolars has been documented in the literature, the sum of the following groups of teeth were pooled and the mean mesiodistal tooth width calculated for each gender, and for the whole sample:
1. mandibular permanent central and lateral incisors.

2. mandibular permanent canines and premolars.

3. maxillary permanent canines and premolars.

The data of the present study was considered to be Normally distributed after using Kolmogorow-Smirnov test.

Two-tailed paired t-tests were performed to examine bilateral symmetry of mesiodistal widths of all measured individual teeth and combined mesiodistal widths of CPM of each arch. Pearson product-moment coefficients were used to evaluate the correlation between the groups of teeth.

Independent t-test was performed to compare the results between males and females. Further, paired t-tests were used to test the significance of the difference between the predicted and the measured values. Furthermore, a simple regression analysis of the dependent variable (the mean sum of the mesiodistal widths of CPM) was performed with the independent variables (mean sum of MPI) to establish a regression equation for the Sudanese sample.

2.8.2 Statistical analysis

Computer software, SPSS (Version 12.0, release 12.0.0, 4 Sep 2003) was used to analyze the statistical data obtained for the present study.
3. Results

3.1 Study sample

A total of 250 sets of dental casts were obtained from 118 males and 132 female participants. The mean age of the males and females was 15.61 years (SD; 1.36 years) and 15.25 years (SD; 1.38 years), respectively.

3.2 Reliability of the measurements

Dahlberg\textsuperscript{75} method error was found to be 0.043 mm, 0.017 mm, and 0.013 mm for the MPI, mandibular CPM, and maxillary CPM respectively which is less than 1 mm; indicating that the measurement is reliable. The independent t-test showed that the differences between the duplicate measurements were found to be statistically insignificant with P-value ranged from 0.404 to 0.735. (Table 1)
Table 1. Reproducibility of the study findings.

<table>
<thead>
<tr>
<th>Tooth group</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Standard error of the mean</th>
<th>t-value</th>
<th>Degree of freedom</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPI</td>
<td>22.807</td>
<td>1.423</td>
<td>0.269</td>
<td>0.841</td>
<td>54</td>
<td>0.404</td>
</tr>
<tr>
<td>MPI'</td>
<td>22.486</td>
<td>1.428</td>
<td>0.270</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPM (mand)</td>
<td>21.411</td>
<td>1.061</td>
<td>0.201</td>
<td>0.444</td>
<td>54</td>
<td>0.659</td>
</tr>
<tr>
<td>CPM' (mand)</td>
<td>21.287</td>
<td>1.035</td>
<td>0.196</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPM (max)</td>
<td>22.168</td>
<td>1.050</td>
<td>0.198</td>
<td>0.340</td>
<td>53</td>
<td>0.735</td>
</tr>
<tr>
<td>CPM' (max)</td>
<td>22.070</td>
<td>1.086</td>
<td>0.209</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MPI: average of the sum of lower permanent incisors.
MPI': re-measurement of MPI.
CPM (mand): average of the sum of mandibular permanent canines and premolars.
CPM' (mand): re-measurement of CPM.
CPM (max): average of the sum of maxillary permanent canines and premolars.
CPM' (max): re-measurement of CPM.
Significance at 5% level, NS = non significant.

3.3 Descriptive statistics for the sample

The total number of the participants enrolled in this study was 250; most of them were from Central Sudan. (Figure 1)

Figure 1. Gender distribution according to the region.
Table 2 presents the descriptive statistics for the mandibular central and lateral incisors for each gender and for both genders, and also for the mandibular and maxillary permanent canines, first and second premolars.

**Table 2.** Mean, range and standard deviation of mandibular and maxillary teeth for the males, females and both genders combined.

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Gender</th>
<th>Mean (mm)</th>
<th>Range (mm)</th>
<th>SD</th>
<th>Mean (mm)</th>
<th>Range (mm)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Incisor (R or L)</td>
<td>M</td>
<td>5.45</td>
<td>4.49-6.72</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5.32</td>
<td>4.29-6.80</td>
<td>0.41</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>5.37</td>
<td>4.29-6.80</td>
<td>0.40</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lateral incisor (R or L)</td>
<td>M</td>
<td>5.97</td>
<td>4.76-7.40</td>
<td>0.42</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5.82</td>
<td>4.70-7.06</td>
<td>0.42</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>5.89</td>
<td>4.70-7.40</td>
<td>0.42</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Permanent Canine (R or L)</td>
<td>M</td>
<td>7.12</td>
<td>5.72-8.20</td>
<td>0.44</td>
<td>8.09</td>
<td>6.55-9.06</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>6.67</td>
<td>5.39-8.90</td>
<td>0.46</td>
<td>7.64</td>
<td>6.57-8.92</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>6.88</td>
<td>5.39-8.90</td>
<td>0.50</td>
<td>7.85</td>
<td>6.55-9.06</td>
<td>0.50</td>
</tr>
<tr>
<td>First Premolar (R or L)</td>
<td>M</td>
<td>7.33</td>
<td>5.96-8.43</td>
<td>0.43</td>
<td>7.36</td>
<td>5.88-8.46</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>7.14</td>
<td>5.83-8.32</td>
<td>0.45</td>
<td>7.18</td>
<td>5.97-8.41</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>7.23</td>
<td>5.83-8.43</td>
<td>0.45</td>
<td>7.26</td>
<td>5.88-8.46</td>
<td>0.49</td>
</tr>
<tr>
<td>Second Premolar (R or L)</td>
<td>M</td>
<td>7.35</td>
<td>6.17-8.49</td>
<td>0.46</td>
<td>6.77</td>
<td>5.80-7.95</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>7.19</td>
<td>5.90-8.43</td>
<td>0.47</td>
<td>6.67</td>
<td>5.27-8.84</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>7.27</td>
<td>5.90-8.49</td>
<td>0.47</td>
<td>6.72</td>
<td>5.27-8.84</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Gender: M = male; F = female
R = right
L = left
SD = standard deviation
Table 3 exhibited that the sum of the mesiodistal crown diameter for the mandibular permanent incisors, upper and lower permanent canines and premolars was the highest in the males compared to the females and both genders combined.

