Incisor Crowding in Untreated Persons 15–50 Years of Age: United States, 1988–1994

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Abstract: The purpose of this study was to (1) describe the prevalence of mandibular incisor irregularity (II) among untreated adults in the United States and (2) evaluate the factors explaining individual differences in II. Data were derived for a random sample of 9044 individuals (49% male and 51% female; 35% Mexican American, 34% black, and 31% white) between 15 and 50 years of age collected as part of the Third National Health and Nutrition Examination Survey. Although the differences were small (0.5 mm), males had significantly greater II than did females; blacks showed less II than did whites (0.9 mm) and Mexican Americans (1.1 mm). Family income was negatively related with II. Incisor irregularity increased in a curvilinear fashion with age, with the greatest increases occurring during early adulthood. Although the number of premolars and molars (first and second) were positively related with II, the presence of third molars had a negative effect on II. Multivariate Poisson regression analyses showed that the ethnicity, the number of first and second molars, sex, and age combined to explain differences in II. Odds ratios were relatively low, indicating that these factors explained relatively small amounts of between-subject variation. We conclude that (1) approximately 50% of individuals in the United States who were 15–50 years of age have little or no II, 23% have moderate II, and 17% have severe irregularity, (2) erupted third molars are not associated with increased crowding, (3) crowding increases most during early adulthood, and (4) although individual differences in crowding are multifactorial, the primary determinants remain unidentified. (*Angle Orthod* 2003;73:502–508.)

Key Words: Incisor Irregularity; NHANES III; Adults; Epidemiology

INTRODUCTION

Even though crowding represents the most common type of malocclusion and the greatest concern of orthodontists for posttreatment stability, limited information exists pertaining to the prevalence of the problem and the sources explaining variation among adults. The Third National Health and Nutrition Examination Survey 1988–1994 (NHANES III) was the first national survey of occlusal characteristics among adults. The design of the NHANES III maximized the precision of sampling for whites, blacks, and Mexican Americans.

Findings from the preliminary NHANES III data release,[1] based on occlusal examinations performed on more than 7000 individuals 8–50 years of age collected during the first half of the survey, showed that 21.9% of the population in the United States had a zero mandibular incisor irregularity index (II); approximately 30% had clinically significant irregularity, and 15% had severe irregularity. The 1988–1991 data also showed that males have significantly greater II than do females, thereby clarifying earlier assessments suggesting no differences[2] or greater irregularity among females.[3,4] Consistent with the earlier NCHS reports,[2,5] the NHANES III showed greater II among whites than among blacks. No differences in II were noted between Mexican Americans and whites. Finally, the NHANES III showed that mandibular II increased with age, from 1.6 mm between 8 and 11 years to 2.5 mm between 12 and 17 years, and then to 3.0 mm between 18 and 50 years. Longitudinal studies have also shown that the incisors become more crowded after the permanent dentition is established.[3,4–11] Importantly, the preliminary NHANES III data release[1] evaluated only a limited number of potential sources of variation that might be expected to influence incisor irregularity, and the estimates were based on a subset of the data collected between 1988 and 1991. Focusing on the

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adult population, the present study uses all the data from the 1988–1994 NHANES III study to estimate the prevalence of II and to identify sources explaining individual differences in irregularity. The sample size and design make it possible to estimate extreme percentiles, obtain more reliable population parameter estimates, simultaneously evaluate multiple sources of variation, and develop multivariate models of factors and their interactions.

MATERIALS AND METHODS

We used publicly available data from the Household Youth Questionnaire and Examination files of NHANES III. The NHANES III was a periodic survey conducted by the National Center for Health Statistics between 1988 and 1994, based on a complex, multistage sampling plan. It was designed to provide national estimates of the health and nutritional status of the United States' civilian, noninstitutionalized population aged two months and older.[12,13] From 19,528 randomly selected households, 33,994 subjects were interviewed, 30,818 were examined in mobile examination centres, and 493 were examined at home. Calibrated physicians and dentists performed all examinations, and extensive health, social, and nutritional histories were obtained by interviewing the subjects or their parents. A detailed discussion of the survey methods is presented in Drury et al.[14]

Our sample includes a total of 9059 individuals representing a population of approximately 95 million (weighted count). They were selected from the larger sample based on the following:

- all six mandibular incisors and canines present and fully erupted;
- ages between 15 and 50;
- occlusal examination performed as part of oral examination; and
- no previous orthodontic treatment.

