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Influence of sex and ethnic tooth-size differences on mixed-dentition space analysis

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Abstract

Introduction—Most mixed-dentition space analyses were developed by using subjects of northwestern European descent and unspecified sex. The purpose of this study was to determine the predictive accuracy of the Tanaka-Johnston analysis in white and black subjects in North Carolina.

Methods—A total of 120 subjects (30 males and 30 females in each ethnic group) were recruited from clinics at the University of North Carolina School of Dentistry. Ethnicity was verified to 2 previous generations. All subjects were less than 21 years of age and had a full complement of permanent teeth. Digital calipers were used to measure the mesiodistal widths of all teeth on study models fabricated from alginate impressions. The predicted widths of the canines and the premolars in both arches were compared with the actual measured widths.

Results—In the maxillary arch, there was a significant interaction of ethnicity and sex on the predictive accuracy of the Tanaka-Johnston analysis ($P = .03$, factorial ANOVA). The predictive accuracy was significantly overestimated in the white female group ($P < .001$, least square means). In the mandibular arch, there was no significant interaction between ethnicity and sex ($P = .49$).

Conclusions—The Tanaka-Johnston analysis significantly overestimated in females ($P < .0001$) and underestimated in blacks ($P < .0001$) (factorial ANOVA). Regression equations were developed to increase the predictive accuracy in both arches. (*Am J Orthod Dentofacial Orthop* 2007;132:332-9)

Unpredictable growth changes can complicate orthodontic treatment planning in the mixed dentition. A valuable tool that assists with the diagnosis and treatment planning of patients is the mixed-dentition space (MDS) analysis. The use of MDS analysis in children of various ethnic backgrounds might be questionable because most commonly used analyses were developed and validated on subjects of northwestern European descent of unspecified sex. Inappropriate and invalid MDS analysis results could lead to extraction decisions that negatively alter a patient's soft-tissue facial profile.

Three of the most commonly used MDS analyses were developed by Tanaka and Johnston,¹ Moyers,² and Hixon and Oldfather.³ Tanaka and Johnston used the erupted permanent

mandibular incisors to estimate the size of the unerupted canines and premolars. From a sample of 506 children of northwestern European descent, they created formulas for each dental arch based on simple linear regression. This method was used in many other MDS analysis studies⁴⁻¹³ because it requires no radiographs or prediction tables as used in the Hixon and Oldfather³ and Moyers² analyses. The Moyers analysis uses the width of the mandibular permanent incisors measured on dental casts and a probability table to complete the MDS analysis. Hixon and Oldfather developed an MDS analysis for the mandibular arch only using 41 subjects of northwestern European ancestry; it requires periapical radiographs, a probability table, and the measured width of the erupted permanent mandibular incisors.

Because of its simplicity, researchers have investigated the accuracy of the Tanaka-Johnston analysis in various ethnic groups and made necessary modifications.⁴⁻¹³ Diagne et al,⁴ Jaroontham and Godfrey,⁵ Yuen et al,⁶ Fränkel and Benz,⁷ and Schirmer and Wiltshire⁸ attempted to develop a race- and sex-specific MDS analysis based on the Tanaka-Johnston analysis. To date, no study has evaluated the effects of both sex and ethnicity on the accuracy of the widely used Tanaka-Johnston MDS analysis. Racial and sex-specific MDS analyses might require revision or validation once every generation (approximately 30 years) because of changing trends in malocclusion, jaw dimension, and tooth size.¹⁴⁻¹⁹

Tooth size has been shown to have a strong association with both sex and ethnicity. Males have consistently larger teeth than females, whereas people of African descent have larger mesiodistal tooth dimensions than those of European descent.^{17,20-24} Santoro et al²⁵ found that the mesiodistal crown widths in Dominican-American sample were similar to black American values, and the mean ratios for both groups were larger than the Bolton standard ratio. Although Bolton²⁶ did not verify ethnicity, investigators have routinely used the Bolton ratios as a substitute for white values when comparing tooth sizes among races. Variation in tooth size has been related to genetics^{18,27} (eg, sex^{5,6,16,17,20,28-36} and ethnicity^{17,21-25,31,35-37}) and environment.³⁸ Some investigators suggested that skeletal malocclusion is also associated with variations in tooth size.^{35,39,40} Anterior tooth-size discrepancies have been found to be more common in patients with Class III skeletal malocclusions. Although the possible mechanisms remain obscure, genes that control tooth size might also be associated or inherited with other genes that control skeletal growth of the jaws.