**Table 3.** Sum of mesiodistal crown diameters for the MPI and CPM in both arches, in males, females and both genders combined.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Tooth group</th>
<th>Range</th>
<th>Mean (mm)</th>
<th>Standard deviation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males N=118</td>
<td>MPI</td>
<td>19.25-28.12</td>
<td>22.82</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>UCPM</td>
<td>19.15-24.84</td>
<td>22.21</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>18.48-23.99</td>
<td>21.79</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>18.72-26.54</td>
<td>22.28</td>
<td>1.51</td>
</tr>
<tr>
<td>Females N=132</td>
<td>UCPM</td>
<td>18.48-24.34</td>
<td>21.48</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>18.01-23.77</td>
<td>21.00</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>18.72-28.12</td>
<td>22.53</td>
<td>1.49</td>
</tr>
<tr>
<td>Combined males &amp; females</td>
<td>UCPM</td>
<td>18.48-24.84</td>
<td>21.83</td>
<td>1.17</td>
</tr>
<tr>
<td>N=250</td>
<td>LCPM</td>
<td>18.01-23.99</td>
<td>21.38</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Table 4 demonstrated the regional distribution of the participants. The majority of the participants were from the central part of the Sudan (n=92), while those from the North (n=82), and the west (n=64), were in the second and the third rank respectively. On the other hand, very few participants were included from the South (n=60 and from the East (n=2). Comparison between the Central, North and West parts revealed that the combined mesiodistal crown diameters of the MPI, UCPM and LCPM of the participants from the West region showed the highest mean value whereas the participants from the North region exhibited the lowest mean value.

The Southern subjects had the highest values whereas the Northern ones had the lowest. However, this finding is not solid since the sample size of the Southern participants was 6 and the Northern was 86.
Table 4. Combined mesiodistal crown diameters of the MPI and CPM for participants of various origins.

<table>
<thead>
<tr>
<th>Origin of the participant</th>
<th>Tooth group</th>
<th>n</th>
<th>Mean (mm)</th>
<th>Standard deviation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>MPI</td>
<td>92</td>
<td>22.44</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>UCPM</td>
<td>92</td>
<td>21.72</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>92</td>
<td>21.27</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>86</td>
<td>22.39</td>
<td>1.53</td>
</tr>
<tr>
<td>North</td>
<td>UCPM</td>
<td>86</td>
<td>21.70</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>86</td>
<td>21.19</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>64</td>
<td>22.65</td>
<td>1.38</td>
</tr>
<tr>
<td>West</td>
<td>UCPM</td>
<td>64</td>
<td>21.99</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>64</td>
<td>21.61</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>2</td>
<td>22.48</td>
<td>3.01</td>
</tr>
<tr>
<td>East</td>
<td>UCPM</td>
<td>2</td>
<td>22.05</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>2</td>
<td>21.57</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>6</td>
<td>24.47</td>
<td>2.45</td>
</tr>
<tr>
<td>South</td>
<td>UCPM</td>
<td>6</td>
<td>22.75</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>LCPM</td>
<td>6</td>
<td>22.29</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Tooth group: MPI: mandibular permanent incisors, UCPM: upper permanent canines and 1<sup>st</sup> and 2<sup>nd</sup> premolars. LCPM: lower permanent canines and 1<sup>st</sup> and 2<sup>nd</sup> premolars. n represents the sample size.
Table 5 showed that the sum of the mesiodistal width of the lower incisors of the present study to be the lowest, whereas for the Jordanians the highest. The same finding was noticed in the UCPM. The present study also showed the lowest value of LCPM while the highest was present in the Hong Kong study.

**Table 5.** Sum of mesiodistal widths of MPI and maxillary and mandibular CPM segments from various studies, in millimeters.

