Original Article

Evidence favoring a secular reduction in mandibular leeway space

Tyler R. Allen[a]; Terry M. Trojan[b]; Edward F. Harris[c]

ABSTRACT

Objective: Researchers have documented secular trends in tooth size among recent generations. This study was a test for a change in mandibular leeway space.

Materials and Methods: Dental casts from participants in the Denver Growth Study (23 boys, 22 girls; born in the 1930s) were compared with casts from a contemporary series of orthodontic patients (23 boys, 22 girls; born in the 1990s). All were phenotypically normal, healthy American whites.

Results: Analysis of variance (accounting for sex) showed that the cumulative mandibular primary canine plus first and second primary molar size (c + m1 + m2) was slightly larger in the recent cohort (23.53 mm earlier vs 23.83 mm recent cohort; mean difference: 0.30 mm; $P = .009$), principally due to larger second primary molars (m2) in the recent cohort. In turn, the sum of the permanent canine and two premolars (C + P1 + P2) was significantly larger in the recent cohort (21.08 mm earlier vs 21.80 mm recent cohort; mean difference: 0.72 mm; $P = .002$). Larger teeth in the contemporary series produced a mean leeway space per quadrant of 2.03 mm versus 2.45 mm in the earlier cohort—a clinically and statistically significant reduction ($P = .030$). Some tooth types (primary second molar and permanent canine) were significantly larger in boys than in girls, but the sex difference in leeway space was not statistically significant.

Conclusion: Results suggest that mandibular leeway space is decreasing in 21st century American whites and may present a challenge to orthodontists in managing tooth size–arch length discrepancies. (*Angle Orthod.* 2017;87:576–582)

KEY WORDS: Leeway; Tooth size; Arch size; Environment; Secular trend

INTRODUCTION

Leeway space is the difference in size of the mesiodistal crown widths of the primary canines and molars compared with that of their permanent successors (canine, first and second premolars; Figure 1).[1–4] The primary teeth typically possess a larger mesiodistal sum than the permanent teeth that replace them—especially in the mandibular arch, predominantly because of the primary second molar's larger mesiodistal crown dimension compared with the second premolar.[5] Orthodontists often rely on leeway space, an anticipated gain of 1–2 mm per quadrant, in their treatment protocols to help resolve anterior crowding.[6–8]

It is unknown who first observed the space resulting from these crown-size differences, but Nance[9,10] commonly is cited as initially describing its clinical application. He coined the term "leeway" and labeled it a "fundamental fact concerning the human dentition." Nance[9] cited descriptive tooth sizes reported as early as 1890 by G.V. Black in the latter's first edition of *Descriptive Anatomy*.[11] Black's sample consisted of extracted teeth (sexes pooled) from an unreported number of cases. Although the source and method of measurement is poorly defined,[12] it is arguably the most commonly cited set of tooth dimensions, certainly so in the clinical literature. Using Black's figures, Nance reported leeway space averages of 0.9 mm per quadrant in the maxilla and 1.7 mm per quadrant in the mandible.

Leeway is not a constant, but differs among people. Nance[9] described cases varying from 0.0 to 4.0 mm of

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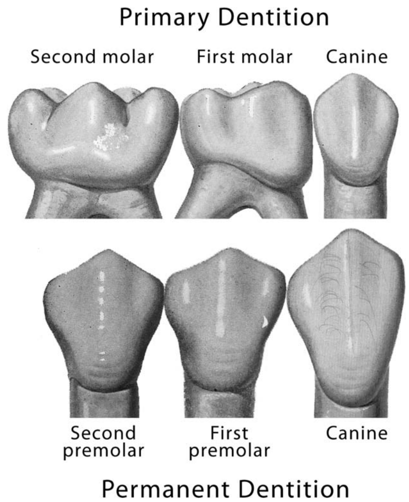

Figure 1. Illustration of the three primary and three successor teeth constituting leeway space in the mandibular right quadrant (labial aspect). Mesiodistal widths were scaled to the mean sizes reported by G.V. Black.

mandibular leeway space. Numerous authors report different averages of leeway space, apparently depending on regional or population tooth crown differences plus sampling variation.[13] In addition, Hille[14] found that mandibular leeway space averaged 2.4 mm in girls, but was significantly smaller in boys (mean = 1.9 mm).

