Original Article

New Regression Equations for Predicting the Size of Unerupted Canines and Premolars in a Contemporary Population

Abdul Wahab Nourallah, MS[a]; Dietmar Gesch, MS[a]; Mohammad Nabieh Khordaji, PhD[b]; Christian Splieth, PhD[c]

Abstract: The determination of a tooth-size to arch-length discrepancy in the mixed dentition requires an accurate prediction of the mesiodistal widths of the unerupted permanent teeth. This is an essential factor in treatment planning. The aim of this study was to validate Tanaka and Johnston's analysis on 600 Syrian patients aged 14–22 years. Tanaka and Johnston's tables, equations, and approximations were modified in order to improve the accuracy of the prediction. The correlation coefficients found between the size of the permanent mandibular central incisors and maxillary first molars (31, 41, 16, and 26) and the maxillary and mandibular canines and premolars were high (r = .72 and .74, respectively). New, more accurate prediction tables applicable at earlier ages, and new regression equations were constructed. In addition, new easier approximations were developed to allow the prediction of the size of the unerupted maxillary canines and premolars 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 canines and premolars was obtained by adding 5.5 mm to the half-widths of same teeth, 31, 41, 16, and 26. (*Angle Orthod* 2002;72:216–221.)

Key Words: Prediction; Analysis; Regression equation; Unerupted; Mixed dentition

INTRODUCTION

Predicting the size of unerupted teeth during the mixed dentition period is a critical factor in managing the developing occlusion of a growing child. The ability to predict the sizes of unerupted posterior teeth in the mixed dentition is of prime importance if a good treatment plan is to be established.[1–3] An accurate prediction can help answer the traditional question of whether the available space in the posterior segments is sufficient to allow the permanent teeth to erupt freely with good alignment in their respective arches.[4]

The widely used Tanaka and Johnston Space Analysis is a simple method to predict the sizes of unerupted canines and premolars in mixed dentition with an acceptable accuracy for both jaws and both genders.[5–8] This analysis has been in use in the Department of Pediatric Dentistry at Damascus University, Syria, since 1987.

More than 10 years experience in implementing the Tanaka and Johnston analysis has shown that it overestimates the sizes of unerupted canines and premolars in the majority of cases when used in Syrian or other Arabian populations.[9]

Accuracy, safety, and simplicity are important criteria for a predictive method to become a part of the comprehensive case analysis in contemporary orthodontic practice. A review of the literature regarding space analysis in the mixed dentition shows four main methods for estimating the sizes of canines and premolars prior to eruption.[10]

Some methods, based on tooth size averages use established tables of average tooth sizes.[11,12] Moorrees[13] set a nomograph to predict the sizes of unerupted teeth based on the average sizes of the primary teeth.

Other methods are based on measurements taken directly from radiographs, as reported by McCoy[14] and Nance,[15] or by a proportional fraction.[12,16] DePaula et al[17] suggested the use of 45-degree cephalometric radiographs to predict the mesiodistal diameter of the relevant teeth.

Still other methods use regression equations 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. Seiple[18] published the first study in this field and Carey[19] was the first who proved the existence of a good linear correlation between

Resident, Department of Orthodontics, Ernst-Moritz-Arndt-University, Greifswald, Germany.

Professor and Head of the Department of Pediatric Dentistry, Damascus University, Damascus, Syria.

Priv Doz, Department of Operative Dentistry, Periodontology and Pediatric Dentistry, Ernst-Moritz-Arndt-University, Greifswald, Germany.

Corresponding author: Dr A. Nourallah, Ernst-Moritz-Arndt-University, Rotgerberstr. 8,D-17487, Greifswald, Germany.
(e-mail: abdulwahabnour@yahoo.com)

Accepted: November 2001. Submitted: July 2001.

