A Digital Method to Predict the Mesiodistal Widths of Canines and Premolars in an Egyptian Sample

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Objective: *Treatment planning in the mixed dentition is important for proper tooth alignment. A mixed dentition analysis, should accurately predict the mesiodistal widths of unerupted permanent teeth. The aim of the present study was to determine which sum of mesiodistal widths (MDW) of permanent teeth will be the best predictor for MDW of unerupted permanent canines and premolars.* ***Study Design***: *The study was conducted on 102 Egyptians, 51 males and 51 females, mean age 16.7±0.5 years with fully erupted permanent teeth, and intact proximal surfaces. Dental casts were obtained and scanned to produce digital images that were used on a specially designed software program to measure the MDW of permanent teeth. Casts were divided into training and validation sets, where 9 models of tooth combinations were used to develop a regression equation that describes the relation between them and sum of MDW of erupted maxillary or mandibular canines, first and second premolars. The validation set was used to test the accuracy of the proposed equation.* ***Results***: *R^2 of regression models ranged from 0.3 (for models #2,4,5 and 8) to 0.36 for model #1. The highest regression in model #1 (sum of MDW of lower first permanent molars and upper central incisors) indicated a high linear association between the sum of MDW of tooth combination model #1 and the MDW of maxillary and mandibular permanent canines and premolars. There was no significant difference between the actual and the predicted MDW, when the proposed equation was checked for its accuracy in the entire validation set ($p > 0.05$).* ***Conclusion***: *The combination of the sums of lower permanent first molars and upper permanent central incisors was the best predictor for the MDW of both maxillary and mandibular permanent canines and premolars.The newly proposed prediction equation may be considered clinically useful for mixed dentition analysis in Egyptian subjects.*

Keywords: *mixed dentition analysis,arch length, mesiodistal width, predicted width, children.*
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INTRODUCTION

Early treatment of malocclusion has definitely become an issue of interest in recent years. It is believed that a large number of cases of malocclusion start during the mixed dentition stage.[1] Arch length discrepancy is one of the most commonly encountered malocclusion problems which could be controlled by early intervention in the form of space supervision or serial extraction.[2]

Mixed dentition space analysis is an important aspect of orthodontic diagnosis and treatment planning. It allows checking for disparity between the amount of dental arch space that is available and the amount of tooth material that should be accommodated in the arch.[3]

Prediction methods for estimation of the mesiodistal widths of unerupted canines and premolars are based on the fact that once crown morphogenesis is complete, the teeth are less susceptible to postnatal modifying factors.[4] According to Proffit *et al* [5] there are three basic approaches for prediction of mesiodistal width of unerupted permanent teeth during the mixed dentition. These include measurements of teeth on radiographs,[6-8] estimation from proportionality tables[9-13] and combination of radiographic and prediction table methods.[14-18]

The radiographic method is seldom used partly because it requires a complete set of periapical radiographs and partly because the clinical reliability of other analyses that do not use radiographs is sufficient for determining major arch inadequacies.[19]

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Prediction methods based on mesiodistal width of permanent teeth usually employ simple or multiple linear regression equations. The problem with multiple linear regression equations is that in some of them, the correlation coefficients between the real sizes of "reference teeth" and "real values" of predicted teeth were not high enough to ensure good prediction. The use of several predictors in multiple linear regression equations may improve prediction, though they may be complicated for clinical use. However, if an appropriate predictor that shows high correlation coefficient with combined mesiodistal width of unerupted permanent canines, first and second premolars is chosen for a linear regression analysis, accuracy can be acceptable.[20]

Prediction tables are suggested to be less reliable when applied to other populations for which they were derived.[21,22] Accordingly, several simple linear regression equations have been proposed for populations of different ethnic origins.[6,7,8,11,23,24,25]

The combination between radiographs and prediction tables combines the best features of both method but sacrifices time saving features.[26]

Digital analysis is based on the use of electronic digital calipers, connected to computer software to measure dental casts. Computer algorithms can accomplish space analysis. In addition, conventional casts can be laser scanned creating digital casts. These casts can be measured electronically so that the teeth or arch dimensions can be evaluated.[5] In addition, statistical analysis, complex calculations of simple and multiple regression models can be performed.[22,27]

Reviewing the literature indicates that several investigators found differences in tooth size between various ethnic groups.[28–32] It could be assumed that the most accurate equation for prediction of tooth size should be based on accurate measurements obtained from the population in question.