Northway et al.[15] found that when maxillary primary first molars were lost prematurely, (1) maxillary primary second molars and permanent first molars drift mesially, (2) canines drift distally, (3) first premolars emerge more mesially, and (4) permanent maxillary canines emerge labially with risk of being blocked out. An effective solution, if treated in time, is to preserve the leeway space with, for example, a distal shoe space maintainer, lingual holding arch, or Nance appliance.[16,17] Leeway space in the mandibular arch is often more critical; there are fewer therapeutic options in this arch because of its limited potential for expansion, unstable labialization of incisors, and difficulty of molar distalization.[18]

Children in first-world countries have been experiencing secular trends over recent generations. Among the best-known examples are increase in stature,[19] reduction in age at menarche,[20] and gain in body weight.[21] The conventional explanations for these generational changes are centered on improved environment; diminished morbidity; and (principally) better, more dependable nutrition. Positive secular trends have been described for tooth crown sizes,[22–24] and larger teeth have been implicated as a contributor to dental crowding.[25–28] Tooth size–arch length discrepancies appear to have increased.[29] Additionally, the tempo of tooth emergence has quickened.[30,31] These observations suggest that environmental improvement might also affect leeway space, which is derived from differences among crown sizes.

For the face and teeth, much of our knowledge is derived from several human growth studies conducted in the 20th century. These are largely now complete.[32,33] Although they reflect children's growth of several generations ago, these studies are a principal source of information for many of today's clinical decisions. The purpose of the present study was to test for a secular trend, focusing on mandibular leeway space. The null hypothesis was that average leeway space has remained unchanged. We examined leeway space in the mandibular arch since it is larger and clinically more challenging than in the maxilla.

MATERIALS AND METHODS

An a priori power analysis was conducted assuming a factorial two-way analysis of variance (ANOVA), partitioning on cohort while controlling for sex in crown size.[34,35] Statistical power is the probability of rejecting the null hypothesis when it truly is false. Assuming a 0.5-mm difference in mandibular leeway space between cohorts (ie, minimum nontrivial effect size), with alpha settings of 0.05 and sample sizes of 45 per cohort (equal arms), expected power was 85%. To be conservative, we assumed that the interaction effect accounted for no variation.[34]

Tests[36] indicated that variables were normally distributed, so inferential tests used two-way ANOVA,[37] with cohort and sex as fixed effects. Subject's sex was included to account for the tendency for boys to have larger crowns than do girls.[38] Statistical significance was set at the conventional level of 0.05, and tests were two-tailed.

A contemporary series (23 boys, 22 girls)—born between 1990 and 2000—was obtained by inspecting all early treatment cases in the University of Tennessee Health Science Center Graduate Orthodontic Clinic (IRB approval 14-03570-XM). Casts with bilateral fully erupted mandibular primary teeth were identified. Those individuals who received a second phase of treatment (when the premolars and permanent canines had emerged into functional occlusion) were selected for inclusion. This created a series of pairs of casts of the same subjects, one with primary teeth and the other with successors.

The earlier cohort used for comparison also consisted of 45 cases (23 boys, 22 girls), participants randomly selected from the Denver Growth Study[39] and born in the 1930s. Casts from successive ages were used to measure the primary and permanent teeth on the same persons.