TABLE 1. The Highest Correlation Coefficients of Tooth Groups by Tooth Type and Gender[a]

		Maxillary Canines and Premolars			Mandibular Canines and Premolars		
Group	Tooth Groups	Male (r)	Female (r)	Total (r)	Male (r)	Female (r)	Total (r)
1	31, 41	.61	.59	.60	.61	.61	.62
2	11, 12, 21, 22	.71	.70	.71	.72	.71	.72
3	16, 26	.68	.66	.68	.71	.70	.71
4	11, 21, 31, 41	.66	.62	.65	.68	.64	.66
5	31, 32, 41, 42	.66	.64	.67	.70	.66	.68
6	16, 26, 26, 46	.68	.65	.68	.74	.74	.74
7	31, 32, 41, 42, 36, 46	.74	.74	.74	.78	.76	.77
8	31, 41, 16, 26	.73	.70	.72	.75	.72	.74
9	31, 32, 41, 42, 11, 21	.69	.65	.67	.76	.66	.69

[a] r indicates correlation coefficient.

the size of the permanent lower incisors and the size of the permanent canines and premolars. Ballard and Wylie[20] more closely examined Carey's study and established the first regression equations. Hixon[21] and Oldfather[22] reached similar results. Moyers[23] suggested two probability tables to predict the sizes of unerupted teeth in the mixed dentition using the sum of the widths of the four mandibular permanent incisors, and presented this as a part of a mixed dentition analysis. Other authors[24,25] devoted a separate equation to each jaw and gender and presented an analysis with a separate equation for each gender. Fonseca[26] introduced an additional variable (maxillary first permanent molars with maxillary four permanent incisors) to establish a multiple regression equation. Tanaka and Johnston[8] reassessed Moyers' analysis and established a simple approximation to predict the widths of unerupted canines and premolars for both jaws and genders by using the sizes of the four mandibular permanent incisors.

A combination of methods two and three uses the tooth widths measured from radiographs in a regression equation. Hixon and Oldfather[21,22,27] established a regression equation where the sizes of unerupted mandibular canines and premolars could be predicted after measuring the mandibular premolars on a radiograph. Stahle[28] modified Oldfather's method by including the sizes of the mandibular permanent incisors. Moyers' analysis was also modified by other authors.[29,30] suggested a modification for Moyers analysis. Several investigators have studied a combined analysis of measurements from radiographs and multiple regression equations.[12,31,32]

Tanaka and Johnston's[8] analysis is in use in the Pediatric Dentistry Department of Damascus University because it is uncomplicated, flexible, relatively accurate and noninvasive. However, tooth sizes vary significantly between different populations and races.[3,33] Because of the secular trend of tooth sizes,[34] this study was designed to examine the accuracy of Tanaka and Johnston's[8] analysis on a Syrian population and to attempt to find a more accurate formula for predicting the sizes of unerupted canines and premolars for a Syrian population.

MATERIALS AND METHODS

Plaster models of 600 14- to 22-year-old patients (320 men and boys, 280 women and girls) were selected from the records of the Orthodontic Department at Damascus University. All patients had all relevant teeth fully erupted and presented with no proximal caries or fillings, morphological anomalies, missing teeth, proximal or occlusal abrasion, or bruxism.

A pointed Vernier Caliper (0.02 mm accuracy) was used to measure the mesiodistal widths of all teeth according to the method described by Seiple[18] and Moorrees et al.[13,35] In each case, one experienced examiner took two separate measurements of each tooth and the mean value was used for further data analysis.

The computerized data were analyzed in cooperation with the Department of Biostatistics at Tishreen University in Syria according to the Tanaka and Johnston analysis. Applying the probability theory, the teeth were divided into more than 100 possible groups. Table 1 indicates the nine most important groups. Correlation coefficients between individual and grouped teeth were calculated[36] and confidence intervals[37] were constructed according to Tanaka and Johnston.[8]

Finally, new equations were developed to optimize the Tanaka and Johnston's[8] analysis. The accuracy of these new equations was tested on a random sample of 50 new cases, and the results were compared with those of Tanaka and Johnston.[8]

RESULTS

The crown widths of all teeth measured were normally distributed. Correlation coefficients were calculated between the tooth groups (Table 1) and were remarkable in groups five and eight, which can be used to establish regression equations. Although other high values were also found, they cannot be used in regressions because of local complicating factors such as distal gingival coverage or late eruption (eg, group seven) or morphological drawbacks such as a deformity of the maxillary lateral permanent incisor (eg, group two).

