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The A.B.F.O. Study of Third Molar Development and Its Use As an Estimator of Chronological Age

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ABSTRACT: Radiographs depicting third molars (M3s) have been used to estimate chronological age in juvenile and adult suspects, but accuracy of the method has been in question. This study provides age benchmarks for American whites (age range: 14 to 24 years) based on cases (n = 823) drawn from diplomates of the American Board of Forensic Odontologists in the United States and Canada. Maxillary M3 formation was slightly advanced over mandibular M3s, and root formation occurred earlier in males than females. Mean and median ages for M3 formation are tabled using Demirjian's eight-grade classification. Regression formulas and empirical probabilities are provided relative to the medicolegal question of whether an individual is at least 18 years of age. The M3 is the most variable tooth in the dentition, but situations arise where M3 formation is the only usable datum for age estimation.

KEYWORDS: odontology, dental age, tooth formation, age determination, third molars

Determination of dental age—using stages of tooth mineralization to gauge an individual's degree of maturity—is one of a few biologic methods for monitoring physiologic development [*1,2*], and the dentition arguably is the only system applicable from prior to birth to early adulthood [*3*]. Dental development can also be used to estimate chronological age, such as age at death of an unidentified person or the age of a suspect without legal documentation of birth. Legal consequences can be quite different if a subject of unknown age is judged to be a juvenile or an adult.

On the other hand, the accuracy of dental aging is not uniform from birth to maturity. Younger ages can be assessed with greater accuracy because more teeth are undergoing formation and the intervals between morphologic stages are shorter and, therefore, more precise [*4*]. Late in adolescence, after formation of the premolars and canines, only the third molars continue to form. Third molars are in many respects the most variable teeth in the dentition [*5–7*]. Still, because there are virtually no other biologic indicators available for this age interval, third molars are sometimes used to judge the juvenile versus adult status of subjects who lack age documentation.

This study was undertaken by the Research Committee of the American Board of Forensic Odontology to evaluate the accuracy of estimating chronological age from the

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developmental status of third molars as viewed radiographically. Data were submitted by Board Diplomates from throughout the United States and parts of Canada and consisted predominantly of Caucasians, though sample sizes were sufficient to provide some comments on the molar development of American Blacks as well.

Materials and Methods

Data were gathered by 24 diplomates of the American Board of Forensic Odontology (A.B.F.O.). The total sample consisted of 823 cases. Chronological age, gender, and race were recorded; cases were between 14.1 and 24.9 years of age at examination. Most records (74%) were panoramic radiographs, the others being periapical films. The sex ratio was near 1:1; 54% were female. Most were white (80%); 19% were black, and 1% consisted of other races or was unspecified.

The contributing dentist scored the degree of third molar development using the eight-grade scheme (Fig. 1) developed by Demirjian and coworkers [*8*]. This use of multiple examiners introduced greater variability into the estimates than if differences in judgment were the result of just one scorer. This was intentional since we wanted to incorporate whatever inter-observer variability might result from among experienced specialists. This seemed the more pragmatic approach. Additionally, all four third molars were scored, so far as possible, to test for left-right symmetry and arch differences in the tempos of formation.