Occlusal variables

The distances between five anatomic contact points from canine to canine were measured using a periodontal probe graduated in millimeters and summed to represent the irregularity index of Little.[15] Both the teeth defining a contact had to have erupted to the level of the occlusal plane. Spacing between contact points of teeth that were aligned was scored as zero.

Statistical analyses

For univariate analyses, we used SUDAAN 7.54 to compute variance estimates, adjusting for the complex survey design. We used generalized estimating equations (GEE), adjusting for the effect of clustering by household, with a Poisson distribution, a log link, and an exchangeable working correlation structure (PC-SAS GENMOD) to describe the relationship between mandibular II and sex, ethnic group (non-Hispanic white, non-Hispanic black, Mexican American), age (5-year bands), 12-month family income (≤\$20,000; >\$20,000), and the number of mandibular molars and premolars. We described the effect of each independent variable in terms of the odds ratio and used least square means to estimate adjusted mean II for each level of the categorical covariates. The odds ratio is the ratio of the odds of crowding for the one group (eg, males) relative to the odds of crowding in the control or reference group (eg, females). It is interpreted as how much more (or less) likely a group is to have the condition of interest (eg, mandibular II) than the control or reference groups. An odds ratio of 1 indicates that the groups have equal odds of having mandibular II, an odds ratio of 2 indicates that a group has twice the odds of having a condition, and an odds ratio of <1 indicates that a group has lower odds of having a condition than does the control or reference group.

For those independent variables from the bivariate regressions with a Wald chi-square $P < .25$, we fitted a multivariate GEE Poisson model using a forward selection approach to identify a model that explained the individual and combined contributions of the most parsimonious set of variables.[16] Variables were added one at a time starting with the independent variable with the strongest association with mandibular II (greatest Wald chi-square) and those with a $P > .10$ were removed. First- and second-order interactions were tested. Odds ratios, least square means adjusted for the effect of the other variables in the model, and a chi-square test for the difference between least square means were determined.

RESULTS

Approximately 22% of the individuals 15–50 years of age had moderate (4–7 mm) II, and almost 17% had severe (≥7 mm) II (Figure 1). Less than 1% of untreated adults had an II ≥15 mm. The distribution of mandibular II was significantly ($P < .001$) skewed and leptokurtotic ($P < .001$). Tables 1 and 2 provide percentile distributions for mandibular II by sex, ethnicity, income, age, and numbers of posterior teeth present.

Table 3 shows sample size, projected population size, mean irregularity, and the 95% confidence interval, as well as the bivariate odds ratio and P value for the variables used in the modelling procedures. Males had greater irregularity than did females ($P < .0001$). The odds ratio of 1.13 indicates that males had 13% greater odds of having mandibular II than did females. Blacks had less irregularity than did whites ($P < .0001$) and 29% lower odds of having mandibular II ($P < .001$) than did the Mexican American reference group. Subjects from households with the lowest yearly incomes (≤\$20,000) had more irregularity than did those with higher incomes ($P = .001$). Incisor irregularity generally increased with age, although the odds ratios were