<table>
<thead>
<tr>
<th>Teeth group</th>
<th>MPI: Mean (SD)</th>
<th>UCPM: Mean (SD)</th>
<th>LCPM: Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Thailand</td>
<td>23.89 (1.37)</td>
<td>23.23 (1.26)</td>
<td>23.31 (1.03)</td>
</tr>
<tr>
<td>South Africa</td>
<td>23.92 (1.90)</td>
<td>23.66 (1.59)</td>
<td>23.45 (1.37)</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>23.15 (1.25)</td>
<td>23.28 (1.22)</td>
<td>22.30 (0.39)</td>
</tr>
<tr>
<td>Senegal</td>
<td>23.71 (1.25)</td>
<td>22.86 (1.12)</td>
<td>22.60 (1.22)</td>
</tr>
<tr>
<td>Jordan</td>
<td>24.14 (1.29)</td>
<td>23.96 (1.28)</td>
<td>23.64 (1.28)</td>
</tr>
<tr>
<td>Present study</td>
<td>22.82 (1.42)</td>
<td>22.28 (1.52)</td>
<td>22.21 (1.05)</td>
</tr>
</tbody>
</table>

Tooth group: MPI: mandibular permanent incisors, UCPM: upper permanent canines and first and second premolars. LCPM: lower permanent canines and first and second premolars.

Gender: M = male; F = female
3.4 Bilateral symmetry

Table 6 exhibited that when comparing the combined mesiodistal widths of the CPM of the right and left side of each jaw for both genders, there was highly significant correlation (r) ranges from 0.892 to 0.921, with P-value <0.05. On the other hand, in both genders it was found that the lower left permanent canine and premolar segments were consistently larger than that of the right segment, while the opposite was observed in the upper arch.

Table 6. Correlation between the sum of the right and left mesiodistal widths of the CPM in both arches for both males and females.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Dental arch</th>
<th>Tooth group</th>
<th>Mean (mm)</th>
<th>SD</th>
<th>SEM</th>
<th>r</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Mandibular</td>
<td>Sum of the right CPM</td>
<td>21.7057</td>
<td>1.1257</td>
<td>0.1015</td>
<td>0.892</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sum of the left CPM</td>
<td>21.8836</td>
<td>1.1518</td>
<td>0.1038</td>
<td>0.913</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td>Maxillary</td>
<td>Sum of the right CPM</td>
<td>22.2315</td>
<td>1.0593</td>
<td>0.0955</td>
<td>0.921</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sum of the left CPM</td>
<td>22.1962</td>
<td>1.0836</td>
<td>0.0977</td>
<td>0.921</td>
<td>0.000***</td>
</tr>
<tr>
<td>Female</td>
<td>Mandibular</td>
<td>Sum of the right CPM</td>
<td>20.917</td>
<td>1.1316</td>
<td>0.0978</td>
<td>0.898</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sum of the left CPM</td>
<td>21.0877</td>
<td>1.2407</td>
<td>0.1071</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maxillary</td>
<td>Sum of the right CPM</td>
<td>21.5334</td>
<td>1.2389</td>
<td>0.1070</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sum of the left CPM</td>
<td>21.4376</td>
<td>1.1725</td>
<td>0.1013</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SD: standard deviation, SEM: Standard error of the mean, r: Correlation CPM: permanent canines and first and second premolars.
Significance at P<0.05
Table 7 revealed that there was a highly statistically significant difference between the right and left sides for the mandibular CPM in males and females as well for the sum of the maxillary CPM in females.

**Table 7.** Right and left comparisons of the sum of the mesiodistal widths of the CPM for males and females.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Tooth Group</th>
<th>Absolute Mean</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>Mandibular ∑CPM</td>
<td>-0.1779</td>
<td>0.530</td>
<td>-3.720</td>
<td>122</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td>Maxillary ∑CPM</td>
<td>0.0353</td>
<td>0.447</td>
<td>0.876</td>
<td>122</td>
<td>0.383 (NS)</td>
</tr>
<tr>
<td>Females</td>
<td>Mandibular ∑CPM</td>
<td>-0.1707</td>
<td>0.546</td>
<td>-3.621</td>
<td>133</td>
<td>0.000***</td>
</tr>
<tr>
<td></td>
<td>Maxillary ∑CPM</td>
<td>0.0958</td>
<td>0.484</td>
<td>2.292</td>
<td>133</td>
<td>0.023*</td>
</tr>
</tbody>
</table>

Tooth group: ∑ = sum of, CPM: permanent canines and first and second premolars.
SD: Standard deviation, t = t-value
df = degree of freedom
Significance at P<0.05 level; NS=non-significant

### 3.5 Gender comparison of mesiodistal tooth widths

The determination of gender differences between the teeth was performed only for the groups that were used in the statistical evaluation of the prediction method. Figures 2, 3 and 4 show obvious gender differences between the means of the sum of mesiodistal widths of MPI, and the sum of CPM of both jaws indicating that males had consistently greater mesiodistal tooth dimension than females.
Figure 2. Gender distribution according to the sum of MPI.

![Bar chart showing gender distribution for MPI sum]

Figure 3. Gender distribution according to the sum of the mandibular CPM.