The correlation coefficients for group five differ from

TABLE 2. Probability of Predicting the Sizes of the Unerupted Maxillary Canines and Premolars from the Sum of Widths of the Four Mandibular Permanent Incisors

	Sum of the Mesiodistal Widths of the Four Mandibular Permanent Incisors													
CI[a]	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27
95%	21.4	21.7	22.0	22.3	22.7	23.0	23.4	23.7	23.9	24.1	24.4	24.6	24.9	25.2
85%	21.2	21.5	21.8	22.1	22.4	22.8	23.1	23.3	23.6	23.8	24.1	24.3	24.6	24.9
75%	21.0	21.3	21.6	21.8	22.2	22.5	22.8	23.0	23.3	23.5	23.8	23.9	24.3	24.7
65%	20.8	21.1	21.4	21.6	21.9	22.1	22.5	22.7	23.0	23.1	23.4	23.7	23.9	24.4
50%	20.6	20.8	21.1	21.3	21.6	21.8	22.1	22.3	22.6	22.8	23.1	23.3	23.6	23.9
35%	20.2	20.5	20.7	21.0	21.3	21.4	21.7	22.0	22.2	22.4	22.7	23.0	23.2	23.6
25%	19.9	20.1	20.4	20.7	21.0	21.1	21.4	21.6	21.9	22.1	22.4	22.7	22.9	23.3
15%	19.6	19.9	20.1	20.4	20.7	20.8	21.0	21.3	21.6	21.9	22.2	22.4	22.6	23.1
5%	19.3	19.6	19.9	20.1	20.3	20.5	20.7	20.9	21.3	21.6	21.8	22.1	22.4	22.8

[a] CI indicates confidence intervals.

TABLE 3. Probability of Predicting the Sizes of the Unerupted Mandibular Canines and Premolars from the Sum of the Widths of the Four Mandibular Permanent Incisors

	Sum of the Mesiodistal Widths of the Four Mandibular Permanent Incisors													
CI[a]	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27
95%	21.5	21.8	22.0	22.4	22.7	23.0	23.2	23.5	23.7	23.9	24.2	24.5	24.8	25.1
85%	21.1	21.4	21.7	22.0	22.4	22.6	22.8	23.1	23.4	23.6	23.8	24.1	24.4	24.8
75%	20.7	21.0	21.4	21.8	22.0	22.2	22.4	22.8	23.1	23.3	23.5	23.9	24.1	24.4
65%	20.4	20.6	20.9	21.3	21.6	21.8	22.0	22.3	22.7	22.9	23.2	23.6	23.8	23.9
50%	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4	23.6
35%	19.4	19.7	19.9	20.4	20.5	20.9	21.2	21.5	21.8	22.1	22.4	22.8	23.1	32.2
25%	18.9	19.3	19.6	20.0	20.1	20.5	20.8	21.2	21.5	21.8	22.1	22.5	22.8	23.0
15%	18.6	19.0	19.3	19.7	19.8	20.2	20.6	20.8	21.1	21.5	21.8	22.2	22.5	22.8
5%	18.3	18.7	19.0	19.3	19.5	19.8	20.2	20.5	20.8	21.2	21.5	21.9	22.3	22.5

[a] CI indicates confidence interval.

TABLE 4. Probability of Predicting the Sizes of Unerupted Maxillary Canines and Premolars from the Sum of the Widths of Mandibular Central Permanent Incisor and Maxillary First Permanent Molars