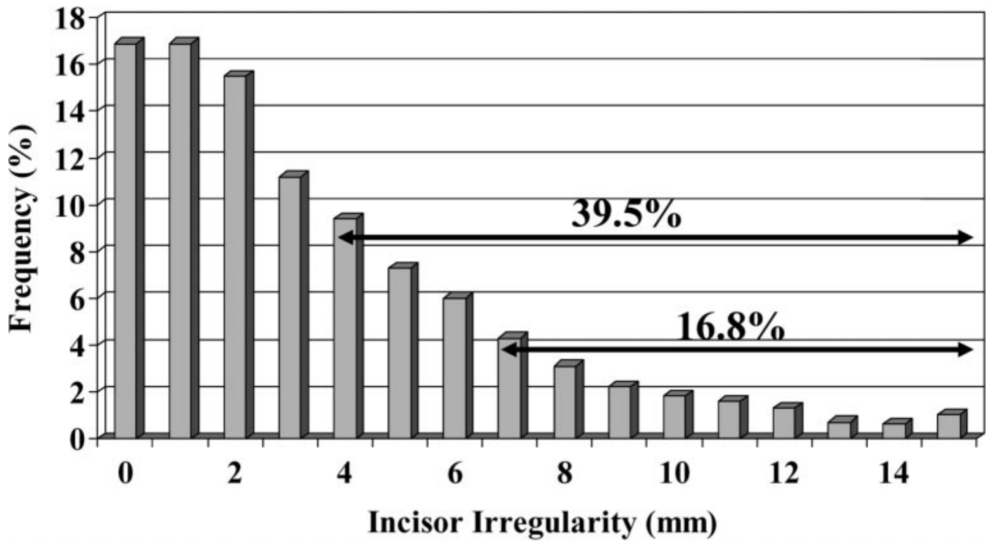

FIGURE 1. Frequencies of mandibular incisor irregularity of untreated individuals in the United States 15–50 years of age.

TABLE 1. Sex, Age, Income and Ethnic Differences in Percentile Distributions of Mandibular Incisor Irregularity (mm) of Untreated Subjects

	Minimum	5%	10%	25%	50%	75%	90%	95%	Maximum
Sex differences									
Males	0	0	0	1	3	5	9	11	28
Females	0	0	0	1	2	5	8	10	24
Ethnic differences									
Whites	0	0	0	1	3	6	9	11	21
Blacks	0	0	0	1	2	4	7	9	28
Mexican American	0	0	1	1	3	6	9	11	28
Income differences									
LE 20K	0	0	0	1	2	5	8	11	24
GT 20K	0	0	0	1	3	5	8	11	28
Age differences									
15–19	0	0	0	1	2	5	8	11	26
20–24	0	0	0	1	2	5	8	11	28
25–29	0	0	0	1	2	5	9	11	21
30–34	0	0	0	1	3	5	8	11	21
35–39	0	0	0	1	3	5	8	10	21
40–44	0	0	0	1	3	5	9	11	24
45–50	0	0	0	1	3	5	8	10	18

weak. Individuals who were 30–40 years of age had significantly more irregularity than did those in the reference (15–20 years of age) group.

Approximately 6% and 8% of the population had missing second or first premolars, respectively. Missing molars were more prevalent, with 24% missing one or both first molars, 19% missing second molars, and 65% missing one or both third molars. With the exception of third molars, subjects with fewer posterior teeth had lower odds of crowding than did those with more teeth. The odds of having increased irregularity were greater for subjects without third molars than for those with third molars.

Multivariate model

Having determined their individual contributions, the sources of variation were evaluated simultaneously to determine their relative contribution. Table 4 shows the odds ratios, least square means, 95% confidence intervals, and chi-square tests for differences between the least square mean estimates. Income, first and second premolars, and third molars did not meet the $P < .10$ retention criterion and were excluded from the final model. None of the interactions was statistically significant.

Least square mean differences increased rapidly from the 15–20 age group to the 30–35 age group, continued to in-

TABLE 2. Distribution of Mandibular Incisor Irregularity (mm) of Untreated Subjects Based on Number (N) of Teeth Present

