

Mixed dentition space analysis in a Thai population

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SUMMARY This study produced simple linear regression equations to be used for mixed dentition space analysis for males and females, and sexes pooled in a population living in northeastern Thailand. Measurements of teeth were made to within 0.01 mm on the dental casts of 215 boys and 215 girls (mean age 15.7 years). All dentitions were required to be free of any signs of dental pathology or anomalies.

It was found that males had significantly larger teeth than females as represented by summations of mandibular incisor, canine, and premolar widths. ANOVA of regression indicated a close relationship between mandibular incisor summation and corresponding summations of canine and premolars. The low coefficients of determination (r^2) of the regressions ranged between 0.29 and 0.42, and were higher for females than males, which might be attributable to the ethnic diversity of the sampled population. The regression equations produced predictions of mesio-distal width summations for maxillary and mandibular canine, and premolar arch segments that were slightly different from other reported Asian studies. Moyers' prediction tables at the 50th percentile were found to under-estimate tooth size summation compared with the present investigation. The predictions from simplified regression equations matched well with those of this study for sexes pooled, and for males and females separately.

Introduction

Although the probability tables of Moyers (1973) have been widely adopted for mixed dentition space analysis (MDSA), there have been questions about their relative accuracy. Tanaka and Johnston (1974) developed tables comparable with Moyers, but realized that simplifying the MDSA would widen its clinical application. They introduced simple, easily remembered and applied regression equations for estimating the summed dimensions of the mandibular and maxillary canine and premolar segments.

There have been several reported methods for improving the accuracy of MDSA predictions using radiographs (Hixon and Oldfather, 1958; Bull, 1959; Bishara and Staley, 1984; Staley *et al.*, 1984). However, these methods require a combination of measurements of erupted incisors and primary teeth, and undistorted images from long-cone radiographs of both erupted and unerupted teeth incorporated into multiple regression equations. Such complex methods

may give only marginal improvement over simpler methods, while also discouraging their use by clinicians.

The most widely employed methods of MDSA have been developed for North American Caucasian children and it is reasonable to question their use in other populations. It is also noteworthy that Moyers has provided two sets of data tables for MDSA, one for sexes combined (1973), which does not correlate with his sexes separated data (1988). There have been several studies of MDSA in other population groups [Al-Khadra (1993), for Saudi Arabians; Bishara *et al.* (1989), for population samples from Egypt, Mexico, and the USA; Otuyemi and Noar (1996), for Tanzanians; and Yuen *et al.* (1998), for Hong Kong Chinese], all of which disagreed with the use of Moyers', and Tanaka and Johnston's methods. There have also been questions about applying these methods, which are based on pooled male and female data, rather than considering the sexes separately (Keiser, 1990). In addition, there is some evidence of

secular trends of changing dimensions of the teeth (Keiser, 1990), which may require progressive modifications of MDSA for different populations.

There have been three reported studies of MDSA among Thai populations, one from the southern region of Thailand (Supanee *et al.*, 1995), another from Bangkok (Dechkunakorn *et al.*, 1990), and the third from the northern region (Boondej and Sirinavin, 1990). All concluded that the methods of Moyers, and Tanaka and Johnston under-estimated the tooth dimensions for their samples. Although the study of Dechkunakorn *et al.* (1990) found the use of the Moyers' tables to be unsatisfactory, the nature of their statistical data does not allow specific comparisons to be made with other MDSA studies, such as those reviewed in this paper.

One aspect of interest with these Thai studies is whether or not they investigated different mixes of groups which, due to these ethnic groups having different genetic backgrounds, may be the sources of variation in dimensions of the teeth. The Thai population is ethnically diverse as a result of combining, over several centuries, indigent Thai with large migrations and invasions, and other acquisitions through local wars involving the now neighbouring countries of Laos, Cambodia, Myanmar, Malaysia, Vietnam and south China, as well as small inputs from South Asia and Europe (Wyatt, 1984). The southern region of Thailand is likely to reflect mixtures of Thai, Malay, Burmese, and Chinese. The northern region of the country is likely to consist of a mix of Thai with Lao, Burmese, and Chinese. On the other hand, the northeastern region appears to have closer affinities with Laos, Cambodia, and Vietnam. Ethnic Chinese appear to be distributed fairly uniformly throughout the country. Thus, the results of the three available Thai MDSA studies may or may not apply so well to a northeastern population. This uncertainty led to the present investigation of a northeastern Thai group to compare its MDSA data with that from other studies.