	Sum of the Widths of the Mandibular Central Permanent Incisors and Maxillary First Permanent Molars													
CI[a]	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35
95%	20.9	21.2	21.5	21.8	22.1	22.4	22.7	22.9	23.2	23.5	23.7	23.9	24.2	24.6
85%	20.7	20.9	21.3	21.6	21.9	22.0	22.3	22.6	23.0	23.1	23.4	23.6	23.9	24.3
75%	20.4	20.7	21.0	21.3	21.6	21.8	22.1	22.4	22.7	22.9	23.1	23.4	23.7	24.0
65%	20.1	20.4	20.7	20.9	21.2	21.4	21.7	21.9	22.2	22.5	22.7	22.9	23.3	23.6
50%	19.9	20.1	20.3	20.6	20.9	21.1	21.4	21.6	21.9	22.1	22.4	22.6	22.9	23.2
35%	19.6	19.9	20.1	20.4	20.7	20.9	21.1	21.4	21.7	21.9	22.2	22.4	22.7	22.9
25%	19.3	19.6	19.9	20.1	20.4	20.7	20.9	21.2	21.5	21.7	21.9	22.1	22.4	22.7
15%	19.0	19.3	19.7	19.9	20.1	20.4	20.7	20.9	21.2	21.5	21.7	21.9	22.2	22.4
5%	18.8	19.1	19.5	19.7	19.9	20.1	20.4	20.7	20.9	21.2	21.5	21.7	21.9	22.1

[a] CI indicates confidence intervals.

those in Tanaka and Johnston's study, and require modification using the equations. The correlation coefficients for group eight were higher and are used here as a base for establishing new equations.

The confidence intervals were calculated[38] and sorted into two prediction tables (Tables 2 and 3), by which the sizes of unerupted teeth can be predicted at different levels of confidence for both jaws (as in Tanaka and Johnston's[8] and Moyers'[23] methods) by using the widths of the four mandibular permanent incisors.

The confidence level of 75% was utilized to constrict a simple form of regression equations: $Y = A + B(X)$ where Y equals the predicted sizes of canines and premolars, A and B are the equation's constants, and X is defined as the sum of widths of the four mandibular permanent incisors.

According to our analysis, the regression equation was:

TABLE 5. Probability for Predicting the Sizes of Unerupted Mandibular Canines and Premolars from the Sum of the Widths of Mandibular Central Permanent Incisors and Maxillary First Permanent Molars

	Sum of the Widths of the Mandibular Central Permanent Incisors and Maxillary First Permanent Molars													
CI[a]	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35
95%	20.1	20.4	20.8	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.0	23.3	23.6	23.9
85%	19.9	20.2	20.6	20.9	20.2	21.5	20.7	22.1	22.2	22.5	22.7	23.1	23.3	23.7
75%	19.7	20.0	20.3	20.6	20.9	21.2	21.4	21.8	21.9	22.2	22.5	22.8	23.0	23.4
65%	19.5	19.8	20.1	20.4	20.6	20.9	21.2	21.5	21.7	22.0	22.2	22.5	22.7	23.1
50%	19.3	19.6	19.9	20.2	20.4	20.7	20.9	21.2	21.5	21.7	22.0	22.3	22.5	22.8
35%	19.1	19.4	19.7	19.9	20.2	20.4	20.7	20.9	21.3	21.5	21.8	22.1	22.3	22.6
25%	18.8	19.1	19.4	19.7	19.9	20.1	20.5	20.7	21.1	21.3	21.6	21.9	22.1	22.3
15%	18.6	18.9	19.1	19.4	19.7	19.9	20.2	20.5	20.8	21.0	21.4	21.6	21.9	22.0
5%	18.3	18.6	18.9	19.1	19.4	19.7	20.0	20.3	20.6	20.8	21.1	21.4	21.6	21.8

[a] CI indicates confidence intervals.

TABLE 6. Comparison of Mean Tooth Sizes

	Study				
	Ballard[41]	Stahle[28]	Black[11]	Moyers[23] (Tanaka and Johnston[8])	Present Study
Maxilla					
Central incisor	8.91	8.68	9.00	8.70	8.79
Lateral incisor	7.08	6.85	6.40	6.90	6.80
Canine	8.00	7.89	7.60	7.75	7.87
1st premolar	7.27	7.07	7.20	6.70	7.02
2nd premolar	7.14	6.84	6.80	6.60	6.72
1st molar	10.98	—	10.70	10.40	10.46
Mandible					
Central incisor	5.67	5.31	5.40	5.45	5.54
Lateral incisor	6.28	6.00	5.90	5.45	6.07
Canine	7.12	6.89	6.90	6.75	6.91
1st premolar	7.36	7.20	6.90	6.85	7.08
2nd premolar	7.50	7.28	7.10	7.20	7.19
1st molar	11.17	—	11.20	10.50	11.23

Y = 9.87 + 0.50(X) for the maxilla, and Y = 9.32 + 0.55(X) for the mandible.