![Bar chart showing gender distribution for mandibular CPM sum]
3.6 Comparison of the predicted and actual tooth size

Two tailed $t$-test was employed to compare the differences between the actual mesiodistal width values of the mean sum of CPM and the predicted values of the same groups of teeth using Tanaka and Johnston\(^9\) formula. High statistically significant differences ($p=0.000$) were observed between the measured and the predicted values. The Tanaka and Johnston\(^9\) prediction equations overestimated the actual measurements of both dental arches. The predicted value was slightly higher in the maxillary arch compared to the mandibular one (Table 8)
**Table 8.** Comparison between the predicted values of mesiodistal widths of CPM, using the T/J method, and the actual values for the whole sample (n=250).

<table>
<thead>
<tr>
<th>Prediction method</th>
<th>Actual value (mm)</th>
<th>Predicted value (mm)</th>
<th>Difference (mm)</th>
<th>SD</th>
<th>r</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/J (9) Mandible</td>
<td>21.38</td>
<td>21.77</td>
<td>0.39 mm</td>
<td>0.872</td>
<td>0.689</td>
<td>0.000***</td>
</tr>
<tr>
<td>T/J (9) Maxilla</td>
<td>21.83</td>
<td>22.27</td>
<td>0.44 mm</td>
<td>0.873</td>
<td>0.670</td>
<td>0.000***</td>
</tr>
</tbody>
</table>

CPM: permanent canines and first and second premolars  
Prediction method: T/J; Tanaka and Johnston  
Significance at P< 0.05

**3.7 Regression equations for the Sudanese sample**

The regression characteristics of the obtained prediction equations for the Sudanese sample were presented (Table 9).

**Table 9.** Regression parameters for prediction of the summation of the mesiodistal widths of CPM in one dental arch segment.

<table>
<thead>
<tr>
<th>Gender</th>
<th>∑ CPM</th>
<th>Correlation coefficient (r)</th>
<th>Constants (mm)</th>
<th>SEM</th>
<th>Coefficient of determination (r²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a (mm)</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>Males Maxilla</td>
<td>0.626</td>
<td>11.66</td>
<td>0.46</td>
<td>0.821</td>
<td>0.391</td>
</tr>
<tr>
<td>Males Mandible</td>
<td>0.618</td>
<td>10.78</td>
<td>0.48</td>
<td>0.874</td>
<td>0.382</td>
</tr>
<tr>
<td>Females Maxilla</td>
<td>0.680</td>
<td>9.67</td>
<td>0.53</td>
<td>0.869</td>
<td>0.463</td>
</tr>
<tr>
<td>Females Mandible</td>
<td>0.726</td>
<td>8.67</td>
<td>0.55</td>
<td>0.797</td>
<td>0.528</td>
</tr>
<tr>
<td>Combined males &amp; females Maxilla</td>
<td>0.670</td>
<td>9.94</td>
<td>0.53</td>
<td>0.874</td>
<td>0.449</td>
</tr>
<tr>
<td>Combined males &amp; females Mandible</td>
<td>0.689</td>
<td>8.91</td>
<td>0.55</td>
<td>0.870</td>
<td>0.475</td>
</tr>
</tbody>
</table>

∑CPM: sum of permanent canines and first and second premolars, SEM: standard error of the mean
The accuracy of the prediction is often expressed as the standard error of the mean, SEM, for the prediction equations. In the present study the SEM ranged from 0.797 (mandibular arch of females) to 0.874 (mandibular arch of males and maxillary arch for the combined males females). The Pearson product moment correlation coefficients (r) ranged from 0.62 (mandibular arch of males) to 0.73 (mandibular arch of females).

The predicted and actual values of the sum of the mesiodistal widths of the lower CPM using the new equation, for each gender separately and combined were presented (Tables 10 and 11).

Table 10. Predicted and actual values of the sum of the mandibular CPM using the new equations, for males, females and both genders combined.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Predicted value of CPM</th>
<th>Actual value of CPM</th>
<th>Difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Males</td>
<td>21.73</td>
<td>0.68</td>
<td>21.79</td>
<td>1.11</td>
</tr>
<tr>
<td>Females</td>
<td>20.92</td>
<td>0.83</td>
<td>21.00</td>
<td>1.16</td>
</tr>
<tr>
<td>Combined males and females</td>
<td>21.31</td>
<td>0.82</td>
<td>21.38</td>
<td>1.20</td>
</tr>
</tbody>
</table>

CPM: sum of permanent canines and first and second premolars
Significance at $P<0.05$
NS=non-significant
Table 11. Predicted and actual values of the sum of the maxillary CPM using the new equations, for males, females and both genders combined.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Predicted value of CPM</th>
<th>Actual value of CPM</th>
<th>Difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>22.16 0.65</td>
<td>22.21 1.05</td>
<td>0.055 0.818</td>
<td>0.454 (NS)</td>
</tr>
<tr>
<td>Females</td>
<td>21.48 0.80</td>
<td>21.49 1.18</td>
<td>0.007 0.867</td>
<td>0.922 (NS)</td>
</tr>
<tr>
<td>Combined males and females</td>
<td>21.89 0.79</td>
<td>21.83 1.18</td>
<td>0.052 0.872</td>
<td>0.341 (NS)</td>
</tr>
</tbody>
</table>

CPM: sum of permanent canines and first and second premolars
SD: standard deviation
Significance at P< 0.05
NS=non-significant

No statistical significant difference was reached between the actual values and the values obtained using the proposed (new) equations (P>0.05).