Subjects and methods

A sample of 430 subjects (215 males and 215 females with mean ages of 15.76 and 15.73 years,

respectively) was selected from among 1750 students (745 males and 1005 females) of Sakon Nakhon Pattanasuksa School in Sakon Nakhon, Thailand. Sakon Nakhon is the main city of the rural Province of the same name and is 650 km northeast of Bangkok. Some of the students came from rural areas of the Province, which has a total population of 1.06 million. This sample was considered to represent the population of the Province and, probably, the northeastern administrative region of Thailand, having a population of 20.8 million (Alpha Research Co. Ltd., 1997).

To be included in this study, the students had to be native Thai, less than 20 years old and all teeth to be measured had to be free of visible fractures, without proximal dental caries or restoration, or significant attrition, and fully erupted so permitting accurate measurement.

Alginate impressions cast in laboratory stone were made for all 430 students, using standard procedures for material mixing and impression disinfection. All models were checked and remade where flaws were found. Measurements of maximum mesio-distal widths of all mandibular and maxillary incisors, canines, and first and second premolars were made by one person (JJ) using a Mitutoyo Digimatic Caliper 207 Series No. 500 (Mitutoyo Corporation, Japan) providing measurements to 0.01 mm. Repeat measurements were made on 90 sets of dental casts to test reliability and the impression taking with casting was checked by 10 repeated measurements using a standard typodont.

Using the collected data, regression equations were formulated to express relationships between summed widths of the four mandibular incisors, and the summations for mandibular and maxillary arch quadrants of canine and two premolars. These equations were then used to compare with MDSA predictions of other studies.

Pearson product-moment coefficients were used to express the correlation between the groups of teeth. The same tests were used to compare the sums of the widths of canine and premolars, between right and left sides of the maxillary and mandibular arches to evaluate possible asymmetry. Statistical calculations and analyses, including standard errors of the estimates (SEE),

coefficients of determination (r^2), and analysis of variance (ANOVA) of the regressions equations were carried out using the SPSS for Windows statistical computer package (Version 7.5.1, SPSS Inc. Chicago, 1996).

Results

Descriptive statistics for the sums of the four mandibular incisors, and maxillary and mandibular canine and premolar segments, measured in this study are presented in Table 1 for sexes combined, and for males and females separately. There were significant differences (all $P < 0.001$) for t -tests comparing the means of males with females for summations of mandibular incisor, and maxillary and mandibular canine and premolar widths, males having the larger values. The averages of right and left side canine and premolar summations were also compared. The mean difference for both maxillary and mandibular summations for males was 0.03 mm with a standard deviation of 0.4 mm. There was a significant difference ($P = 0.04$) for females between mandibular right and left canine, and premolar summations. However, because of the high coefficient of correlation (0.96) and closely comparable standard deviations (1.02 and 1.002 mm for females, and 1.03 and 1.03 mm for males, respectively) for the separate summations, it was assumed that the right-left differences were distributed randomly, so that the results of right and left summations were averaged.

Coefficients of test-retest reliability for measurements on 90 sets of models were calculated from

method errors (S_e) and total variances of the double determinations according to the method of Houston (1983). These gave coefficients of reliability of between 96 and 98 per cent for summations of mandibular incisors, and all four sets of canine and premolar widths. This confirmed the reliability of the measurements.

Coefficients of correlation for the canine and premolar segments of each dental arch, and the regression values of a and b in the standard linear regression equation, $y = a + bx$, and the standard errors of the estimates (SEE's) and coefficients of determination (r^2) of the maxillary and mandibular regression equations are shown in Table 2, for sexes combined, and for males and females separately.

Analysis of variance (ANOVA) of linear regression of the respective equations of the present study produced F -values ranging between 87.56 (1 and 213 degrees of freedom) and 291.57 (1 and 428 degrees of freedom), all indicating significant P -values less than 0.001. These statistical results indicate that all the variances due to regression were highly significant, so that it is highly unlikely that the relationship between x and y in all the regression equations is due to chance.

It was found that the error associated with dimensional change in impression taking and model casting was low, the change in cast measurements in this study varying between 0.4 per cent for shrinkage and 0.9 per cent for expansion. Therefore, one would have to accept a linear discrepancy of between 0.1 mm for shrinkage and 0.2 mm of expansion effects for the average sized

Table 1 Descriptive statistics for summations of mesiodistal widths of mandibular incisors, and maxillary and mandibular canine and premolar segments.