Scarce information on mixed dentition analysis for Arabic population is available, especially in Egyptians, where some of the studies that attempted to formulate prediction charts[33, 34] used a limited number of patients.

It was thus found necessary to make use of computerized analysis to determine which sum of permanent tooth widths of different tooth combination would present the best prediction capability for the sum of maxillary and mandibular canines and premolars pertaining to an Egyptian sample using digital casts and a specially designed software and to validate the regression equation showing the best fit on a new validation sample.

MATERIALS AND METHOD

The sample size of the present study was required to achieve a correlation coefficient of 0.55. This was estimated using MedCalc software.[35] Although 0.7 correlation coefficient or higher is considered clinically useful, the study was designed to identify weaker correlation equal to 0.55. This would provide enough power for the study to detect any reasonable correlation and at the same time ensure power for higher correlations. Thus, based on an estimated correlation coefficient of 0.55, with an alpha error rate set at 5% and a beta error rate set at 5%, the minimal required sample size per group (male and female) is estimated to be 36. A total sample of 72 subjects was thus used to develop the regression equation describing the relation between combinations of sums of permanent tooth widths and sum of widths of permanent canine, first and second premolars. To validate the obtained regression equation, another validation set of 30 subjects (15 males, 15 females) was examined raising the total number to 102 cases (51 males and 51 females). Their age ranged from 16 to 18 years. They were selected from the first year dental students of Faculty of Dentistry, Pharos University, Alexandria, Egypt after obtaining a written approval from the Dean and securing official consents that were approved by the committee of Ethics, Faculty of Dentistry, Alexandria University.

Inclusion criteria comprised fully erupted permanent dentition from first permanent molar to first permanent molar, with intact proximal surfaces, marginal ridges, incisal edges and contact points, without clinically visible caries, restoration or attrition. All subjects were free from any systemic diseases or syndromes and had Egyptian parents. Subjects were excluded if they had extracted permanent teeth, any anomalies in number, size, shape and structure that could affect the mesiodistal width of the tooth, crowding and previous orthodontic treatment.

Preliminary screening was carried out using a sterile set of mirror and probe for each subject. About 150 students consented to participate in the study. Clinical examinations were conducted on dental units. From these, a sample of 102 subjects who met the inclusion criteria was chosen. Maxillary and mandibular alginate impressions were taken, poured into stone and placed in plaster filled rubber base forms that were trimmed, finished[36] and identified with the name, age and gender of each subject.

A pilot study was done, where the measurements of 4 pairs of dental casts that were determined by the digital tracer (Tracer version 2, Nile Delta) were compared with those obtained by the digital caliper (Mitutoyo digimatic caliper 207 series No.500 ,Mitutoyo Corporation, Japan) to check the accuracy of the tracer. Intra examiner calibration was done by measuring 10 dental casts twice at 24 hour interval.[37]

A training set that included the dental casts of 72 subjects (36 males and 36 females), where the mesiodistal widths of erupted permanent teeth from first permanent molar to the first permanent molar on the other side were measured digitally. They were used to develop a regression equation describing the relation between combinations of sums of permanent tooth widths and sum of mesiodistal widths of erupted maxillary or mandibular canines, first and second premolars. Different models of tooth combinations were selected as presented in Table 1.

A validation set that included the dental casts of another 30 subjects (15 males and 15 females) was used to validate the obtained regression equation.

An image scanning of dental casts was performed using a flatbed scanner (HP scanjet 2400). The maxillary and

Table 1. Models of different tooth combinations.

Tooth combination model #	Description
1. (11, 21, 36, 46).	Sum of upper central incisors and sum of lower first permanent molars.
2. (11, 21, 16, 26).	Sum of upper central incisors and sum of upper first permanent molars.
3. 11, 21, 16, 26, 36, 46).	Sum of upper central incisors and sum of upper first and lower first permanent molars.
4. (31, 41, 32, 42).	Sum of lower central incisors and sum of lower lateral incisors.
5. (11, 21, 31, 41, 32, 42).	Sum of upper central incisors, sum of lower central incisors and sum of lower lateral incisors.
6. (31, 41, 32, 42, 36, 46).	Sum of lower central incisors, sum of lower lateral incisors and sum of lower first permanent molars.
7. (31, 41, 32, 42, 36, 46, 16, 26).	Sum of lower central incisors, sum of lower lateral incisors, and sum of lower and upper first permanent molars.
8. (31, 41, 11, 21, 32, 42, 16, 26).	Sum of lower and upper central incisors, sum of lower lateral incisors and sum of upper first permanent molars.
9. (31, 41, 11, 21, 32, 42, 16, 26, 36, 46).	Sum of lower and upper central incisors, sum of lower laterals, sum of upper and lower first permanent molars.