	N	Minimum	5%	10%	25%	50%	75%	90%	95%	Maximum
Premolars										
First	0	0	0	0	0	2	4.3	7	93	10
	1	0	0	0	1	2	4	6	7	12
	2	0	0	0	1	3	5	8	11	28
Second	0	0	0	0	1	2	4	7	9	16
	1	0	0	0	1	2	4	7	8	15
	2	0	0	0	1	3	5	8	11	28
Molars										
First	0	0	0	0	1	2	4	6	7	17
	1	0	0	0	1	2	5	8	10	21
	2	0	0	0	1	3	6	9	11	28
Second	0	0	0	0	1	2	4	6	8	17
	1	0	0	0	1	2	5	7	10	21
	2	0	0	0	1	3	5	9	11	28
Third	0	0	0	0	1	3	6	9	11	28
	1	0	0	0	1	3	5	8	11	21
	2	0	0	0	1	2	5	8	10	26

crease through the 40–45 year group and then decreased markedly for the 45–50 age group. Males had 0.33 mm more crowding than did females. Whites had slightly less crowding, and blacks had significantly less (0.70 mm) crowding than did Mexican Americans. Crowding also increased with increasing numbers of first and second molars. On the basis of the multivariate odds ratios, ethnicity was the most important variable explaining variation in II. The first and second molars, sex, and age showed lower odds ratios.

DISCUSSION

The results provide the best estimates and the most detailed percentile distributions of the mandibular II of untreated individuals who were 15–50 years of age and residing in the United States. Importantly, they show that crowding is not ubiquitous; 17% of the untreated population had zero II and almost 50% had an II ≤2 mm (Figure 1). Although adult estimates were not provided, the preliminary NHANES III report showed that 21.9% and 59.5% of the individuals in the United States between 8 and 50 years of age had zero mm and less than or equal to two mm II, respectively.[1] Kelly and Harvey[2] estimated that 13.4% of the population in the United States, 12–17 years of age, had no obvious tooth displacements or rotations. The differences between our adult estimates and the preliminary NHANES results may be due to higher prevalence of aligned teeth among children and adolescents.

We showed that slightly less than 40% of untreated adults have clinically relevant amounts (≥4 mm) of II and 17% have severe (≥7 mm) crowding. On the basis of the 2000 US Census population estimates, this suggests that there are approximately 56 million individuals in the United States who are 15–50 years of age with clinical crowding and approximately 24 million with severe crowding. This is a large segment of the population for whom treatment might be deemed necessary. The preliminary NHANES III[1] reported substantially fewer individuals with severe irregularity, which again may be attributed to the younger individuals included in their estimates.

Although sex differences were small, males were shown to have greater II than females. (0.52 mm unadjusted; 0.33 mm adjusted). Our unadjusted sex difference for subjects 15–50 years of age was 0.22 mm greater than that reported for adults 18–50 years in the initial phase of the NHANES III. We attribute this to restricting our sample to subjects with all mandibular incisors and canines present. Notwithstanding previous reports showing no consistent pattern of sex differences[2] or greater incisor crowding for adult females than for males,[3,4] the sex difference is present even after adjusting for covariates. As such, our data support and extend the earlier work of Bondevik[10] and Fastlicht.[17]

There were also differences in II between the three dominant ethnic groups in the United States. Previous analyses of occlusal data did not provide adjusted mean differences from a multivariate model. We showed that blacks have significantly less II than do whites (0.84 mm unadjusted; 0.71 mm adjusted), as previously reported.[1,2] Our results also showed that Mexican Americans have slightly greater II than do non-Hispanic whites (0.20 mm unadjusted; 0.19 mm adjusted) and significantly greater II than do blacks (1.14 mm unadjusted; 0.90 mm adjusted).