The standard error of the estimated values was 0.79 for the maxillary equations and 0.83 for the mandibular equations. To predict the sizes of unerupted canines and premolars in the mixed dentition for maxillary teeth, a simple approximation was established by adding 10.6 mm to half the widths of the four mandibular permanent incisors, and by adding 10.2 mm to the same teeth to predict the sizes of mandibular canines and premolars.

The New Analysis Equations

A strong correlation between the sizes of mandibular central permanent incisors and maxillary first permanent molars and the sizes of the unerupted canines and premolars in both jaws (maxilla $r = 0.72$; mandible $r = 0.74$, Table 1) calls for new and more accurate equations based on the use of different teeth as an index.

As in Tanaka and Johnston's[8] study, confidence intervals were calculated and sorted into two prediction tables (Tables 4 and 5). The confidence level of 75% was used to construct an uncomplicated form of the equation: Y' = A' + B'(X'), where Y' equals the predicted size of canines and premolars, A' and B' are the equation's constants, and X' is defined by sum of widths of mandibular central permanent incisors and maxillary first permanent molars. The equation is: Y' = 5.38 + 0.50(X') for the maxilla, and: Y' = 4.93 + 0.52(X') for the mandible.

The standard errors for the estimated values were 0.61 for the maxillary equation and 0.59 for the mandibular equations, which means that the accuracy of the new analysis is higher than that of Tanaka and Johnston. It also shows that the modification we did applies to our population since it shows the lowest standard errors.

TABLE 7. Comparison of Correlation Coefficients, Regression Coefficients, and Standard Errors Between Tanaka and Johnston,[8] the Present Study, and the New Analysis

Canines and Premolars	Correlation Coefficient			Regression Coefficients A			Regression Coefficients B			Standard Errors of Estimated Values		
	1	2	3	1	2	3	1	2	3	1	2	3
Maxilla	0.67	0.63	0.72	9.87	10.4	5.38	0.50	0.51	0.50	0.79	0.86	0.61
Mandible	0.68	0.65	0.73	9.32	9.18	4.93	0.55	0.54	0.52	0.83	0.85	0.59

1 indicates present study; 2, Tanaka and Johnston; 3, new analysis.

A simple approximation was established to predict the sizes of the unerupted maxillary canines and premolars in the mixed dentition by adding 6 mm to the half the widths of mandibular central permanent incisors and maxillary first permanent molars. The analogous value for sizes of the unerupted maxillary canines and premolars in the mixed dentition in the mandible can be obtained by adding 5.5 mm to the half widths of the same mandibular central permanent incisors and maxillary first permanent molars.

Equations of both the modified Tanaka and Johnston[8] analysis and the new analysis were applied to a sample of 50 new cases to examine their accuracy. The results indicated that, between the actual and estimated sizes of the canine and premolars, the modified equations showed less percentage differences (maxillary 0.67%, mandibular 0.87%) when compared with Tanaka and Johnston (maxillary 0.81%, mandibular 1.03%), but the new analysis showed the least percentage differences (maxillary 0.53%, mandibular 0.79%).

DISCUSSION

The Tanaka and Johnston analysis of 600 Syrian adolescents resulted in higher correlation coefficients (maxilla $r = .67$, mandible $r = .68$) than given in the original Tanaka and Johnson[8] study (maxilla r = .63, mandible $r = .65$) or in Bolton,[1] Ballard and Wylie[20], Hixon and Oldfather,[21] Greiwe,[39] or Shelly.[40]

A comparison of tooth sizes shows that the mean sizes of most permanent teeth in our study exceeded their counterparts in other studies, especially those of Moyers and Tanaka and Johnston (Table 6).

The increased mean widths of the relevant teeth in the present study compared with Tanaka's and Moyer's values can explain the decrease in values of constant A in our equations. In contrast, the value of the constant B remained stable in both studies as shown in Table 7, although there was little difference in the prediction tables between the two studies.