Sex	Tooth group	Range (mm)	Mean (mm)	SD (mm)
Combined ($n = 430$)	Σ Mand 2 111 2	20.30–31.18	23.56	1.36
	Σ Max 3 4 5	19.83–27.21	22.87	1.05
	Σ Mand 3 4 5	18.91–25.85	22.01	1.06
Males ($n = 215$)	Σ Mand 2 111 2	20.90–31.18	23.89	1.37
	Σ Max 3 4 5	20.74–27.21	23.16	1.04
	Σ Mand 3 4 5	19.58–25.85	22.31	1.03
Females ($n = 215$)	Σ Mand 2 111 2	20.30–26.32	23.23	1.26
	Σ Max 3 4 5	19.83–25.91	22.64	1.00
	Σ Mand 3 4 5	18.91–24.83	21.77	1.02

Table 2 Regression parameters for prediction of summation of mesiodistal widths of canine and two premolars in one dental arch segment.

Sex	Σ 3 4 5 segment	Correlation coefficient (r)	Constants		SEE (mm)	Coefficient of determination (r^2)
			a (mm)	b		
Combined	Maxilla	0.60	11.87	0.47	0.84	0.36
	Mandible	0.64	10.30	0.50	0.82	0.41
Males	Maxilla	0.54	13.36	0.41	0.88	0.29
	Mandible	0.58	11.92	0.43	0.85	0.34
Females	Maxilla	0.62	11.16	0.49	0.78	0.39
	Mandible	0.65	9.49	0.53	0.78	0.42

sum of four mandibular incisors, and similarly for canine and premolar segments.

Discussion

The descriptive statistics in Table 1 show that the ranges and means of the sums of the widths of the mandibular incisors, and the maxillary and mandibular canine and premolar segments in males were greater than in females, while the standard deviations were similar. This observation agrees with numerous other studies cited by Keiser (1990).

The coefficients of determination (r^2) in Table 2 are indicators of predictive accuracy of the regression equations for y (the sum of mesiodistal widths of canine and premolars) based on values of x (the corresponding sum of mesiodistal widths of four mandibular incisors). This coefficient represents the proportion (often expressed as a percentage) of the total variance of y , which is determined by the x value of each regression equation. $1 - r^2$ represents the proportion of the error variance of the prediction. (Portney and Watkins, 1993). From data for sexes pooled, in the present study (Table 2), the coefficients of determination (r^2) show 0.36 for the maxillary teeth and 0.41 for the mandibular teeth. Therefore, 36 and 40 per cent of the total variances for the sum of maxillary and mandibular canine and premolar summations, respectively, are accounted for by knowing the sum of the mandibular incisor widths. In Table 2, females

show higher r^2 values (0.39 for the maxillary teeth and 0.42 for the mandibular teeth) than males (0.29 and 0.34, respectively). Yuen *et al.* (1998) obtained higher r^2 values (0.63 and 0.60 for 61 males, and 0.43 and 0.48 for 61 females, for maxillary and mandibular groups, respectively). The r^2 values obtained by Supanee *et al.* (1995) from 70 sets of models from southern Thailand were 0.46 and 0.47 for maxilla and mandible, respectively. The differences in error variances between the sets of r^2 of these three studies might be attributable to the effects of different sample sizes and ethnic mixes.

The error involved in the use of prediction equations is also indicated by the SEE (Table 2): the lower the SEE, the better the prediction equation. The SEE for the maxillary arch equation developed in this study was 0.84 mm for the pooled sexes (Table 2). As an example, approximately 68 per cent of all possible subjects will have a predicted sum of canine and premolar widths accurate to within 1 SEE (0.84 mm) of their true sum. In 95 per cent of all subjects, the true sum of canine and premolar widths would fall in the range of values between two SEE's above and below the value found from the regression equation. The SEE's for Moyers' (1973, cited by Staley *et al.*, 1984), and Tanaka and Johnston's (1974) prediction methods are slightly higher than those in the present study. Compared with Yuen *et al.*'s (1998) findings, the SEE's for males in the present study are higher, but those for females are slightly lower.

Table 3 Regression equations from various studies at the 50th percentile.