3.8 The new regression equations

The regression equations take the form:

\[ Y = a + b \times X \]

where:

\( Y \) represents the predicted value of the sum of the unerupted permanent canines, first and second premolars in one quadrant in millimeters.
\( X \) represents the measured value of the sum of the permanent lower incisors in millimeters.
\( a \) represents the y-intercept, in millimeters (regression constant)
\( b \) represents the slope of the regression line (regression coefficient).
Using the values of coefficients \((a)\) and \((b)\) listed in table 9, six equations for the prediction of the upper and lower combined canine-premolar crown diameters for each gender and for both genders combined were drawn as follows:

**Males**

1/ Maxillary permanent canine, first and second premolars:
\[
Y = 11.66 + 0.46X
\]

2/ Mandibular permanent canine, first and second premolars:
\[
Y = 10.78 + 0.48X
\]

**Females**

3/ Maxillary permanent canine, first and second premolars:
\[
Y = 9.67 + 0.53X
\]

4/ Mandibular permanent canine, first and second premolars:
\[
Y = 8.67 + 0.55X
\]

**Males and females combined:**

5/ Maxillary permanent canine, first and second premolars:
\[
Y = 9.94 + 0.53X
\]

6/ Mandibular permanent canine, first and second premolars:
\[
Y = 8.91 + 0.55X
\]
4.1 Discussion

Prediction of the mesiodistal dimensions of unerupted CPM during the mixed dentition is of clinical importance in diagnosis and treatment planning. Accurate estimation of the size of CPM allows the dentist to manage tooth size/arch length discrepancies in the best way.

The purpose of the present investigation was to examine the applicability of the Tanaka and Johnston\textsuperscript{9} method of prediction in a sample of Sudanese population and to develop a new prediction method for this specific population if it is not applicable.

4.1.1 Reliability of the measurements

The reliability of the measurements is one of the most important aspects of odontometric studies. Attempting to improve the reliability of the measurements undertaken in the present study the following procedures were employed:

- Use of high quality dental casts made from dental stone (Type III, Zhermack\textsuperscript{TM}, Italy).\textsuperscript{65}
- Use of caliper with digital display (Mitutoyo\textsuperscript{TM}, Japan) that could greatly help to reduce eye fatigue and the possibility of reading error.\textsuperscript{65}
• Dahlberg’s formula\textsuperscript{72} was used in assessing the intra-examiner reliability.

The present study showed that the highest method error was found to be 0.043 mm for the mandibular CPM and the lowest was 0.013 mm for the maxillary CPM, which was considered within the acceptable range. Yuen et al.\textsuperscript{75} stated that values of this range were acceptable for the study of tooth sizes. Other investigators reported similar values to those of the present study.\textsuperscript{35,73,76} However, these values were even better than those reported by other investigators. Buschang et al.\textsuperscript{77} reported a method error of 0.14 mm as the highest value and 0.06 mm as the lowest one using the same method. Yuen et al.\textsuperscript{78} found that the highest value was 0.11 mm and the lowest one was 0.04 mm.

Referring to the above data, the measurements performed in the present study were considered reliable and within the acceptable range. Therefore, any differences in the mesiodistal tooth widths, if observed, would result from the tooth size variability in the present sample and the prediction method tested.

4.1.2 Representativeness of the sample

The sample size of the present study was determined from the equation: \( n = \frac{z^2 \, pq}{d^2} \), where: \( n \) = the sample size, \( z \) = the standard
deviation, \( p = \) the proportion in the target population, \( q = \) the probability of failure (equals to 1 - \( p \)). A pilot study suggested that ‘\( p \)’ to be 25% of the total population. Therefore the sample size was estimated to be 288.

One school from each gender was randomly selected. The total number of the students of both schools was 610. All of them were examined but only those who fulfilled the criteria of selection were included. Due to financial and time constraints, the maximum sample size achieved was 250.

The age of the participants (13-19 years) was selected because of the minimal attrition expected. This specific age group was chosen because younger participants might not have full eruption of the teeth under investigation. Older participants could have significant interproximal attrition which might affect the result.⁵⁹

### 4.1.3 Mesiodistal tooth width

The mean of the mesio-distal tooth widths established in the present study re-introduced some odontometric data for the Sudanese population. However, these values had some limitations. These limitations include that the upper permanent central and lateral incisors were not measured because they were not considered in the regression parameters of the regression parameters of the prediction equation under investigation. Moreover, only
the mean values of the mesiodistal tooth diameters, and not the individualized right and left mesiodistal tooth diameters, were included. In addition to that the sample size may not be representative of the Sudanese population.

The results of the present study cannot be compared with results of the previous study done in Sudan by Hashim et al. This is due to the fact that in the previous study the sample size was very small (n=30), the gender was not specified and the age of the participants was different (20-25 years old). Moreover, the descriptive statistics for each tooth was presented for the right and left sides separately.