Table 1. Results of Two-factor Analysis of Variance for Mandibular Teeth[a]

	Cohort			Sex			Interaction		
	df[b]	F	*P*	df	F	*P*	df	F	*P*
Primary Teeth									
Canine (c)	1	0.54	.4638	1	0.74	.3907	1	0.07	.7919
First molar (m1)	1	0.05	.8325	1	0.48	.4890	1	0.03	.8563
Second molar (m2)	1	7.58	.0072	1	6.05	.0159	1	0.55	.4624
Sum c + m1 + m2	1	2.43	.1226	1	1.40	.2407	1	0.11	.7436
Permanent Teeth									
Canine (C)	1	2.10	.1505	1	14.05	.0003	1	3.50	.0648
First premolar (P1)	1	8.80	.0039	1	0.70	.4048	1	0.50	.4816
Second premolar (P2)	1	13.71	.0004	1	0.63	.4289	1	1.42	.2364
Sum C + P1 + P2	1	11.09	.0013	1	4.69	.0330	1	2.19	.1426
Leeway space	1	5.08	.0267	1	1.69	.1970	1	1.90	.1719

[a] Each row is a separate analysis, with "cohort" and "sex" as fixed effects. F indicates the F-ratio; P, the associated probability value. Leeway space is (c + m1 + m2) minus (C + P1 + P2).
[b] df indicates degrees of freedom.

All individuals in both cohorts were phenotypically normal American whites (based on photographs and patient records) with no congenitally missing teeth and no known syndrome or systemic condition that might affect growth. Cases with exfoliated or extracted teeth in the midarch, either primary or permanent, were eliminated. Teeth with marginal restorations or carious defects were excluded, as well as any distortions or irregularities in the model.

Maximum mesiodistal crown diameters of the mandibular teeth were measured in both the left and right quadrants on plaster dental casts using a digital-readout sliding caliper (Mitutoyo, Aurora, Ill). The beaks of the caliper had been machined to fit well into the dental embrasures. Measurements were made in a standardized manner[40] and recorded to the nearest 0.01 mm even though the caliper's readout was precise to 0.005 mm. All data were acquired by the senior author. Initial testing showed no significant side difference, so the arithmetic means of the left and right homologues were used for subsequent analysis. A subset of the casts (n = 20 casts, 240 paired measurements), both primary and permanent, were remeasured after a washout period to estimate intra-observer reliability.[41,42]

RESULTS

Intraobserver repeatability was high. No variable showed a systematic difference between measurement sessions, and Dahlberg's d_i was less than 0.1 mm (mean = 0.07 mm), making measurement error appreciably less than the observed cohort differences. Cronbach's alpha was 0.998, and the intraclass correlation between measurements (mixed model, fixed observer) was also 0.998 (95% CI: 0.998–0.999), which was highly significant ($P < .001$).

Neither the primary canine nor primary first molar differed in size between cohorts (Table 1). Despite

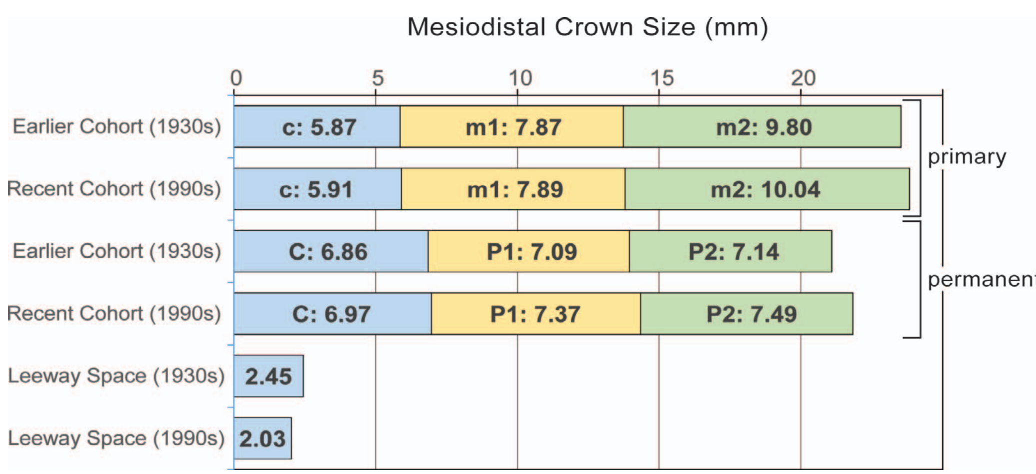

Figure 2. Comparison of average tooth sizes defining mandibular leeway space (sexes pooled). Mandibular tooth codes: primary canine (c), primary first molar (m1), primary second molar (m2), permanent canine (C), first premolar (P1), and second premolar (P2). Leeway space: (c + m1 + m2) minus (C + P1 + P2).