Study	Population source	Sex	Arch	Regression equation
Moyers (1973)*	North American White	M + F	Maxilla	$y = 9.23 + 0.55x$
			Mandible	$y = 7.82 + 0.59x$
Moyers (1988)*	North American White	F	Maxilla	$y = 14.17 + 0.28x$
		F	Mandible	$y = 8.85 + 0.52x$
		M	Maxilla	$y = 9.73 + 0.51x$
		M	Mandible	$y = 10.79 + 0.45x$
Tanaka and Johnston (1974)	North American White	M + F	Maxilla	$y = 10.41 + 0.51x$
		M + F	Mandible	$y = 9.18 + 0.54x$
Tanaka and Johnston (1974) (simplified eqn)	To match Moyers' tables (1973) values at 75th percentile	M + F	Maxilla	$y = 11.0 + 0.5x$
		M + F	Mandible	$y = 10.5 + 0.5x$
Boondej and Sirinavin (1990)	Northern Thailand	M + F	Maxilla	$y = 10.41 + 0.51x$
			Mandible	$y = 9.18 + 0.54x$
Supanee <i>et al.</i> (1995)	Southern Thailand	M + F	Maxilla	$y = 7.94 + 0.62x$
			Mandible	$y = 3.70 + 0.77x$
Yuen <i>et al.</i> (1998)	Hong Kong	F	Maxilla	$y = 8.30 + 0.61x$
		F	Mandible	$y = 6.66 + 0.64x$
		M	Mandible	$y = 7.97 + 0.66x$
		M	Maxilla	$y = 8.82 + 0.58x$
Present study	Northeastern Thailand	M + F	Maxilla	$y = 11.87 + 0.47x$
		M + F	Mandible	$y = 10.30 + 0.50x$
		F	Maxilla	$y = 11.16 + 0.49x$
		F	Mandible	$y = 9.49 + 0.53x$
		M	Maxilla	$y = 13.36 + 0.41x$
		M	Mandible	$y = 11.92 + 0.43x$

*Regression equations derived from Moyers' tables (1973, 1988) at the 50th percentile.

Table 3 records regression equations from several studies for comparison. Calculations of unilateral maxillary and mandibular canine and premolar summations made from the regression equations in Table 3 are shown in Tables 4 and 5. It is interesting that the predictions using the Tanaka and Johnston (1974) simplified equations lie between the lower values for the two Thai groups of Boondej and Sirinavin (1990), and Supanee *et al.* (1995), and the higher values for the Thai group of the present study and the Chinese group of Yuen *et al.* (1998), whether comparing sexes pooled or sexes separated. An exception to this general observation is the set of predictions resulting from applying the equations of Supanee *et al.* (1995), which were lower for the low values of mandibular incisor summations, but similar for higher mandibular incisor summations. On the other hand, Moyers', and Tanaka and Johnston's regression equations for the 50th percentile both gave lower predicted values for

maxillary and mandibular canine and premolar summations, being as much as 2.0 mm less than the other studies for higher summations of the mandibular incisors for sexes pooled and sexes separated.

The predictions from the regression equations of this investigation for separated male and female data, and those of the Hong Kong study (Yuen *et al.*, 1998) in Tables 4 and 5 are similar, the main differences being in the male figures for both maxillary and mandibular canine and premolar summations, which become progressively larger for the latter study as the values of x increase. For females, the predicted values vary, but by no more than 0.4 mm or 1.8 per cent.

The clinician may prefer not to apply regression equations derived from pooled sex data. Nevertheless, comparing predictions calculated from the simplified equations of Tanaka and Johnston (1974) for sexes pooled with those derived from the equations for sexes separated of

Table 4 Comparison of different MDSA predictions of maxillary canine and premolar summations in millimetres for three different mandibular incisor summations.

Sex	Mandibular incisor summation								
	21.0 mm			23.0 mm			25.0 mm		
	M + F	M	F	M + F	M	F	M + F	M	F
Moyers*									
95th percentile	22.4	21.9	21.8	23.5	22.8	22.3	24.9	23.9	22.9
75th percentile	21.5	21.0	20.8	22.6	22.0	21.3	23.7	23.0	21.9
50th percentile	20.8	20.4	20.1	21.9	21.5	20.6	23.0	22.5	21.2
Tanaka and Johnston*									
95th percentile	22.5			23.5			24.5		
75th percentile	21.6			22.6			23.6		
50th percentile	21.0			22.1			23.1		
Tanaka and Johnston (1974)	21.5			22.5			23.5		
<i>Simplified equations</i> [†]									
Boondej and Sirinavin (1990) [†]	21.1			22.1			23.2		
Supanee <i>et al.</i> (1995)	21.0			22.2			23.4		
Yuen <i>et al.</i> (1998) [†]		21.8	21.1		23.2	22.3		24.5	23.6
Present study [†]	21.7	22.0	21.5	22.7	22.8	22.4	23.6	23.6	23.4

*M + F values from Moyers' tables (1973); separate M and F values from Moyers' tables (1988). Tanaka and Johnston values from their prediction tables (1974).

[†]Tabulated values calculated from respective regression equations.

Table 5 Comparison of different MDSA predictions of mandibular canine and premolar summations in millimetres for three different mandibular incisor summations.