The lower standard errors in the present study (Maxilla: Tanaka and Johnston SE = .86, present study SE = .79; Mandible: Tanaka and Johnston SE = .85, present study SE = .83) prove that these equations are more accurate when used on a Syrian population.

The following factors may have contributed the increase in accuracy and the decrease in the standard errors (Table 7):

a. The mesiodistal widths of all teeth (from second permanent molar to its counterpart in both jaws) were measured at two separate times and the mean values were used for the analysis.
b. A limited numbers of cases were measured (maximum 24 cases) in each session.
c. The more accurate Vernier Caliper used (0.02 mm) compared with that used by Tanaka and Johnston (0.05 mm).
d. One experienced examiner did all measurements.
e. The sample size of 600 cases was much greater.

A literature review revealed that there are no studies that used the mandibular permanent central incisors in combination with the maxillary first permanent molars as an index to predict the widths of unerupted canines and premolars. However, there is a strong correlation between these tooth groups, as shown in Table 7.

The constant B values in the new analysis equations are similar to the previous calculation, while constant A values clearly differ. This is because A relates to the value of the of the sum widths of the index teeth which are higher in the new analysis.

A remarkable reduction in the standard errors of the estimated values (Table 7) and in the percentage difference was observed, demonstrating that this new analysis is even more accurate than Tanaka and Johnston's and the modified equations.

CONCLUSIONS

Modifications made on both the prediction tables and the regression equations of Tanaka and Johnston's analysis allowed a simplified approximation the sizes of the mandibular permanent canines and premolars to be predicted with higher accuracy in a Syrian population.

The new analysis prediction tables and new regression equations based on teeth 31, 41, 16, and 26, which erupted earlier than the teeth used by Tanaka and Johnston, proved even more accurate than both previous equations.

ACKNOWLEDGEMENTS

Special thanks to Mr A. Belal, biostatistician, and to Mr S. Basel for the great help in computer programming.

REFERENCES

1. Bolton WA. Disharmony in tooth size and its relation to the analysis in treatment of malocclusion. *Angle Orthod.* 1958;28:113–130.
2. Bolton WA. The clinical application of a tooth Size analysis. *Am J Orthod.* 1962;48:504–529.
3. Schirmer UR, Wiltshire WA. Orthodontic probability tables for black patients of African descendent mixed dentition analysis. *Am J Orthod Dentofacial Orthop.* 1997;112:545–551.
4. Kirschen RH, OHiggins EA, Lee RT. The Royal London Space Planning: an integration of space analysis and treatment planning: Part I: assessing the space required to the treatment objectives. *Am J Orthod Dentofacial Orthop.* 2000;118:448–455.
5. Foster HR. An analysis of the developing dentition. *JADA* 1951; 42:376–387.
6. Foster HR. Arch length deficiency in the mixed dentition. *Am J Orthod.* 1958;44:464–476.
7. Gardner RB. A comparison of four methods of predicting arch length. *Am J Orthod.* 1989;75:387–398.
8. Tanaka MM, Johnston LE. The prediction of the size of unerupted canines and premolars in contemporary orthodontic population. *JADA* 1974;88:798–801.
9. al-Khadra BH. Prediction of the size of unerupted canines and