Table 2. Descriptive Statistics of Tooth Crown Sizes by Cohort and Sex (mm)

	Earlier Cohort (1930s)						Recent Cohort (1990s)					
	Boys		Girls		Sexes Pooled		Boys		Girls		Sexes Pooled	
	LS Mean[a]	SEM	LS Mean	SEM	Mean	SEM	LS Mean	SEM	LS Mean	SEM	Mean	SEM
Primary canine	5.89	0.061	5.85	0.059	5.87	0.045	5.95	0.061	5.89	0.061	5.91	0.039
Primary first molar	7.84	0.090	7.89	0.088	7.87	0.070	7.85	0.090	7.93	0.088	7.89	0.055
Primary second molar	9.66	0.087	9.94	0.085	9.80	0.065	9.96	0.087	10.11	0.085	10.04	0.060
Sum c + m1 + m2	23.39	0.191	23.67	0.187	23.53	0.148	23.75	0.191	23.91	0.187	23.83	0.117
Permanent canine	6.63	0.082	7.08	0.080	6.86	0.066	6.89	0.082	7.05	0.080	6.97	0.057
First premolar	7.02	0.096	7.16	0.094	7.09	0.067	7.37	0.096	7.38	0.094	7.37	0.066
Second premolar	7.04	0.096	7.23	0.094	7.14	0.061	7.49	0.072	7.47	0.094	7.49	0.072
Sum C + P1 + P2	20.68	0.219	21.47	0.214	21.08	0.174	21.72	0.219	21.87	0.214	21.80	0.174
Leeway space[b]	2.71	0.190	2.20	0.186	2.45	0.140	2.03	0.190	2.04	0.186	2.03	0.139

[a] LS means indicates least squares means; SEM, standard error of the mean; sample sizes were 23 earlier boys, 22 earlier girls, 23 recent boys, and 22 recent girls.

[b] Leeway space indicates mandibular leeway space per quadrant.

these findings, the cumulative mandibular primary canine plus first and second primary molar size (c + m1 + m2) was slightly larger in the recent cohort (23.53 mm earlier vs 23.83 mm recent cohort, a mean difference of 0.30 mm; $P = .009$), principally due to larger second primary molars (m2) in the recent cohort (Figure 2).

When we compared the permanent dentitions, we found that the first and second premolars were each significantly larger in the recent cohort, resulting in a significant difference of leeway space. Leeway space averaged 2.45 mm per quadrant in the earlier cohort and 2.03 mm in the recent group (sexes pooled), though sample variability remained the same (Table 2).

The increases in tooth size were at the expense of leeway space. Tests of this are the association between tooth size and leeway space (Figure 3). Table 3 lists the results of three ANOVA tests, considering the effects of cohort and sex on the association between crown size and mandibular leeway space. Of note, none of the interaction effects was significant statistically. Figure 3A shows that the leeway space regressed on primary tooth size (ie, sum of c + m1 + m2). The association was positive and statistically significant ($P = .0166$), so the larger the primary teeth, the larger the predicted leeway space. This is intuitive in that larger primary teeth preserve more arch space that contributes to leeway space. The earlier cohort had a higher *y*-intercept ($a = -3.58$), but the regression coefficient—the change in leeway space per unit of primary-tooth size (c + m1 + m2)—was less. In the recent cohort, the *y*-intercept was lower ($a = -7.41$), but the regression slope was steeper. In clinical practice, though, the difference in slopes (0.26 vs 0.40; Figure 3A) is unlikely to be noticeable. Regression coefficients are listed in Table 4.

Figure 3B shows that permanent tooth size (C + P1 + P2) was negatively associated with leeway space; an increase of 1 mm in C + P1 + P2 predicted that the leeway space was reduced by 0.51 mm. Cohort and sex are combined since they differed insignificantly (Table 3B).