mandibular casts of each subject were placed with their occlusal surfaces facing the glass window of the scanner and located in a standardized position in relation to a special plastic ruler in the middle of the glass window .A black box was used to cover the casts to decrease the amount of scattered light. All casts were laser scanned in order to reproduce a digital image of the cast.

In order to determine the real cast dimensions, the standard error was estimated using a special calibration system, so that any magnifications caused by the scanning process were automatically calculated using a known reference scale on the X-Y axes. Four calibration reference points X_1, X_2, Y_1, Y_2 were located.

With the aid of the cursor, contact points of each permanent tooth were first marked on the image of the scanned casts. All permanent teeth have their contact points centered labio-lingually. However, the contact points at the mesial surface of the maxillary first premolars and first molars as well as the mandibular first molars are slightly located buccal to the center in a buccolingual direction.[38]

A specially designed software program (Patency #11/1782) was used to measure the widest mesiodistal width of each tooth by a line drawn between the two determined contact points (Figure 1). This was recorded in mm digitally.

After two weeks, the same investigator repeated all the measurements again. If the second measurements differed more than 0.2 mm from the first ones, the mesiodistal diameter of each tooth was remeasured and only the new measurements were registered [39-41] and transferred to the Excel

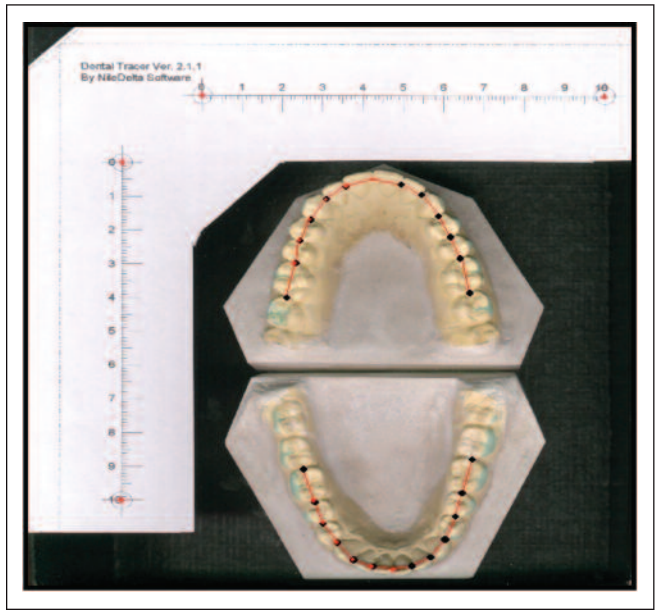

Figure 1. Line drawn between the contact points to determine the mesiodistal widths of each tooth with the four calibration reference points X1, X2, Y1, Y2.

sheets. Based on the measurements of the mesiodistal width of each tooth, a linear regression equation was established.[3] The linear association between the models of sum of different tooth combinations and mesiodistal diameters of maxillary or mandibular canines and premolars were then evaluated.

The model of tooth combination that showed the highest correlation coefficient value was selected to test the accuracy of the proposed regression equation on the validation sample. In each cast, the predicted mesiodistal widths of maxillary and mandibular permanent canines, first and second premolars calculated by the equation were compared to their actual mesiodistal width measured on the dental casts.

Mesiodistal widths (MDW) of teeth or sum of tooth combination widths were calculated as mean ± standard deviation.

The training set (36 males and 36 females) was used to develop the equation predicting MDW of canine and premolars as follows:

Pearson correlation coefficient (r) was calculated between MDW of maxillary and mandibular, right and left canine, first and second premolars on one side and MDW of different tooth combinations in the nine selected models on the other side.

Regression models were fitted for predicting the MDW of canine and premolars, where predictor variables were gender, arch, side of the arch and MDW of different tooth combinations in the nine selected models. The model with the best fit was that with the highest R^2.