Our results are consistent with previous studies reporting increases in incisor crowding with age for untreated adults.[3,8,9,11] Sinclair and Little[3] showed small but significant increases (0.7 mm) in II for 13-year-old subjects with normal occlusion followed longitudinally through 20 years of age. In another longitudinal study of subjects with normal occlusion, Bishara et al[9] demonstrated that tooth-size/arch-length discrepancies increased 0.5 and 0.9 mm for women and men, respectively, between 25 and 46 years of age. Richardson[6,7] and Richardson and Gormley[8] reported that lower incisor crowding increased 2.3 mm between 13 and 18 years of age, 1.3 mm between 18 and 28 years of age, and 1.2 mm between 21 and 28 years of age. Buschang et al[18] showed that mandibular II was 0.8 mm larger for individuals greater than 35 years of age (5.9 mm) than for those who were 17–25 years of age (5.1 mm). The initial NHANES III also reported greater II for adults 18–50 years of age (2.9 ± 0.09 mm) than for 12 to 17 year olds (2.5 ± 0.15 mm) or 8 to 11 year olds (1.6 ± 0.14 mm), although they did not evaluate differences among adults.[1] Although the sampling methods used ensure high external validity for our prevalence estimates, incidence rates would have been preferable for describing changes in II of untreated adults in the United States.

The results of this study suggest that crowding does not increase in a linear fashion with time. Most of the age dif-

TABLE 3. Mandibular Irregularity in Untreated Subjects by Sex, Income, Race, Age Group, and the Presence of Mandibular Posterior Teeth and Bivariate Odds Ratios

	Sample Size	Population Size	Mean Irregularity (mm)	95% CI	Odds Ratio	*P*
Sex[a]	9059	94,894,881	3.66	3.36, 3.96		
Male	4281	48,080,983	3.92	3.62, 4.42	1.13	<.0001
Female	4778	46,813,898	3.40	3.08, 3.72	1.00	
Race/ethnic[b]	8633	85,277,319	3.63	3.34, 3.92		
White	2222	63,702,095	3.77	3.44, 4.10	0.95	.0077
Black	3208	14,116,685	2.83	2.48, 3.18	0.71	<.0001
Mexican American	3203	7,458,539	3.97	3.55, 4.39	1.00	
Family income	8910	93,769,472	3.66	3.36, 3.96		
>$20,000	4278	30,210,686	3.62	3.26, 3.98	0.93	.001
≤$20,000	4632	63,558,786	3.68	3.35, 4.01	1.00	
Age[c]	9059	94,894,881	3.66	3.36, 3.96		
15–20	1796	14,224,289	3.34	3.00, 3.68	1.00	
20–25	1481	13,470,803	3.62	3.18, 4.06	1.06	.1108
25–30	1415	15,335,975	3.65	3.27, 4.03	1.04	.2966
30–35	1383	15,367,696	3.90	3.39, 4.41	1.06	.0968
35–40	1303	15,769,525	3.79	3.38, 4.20	1.07	.0339
40–45	1096	13,185,040	3.79	3.31, 4.27	1.09	.0180
45–50	585	7,541,555	3.38	2.88, 3.88	1.06	.2088
First premolar[d]	9057	94,888,817	3.66	3.36, 3.96		
One	197	1,957,924	2.84	2.04, 3.64	0.77	<.0001
None	55	774,761	2.88	1.74, 4.02	0.72	.0206
Both	8805	92,156,132	3.69	3.39, 3.99	1.00	
Second premolar[e]	9059	94,894,881	3.66	3.36, 3.96		
None	166	2,112,098	2.55	1.84, 3.26	0.75	.0006
One	536	4,894,527	3.22	2.68, 3.76	0.83	<.0001
Both	8357	87,888,257	3.71	3.40, 4.02	1.00	
First molar[f]	9059	94,894,881	3.66	3.36, 3.96		
None	1301	11,781,278	2.55	2.22, 2.88	0.69	<.0001
One	1364	13,201,369	3.25	2.89, 3.61	0.87	<.0001
Both	6394	69,912,233	3.93	3.61, 4.25	1.00	
Second molar[g]	9055	94,795,334	3.67	3.36, 3.96		
None	677	5,867,495	2.75	2.33, 3.17	0.75	<.0001
One	1111	9,466,720	3.17	2.80, 3.54	0.92	.0033
Both	7267	79,461,118	3.79	3.47, 4.11	1.00	
Third molar[h]	8074	87,102,407	3.70	3.36, 3.96		
None	3307	45,461,774	3.87	3.53, 4.22	1.12	<.0001
One	1634	15,933,114	3.53	3.16, 3.90	1.04	.1621
Both	3133	25,707,518	3.51	3.12, 3.90	1.00	