The most common mesio-distal widths analysis of tooth size is carried out by using teeth on one side of the jaw, or, alternatively, by using average of the teeth from the right and left sides. Accordingly, the averaged values of right and left sides of each jaw were used in the statistical analyses of the present study. The same was done by Lee-Chan et al., Jaroontham and Godfrey and Moorrees and Reed.

The mean of the sum of the mesiodistal tooth diameter of the present study was found to be smaller than those of the South Africans, Thai population, Hong Kong Chinese and Jordanian populations, whereas it
is relatively similar to Senegalese population. These differences could be attributed to the methodology, sample selection, racial and ethnic variations.

### 4.1.4 Bilateral symmetry

Using the correlation coefficients, $r$, between the combined mesiodistal widths of the CPM, the result of the present study indicated that the right and left sides were highly correlated. However, statistically significant right-left differences were observed in the mandibular CPM in males and in the mandibular and maxillary CPM in females. This could be a misleading result because of its very small clinical value that ranged from 0.04 mm to 0.18 mm. Hashim et al. found that the difference in individual tooth widths between the two sides of the jaws was statistically insignificant and concluded that the measurements from one side could be considered as truly representative when the corresponding measurements of the other side is unobtainable.

The result of the current study showed that the mean value of the tooth widths in the right side of the upper arch was relatively greater than that of the left side, while the opposite was observed in the lower arch. This was in agreement with the study done on a Sudanese sample by Hashim et al.
The present study demonstrated that the mean values of the mesiodistal widths of the sum of the MPI, maxillary and mandibular CPM were found to be different when the location of the participants was considered. This could be attributable to the different racial and ethnic constituents of various Sudanese areas. Several studies have shown that tooth size varies between populations of different ethnic origin.14-17

4.1.5 Gender variations

In the present study, the mean of the summations of the MPI, maxillary and mandibular CPM width was greater in males than females. This was supported by several previous studies.10,25,27,38,50,58 This may be attributed to genetic and environmental variations.

4.1.6 Correlation coefficient "r"

The correlation coefficient ‘r’ between the total mesiodistal width of the MPI and that of the maxillary and mandibular CPM of the present study ranged between 0.63 and 0.73, which is stronger than that obtained by Tanaka and Johnston9 which is 0.63-0.65. Some studies10,14,39 reported a lower ‘r’ value. However, the moderately high degree of linear correlation that was established in the present study made it possible to measure the total width of the MPI to predict more precisely the size of teeth that have not yet erupted.
4.1.7 Coefficient of determination ($r^2$)

The coefficient of determination for the combined males and females, as an indicator of the predictive accuracy of the regression equation, was found to be 0.45 and 0.48 for the maxillary and the mandibular teeth, respectively. This means that 45% and 48% of the total variances for the sum of the maxillary and mandibular canine and premolar segment, respectively, were accounted for by knowing the sum of the mandibular incisor width. In the study conducted by Diagne et al.\textsuperscript{50}, the coefficient of determination was found to be relatively similar to the value obtained in the maxillary arch ($r^2 = 0.46$) in the present study and a higher value for the mandibular arch ($r^2 = 0.54$).

In the present study the female subjects exhibited higher coefficient of determination values (0.46 for maxillary teeth and 0.53 for mandibular teeth) than the male subjects (0.39 and 0.38, respectively). This finding was consistent with that of Jaroontham and Godfrey\textsuperscript{58}, where the coefficient of determination value for the females was 0.39 for the maxillary arch and 0.42 for the mandibular one while in the male group it was 0.29 and 0.34, respectively. In contrast to this, coefficient of determination value for the male subjects was higher than that of females in Hong Kong Chinese\textsuperscript{38}, Senegalese\textsuperscript{50} and Thai populations.\textsuperscript{58}
Table 12 shows regression parameters, including the correlation coefficients and the coefficients of determination, for the sum of CPM width, for the present study as well as from various other investigations.