Estimates of the predictor variables were calculated to derive the equation for predicting the MDW of canine, first and second premolars.

To validate the developed equation, comparison of actual and predicted MDW in the validation set was done using paired t test for the entire validation set, by gender, arch and side of the arch. The error between both measurements (defined as actual – predicted values) was calculated also for the entire validation set, by gender, arch and side of the arch.

Statistical analysis was performed using SPSS version 13.

RESULTS

This study was conducted on a training set of 72 subjects with an age range from 16 to 18 years, with a mean age of 16.7±0.5. The validation set consisted of another 30 subjects. Their age ranged from 16 to 17.5 years, with a mean age of 16.6±0.5.

Table 2 shows the correlation [measured by Pearson correlation coefficient r] between different tooth combination widths and the MDW of maxillary and mandibular permanent canines and premolars. A statistically significant moderately positive correlation was observed between the sum of MDW of tooth combination model #1 and MDW of each of maxillary right and left canines and premolars (P=0.01 and 0.03 respectively). Correlation with the mean MDW of maxillary canines and premolars was also moderately positive and statistically significant (P=0.01).

Correlation between the sum of different tooth combination widths in model #1 and mandibular right canines and premolars was weakly positive but not significant (P=0.07) while correlation with the mandibular left canines and premolars was moderately positive and statistically significant (P=0.009). Correlation between the mean MDW of mandibular canines and premolars was moderately positive and statistically significant (P=0.02).

A statistically significant moderately positive correlation was also observed between the sum of MDW of tooth combinations in model # 6 and MDW of maxillary right canine and premolars (P=0.03). However, the correlations with the MDW of maxillary left canines and premolars as well as right and left mandibular canines and premolars in the same model were not statistically significant (P=0.21, 0.42 and 0.23 respectively). Neither correlations with the means of MDW of maxillary and mandibular canines and premolars in tooth combination model # 6 were statistically significant (P=0.06 and 0.31 respectively).

The sum of different tooth combination widths in models 2, 3, 4, 5, 7, 8 and 9 did not reveal any significant correlation with the MDW of maxillary or mandibular permanent canines, first and second premolars.

Table 3 shows R^2 of the regression models for predicting MDW of permanent canines and premolars. R^2 ranged from 0.30 (for models # 2, 4, 5 and 8) to 0.36 for model # 1. The highest regression R^2 reported in model # 1 indicated a high linear association between the sum of MDW of tooth combination model # 1 and the MDW of maxillary and mandibular permanent canines and premolars.

Table 4 shows the regression model for predicting the MDW of permanent canine and premolars using the sum of MDW of teeth in model #1**.** Almost all of the predictors (gender, maxillary and mandibular arches and MDW of teeth in model #1) were statistically significant (P=0.004, <0.0001 and <0.0001), except the side of the arch (P=0.18). Accordingly, these variables were used as predictors in the following equation:

Table 2. Pearson correlation coefficients (r) between different tooth combination widths and MDW of upper and lower permanent canines and premolars.

Tooth combination models	MDW of Upper 3,4 and 5						MDW of Lower 3,4 and 5					
	Right		Left		Mean		Right		Left		Mean	
	r	P value	r	P value	r	P value	r	P value	r	P value	r	P value
1	0.35	0.01*	0.32	0.03*	0.37	0.01*	0.27	0.07	0.37	0.009*	0.33	0.02*
2	0.18	0.22	0.13	0.37	0.17	0.24	0.07	0.65	0.14	0.33	0.11	0.48
3	0.25	0.09	0.20	0.17	0.25	0.09	0.18	0.21	0.27	0.06	0.23	0.11
4	0.21	0.16	0.01	0.93	0.12	0.43	0.18	0.23	0.17	0.25	-0.18	0.23
5	0.28	0.06	0.12	0.41	0.22	0.14	0.10	0.49	0.05	0.73	-0.08	0.58
6	0.31	0.03*	0.19	0.21	0.27	0.06	0.12	0.42	0.18	0.23	0.15	0.31
7	0.22	0.14	0.13	0.38	0.19	0.20	0.10	0.49	0.16	0.27	0.13	0.37
8	0.22	0.13	0.11	0.47	0.19	0.23	0.01	0.93	0.05	0.74	0.02	0.92
9	0.27	0.07	0.17	0.24	0.24	0.10	0.10	0.50	0.18	0.23	0.14	0.35

*: P<0.05.