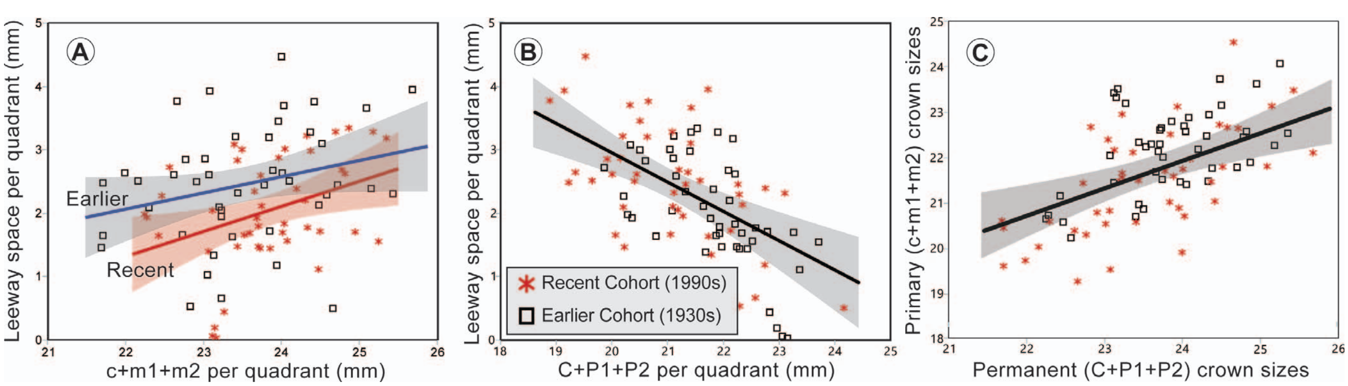

Figure 3. (A) Primary tooth size (c + m1+ m2) was significantly predictive of leeway space, and the recent cohort had a lower intercept and a steeper slope. (B) Permanent tooth size (C + P1 +P2) likewise was significantly (negatively) predictive of leeway space. (C) There was a highly significant positive association between primary (c + m1 + m2) and permanent (canine plus the premolars) tooth size. Error bands are the 95th confidence limits of the regression lines. The relationships were unaffected by the subject's sex. Statistical tests are shown in Table 3.

Table 3. Results of Three-way Analyses of Variance

A. Leeway Space Predicted by Primary Tooth Sizes

Source	df	F Ratio	*P* Value
Cohort	1	7.30	.0084
Subject's sex	1	2.14	.1473
Primary (c + m1 + m2)	1	11.21	.0012
Cohort-x-sex	1	2.40	.1255
Cohort-x-primary	1	0.52	.4729
Sex-x-primary	1	0.36	.5498
Cohort-x-primary-x-sex	1	2.87	.0943

B. Leeway Space Predicted by Permanent Tooth Sizes

Source	df	F Ratio	*P* Value
Cohort	1	0.03	.8708
Subject's sex	1	0.05	.8295
Permanent (C+P1+P2)	1	40.70	<.0001
Cohort-x-sex	1	0.16	.6945
Cohort-x-permanent	1	1.12	.2940
Sex-x-permanent	1	1.28	.2604
Cohort-x-permanent-x-sex	1	0.02	.8817

C. Primary Sizes Tested Against Permanent Sizes

Source	df	F Ratio	*P* Value
Cohort	1	3.39	.0693
Subject's sex	1	0.48	.4925
Primary (c+m1+m2)	1	1667309.00	<.0001
Permanent (C+P1+P2)	1	2270952.00	<.0001
Cohort-x-sex	1	0.33	.5655
Cohort-x-primary	1	0.78	.3808
Cohort-x-permanent	1	0.01	.9144
Sex-x-primary	1	0.46	.4980
Sex-x-permanent	1	0.14	.7108

[a] Interaction terms, such as cohort-by-sex are coded as "Cohort-x-sex". These are first-order interaction terms; the one second-order term is "Cohort-x-primary-x-sex".