[a] Difference between males and females: $P > .0001$.
[b] Differences between whites and blacks: $P > .0001$; Blacks and Mexican Americans: $P > .001$.
[c] Differences between 15–19 and 40–44: $P = .023$.
[d] Difference between both and one first premolar: $P = .026$.
[e] Difference between both and one second premolar: $P = .023$.
[f] Difference between both and no first molars: $P < .0001$; one and no first molars: $P = .0003$; both and 1: $P < .0001$.
[g] Difference between both and no second molars: $P < .0001$; both and 1: $P = .0001$.
[h] Difference between both and no third molars: $P = .0386$; 1 and none: $P = .0280$.

ferences in II occurred during the late teens and early twenties. Estimates of yearly velocities, derived from the overall changes reported by various longitudinal studies of untreated subjects (Figure 2), support the notion of a rapidly decelerating pattern of incisor crowding. This pattern closely follows vertical growth potential of the mandible, indicating that crowding may be growth related, as suggested by Driscoll-Gilliland et al.[11]

Although limited by our inability to distinguish between third molars that are missing or not erupted, the findings clearly showed that erupted third molars are not significantly associated with increased mandibular incisor crowding. It is particularly important that the multivariate results, which control for the effects of other missing teeth, showed no significant third molar effects. Although there have been numerous cross-sectional[19] and longitudinal[20,21] studies re-

TABLE 4. Odds Ratios, Least Square Means, 95% Confidence Intervals (CI), and Chi-square Tests for Differences Between Least Square Means from Multivariate Poisson Regression Model adjusting for Age, Race, Sex, and the Presence of Mandibular First and Second Molars

Independent Variable	Levels	Odds Ratio	LS Mean	95% CI	χ^2	$P > \chi^2$
Age	15–20	1.00	2.84	2.65, 3.04		
	20–25	1.07	3.03	2.85, 3.04	3.33	.0679
	25–30	1.07	3.04	2.87, 3.23	3.60	.0578
	30–35	1.13	3.21	3.04, 3.40	11.23	.0008
	35–40	1.16	3.29	3.12, 3.48	16.58	<.0001
	40–45	1.18	3.34	3.14, 3.55	17.16	<.0001
	45–50	1.15	3.26	3.02, 3.52	8.78	.0030
Sex	Male	1.08	3.31	3.17, 3.45	25.65	<.0001
	Female	1.00	2.98	2.86, 3.11		
Race/ethnicity[a]	Whites	0.95	3.34	3.18, 3.52	3.79	.0514
	Blacks	0.75	2.63	2.51, 3.52	112.72	<.0001
	Mexican Americans	1.00	3.53	3.36, 3.70		
Mandibular first molars[b]	2	1.38	2.65	2.49, 2.81	94.00	<.0001
	1	1.21	3.20	3.02, 3.39	23.32	<.0001
	0	1.00	3.66	3.51, 3.82		
Mandibular second molars[c]	2	1.12	2.92	2.69, 3.17	5.88	.0153
	1	1.12	3.26	3.07, 3.47	4.92	.0265
	0	1.00	3.26	3.15, 3.37		

[a] White vs Black: $\chi^2 = 67.33$; $P < .0001$.
[b] Two first molars vs one first molar: $\chi^2 = 0.014$; $P = .9453$.
[c] Two second molars vs one second molar: $\chi^2 = 0.0012$; $P = .9453$.