Table 3. R^2 of the regression models of different tooth combinations widths for predicting MDW of 3, 4 and 5.

Tooth combination groups	R^2
1. (11, 21, 36, 46)	0.36
2. (11, 21, 16, 26)	0.30
3. (11, 21, 16, 26, 36, 46)	0.33
4. (31, 41, 32, 42)	0.30
5. (11, 21, 31, 41, 32, 42)	0.30
6. (31, 41, 32, 42, 36, 46)	0.33
7. (31, 41, 32, 42, 36, 46, 16, 26)	0.31
8. (31, 41, 11, 21, 32, 42, 16, 26)	0.30
9. (31, 41, 11, 21, 32, 42, 16, 26, 36, 46)	0.32

Table 4. Regression model for predicting MDW of permanent canine, first and second premolars using model # 1 tooth combination measurements.

Predictors	Estimate (B)	SE	T	P value
Constant	15.24	2.47	6.18	<0.0001*
Gender	- 0.62	0.22	2.88	0.004*
Arch	-1.87	0.22	8.72	<0.0001*
Side	- 0.29	0.22	1.35	0.18
Model 1 tooth combination widths	0.27	0.06	4.47	<0.0001*

*: P<0.05

Predicted MDW of canine, first and second premolars = Constant - 0.62 genders -1.87 arches – 0.29 side + 0.27 sum of model # 1 tooth combination.
Where constant = 15.24.
Gender =1 for male and 2 for female.
Arches = 1 for maxilla and 2 for mandible.
Sides = 1 for right and 2 for left.

The accuracy of the produced regression model was tested on the validation sample.

Table 5 shows the comparison between actual and predicted MDW of canines and premolars in the validation set according to gender, maxillary and mandibular arches and the side of the arch. No statistically significant differences were observed between means of the actual and predicted MDW (P=1.00 for entire validation sample and other predictors).

Table 6 shows the error in mm between actual and predicted canine and premolar widths of model # 1 in the validation set according to gender, arch and side of the arch. Median error was 0.13 in the entire validation set, while it ranged from -0.23 for female to 0.23 for male, from -0.27 in the mandible to 0.33 in the maxilla and from -0.03 for the right side to 0.24 for the left side.

Table 5. Comparison between actual and predicted MDW of canine, first and second premolars based on regression model in the validation set according to gender, arch and side of the arch.

Factors		MDW Mean ± SD		Paired t test	P value
		Actual	Predicted		
Entire validation set		21.67 ± 1.94	21.69 ± 1.00	0	1.00
Gender	Male	21.72 ± 2.22	21.72 ± 0.93	0	1.00
	Female	21.65 ± 1.65	21.65 ± 1.06	0	1.00
Arch	Maxilla	22.20 ± 2.05	22.20 ± 0.85	0	1.00
	Mandible	21.17 ± 1.69	21.17 ± 0.85	0	1.00
Side	Right	21.37 ± 2.06	21.37 ± 0.97	0	1.00
	Left	22.01 ± 1.78	22.01 ± 0.97	0	1.00

Table 6. Error in mm in regression model #1 in the validation set according to gender, arch and side of the arch.

Factors		Error in mm	
		Median	Mean ± SD
Entire validation set		0.13	0 ± 1.67
Gender	Male	0.23	0 ± 2.01
	Female	-0.23	0 ± 1.25
Arch	Maxilla	0.33	0 ± 1.79
	Mandible	-0.27	0 ± 1.56
Side	Right	-0.03	0 ± 1.56
	Left	0.24	0 ± 1.79

DISCUSSION

The mixed dentition stage is the time of developing occlusion in which permanent and primary teeth are present simultaneously. Mixed dentition analysis intends to predict the widths of unerupted permanent canines and premolars and to determine the difference between the amount of dental arch space that is available and the amount of tooth material that should be accommodated. Maintaining space allows many patients to obtain good occlusion, proper growth and facial development.[42]

The most commonly used methods to predict widths of unerupted permanent teeth were developed from American children of Northwestern European descents.[5, 22] Later on, several studies were carried out on Arabic populations to check the applicability and the effectiveness of these commonly used methods.[30-34,43,44] It was concluded that these methods are uncertain when applied to a population of different ethnic origin, where it is difficult to know whether the prediction is over or underestimated.[30,32,43,44]

The most widely used mixed dentition analysis methods reported in the literature are regression equations. The present study was performed on an Egyptian sample to determine which model of tooth combination would present the best prediction capability for the mesiodistal widths of permanent canines and premolars and to develop and validate a multiple linear regression equation for this sample.