**Table 12.** Regression parameters for the sum of CPM width from various investigations.

<table>
<thead>
<tr>
<th>Study</th>
<th>Gender</th>
<th>Dental Arch</th>
<th>( r )</th>
<th>Constants</th>
<th>SEM (mm)</th>
<th>( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( a )</td>
<td>( b )</td>
<td></td>
</tr>
<tr>
<td>Jaroontham and Godfrey(^{58}) (Thailand)</td>
<td>M</td>
<td>Mandible</td>
<td>0.58</td>
<td>11.92</td>
<td>0.43</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Maxilla</td>
<td>0.54</td>
<td>13.36</td>
<td>0.41</td>
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</tr>
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<td></td>
<td></td>
<td>Mandible</td>
<td>0.65</td>
<td>9.49</td>
<td>0.53</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxilla</td>
<td>0.62</td>
<td>11.16</td>
<td>0.49</td>
<td>0.78</td>
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<tr>
<td></td>
<td></td>
<td>Mandible</td>
<td>0.64</td>
<td>10.30</td>
<td>0.50</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxilla</td>
<td>0.60</td>
<td>11.87</td>
<td>0.47</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Mandible</td>
<td>0.77</td>
<td>8.82</td>
<td>0.58</td>
<td>0.61</td>
</tr>
<tr>
<td>Yuen et al.(^{38}) (Hong Kong)</td>
<td>F</td>
<td>Maxilla</td>
<td>0.79</td>
<td>7.97</td>
<td>0.66</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxilla</td>
<td>0.69</td>
<td>6.66</td>
<td>0.64</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxilla</td>
<td>0.65</td>
<td>8.30</td>
<td>0.61</td>
<td>0.81</td>
</tr>
<tr>
<td>Al Khadra(^{14}) (Saudi Arabia)</td>
<td>M+F</td>
<td>Mandible</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Maxilla</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Mandible</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Maxilla</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Abu Alhaija and Qudeimat(^{10}) (Jordan)</td>
<td>M+F</td>
<td>Maxilla</td>
<td>0.65</td>
<td>7.20</td>
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<tr>
<td></td>
<td>M</td>
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<td>0.60</td>
<td>9.80</td>
<td>0.54</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Maxilla</td>
<td>0.51</td>
<td>12.80</td>
<td>0.43</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Mandible</td>
<td>0.59</td>
<td>9.79</td>
<td>0.56</td>
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</tr>
<tr>
<td></td>
<td>F</td>
<td>Maxilla</td>
<td>0.64</td>
<td>8.31</td>
<td>0.64</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>Mandible</td>
<td>0.59</td>
<td>9.41</td>
<td>0.56</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Maxilla</td>
<td>0.57</td>
<td>10.55</td>
<td>0.53</td>
<td>0.99</td>
</tr>
<tr>
<td>Present study (Sudan)</td>
<td>M</td>
<td>Mandible</td>
<td>0.62</td>
<td>10.78</td>
<td>0.48</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Maxilla</td>
<td>0.63</td>
<td>11.66</td>
<td>0.46</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Mandible</td>
<td>0.73</td>
<td>8.67</td>
<td>0.55</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Maxilla</td>
<td>0.68</td>
<td>9.67</td>
<td>0.53</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>Mandible</td>
<td>0.70</td>
<td>8.91</td>
<td>0.55</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>M+F</td>
<td>Maxilla</td>
<td>0.67</td>
<td>9.94</td>
<td>0.53</td>
<td>0.87</td>
</tr>
</tbody>
</table>

CPM: permanent canines, first and second premolars. \( a \) and \( b \) = constants of the regression equation

\( R \) = correlation coefficient, \( r^2 \) = coefficient of determination

Gender: M = male; F = female, SEM: standard error of the mean
4.1.8 Standard Error of the Mean (SEM)

The accuracy of the prediction is often expressed as the standard error of the mean (SEM) for the prediction equation.\(^79\) The smaller the SEM, the more accurate is the prediction equation. The SEM for the combined genders in the present study (SEM=0.87) was found to be slightly higher than that of Tanaka and Johnston\(^9\) study (SEM=0.86 and 0.85, for the maxillary and mandibular arches, respectively). The same was found when compared with other studies.\(^{38,39,50,58}\) Abu-Alhaija and Qudeimat\(^10\) showed a very high SEM (SEM= 0.99 for both genders) and even higher values in mandibular arch for the females (SEM=1.00).

The magnitude of the standard error of the mean is inversely proportional to the number of observations (that is, the larger sample size the smaller the SEM). This made the comparison between the Sudanese prediction equation and several other studies not reasonable due to the difference in the sample size.

4.1.9 Comparisons of prediction methods with actual values

When the Tanaka and Johnston\(^9\) prediction method was applied on the whole Sudanese sample, it was found that the Tanaka and Johnston\(^9\) equations overestimated the actual values of the mesiodistal width of the canine and premolar segments, in both dental arches, especially in the
maxilla. There were statistically significant differences between the predicted values of those teeth and their actual (measured) ones (P<0.001). (Table 9)

Several studies found that the Tanaka and Johnston\textsuperscript{9} prediction equations overestimated the actual values of the CPM segments.\textsuperscript{14,39,46,50} This is in harmony with the present study. However, few studies agreed with the Tanaka and Johnston\textsuperscript{9} equation.\textsuperscript{58} On the other hand Abu-Alhiaja and Qudeimat\textsuperscript{10} observed that Tanaka and Johnston\textsuperscript{9} prediction equation underestimated all the values of the CPM segment.

Due to the fact that Tanaka and Johnston\textsuperscript{9} prediction equations overestimated the values of the unerupted permanent canines, first and second premolars, new prediction equations for the Sudanese sample was proposed with different prediction constants for males and females separately and combined for each dental arch. The regression parameters discussed above produced a more accurate prediction equation. When the predicted values of the CPM using the new equations were compared with the actual measured teeth, the difference was found to be statistically insignificant. (Tables 10, 11)
4.2 Conclusion

1. From our odontometric analysis, a database was constructed for the average mesiodistal tooth width for the maxillary and mandibular permanent canines, first and second premolars as well as the mandibular permanent incisors for both males and females.

2. The correlation coefficient between the sum of MPI and the sum of CPM in the present study was found in the range between 0.62-0.73.