The objective of this study was to determine the predictive accuracy of the Tanaka-Johnston MDS analysis in male and female subjects of European and African descent in North Carolina.

MATERIAL AND METHODS

A total of 787 consecutive pretreatment records of patients undergoing treatment in the graduate orthodontic, graduate pediatric dentistry, and faculty practice clinics at the University of North Carolina School of Dentistry were examined until records of 60 white and 60 black (30 males and 30 females in each group) who met the following inclusion criteria were identified: (1) all teeth on the initial plaster study models in good clinical condition (restorations, if present, were well contoured); (2) mandibular permanent incisors with no proximal reduction; (3) no clinical evidence of enamel defects, such as hypoplasia; (4) no congenitally missing teeth; (5) younger than 21 years of age at the beginning of the study to exclude mesiodistal loss of tooth structure because of age-related proximal wear⁴¹; and (6) sufficiently erupted permanent canines and premolars to allow accurate mesiodistal width measurements. Only subjects with a homogeneous lineage of 2 previous generations verified by questionnaire were included in the study.

Approval for this study was obtained from the University of North Carolina Institutional Review Board. Appropriate informed consent and assent were obtained for all subjects.

Each study model was assigned a random identification number to ensure examiner masking for sex and race. By using digital calipers (MAX-CAL; Fowler & NSK Co, Tokyo, Japan) with accuracy of ± 0.03 mm and resolution of 0.01 mm, the greatest distances between contact points on the proximal surfaces of each tooth except the second and third molars were measured with the calipers parallel to the occlusal plane on plaster casts obtained at the initial records orthodontic appointment. Symmetry and space analysis differences for the maxilla and the mandible were analyzed separately. The mesiodistal widths of each antimeres in each arch were averaged before use in other calculations, because the average difference between the right and left sides did not differ statistically among the 4 groups for either arch. This protocol for averaging antimeres has been used in many investigations.^{5,6,18,20,22,24,29,30}

The predicted widths of the canines and the premolars in both arches were calculated by using the Tanaka-Johnston MDS analysis. In the maxillary arch, the predicted combined mesiodistal width of the canine, the first premolar, and the second premolar in a quadrant was calculated by adding 11.0 mm to half the combined width of the 4 mandibular incisors. In the mandibular arch, the combined width of the same 3 teeth in a quadrant was calculated by adding 10.5 mm to half the combined width of the 4 mandibular incisors. The predicted widths of these teeth were compared with the actual widths measured on the study models. A difference of ± 2 mm per arch between the predicted width and the actual width was considered clinically significant because discrepancies of that magnitude might significantly affect extraction decisions in patients with moderate crowding (4-7 mm) in the mixed dentition.

All statistical analyses were performed with STAT software (SAS Institute, Cary, NC). For a method comparison (intraoral clinical measurement vs plaster cast measurement), intraclass correlation as an estimate of consistency and paired *t* tests to assess bias were calculated by using intraoral clinical and plaster-cast mesiodistal widths measurements from 4 randomly selected teeth in each of 10 subjects. Intraexaminer model reliability was assessed by randomly selecting 10 models from each ethnic and sex group. The measurements were repeated twice at least 1 day apart. A paired *t* test was used to evaluate the bias and intraclass correlation to quantify the reliability of the measurement technique.

Two-way analysis of variance (ANOVA) with ethnicity and sex as the between-subject factors was used to assess the difference between the predicted and actual widths of the canines and premolars by using antimeres preliminarily and then the averaged value for antimeres in each arch. The pairwise interaction of sex by ethnicity was included in each analysis.

The least means approach in Proc GLM (SAS Institute) was used to compare groups when the interaction was statistically significant. The level of significance was set at .05. Linear regression analysis was performed separately for each dental arch in the 4 subject groups (ethnicity and sex). The dependent variable was the actual sum of the mesiodistal widths of the canines and the premolars, whereas the explanatory variable was the summed mesiodistal widths of the permanent mandibular incisors.

To test the validity of these newly derived regression formulae, space analyses were completed by using the Tanaka-Johnston method and the new linear regressions formulae in a test sample of 40 subjects (20 whites and 20 blacks with 10 males and 10 females in each group) from the graduate orthodontic clinic at the University of North Carolina School of

Dentistry. None of these subjects was included in the sample from which the linear regression equations were developed.