The age of the sample was selected in the range from 16 to 18 years old, in order to minimize the influence of proximal wear and tooth loss.[38]

The software specially designed for measuring the mesiodistal widths of teeth has been tested, and was found to be accurate and reliable in determining tooth sizes automatically in millimeters. This method was fast, simple and needed minimal training.[20,45]

Several tooth combination models were used in the present study, in contrast to some researches that only focused on one or two tooth combination models.[45,46] This gave the present study the chance to find more predictors than the commonly used ones.

The highest correlation was observed between model #1 and widths of permanent canines and premolars. Actually, the same model obtained the highest rank in the regression model. This agrees with Paredes *et al*[20] who found that the combination of the sums of the permanent maxillary central incisors and the mandibular first permanent molars was the best predictor for canines and premolars widths in a Spanish sample. The similarity between the findings of the present study and that of the Spanish sample may be attributed to their racial distribution, where both are from the Mediterranean region. Also a percentage of the Spanish population descends from a genuine Arabic ancestry. It has been noticed that model #1 has the advantage that these teeth erupt early enough in the mixed dentition period to rely on for prediction.

In this study, it was found that two tooth combination models showed the second best predictors namely model #3, and model #6. A common factor was observed between model # 1 and that of model # 3, which is the repetition of the maxillary central incisors and the mandibular first permanent molars. The incorporation of these teeth in model #1 increased its prediction capability as reported in this study.

Model # 4 which is the combined mesiodistal widths of the four mandibular permanent incisors was the weakest predictor in this study, in contrast to the well known, widely used studies as Moyer's[42] and Tanaka and Johnston.[13] This could be related to the fact that the Moyers and Tanaka and Johnston methods based their prediction methods on Northern European descents. Also, Van der Merwe *et al*[47] reported in their study that the sum of the four lower incisors was the best predictor in Western Cape Caucasian population, after comparing linear associations with other tooth-type combinations.

Although previous studies[34,48-50] agreed that the four mandibular permanent incisors are the best predictors, they found that these commonly used methods tend to over and/or underestimate the mesiodistal widths of permanent teeth. Subsequently, they developed specific regression equations for their own populations.

The prediction equation used for space analysis of Iowa population has long been used for Egyptian subjects and for those from the northern parts of Mexican Republic but with some modifications.[29] The Iowa model used the four mandibular permanent incisors as best predictors. The magnitude of the statistical difference was thought to be of little clinical significance. As evident from the present study, the Iowa model for prediction would thus provide the least favorable predictive values for an Egyptian sample.

A primordial issue with mixed dentition analysis is the accuracy that can be obtained using the prediction equation that was established in this study. Testing the prediction equation derived from the present study would serve to substantiate the reliability of the analysis. When the proposed multiple linear regression equation was applied to the validation set, the results demonstrated that the difference between the mean actual and the mean predicted widths was not statistically significant. This finding proves that the equation was accurate and relevant to this specific sample. Therefore, it may be applied to determine the sum of mesiodistal widths of unerupted permanent canines and premolars.

The results of the present study endorses the fact that a special model which pertains to a specific ethnic and/or racial group is of crucial importance if a proper treatment plan is to be considered for any patient on individual basis.

CONCLUSIONS

The combination of the sums of mandibular permanent first molars and of maxillary permanent central incisors was the best predictor for the mesiodistal widths of both maxillary and mandibular permanent canines and premolars in a sample of Egyptian subjects.

The newly proposed prediction equation may be considered clinically useful for Egyptian mixed dentition analysis.