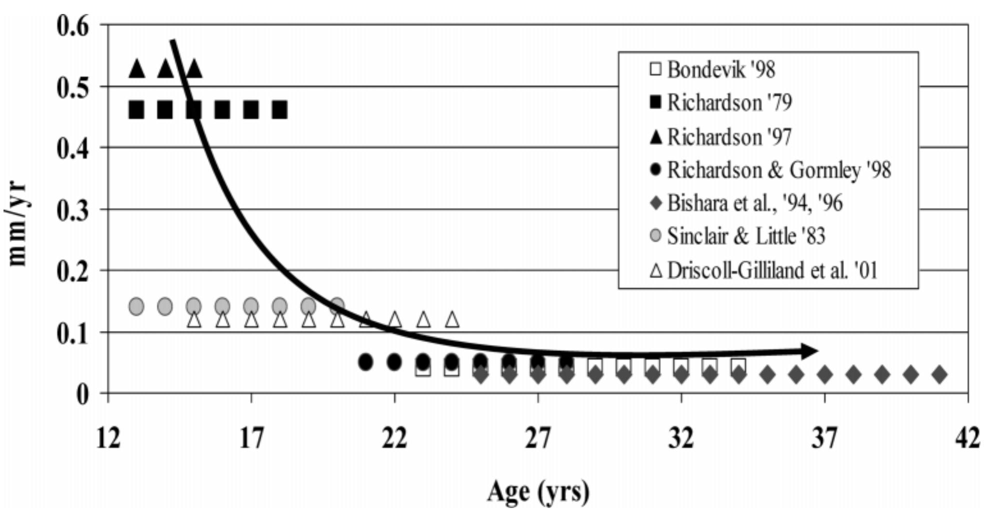

FIGURE 2. Annualized rates of crowding showing age effects.

lating crowding to third molars, most long-term follow-up studies show no differences in posttreatment crowding between individuals with erupted third molars, those with impacted third molars, those with bilateral agenesis of third molars, and those with extracted third molars.[17,22–27] Our results support the consensus that removal of asymptomatic third molars cannot be justified.[19,23–26]

In contrast to the third molars, the results clearly show that the presence of first and second molars is associated with increased crowding. The presence or absence of the premolars might also be expected to influence crowding. For example, Papandreas et al[27] reported 50–60% spontaneous reduction in II after first premolar extractions. Others have reported that 67–80% of the space created with first premolar extractions is accounted for by distal canine.[28–30] Although our odds ratio for the presence of first premolars was high, it did not meet the conventional .05 probability level. We suspect that this is due to the lack of power resulting from the small number of subjects who had one (197) or zero (55) first premolars.

CONCLUSIONS

On the basis of our original aims and the foregoing results, three general conclusions can be drawn for untreated individuals in the United States who were 15–50 years of age.

- Almost half of the population displays little or no crowding. Approximately 40% have clinically unacceptable incisor irregularity, and 17% have severe problems for which treatment might be deemed as highly desirable.
- Independently, seven factors explained statistically significantly amounts of variation in incisor irregularity. The differences in II were as follows:

Men > women;
Mexican Americans > whites > blacks;
Income greater than $20,000 < income less than $20,000;
Older adults > younger adults;
W/mandibular premolars > w/o premolars;
W/first and second molars > w/o first and second molars and;
W/third molars < w/o third molars.

Finally, multiple regression analyses showed that five variables combined to explain variation in the incisor irregularity index. Race, sex, age, and the presence/absence of first and second molars all explained significant, but relatively small, amounts of variation in irregularity.