RESULTS

Intraclass correlation coefficients (ICC) for tooth measurements on the models ranged from ICC = 0.93 (mean = -0.03, $P = .78$) to ICC = 0.98 (mean = -0.01, $P = .93$), indicating very high consistency in the measurement technique from day to day. The average error associated with any potential dimensional changes in the model fabrication process was low and not statistically different from zero, indicating that plastercast measurement was a suitable proxy for the clinical measurement of teeth (range, ICC = 0.94, mean = -0.07, $P = .51$ to ICC = 0.77, mean = 0.12, $P = .06$). All subjects were under 21 years of age and had a full complement of permanent teeth according to the inclusion criteria. On average, male and black subjects had larger teeth than their counterparts (Table I).

In the maxillary arch, the pairwise interaction of ethnicity and sex was statistically significant ($P = .03$, ANOVA) indicating that the pattern of predictive accuracy for males and females was not the same for black and white subjects (Fig 1). The Tanaka-Johnston method consistently overestimated the widths of the canines and the premolars in the white females, with an average overestimation of almost 2 mm per arch ($P < .001$, least square means). On average, the Tanaka-Johnston analysis slightly underestimated the actual widths of the canines and the premolars for the remaining groups, with the black male group having the greatest underestimation.

The criterion for a clinically relevant prediction was arbitrarily set at an absolute difference of more than 2 mm from the actual widths of the canines and the premolars per arch. In the maxillary arch, the Tanaka-Johnston analysis overpredicted in 50% of the white females, whereas most predictions for all male subjects and black female subjects were within 2 mm per arch (Fig 2).

There was no significant interaction between sex and race on the predictive accuracy of the Tanaka-Johnston method in the mandible ($P = .49$, ANOVA). Significant sex differences ($P < .0001$) showed consistent underestimation in males and overestimation in females, and significant ethnic differences ($P < .0001$) showed consistent underestimation in blacks (ANOVA) (Fig 3). Clinically, the Tanaka-Johnston method overpredicted by more than 2 mm in 60% of the white females and underestimated by at least 2 mm in over 50% of the black males (Fig 4).

Linear regression formulae were developed for each ethnic and sex group from the data and compared with the results of other studies (Table II). Because of the statistically significant interaction in the maxillary arch, these formulae were developed separately for each group for each jaw as follows.

White females: maxilla, $y = 0.58x + 8.28$; mandible, $y = 0.65x + 6.20$

White males: maxilla, $y = 0.32x + 15.02$; mandible, $y = 0.59x + 8.47$

Black females: maxilla, $y = 0.39x + 13.68$; mandible, $y = 0.47x + 11.52$

Black males: maxilla, $y = 0.34x + 15.10$; mandible, $y = 0.35x + 15.30$

The correlation coefficients between the actual measured values (canine, first and second premolars) and the values predicted with the new equations in the additional test sample are shown in Table III. The mean differences between the predicted and actual values with both the new linear regression equations and the Tanaka-Johnston method for this additional test sample are shown in Table IV. Table V shows the clinical significance (percentages of

subjects overestimated or underestimated by > than 2 mm per arch) of the linear regression equation predictions in the test sample of 40 subjects.

DISCUSSION

This study was undertaken to determine the accuracy of the Tanaka-Johnston MDS analysis in white and black subjects in North Carolina. Several similar linear regression-based studies were done with various ethnic groups and larger sample sizes, but these were not well controlled for sex, age, and ethnicity. Our study focused on sex-specific grouping, the verification of a homogeneous ancestry of 2 previous generations, and the exclusion of subjects older than 21 years of age.

Five previous investigations have customized linear regression-based MDS analysis to the race and sex of subjects.⁴⁻⁸ In each of these studies, ethnicity was assumed to be homogeneous but not confirmed as part of the protocol. This might be important because tooth size had been shown to be variable even in similar Chinese subgroups.⁴² To date, there has not been comparative investigation of ethnicity and sex in more than 1 race with a linear regression-based MDS analysis. Fränkel and Benz⁷ studied the predictive accuracy of the Tanaka-Johnston method in black male and female subjects and compared their results only with white male and female norms.

Invalid assumptions can occur when statistically significant results are interpreted as clinically significant. In this study, the level of clinical significance was arbitrarily set at 2 mm of crowding or spacing per arch from the measured value because such a discrepancy could affect treatment-planning decisions such as extractions. This suggests that a patient with moderate crowding might be at risk to receive unwarranted extractions if the MDS analysis overpredicted an additional 2 mm of crowding per dental arch.