REFERENCES

1. Rakosi T. Differential diagnosis and planning in treatment of malocclusion in the mixed dentition. In Graber TW. Orthodontics: State of the Art, Essence of the science. St Louis: CV Mosby Inc, pp. 120–9, 1986.
2. Bernabe E, Flores-Mir C. Estimating arch length discrepancy through little's irregularity index for epidemiological use. Eur J Orthod, 28: 269–73, 2006.
3. Moyers RE. Handbook of Orthodontics for the Student and General practitioner. 3rd ed. Chicago: Yearbook medical publisher Inc, pp. 369–79, 1973.
4. Bishara SE, Fernandez GA, Jakobsen JR, Fahl JA. Mesiodistal crown dimensions in Mexico and the United States. Angle Orthodont, 56: 315–23, 1989.
5. Proffit WR, Sarver DM, Ackerman JL. Orthodontic diagnosis: The development of a problem list. In: Proffit WR, Fields HW, Sarver DM. Contemporary Orthodontics. 4th ed. St Louis, Missouri: Mosby Inc, pp. 195–201, 2007.
6. Nance HN. The limitation of orthodontic treatment I. Mixed dentition diagnosis and treatment. Am J Orthod Oral Surg, 33: 177–233, 1947.
7. Cohen MI. Recognition of the developing malocclusion. Dent Clin North Am, 6: 299–311, 1959.
8. De Paula S, Almedia de Oliveira MA, Lee PCF. Prediction of the mesiodistal diameter of unerupted lower canines and premolars using 45º cephalometric radiographs. Am J Orthod Dentofacial Orthop, 107: 309–14, 1995.
9. Carey CW. Linear arch dimensions and tooth size. Am J Orthod, 35: 762–75, 1946.
10. Seiple CM. Variation of tooth position, a metric study of the adaptation in the deciduous and permanent dentition. Svensk variation Tandlak Tidsker. 1946; 26: 39-44. Quoted from: Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian-American. Am J Orthod Dentofacial Orthop, 113: 293–9, 1998.
11. Ballard ML, Wylie WL. Mixed dentition case analysis-Estimating size of unerupted permanent teeth. Am J Orthod, 33: 754–9, 1947.
12. Moyers RE. Handbook of Orthodontics for Student and General Practitioner. Chicago: Yearbook medical publisher Inc, 1958, pp. 369–72.
13. Tanaka MM. Johnston LE. The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. J Am Dent Assoc, 88: 798–801, 1974.
14. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod, 28: 236–40, 1958.
15. Stahle H. Determination of mesiodistal crown width of unerupted permanent cuspids and bicuspids. Acta Odontol Helvetica, 3: 14–7, 1959.
16. Kaplan RG, Smith CC, Kanarek PH. An analysis of three mixed dentition analyses. J Dent Res, 56: 1337–43, 1977.
17. Staley RN, Kerber PE. A revision of the Hixon and Oldfather mixed dentition prediction method. Am J Orthod, 78: 296–302, 1980.
18. Bishara SE, Staley RN. Mixed dentition arch analysis step-by-step approach using the revised Hixon-Oldfather prediction method. Am J Orthod, 86: 130–5, 1986.
19. Dean JA, McDonald RE, Avery DR. Dentistry for the child and adolescent. 8th ed. Missouri. Mosby, Inc, pp. 627–683, 2004.
20. Paredes V, Gania JL, Cibrian R. A new, accurate and fast digital method to predict unerupted tooth size. Angle Orthod, 76: 14–9, 2006.
21. Buwembo W, Luboga S. Moyers method of mixed dentition analysis: a meta-analysis. Afr Health Sci, 4: 63–6, 2004.
22. Casamassimo PS, Christensen JR, Fields HW. Examination, Diagnosis, and treatment planning. In: Pinkham JR, Casamassimo PS, Fields HW, McTigue DJ, Nowak AJ. Pediatric Dentistry: Infancy through Adolescence. 4th ed. Missouri: Elsevier Inc, pp. 492–9, 2005.
23. Foster RR, Wylie WL. Arch length deficiency in mixed dentition. Am J Orthod, 44: 464–76, 1958.
24. Bull RL. Radiographic method to estimate the mesiodistal dimensions of unerupted teeth. Am J Orthod, 45: 711–2, 1959.
25. De Paula S, Almedia de Oliviera MA, Lee PCF. Prediction of the mesiodistal diameter of unerupted lower canines and premolars using 45º cephalometric radiographs. Am J Orthod Dentofacial Orthop, 107: 309–14, 1995.