premolars in contemporary Arab population. *Am J Orthod Dentofacial Orthop.* 1993;104:369–372.
10. Brown JE. *Predicting the mesiodistal crown width of the unerupted maxillary canines, first and second premolars* [master's thesis]. Memphis, Tenn: University of Tennessee School of Dentistry; 1955.
11. Black GV. *Descriptive Anatomy of Human Teeth.* 5th ed. Philadelphia, Penn: SS White Dental Manufacturing; 1902.
12. Hoag JF. *Estimation of the mesiodistal diameters of maxillary canines and premolars.* [master's thesis]. Iowa City, Iowa: Department of Orthodontics, University of Iowa; 1975.
13. Moorrees CF, Thomsen SN, Jensen E, Yen PK. Mesiodistal crown diameters of the deciduous and permanent teeth in individuals. *J Dent Res.* 1957;36:39–47.
14. McCoy JD. Indications for the use of the x-ray in orthodontics. *Int J Orthod.* 1917;3:483–489.
15. Nance HN. The limitations of orthodontic treatment. I and II. *Am J Orthod.* 1947;33:177–253.
16. Bull RL. Radiographic method to predict the mesiodistal dimension of unerupted teeth. *Am J Orthod.* 1959;44:711–712.
17. de Paula S, Almeida MA, Lee PC. Prediction of the mesiodistal diameter of unerupted lower canines and premolars using 45 degree cephalometric radiography. *Am J Orthod Dentofacial Orthop.* 1995;107:309–314.
18. 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.
19. Carey CW. Linear arch dimension and tooth size. *Am J Orthod.* 1946;35:762–775.
20. Ballard ML, Wylie WL. Mixed dentition case analysis—estimating size of unerupted permanent teeth. *Am J Orthod.* 1947;33:754–759.
21. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. *Angle Orthod.* 1958;28:236–240.
22. Oldfather RH. Estimation of the sum of the widths of unerupted mandible cuspid, first bicuspid, and second bicuspid. *Am J Orthod.* 1957;43:788–789.
23. Moyers RE. *Hand Book of Orthodontics: For Student and General Practioner. Chicago, Ill: Year Book of Medical Publishers Incorporated;* 1958:195:369–372.
24. Groper JN. The mixed dentition analysis, a review. *J South Calif Dent Assoc.* 1968;36:167–169.
25. Jaroontham J, Godfrey K. Mixed dentition space analysis in a Thai population. *Eur J Orthod.* 2000;22:127–134.
26. Foneseca CC. *Predicting of mesiodistal crown width of the canine-premolars segment in maxillary dental arches.* [master's thesis]. Memphis, Tenn: University of Tennessee School of Dentistry; 1961.
27. Staley RN, Kreber RE. A revision of the Hixon Oldfather mixed dentition prediction method. *Am J Orthod* 1980;78:296–302.
28. Stahle H. Determination of mesiodistal crown width of the unerupted permanent cuspids and bicuspids. *Helv Orthod Acta.* 1959;3:14–19.
29. Huckaba GW. Arch size analysis and tooth size prediction. *Dent Clin North Am.* 1964;11:431–440.
30. Proffit WR, Henry WF. *Contemporary Orthodontics.* 2nd ed. Philadelphia, Penn: CV Mosby; 1986:121–143.
31. Staley RN, Hoag JF. Prediction of the mesiodistal widths of the maxillary permanent canines and premolars. *Am J Orthod.* 1978;73:169–177.
32. Staley RN, Shelly TH, Martin JF. Prediction of lower canines and premolar widths in mixed dentition. *Am J Orthod.* 1979;76:300–309.
33. Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian-Americans. *Am J Orthod Dentofacial Orthop.* 1998;113:293–299.
34. Stanley MG, Arthur BL, Arline W. Evidence for secular trend in tooth size over two generations. *Arc Oral Biol.* 1967;12:503–504.
35. Moorrees CF, Reed RB. Correlation's among crown diameter of human teeth. *Arch Oral Bio.* 1964;9:685–697.
36. Dahlberg G. *Statistical Methods for Medical and Biological Students.* London: Georg allemande Unwin, Ltd.; 1948.
37. Bulman JS, Osborn JF. *Statistics in Dentistry.* London: British Dental Association; 1989:25,44,45,60,61.
38. Sendecor GW. *Statistical Method: Applied to Experiments in Agriculture and Biology.* 5th ed. Iowa City, Iowa: Iowa State University Press; 1956:170–175.
39. Griewe PW. *Tooth size and asymmetry in the human dentition* [master's thesis]. Iowa City, Iowa: State University of Iowa School of Dentistry; 1949.
40. Shelly TH. *Estimation of the mesiodistal diameters of Mandible canines and premolars.* [master's thesis]. Iowa City, Iowa: Department of Orthodics, University of Iowa; 1976.
41. Ballard ML. Asymmetry in tooth size: a factor in the etiology, diagnosis and treatment of malocclusion. *Angle Orthod.* 1944;14:67–71.