REFERENCES

1. Brunelle JA, Bhat M, Lipton JA. Prevalence and distribution of selected occlusal characteristics in the US Population, 1988–1991. *J Dent Res.* 1996;75(special issue):706–713.
2. Kelly JE, Harvey CR. An assessment of the occlusion of the teeth of youths 12–17 years. Washington, DC: National Center for Health Statistics, US Public Health Service, DHEW Pub No (HRA) 77–1644, Series 11, No 162; 1977.
3. Sinclair PM, Little RM. Maturation of untreated normal occlusion. *Am J Orthod.* 1983;83:114–123.
4. Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. *Am J Orthod Dentofacial Orthop.* 1994;106:175–186.
5. Kelly JE, Sanchez M, Van Kirk LE. An assessment of the occlusion of the teeth in children. Washington, DC: National Center for Health Statistics, US Public Health Service, DHEW Pub No (HRA) 74–1612, Series 11, No 130; 1973.
6. Richardson ME. Late lower arch crowding: facial growth or forward drift? *Eur J Orthod.* 1979;1:219–225.
7. Richardson ME. Later lower arch crowding in relation to soft tissue maturation. *Am J Orthod Dentofacial Orthop.* 1997;112:159–164.
8. Richardson ME, Gormley JS. Lower arch crowding in the third decade. *Eur J Orthod.* 1998;20:597–607.
9. Bishara SE, Treer JE, Damon P, Olsen M. Changes in the dental arches and dentition between 25 and 45 years of age. *Angle Orthod.* 1996;66:417–422.
10. Bondevik O. Changes in occlusion between 23 and 34 years of age. *Angle Orthod.* 1998;68:75–80.
11. Driscoll-Gilliland J, Buschang PH, Behrents RG. An evaluation of growth and stability in untreated and treated subjects. *Am J Orthod Dentofacial Orthop.* 2001;120:588–597.
12. National Center for Health Statistics. Plan and operation of the Third National Health and Nutrition Examination Survey, 1988–1994. *Vital Health Stat.* 1994;1.
13. Ezzati TM, Massey JT, Waksberg J, Chu A, Maurer KR. Sam design: Third National Health and Nutrition Examination Survey. *Vital Health Stat.* 1992;1–129.
14. Drury TF, Winn DM, Snowden CB, Kingman A, Kleinman DV, Lewis B. An overview of the oral health component of the 1988–1991 National Health and Nutrition Examination Survey (NHANES III-Phase 1). *J Dent Res.* 1996;75(special issue):620–630.
15. Little RM. The irregularity index: a quantitative score of mandibular anterior alignment. *Am J Orthod.* 1975;75:554–563.
16. Hosmer DW, Lemeshow S. *Applied Logostic Regression.* New York, NY: John Wiley & Sons; 1989. pp 38–42.
17. Fastlicht J. Crowding of mandibular incisors. *Am J Orthod.* 1970;58:156–163.
18. Buschang PH, Stroud J, Alexander RG. Differences in dental arch morphology among adult females with untreated Class I and Class II malocclusion. *Eur J Orthod.* 1994;16:47–52.
19. Bergström K, Jensen R. Responsibility of the third molar for secondary crowding. *Sven Tandlak Tidskr.* 1961;54:111–124.
20. Vego L. A longitudinal study of mandibular arch perimeter. *Angle Orthod.* 1962;32:187–192.
21. Lindqvist B, Thilander B. Extraction of third molars in cases of anticipated crowding in the lower jaw. *Am J Orthod.* 1982;81:130–139.
22. Sampson WJ, Richards LC, Leighton BC. Third molar eruption patterns and mandibular dental arch crowding. *Aust Orthod J.* 1983;8:10–20.
23. Ades AG, Joondepth DR, Little RM, Chapko MK. A long-term study of the relationship of third molars to changes in the mandibular dental arch. *Am J Orthod Dentofacial Orthop.* 1990;97:323–335.
24. Harradine NW, Pearson MH, Toth B. The effect of extraction of third molars on later lower incisor crowding: a randomized controlled trial. *Br J Orthod.* 1998;25:117–122.
25. Lundström A. Changes in crowding and spacing of the teeth with age. *Dent Pract.* 1969;19:218–224.
26. Bishara SE, Andreasen G. Third molars: a review. *Am J Orthod.* 1983;83:131–137.
27. Papandreas SG, Buschang PH, Alexander RG, Kennedy DB, Koyama I. Physiologic drift of the mandibular dentition following first premolar extractions. *Angle Orthod.* 1993;63:127–134.
28. Weber AD. A longitudinal analysis of premolar enucleation. *Am J Orthod.* 1969;56:394–402.
29. Glauser R. An evaluation of serial extraction among Navajo Indian children. *Am J Orthod.* 1973;63:622–632.
30. Berg R, Gebauer K. Spontaneous changes in the mandibular arch following first premolar extractions. *Eur J Orthod.* 1982;4:93–98.