Sex	Mandibular incisor summation								
	21.0 mm			23.0 mm			25.0 mm		
	M + F	M	F	M + F	M	F	M + F	M	F
Moyers*									
95th percentile	22.0	22.2	21.5	23.2	23.0	22.5	24.4	23.9	23.3
75th percentile	21.0	21.0	20.3	22.2	21.9	21.3	23.4	22.8	22.4
50th percentile	20.3	20.2	19.5	21.5	21.1	20.5	22.7	22.0	21.6
Tanaka and Johnston*									
95th percentile	21.9			22.9			24.0		
75th percentile	21.0			22.1			23.5		
50th percentile	20.5			21.5			22.6		
Tanaka and Johnston (1974)	21.0			22.0			23.0		
<i>Simplified equations</i> [†]									
Boondej and Sirinavin (1990) [†]	20.5			21.6			22.7		
Supanee <i>et al.</i> (1995)	19.9			21.4			23.0		
Yuen <i>et al.</i> (1998) [†]		21.0	20.1		22.2	21.4		223.3	22.7
Present study [†]	20.8	21.0	20.6	21.8	21.8	21.7	22.8	22.7	22.7

*M + F values from Moyers' tables (1973); separate M and F values from Moyers' tables (1988). Tanaka and Johnston values from their prediction tables (1974).

[†]Tabulated values calculated from respective regression equations.

the present study over the range of mandibular incisor summations (21.0–25.0 mm) for both maxillary and mandibular canine and premolar summations, the differences were all less than 0.6 mm, and mostly 0.3 mm or less (Tables 4 and 5). This indicates the general clinical utility of applying the simplified Tanaka and Johnston equations to both male and female children from northeastern Thailand. The calculations based on the Hong Kong findings of Yuen *et al.* (1998) indicate some wider variations compared with results from the Tanaka and Johnston formulae.

It must be noted that all regression equations correspond to the 50th percentile estimations, which minimize bias in either over- or under-estimation of the true canine and premolar summation. Also, since these equations give estimations at the 50th percentile, it is not reasonable to compare them with the results from using Moyers' tables (1973, 1988) at the 75th percentile. It is only by coincidence that the simplified regression equations of Tanaka and Johnston (1974) approximately matched those of this study. Their equations were intended to match the 75th percentiles of the original Moyers' tables (1973). Tables 4 and 5 show that the 50th percentile values from the Moyers' tables (1988) for predicting the sum of maxillary canine and premolars for both sexes do not compare with the Thai findings.

Conclusions

Reliability of measurement of the casts was confirmed by repeat measurements of the teeth on 90 sets of casts. Males had significantly larger teeth than females as shown by the differences in summations of widths of the mandibular incisors, and maxillary and mandibular canine and premolars of each dental arch segment. Generally, there were no significant right-left differences of canine and premolar summations, so that the averages of both were used.

Linear regression equations, based on the dental measurements of 215 males and 215 females, were developed for predicting the sum of the mesiodistal widths of unerupted canine and premolar segments for both maxillary and

mandibular dental arches during the mixed dentition period for a population from north-eastern Thailand. The following are equations derived in this study for prediction of such summations:

Both sexes

Maxilla: $y = 11.87 + 0.47x$

Mandible: $y = 10.30 + 0.50x$

where x = summed mesiodistal widths of the four mandibular incisors in millimetres, and y = estimated sum of mesiodistal widths of canine and two premolars in one arch quadrant, whether of the maxilla or mandible, in millimetres.

Females

Maxilla: $y = 11.16 + 0.49x$

Mandible: $y = 9.49 + 0.53x$

Male

Maxilla: $y = 13.36 + 0.41x$

Mandible: $y = 11.92 + 0.43x$

ANOVA of regression showed highly significant relationships between corresponding x and y values used for developing the regression equations. These findings, coupled with low coefficients of determination (r^2) of the regressions, ranging from 0.29 to 0.41, suggest that ethnic diversity of the sampled population may limit the accuracy of predictions.

Differences between the present findings and those of other Thai and Asian investigations may also be attributed to different ethnic mixes of the respective sample populations. Moyers' probability tables (1973, 1988) are not suitable for predicting the summed widths of unerupted canine and premolars in Thai subjects.

It is coincidental, that the simplified prediction equations of Tanaka and Johnston (1974) gave predictions that were close to those of this study and are therefore acceptable for this population group. These equations offer the benefit of ease of use compared with prediction tables and graphical representations of regression equations, and may be appropriate for clinical use with other Asian groups of various ethnic origins.

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