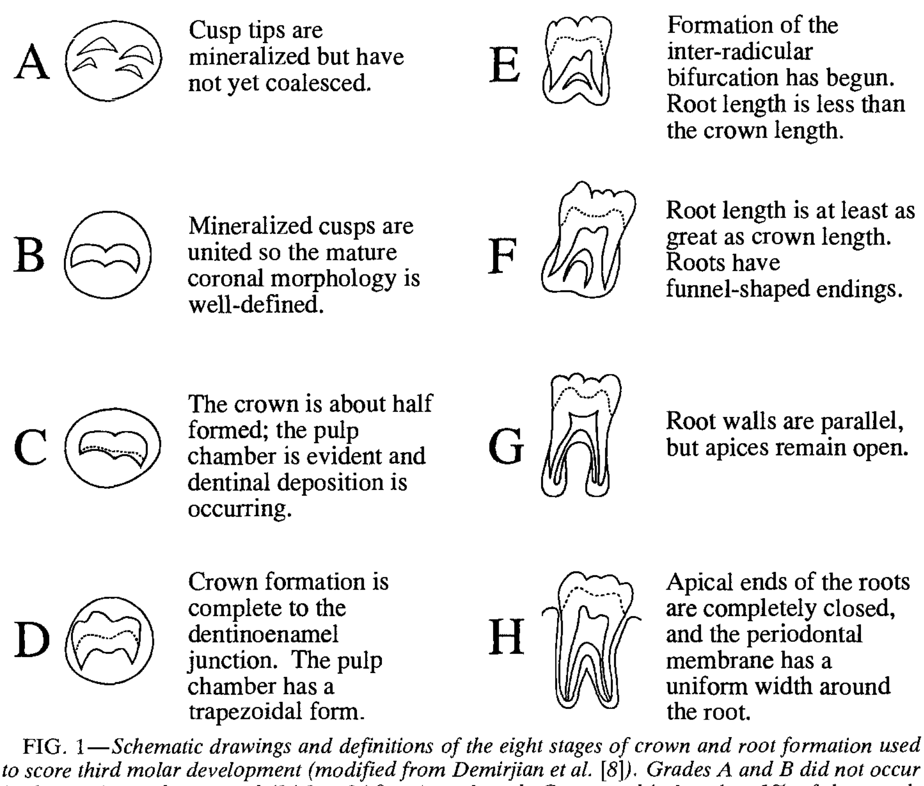

FIG. 1—*Schematic drawings and definitions of the eight stages of crown and root formation used to score third molar development (modified from Demirjian et al.* [8]*). Grades A and B did not occur in the age interval examined (14.1 to 24.9 yrs), and grade C occurred in less than 1% of the sample and was omitted from analysis.*

Results

Symmetry

Left-right symmetry in formation was somewhat higher in the maxilla (82%) than the mandible (74%) in those cases where both molars were scorable; the overall percentage of concordance, pooling both arches, was moderate (78%). This suggests that information from all available teeth should be used in an age determination.

Only 54% of the cases exhibited the same grade of crown-root formation in the maxilla and mandible. Maxillary third molars tended to develop somewhat faster than their mandibular counterparts. The maxillary and mandibular third molars were within one grade of each other just 67% of the time (Table 1). Every possible relationship was observed, from the mandibular tooth being far advanced over the maxillary homologue to the converse.

Age at Formation

The mean chronological age at each formative grade was calculated after partitioning the sample by sex and race (Table 2). Too few blacks were available to yield reliable estimates except at the older grades of root formation.

There was significant sex dimorphism in the white data, but not in the data for American blacks—perhaps because of small sample sizes. The unusual nature of the sex dimorphism—as previously reported by Moorrees et al. [*9*], Levesque et al. [*10*], and others—is that *males* achieve the maturity indicators sooner (that is, third molars develop earlier) than females. This faster rate of formation is evident when the data are presented in terms of their percentile distributions (Table 3). In each of the 10 comparisons, the median age for males was younger than that for females.

Prediction of Age 18

Medicolegal questions confronting the forensic odontologist sometimes involve the conceptually simple question of whether an individual is a juvenile or an adult, that is, younger or older than 18 years of age. The data were formatted to address this question. Predictions were cast in terms of normal curve theory [*11*]; an example is illustrated in Fig. 2. Mean age and the standard deviation at each grade of formation were used to calculate the empirical likelihood that an individual is at least 18 years of age.

TABLE 1—*Cross-tabulation of stages of formation between maxillary and mandibular third molars within individuals showing the considerable variability among arches.*[a]

Maxillary Stage	Mandibular Stage				
	D	E	F	G	H
D	96	34	13	8	11
E	54	50	45	14	6
F	11	86	83	38	10
G	9	18	74	130	58
H	14	27	11	87	375

[a]Numbers are raw counts of cases; total sample is 1362 maxillary-mandibular comparisons (sides pooled).