Sex and ethnicity appear to have synergistic effects on tooth size: white females, on average, had the smallest teeth, and black males had the largest. The Tanaka-Johnston analysis overestimated tooth size in both arches for white females. This would be expected because males consistently have larger teeth than females, and those of African descent have larger mesiodistal tooth dimensions than those of European descent.^{17,20-24} As a result, white females could be in jeopardy of having unnecessary extractions based on inaccurate MDS analysis predictions.

Based on this information, new linear regression equations were developed for all 4 groups. The standard error estimates and correlation coefficients from this study were in relatively good agreement with comparable studies (Tanaka-Johnston, white females; Fränkel-Benz and Diagne et al, black males) (Table II) with the exception of a slightly higher standard error of the regression coefficient in white females and lower correlation coefficients in black males. Possible reasons for these differences could be the genetic variability in each study's subjects and the sample size of our study. Furthermore, because of lack of true homogeneity in ethnic groups in the United States, a self-reported ancestry of 2 previous generations might not be adequate to confirm a homogeneous ethnic background.

To determine whether the new linear regression equations would improve the accuracy of the prediction of the summed widths of the unerupted canines and premolars, MDS analyses were performed on a test sample, an additional 10 subjects in each of the 4 groups. In general, the new regression formulae predictions were more accurate than the Tanaka-Johnston analysis for both dental arches in all 4 groups (Table IV). The clinical significance of the regression predictions in the test sample (Table V) can be compared the Tanaka-Johnston method in the study sample (Figs 2 and 4). The regression equation predictions in the sample reduced the overprediction in both arches for white females and the

underprediction in the mandibular arch for black males. The other groups had more modest differences.

The Tanaka-Johnston method was intentionally designed to overpredict 75% of the time; this was thought to provide protection if more space was actually needed. We used regression line slope and intercept estimates in this study rather than the 75% confidence interval used by Tanaka and Johnston because gross overprediction by that method in the white female subjects could result in unnecessary extractions and negative effects to the lips and soft-tissue facial profile. Underprediction might be more desirable because of the current societal preference for fuller lips and facial profiles.

An MDS analysis predicts the amount of future crowding or spacing in the permanent dentition. Other important clinical relationships must also be closely examined in conjunction with the numerical results of the space analysis to develop a treatment plan for each patient. Lip posture, lip competence, incisor position, and depth of the curve of Spee affect the ability to align the teeth in the dental arches without compromising periodontal health and soft-tissue esthetics. Occlusal relationship of the first permanent molars and management of the leeway space are also key factors during treatment planning in the mixed dentition. Along with these variables, clinicians should be aware that sex and ethnic differences affect the results of MDS analysis and might influence treatment-planning decisions in children.

CONCLUSIONS

1. The Tanaka-Johnston linear regression-based MDS analysis predicts reasonably well for both arches in white males and black females, and in the maxillary arch of black males. The method significantly overpredicted in both arches in white females and underpredicted in the mandibular arch for black males.
2. New linear regression equations were developed for both dental arches in white and black subjects in North Carolina.

Acknowledgments

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Fig 1.

Difference between Tanaka-Johnston predicted values and actual values in maxillary arch. Statistically significant difference between males and females ($P < .0001$, $F = 18.21$, $df = 1$) and between white and blacks ($P < .0001$, $F = 18.32$, $df = 1$). Significant interaction between sex and race ($P = .03$, $F = 4.78$, $df = 1$) with 2-way ANOVA. Predicted-actual value greater than 0 indicates overestimation; predicted-actual value less than 0 indicates underestimation.

Fig 2.
Clinical significance of Tanaka-Johnston analysis in maxillary arch.

Fig 3.

Difference between Tanaka-Johnston predicted values and actual values in mandibular arch. Statistically significant difference between males and females ($P < .0001$, $F = 27.7$, $df = 1$) and between whites and blacks ($P < .0001$, $F = 56.75$, $df = 1$). No significant pairwise interaction ($P = .49$, $F = 0.49$, $df = 1$) with 2-way ANOVA. Predicted-actual value greater than 0 indicates overestimation; predicted-actual value less than 0 indicates underestimation.

Fig 4.
Clinical significance of Tanaka-Johnston analysis in mandibular arch.