3. The Tanaka and Johnston equations overestimated the mesiodistal width of the permanent canine, first and second premolar segments in both dental arches.

4. New, more accurate prediction equations of the mesiodistal width of the permanent canine, first and second premolar segments, were proposed.
4.3 Recommendations

It was found that our new prediction equations produced more accurate results than the Tanaka and Johnston equations. This implies that our proposed equations are more appropriate for use in the Sudanese population. Since there are different ethnic constituents in the Sudanese population, the results of the current investigation support the need for further studies using a large representative sample from different parts of Sudan to account for the ethnic differences.
References


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74. Dahlberg G. Statistical methods for medical and biological students. London: George Allan and Unwin Ltd; 1940.
Appendix (1)

University Of Khartoum
Graduate College
Post-Graduate Medical and Health Sciences Board
Faculty of Dentistry

Questionnaire & Examination Sheet

Mixed dentition space analysis among a sample of a high secondary school Sudanese students: an odontometric study

Date:         Code No.:

Personal data:
Name:                       Nationality:
Gender: male: female:       Date of Birth:
Age:  

Residence:
History of orthodontic treatment: yes: no:
Address in Khartoum:
Origin of the family: East: West: North:
South: Centre: Mixture:

Tribe:
Phone No.:

Examination:
Extraoral Examination:
Facial symmetry: yes: no:
Gross abnormality: yes: no:

Intraoral Examination:
Teeth present:
Upper arch: full set: missing:
Lower arch: full set: missing:
Interproximal caries: yes: no:
Crown fractures: yes: no:
Attrition: yes: no:

Restorations:
Proximal fillings: yes: no:
Crowns: yes: no:
Obvious tooth abnormality: yes: no:

Occlusion:
Molar classification: Angle's I: Angle's II:
Angle's III:
Canine relation: Class I: Class II:
Class III:
Incisor relationship:
overjet: increased: reduced: normal:
overbite: increased: reduced: normal:
Crowding: no: mild:
moderate: severe:
Spacing: no: mild:
moderate: severe:
Appendix (2)
Consent Form

I ask from your honor to participate in this study that deals with measurements of the size of erupted permanent teeth in a Sudanese population. Your participation is voluntary, and you can refuse or withdraw at anytime you like. So, please read this carefully before you sign. According to your acceptance we will collect some information about you, examine your face and teeth, and take impressions for the teeth. Examination and impression processing will be under aseptic conditions, lest none of the participants will be subjected to cross infection. All your data will be treated with high care and confidentiality and kept in the Department of Paedodontics and Orthodontics, Faculty of Dentistry, University of Khartoum, for any scientific use in the future, without referring back to you, considering your first acceptance.

Your participation will be free and there will be no direct benefit of this research for you but it may help very much in the diagnosis of occlusal problems of the children of this country.

The researcher will deal with your records as a number only and your name will not be written on your dental cast.

I (the participant) read the above explanation and given a chance for asking and I:

Agree to participate and be involved in this research and answer the required questions correctly.

Disagree to participate and be involved in this research.

Signature of the participant:………………………………..
Date:……………

And I (the researcher) promise to undertake this research honestly, with the provision of privacy and accuracy.

Signature of the researcher:………………………………
Date:……………..
Appendix (3)
إقرار بالموافقة

نطلب من سيادتكم المشاركة في الدراسة الخاصة بقياسات الأسنان الدائمة لدى السودانيين. مشاركتك في الدراسة طوعية ويستنك رفض المشاركة أو طلب إلغاءك من الدراسة في أي وقت متي ما رغبت لذا نرجو أن تقرأ هذا الإقرار بحرص قبل التوقيع عليه. بناء على موافقتكم سنأخذ بعض المعلومات عنك ثم نفحص الوجه والأسنان ثم نقوم بإخذ طبعة للاسنان. إجراءات الكشف وعمل الطبيعات ستكون خاضعة للتقييم المناسب. كل هذه المعلومات سيتم التعامل معها بعناية فائقة وسرية تامة وستحفظ بعد انتهاء الدراسة بقسم التقييم وأسنان الأطفال بكلية طب الأسنان بجامعة الخرطوم، وقد تستخدم في دراسات مستقبلية اعتماداً على موافقتك الأولية. لن يكون هناك مقابل مادي لقاء هذه المشاركة. سيقوم الباحث بالتعامل مع المعلومات كرقم ولن يكتب اسمك عليها.

ربما لن تكون لهذه البحث فائدة مباشرة لك ولكنه ذو قيمة كبيرة للأطفال من السودان.

شهادة التوضيح الخاص:

لقد قرأت التوضيح الخاص بهذه الدراسة وأعطيت فرصة للسؤال أو الاستيضاح وأنا:
أوافق لا أوافق

توقيع المشارك:

التاريخ:

و أتعهد أن (الباحث) بالتعامل مع هذا البحث بصدق وإخلاص، مراعيا الأمانة وملتزما بالسرية التامة.

توقيع الباحث:

التاريخ:
Appendix 4:

Tooth measurement procedure for a selected case