26. Gardner RB. A comparison of four methods of predicting arch length. Am J Orthod, 75: 387–98, 1979.
27. Mok KH, Cooke MS. Space analysis: a comparison of sonic digitization (DigiGraph Workstation) and the digital calliper. Eur J Orthod, 20: 653–61, 1998.
28. Ferguson FS, Macko DJ, Sonnenberg EM, Shakun ML. The use of regression constants in estimating tooth size in Negro population. Am J Orthod, 73: 68–72, 1978.
29. Bishara SE, Jakobsen JR, Abdallah EM, Fernandez G. A comparison of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico and the United States. Am J Orthod Dentofacial Orthop, 96: 416–22, 1989.
30. Al-Khadra BH. Prediction of the size of unerupted canines and premolars in a Saudi Arab population. Am J Orthod Dentofacial Orthop, 104: 369–72, 1993.
31. Otuyemi OD, Noar JH. A comparison of crown size dimensions of the permanent teeth in a Nigerian and a British population. Eur J Orthod, 18: 623–8, 1996.
32. Al-Bitar ZB, Al-Omari LK, Sonbol HN, Al- Ahmad HT, Hamdan AM. Mixed dentition analysis in a Jordanian population. Angle Orthodont, 78: 670–5, 2008.
33. Abdallah EM. Arch length analysis in mixed dentition period. Master thesis, Faculty of Dentistry, Alexandria University, pp. 20–65, 1981.
34. Dowidar KS. Verification of Moyers' arch length analysis on young Egyptian adults. Master thesis, Faculty of Dentistry, Alexandria University, pp. 1–43, 1982.
35. Schoonjans F, Zalata A, Depuydt CE, Comhaire FH. MedCalc: A new computer program for medical statistics. Computer Methods and Programs in Biomedicine. 48: 257–62, 1995.
36. Graber TW. Orthodontics principles and practice. Philadelphia: WB Saunders Company, pp. 335–84, 1967.
37. Bernabe E, Flores-Mir C. Are the lower incisors the best predictors for the unerupted canines and premolars? An analysis in a Peruvian sample. Angle Orthod, 75: 198–203, 2004.
38. Wheeler RC. Dental anatomy, Physiology and Occlusion. 7th ed. Philadelphia: Harcourt Brace Jovanovich Inc; 1993, pp. 102–29, 1993.
39. Bernabe E, Flores-Mir C, Major PW. Tooth-width ratio discrepancies in a sample of Peruvian adolescents. Am J Orthod Dentofacial Orthop, 125: 361–5, 2004.
40. Bernabe E, Villanueva KM, Flores-Mir C. Tooth-width ratios in crowded and non-crowded dentitions. Angle Orthod, 74: 31–7, 2004.
41. Flores-Mir C, Bernabe E, Camus C, Carhuayo MA, Major PW. Prediction of mesiodistal canine and premolar tooth width in a sample of Peruvian adolescents. Orthod Craniofac Res, 6: 173–6, 2003.
42. Moyers RE. Handbook of Orthodontics. 4th ed. Chicago: Yearbook medical publishers Inc, pp. 235–40, 1988.
43. Nourallah AW, Gesch D, Khordaji MN, Spleith C. New regression equations for predicting the size of unerupted canines and premolars in a contemporary population. Angle Orthod, 72: 216–21, 2002.
44. Abu Alhaija ESJ, Qudeimat MA. Mixed dentition space analysis in a Jordanian population: comparison of two methods. Inter J Pediatr Dent, 16: 104–10, 2006.
45. Melgaco CA, Araujo MT, Ruellas AC. Mandibular permanent first molar and incisor width as predictor of mandibular canine and premolar width. Am J Orthod Dentofacial Orthop, 132: 340–5, 2007.
46. Legovic M, Novosel A, Legovic A. Regression equations for determining mesiodistal crown diameters of canines and premolars. Angle Orthod, 73: 314–8, 2002.
47. 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, 46: 475–9, 1991.
48. Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian-American. Am J Orthod Dentofacial Orthop, 113: 293–9, 1998.
49. Jaroontham J, Godfrey K. Mixed dentition analysis in a Thai population. Eur J Orthod, 22: 127–34, 2000.
50. Diagne F, Diop-BA K, Ngom PI, Mbow K. Mixed dentition analysis in a Senegalese population: elaboration of prediction tables. Am J Orthod Dentofacial Orthop, 124: 178–83, 2003.