Table 1

Descriptive statistics for all subject groups (mm)

Sex	Segment	Ethnicity							
		White				Black			
		Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum
Male	Md 2-2	22.69	1.34	26.21	19.92	23.91	1.58	26.73	21.06
	Mx 3-5	22.39	1.10	24.67	20.3	23.33	0.86	25.45	21.71
	Md 3-5	21.81	1.22	24.43	19.06	23.60	1.13	25.79	21.50
	Mx 6-6	97.00	4.41	107.51	88.80	102.02	3.84	110.48	92.31
	Md 6-6	88.90	4.22	98.30	80.01	94.47	4.10	102.48	84.28
Female	Md 2-2	22.34	1.27	25.09	19.95	23.56	1.78	27.78	20.10
	Mx 3-5	21.19	1.23	24.99	18.75	22.83	0.95	25.07	20.37
	Md 3-5	20.62	1.21	24.24	18.44	22.64	1.22	25.09	19.91
	Mx 6-6	92.79	4.56	106.46	97.19	99.31	5.08	109.71	88.40
	Md 6-6	85.12	4.16	84.91	78.26	91.79	5.07	103.2	82.05

Md, Mandibular; *Mx*, maxillary; 2, lateral incisor; 3, canine; 5, second premolar; 6, first molar.

Table II

Comparison of new linear regression equations and results of previous studies

<i>Study</i>	<i>Ethnic group</i>	<i>Arch</i>	<i>r</i>	<i>R²</i>	<i>Intercept</i>	<i>Beta (mm)</i>	<i>SE (mm)</i>
Present study	White American	Male Mx	0.40	0.16	15.02	0.32	1.06
		Male Md	0.65	0.42	8.47	0.59	0.89
		Female Mx	0.60	0.36	8.28	0.58	1.01
		Female Md	0.68	0.46	6.20	0.65	0.81
	Black American	Male Mx	0.64	0.41	15.1	0.34	0.46
		Male Md	0.49	0.24	15.3	0.35	1.01
		Female Mx	0.73	0.53	13.68	0.39	0.44
		Female Md	0.69	0.48	11.52	0.47	0.81
Tanaka and Johnston (1974)	White American	Mx	0.63	0.40	11	0.50	0.86
		Md	0.65	0.42	10.5	0.50	0.85
Fränkel and Benz (1986)	Black American	Male Mx	0.72	0.52	9.15	0.58	0.92
		Male Md	0.79	0.62	5.97	0.72	0.91
		Female Mx	0.61	0.37	12.83	0.39	0.67
		Female Md	0.66	0.44	10.34	0.49	0.71
Diagne et al (2003)	Senegalese	Male Mx	0.68	0.46	9.60	0.55	0.74
		Male Md	0.73	0.54	5.45	0.72	0.82
		Female Mx	0.51	0.26	13.77	0.35	0.66
		Female Md	0.63	0.40	8.74	0.56	0.76
Ferguson et al (1978)	Black American	Mx	0.63	0.40	12	0.45	NA
		Md	0.71	0.50	10	0.53	NA

Mx, Maxilla; *Md*, mandible; *NA*, not applicable.

Table III

Correlation coefficients between actual values and values predicted with new linear regression equations

<i>Ethnic group</i>	<i>Sex</i>	<i>Maxillary arch</i>	<i>Mandibular arch</i>
White	Male	.93 [*]	.79 [*]
	Female	.76 [†]	.81 [*]
Black	Male	.39	.54 [*]
	Female	.61	.65 [†]

* Statistically significant, $P < .01$.† Statistically significant, $P < .05$.

Table IV

Mean difference (mm/arch) and SD between actual measured values and predicted values with new linear regression equations and Tanaka-Johnston method

<i>Ethnic group</i>	<i>Sex</i>	<i>Arch</i>	<u><i>Regression equation</i></u>		<u><i>Tanaka-Johnston</i></u>	
			<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
White	Male	Maxilla	1.00	1.40	1.14	1.04
		Mandible	0.69	1.92	0.64	2.02
	Female	Maxilla	0.06	1.34	2.00	1.37
		Mandible	-0.30	1.54	1.75	1.68
Black	Male	Maxilla	-0.32	1.87	-0.86	1.93
		Mandible	0.50	1.67	-1.60	1.68
	Female	Maxilla	-0.45	2.24	-0.52	2.25
		Mandible	-0.97	2.37	-1.68	2.37

Predicted-actual value greater than 0 indicates overestimation, value less than 0 indicates underestimation.

Table V

Clinical significance of linear regression equations in test sample of 40 subjects

<i>Arch</i>	<i>Sex and ethnicity</i>	<i>Overestimated (%)</i>	<i>Underestimated (%)</i>
Maxilla	Male white	30	0
	Male black	10	20
	Female white	10	10
	Female white	20	30
Mandible	Male white	30	0
	Male black	20	10
	Female white	10	20
	Female black	10	30

Overestimated or underestimated defined as > 2 mm per arch.