TABLE 2—*Mean ages at attainment of stages of third molar crown-root formation.*

Grouping	Statistic	Grade of Formation				
		D	E	F	G	H
		Maxilla				
Whites						
Males	$\bar{x}$	16.0	16.6	17.7	18.2	20.2
	sd	1.97	2.38	2.28	1.91	2.09
Females	$\bar{x}$	16.0	16.9	18.0	18.8	20.6
	sd	1.55	1.85	1.95	2.27	2.09
Blacks						
M + F	$\bar{x}$				19.3	20.4
	sd				3.37	3.14
		Mandible				
Whites						
Males	$\bar{x}$	15.5	17.3	17.5	18.3	20.5
	sd	1.59	2.47	2.14	1.93	1.97
Females	$\bar{x}$	16.0	16.9	17.7	19.1	20.9
	sd	1.64	1.75	1.80	2.18	2.01
Blacks						
M + F	$\bar{x}$			17.2	18.5	21.4
	sd			3.14	2.68	2.34

TABLE 3—*Percentile distributions of the age at attainment of stages of third molar crown-root formation in American whites.*[a]

Gender	Centile	Grade of Formation				
		D	E	F	G	H
		Maxilla				
Males	10th	14.21	14.38	15.39	15.96	17.58
	25th	14.64	15.02	15.75	16.64	18.82
	50th	15.53	16.09	17.34	17.92	20.02
	75th	16.76	17.26	18.40	19.43	21.52
	90th	19.60	20.70	20.91	20.74	23.18
Females	10th	14.18	14.75	15.91	15.88	18.07
	25th	14.49	15.35	16.62	17.11	19.09
	50th	15.93	16.87	17.93	18.60	20.74
	75th	17.03	18.28	19.38	20.52	22.23
	90th	18.13	19.11	20.18	21.86	23.42
		Mandible				
Males	10th	14.19	15.14	15.15	15.87	18.27
	25th	14.40	15.66	16.13	16.89	19.47
	50th	15.02	16.74	16.98	17.91	20.30
	75th	16.52	17.90	18.19	19.55	22.00
	90th	16.91	21.42	20.58	20.79	23.28
Females	10th	14.12	14.49	15.48	16.49	18.27
	25th	14.46	15.82	16.47	17.63	19.23
	50th	15.83	16.91	17.71	18.96	20.81
	75th	17.03	18.11	18.75	20.76	22.60
	90th	18.47	18.94	20.15	21.85	23.57

[a]Sample sizes are 271 males and 323 females. Percentiles for grade H presume that independent criteria can be used to eliminate cases over 25 years of age from consideration.

Multiple Predictors

Because there is appreciable left-right asymmetry and since the maxillary and mandibular third molars often develop at different rates, it seemed likely that information from multiple teeth would give more accurate estimates of chronological age than any of the third molars taken singly. This was tested using multiple linear regression [*12*]. The modal age of the sex-specific data for each grade (Table 2) was assigned to each third molar in each case, and these four dental ages were used to predict chronological age (Table 5).

There was a *modest* improvement in the fit of the model when multiple teeth were used. Taken singly, third molars accounted for 37 to 46% of the variation in chronological age. The two mandibular teeth yielded slightly higher correlations than the maxillary molars in these data. The coefficient of determination (r^2) increased to 50% when two teeth were used. As shown in the multiple and stepwise regression analysis (Table 3), the use of one maxillary third molar and one mandibular third molar provided a statistically significant improvement in predictive accuracy.

It was inconsequential that the two left third molars were entered into the equations. This occurred because they had very slightly higher associations with chronological age in this specific set of data. Equivalent results were obtained when either the left or right antimeres were entered into the equations.

Accuracy

Intuitively, accuracy of this technique should not be particularly high since there are, at most, eight grades of formation distributed across an 11-year age span. In practice, grades A, B, and C occurred rarely if at all in the age interval under examination, and the morphologic grades were not equally spaced across this age span (Table 2).

Accuracy was assessed by taking the difference between actual (observed) age and that predicted from the degree of tooth development. There was a trend for the older age grades to be more variable in both arches (Fig. 3). Also, except at the terminal grade (H), the distribution of observed-minus-expected age differences was positively skewed: There were more cases in which dental age lagged behind chronological age (so the O-E difference was positive) than the reverse. When the sign of the difference was ignored (Table 4), the average difference between chronological age and that predicted from