Primary and permanent tooth sizes were positively correlated (Figure 3C); children with large primary teeth were likely to have large permanent teeth. The correlation coefficient between c + m1 + m2 and C + P1 + P2 was 0.599 (95% CL = 0.447 and 0.717, respectively; $r^2 = 0.395$). While this sample is small (n = 45), the association shows the weak predictive power in mixed dentition analyses. Statistical significance is attainable with adequate sample sizes, but clinical precision cannot be improved because of the biologic limit of the association.

DISCUSSION

Tooth size is regulated by the size of the pulp cavity, which is established before deposition of mineralized tissue.[43,44] Statistically significant differences (Tables 1 and 2) were found between cohorts for the two premolars. These crowns mineralize perinatally,[45] after the in utero formation of most primary crowns.[46,47] One explanatory scenario is that the prenatal environment—depending principally on maternal physiology[48]—has remained generally static across the two cohorts, but childhood nutrition has improved (and morbidity has lessened),[49] thus promoting larger postnatal permanent tooth development,[50,51] while primary tooth sizes remain unchanged.

As leeway space seems to be less dependable now than in the past, orthodontists should consider relying more on alternate solutions to resolve anterior crowding. Solutions can involve extraction therapy or greater use of interproximal reduction. Not all tooth types were measured, but the positive associations among tooth

Table 4. Linear Regression Equations

A. Mandibular Primary Tooth Size (c + m1 + m2) Predicting Leeway Space (per Cohort)

Earlier Cohort Alone

Term	Estimate	St Error	L_1	L_2	*t*-test	*P* value
Y-intercept	−3.579	3.270	−10.172	3.015	−1.09	.2798
Coefficient (c + m1 + m2)	0.256	0.139	-0.024	0.536	1.85	.0719

Recent Cohort Alone

Term	Estimate	St Error	L_1	L_2	*t*-test	*P* value
Y-intercept	−7.408	3.692	−14.853	0.038	−2.01	.0511
Coefficient (c + m1 + m2)	0.396	0.155	0.084	0.708	2.56	.0141

B. Permanent Tooth Size (C + P1 + P2) Predicting Leeway Space (Cohorts Pooled)

Term	Estimate	St Error	L_1	L_2	*t*-test	*P* value
Y-intercept	13.220	1.490	10.259	16.182	8.87	<.0001
Coefficient (C + P1 + P2)	−0.512	0.069	−0.650	−0.374	−7.38	<.0001

C. Primary Tooth Size (c + m1 + m2) Predicting Permanent Tooth Size (C + P1 + P2) (Cohorts Pooled)

Term	Estimate	St Error	L_1	L_2	*t*-test	*P* value
Y-intercept	4.025	2.485	−0.914	8.963	1.62	.1089
Coefficient (c + m1 + m2)	0.735	0.105	0.527	0.944	7.01	<.0001

sizes[52] suggest that other permanent teeth will also contribute to a greater space requirement in the typical patient. Large tooth size per se is a risk factor for malocclusion.[25–28]

A limitation of the study is that results extrapolated from only two localized samples of American whites were used to interpret childhood conditions in general. It remains to be seen whether geographic differences affect interpretation. In addition, we compared data from this study from 45 subjects in each cohort. The study may promote interest in further examining this potential secular trend in other samples. Also, secular trends do not occur globally or synchronously across a population. They reflect environmental changes. Responses seem largely to have been completed in first-world countries,[53] but may be ongoing elsewhere as living conditions improve.

CONCLUSIONS

Comparing an earlier cohort of American whites (born in the 1930s) with a recent cohort (born in the 1990s) to test for a secular change in leeway space showed that

- Mandibular leeway space ranged from 0.0 mm to 3.3 mm in the recent cohort, with an average of 2.0 mm per quadrant.
- Mandibular leeway space was lower by an average of 0.42 mm per quadrant between cohorts—a clinically and statistically significant finding. This difference is mostly attributed to a secular trend for larger premolars.

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