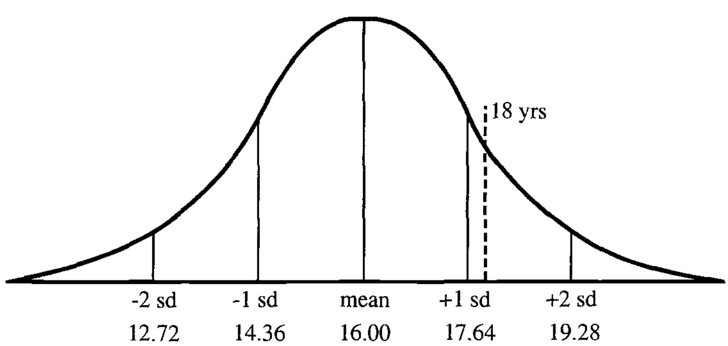

FIG. 2—*Representation of a normal distribution with a mean of 16.0 years and a standard deviation of 1.64—which corresponds to grade D for the mandibular molar in females (Table 2). Eighteen years of age is 1.21 standard deviations above the mean, and, from areas under the normal curve, this means that 89% of the cases are less than 18 years of age. In other words, there is an 11% chance of a female with grade D being 18 years of age or older.*

molar formation (listed in the table as |resid|) was about 1.6 years (sd = 1.20). This translates to a span of about 4.8 years to encompass the 95% confidence limits (that is, ± 2 sd) for any given age estimate.

Inspection of the regression analyses (Table 5) discloses a statistically significant improvement in predictive accuracy when a maxillary *and* a mandibular third molar were used to predict chronological age. However, the improvement is of little practical consequence. The average residual (that is, observed minus predicted age) was about 1.6

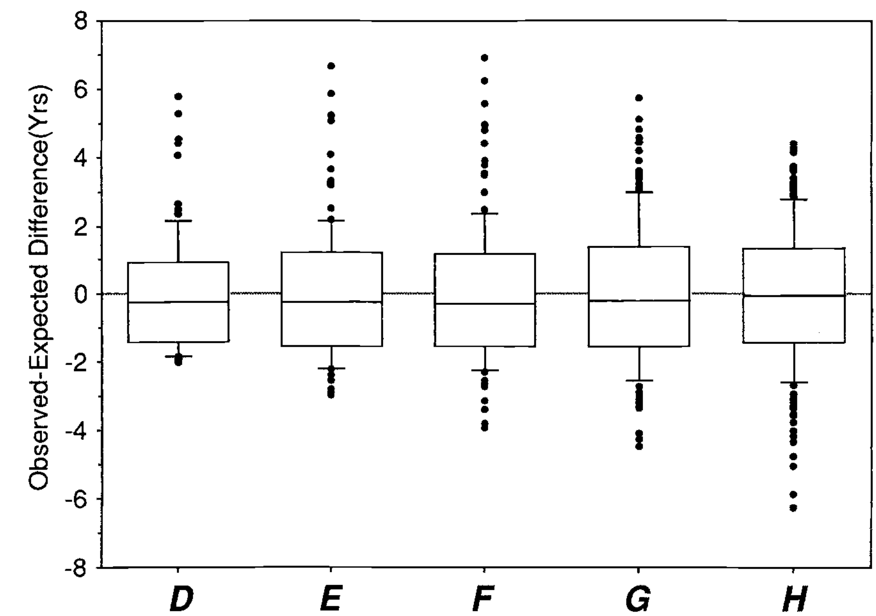

FIG. 3—*Box plots for observed-minus-expected age differences for the five grades observed for the maxillary third molar (sides pooled). The horizontal lines in each "box" are, from bottom to top, the 10th, 25th, 50th, 75th, and 90th percentiles. Dots outside the boxes are extreme individual cases. Mandibular results were highly concordant with these. Note that the error increases with age (from D through H) and that most of the extreme cases are positive—so the actual chronologic ages were greater than predicted from molar formation in these instances.*

TABLE 4—*Empirical probabilities (%) of an individual being at least 18 years of age based on the grade of third molar formation.*[a]

Group	Grade of Formation D	E	F	G	H
			Maxilla		
Males	15.9	27.8	44.0	46.8	85.3
Females	9.7	28.4	50.4	63.3	89.6
			Mandible		
Males	6.1	69.4	40.5	56.0	90.1
Females	11.3	27.4	43.2	69.8	92.2

[a]Values are based just on whites. Probabilities for the terminal grade (H) presume that, based on other criteria, the subject is less than 25 years of age.

TABLE 5—*Results of regression analyses predicting chronologic age from stages of third molar crown-root formation.*[a]

Univariate Regression	Intercept	Regression Coefficient	F-Ratio[b]	r	r^2	|resid|	sd
Maxillary Right M3	0.33	0.98	323.0	0.61	0.37	1.64	1.25
Maxillary Left M3	−0.39	1.02	356.4	0.63	0.40	1.60	1.22
Mandibular Left M3	−0.18	1.01	467.4	0.68	0.46	1.55	1.13
Mandibular Right M3	0.25	0.99	423.9	0.66	0.44	1.57	1.19
Multiple Regression		**Regression Coefficient**	**F-Ratio[b]**	**r**	**r^2**	**|resid|**	**sd**
Intercept = −2.10			115.1	0.70	0.50	1.48	1.10
Maxillary Right M3		0.02					
Maxillary Left M3		0.31[d]					
Mandibular Left M3		0.72[d]					
Mandibular Right M3		0.06					
Stepwise Regression[c]		**Regression Coefficient**	**F-Ratio[b]**	**r**	**r^2**		
Intercept = 2.07				0.70	0.50		
1. Maxillary Left M3		0.34	15.8				
2. Mandibular Left M3		0.76	95.2				

[a]Results are for just the white data. Residual statistics are means of the absolute values of observed-minus-predicted age (|resid|) and their standard deviations (sd).

[b]All F-ratios are significant at $P < 0.0001$.

[c]Just the final solution is listed.

[d]Partial F-ratios are significant ($P < 0.01$) for the two left molars but not for the two antimeres on the right side.

years when any one molar was used; this decreased, but only to 1.5 years, when a molar from each arch was used. In practice then there is no obvious gain, and the statistical improvement would not have been seen except that the sample sizes are large, exceeding 500 in each analysis.

Discussion

The single compelling reason to rely on third molar formation to estimate chronological age is that there are very few alternative methods during the interval roughly between the middle teens and early 20s. All of the other teeth have erupted and completed root formation [*8,9,13*]. All of the hand-wrist bones have achieved their adult morphologies and their epiphyses have fused [*1,14*], and the onset of secondary sex characteristics has occurred [*15,16*]. Consequently, except for the ossification of some early-fusing cranial and postaxial sutures—which are themselves quite variable [*17*]—there are no biological criteria by which to estimate chronological age.

The third molar is far from an ideal developmental marker. It frequently is congenitally absent [*18–21*], malformed [*22*], impacted, or extracted [*23–27*]. Further, it is the most variable tooth in the dentition as regards size [*28,29*], time of formation and time of eruption [*30–35*]. It is not surprising, then, that the association between chronological age and formation of the third molar is, at best, moderate.

Left-right asymmetry in formation is more common for the third molar than elsewhere in the dentition [*33,36,37*], but the side difference is random; neither side is systematically advanced, which agrees with previous studies [*10,38*]. In practice, then, it would be useful to average the dental age obtained from the left and right sides when they are both scorable but asymmetric.

Differences in the tempos of formation of teeth often occur between the arches. The somewhat faster rate of formation found here for the maxillary third molars has been a common finding in previous studies [*20,34,36,39,40*]. This difference in tempo presumably reflects different control mechanisms in the two arches. In turn, the use of teeth in both arches should provide a better estimate of chronological age than when taken singly. Statistically this was true (Table 5); there was a significant increase in explained variation when multiple third molars were used in age prediction. In practice, though, the reduction in the average error was only about 0.1 years. So, while the multiple regression equations are supplied (Table 5), they yield little more accuracy than the univariate equations.

Gender also has an influence, but, as detailed by Levesque et al. [*10*], third molar root formation and eruption occur in *males ahead of females*—which is opposite the pattern of development seen for all of the earlier-forming teeth [*41–44*]. This difference averages 3 to 4 months for grades D through H, and is somewhat greater at the terminal phases of root formation. There is, then, a slight advantage in using sex-specific norms. In postmortem cases where gender cannot be determined, a dental age should be obtained by averaging the male and female standards.

Prior studies have documented an appreciable difference in tooth formation and eruption between blacks and whites, with blacks developing faster than whites [*13,45–47*]. No such difference was found in the present study (Table 2), but this may be due to limited sample sizes. Additional data on American blacks certainly would be desirable in this context, and, indeed, very limited data are available on several other segments of the population such as Hispanics [*48,49*].

It merits clarification that two, conceptually different questions about age estimation were addressed in this study. One approach used the grade of tooth formation to predict chronological age. The second method assessed the degree of confidence an investigator can place in whether a subject is at least a certain chronological age.

In the first instance, the standard deviations average about two years for each grade of third molar formation (Table 2). This means that the "dental age" assigned to a tooth is centered on an interval of about eight years: Plus-and-minus one standard deviation (that is, 4 years encompasses about 68% of the distribution and ± 2 standard deviations—that is, about 8 years—incorporates 95% of the sample. It seems obvious that this is far too imprecise to be of much use in forensic dentistry. Regression equations—either simple or multivariate—involve the same problem; there are too few grades to accurately affix a precise chronological age. Thorson and Hägg [*50*] have recently conducted a similar study and drew the same conclusion—that the average difference between assigned dental age and chronological age is too great for routine use. Another hindrance (not routinely appreciated) is the unrepresentative nature of published "standards." Subjects in longitudinal growth studies [*8,9,34*] typically are of above-average socioeconomic status and receive frequent health appraisals so they tend to grow "better" and faster than the population at large [*51–53*]. In addition, "standards" based on subadults from one locality are biased in terms of their ethnicity and sociocultural milieu. We previously have documented rather striking differences in the tempo of growth of children from different regions of the United States even when controlling for obvious racial differences [*13,54*].

The second approach (Table 4) asked a more specific question, namely, what is the likelihood of a subject being at least X years old knowing the stage of third molar formation? In this context the chronological age is dichotomized instead of being continuous and open-ended. For medicolegal purposes, 18 years of age is an important cutpoint, but other ages (for example, 21 years) could be used just as easily. Inspection of Table 4 shows that reasonable accuracy can be attained at the two extremes: If a subject presents with a grade A through D there is little likelihood that he or she is 18 years of age. At the other extreme, if the root apices are closed (grade H), one can be reasonably confident that the subject is indeed at least 18 years of age.

This leaves three ambiguous stages, grades E, F, and G. It is essentially a coin toss (50:50) whether a subject with one of these three grades is younger or older than 18. One might suggest that finer discrimination could be achieved by dividing the continuum of crown-root formation into more categories. This does not work because it substitutes the different problem of being unable to confidently distinguish between finely-partitioned grades [*50,55*]. Indeed, those experienced with the present system (Fig. 1) can have trouble differentiating between grades G (root complete) and H (apex closed) when film quality or orientation are not satisfactory.

In sum, then, when a case possesses early-forming (grades A-D) or complete (H) third molars, the investigator can be reasonably certain that the person is less than or older than 18.0 years of age, respectively. This dichotomous question (< 18 vs. ≥ 18) is much more restrictive than trying to estimate chronological age from a span of many years.

Finally, an important caveat needs reemphasis. Grade H (apex closed) occurs in *all* mature third molars regardless of age. Consequently, the age estimates for this terminal grade (Tables 2, 3) assume that independent criteria can be used to exclude subjects over 24 years of age. The onset of root maturity in the third molar (H) is a valuable developmental event; it is the one marker in this tooth indicating that an individual is quite likely to be at least 18 years of age (Table 4). This is why it was included in Tables 2 and 3 even though, without imposing an upper age limit, the specific time at which grade H occurs cannot be gauged from cross-sectional data [*13,56*].

In overview, the formative stage of the third molar can be the only quantitative biologic variable available for estimating the age of a person in his late teens or early 20s. Although the considerable variability of the third molar detracts from precise age estimates, it can be suggestive in the absence of better information. Two kinds of questions can be addressed: If the third molar is used to estimate chronological age from the 14 to 25 year interval examined here, then regression equations (Table 5) are most useful. If, on the other hand, the medicolegal question hinges on whether a subject is at least 18 years of age, then the empirical probabilities (Table 4) can prove useful, particularly if the molar is just starting or ending its crown-root development.

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Errata

In the March 1993 issue, a misprint occurred. Table 4 of Mincer et al. p. 384 should have appeared as follows.

TABLE 4—*Empirical probabilities (%) of an individual being at least 18 years of age based on the grade of third molar formation.*[a]

	Grade of Formation				
Group	D	E	F	G	H
		Maxilla			
Males	15.9	27.8	44.0	46.8	85.3
Females	9.7	28.4	50.4	63.3	89.6
		Mandible			
Males	6.1	29.4	40.5	56.0	90.1
Females	11.3	27.4	43.2	69.8	92.2

[a]Values are based just on whites. Probabilities for the terminal grade (H) presume that, based on other criteria, the subject is less than 25 years of age.