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ORIGINAL ARTICLE

Effectiveness of Bang and Ramm's formulae in age assessment of Indians from dentin translucency length

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Abstract Age assessment may be a crucial step in postmortem profiling leading to confirmative identification. Among the traditional dental parameters used for estimating age, root dentin translucency is considered to be least affected by external stimuli and most suitable for the purpose. Using this variable, Bang and Ramm in 1970 developed an elaborate method and formulae for predicting age in Norwegians, and its efficacy has been examined in Indians. A total of 100 tooth sections 250-µm thick were obtained from as many subjects, scanned on a flat-bed scanner and the translucency length measured using a commercially available image-editing software program. Since age estimates in Indians was less accurate compared to the original sample, translucency measurements were subjected to regression analysis, and India-specific formulae were derived. The new formula was applied to a control group (n=18), and the estimated age was marginally better, validating to some extent the use of population-specific formulae in forensic age estimation. However, moderate correlation of translucency length to age inherent in Indians may undermine optimal age prediction.

Keywords Age estimation · Digital method · Population variation · Regression analysis

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Introduction

Age estimation constitutes an important step in building a profile of the deceased and may be vital to postmortem identification. Conventional dental age assessment is usually quickly achieved and relatively less technique-intensive [1–3] compared to alternative methods, which analyze amino acid racemization and ^{14}C content in teeth [4, 5]. Among the routine techniques, diverse approaches exist for age prediction in adolescents and adults which employ radiographs [3, 6], extracted teeth and tooth sections [1, 2]. Age determination is a highly researched area, and new methods using the dentition and other skeletal parameters continue to be developed [7–10] and compared to standard methods [11, 12]. In attempts to standardize and optimize age prediction, guidelines and criteria have also been developed [13, 14].

Among the traditional methods for estimating age in adults, the morpho-histological parameters suggested by Gustafson [1] continue to find widespread use. Of the six variables that he suggested, dentinal translucency is perhaps the easiest to assess while also relatively accurate in age prediction. In fact, Johanson [2] found that translucency was best correlated to age when used alone. Gustafson [1] and Johanson [2] assessed increase in translucency using a subjective scale, while Miles [15] proposed a more objective examination by measuring its length. Later, Bang and Ramm [16] put forward a more detailed method of measuring translucency length; they developed tooth-specific formulae for age estimation on a Norwegian sample of 926 teeth. These formulae have been tested on other European as well as American samples with relatively good results [17–19]; however, its utility in Asians is hitherto unexplored. The objective of this study was to test the efficacy of Bang and Ramm's formulae [16] in estimating age on an Indian sample. Whittaker and Bakri [20] found different rates of translucency formation in Asians vis-à-vis Europeans, implying that population origin and geographic location may influence its development. Recently, Ubelaker and Parra [19] concluded that "maximum accuracy is obtained with population-specific formulae." Hence, it is essential to validate a method on the population of interest before its routine use in forensic age estimation; in the event of large errors in age estimation from Bang and Ramm's equations [16], new formulae specific to the Indian population will be generated to ascertain if age prediction is enhanced.

Materials and methods

The material consisted of 100 teeth collected from the Department of Oral and Maxillofacial Surgery of the institution and private clinics of the region. The teeth were obtained from 100 subjects aged 19–82 years (mean= 47.13), spread across different age groups in relatively equal numbers (Table 1). Tooth specimens included were fully erupted permanent teeth extracted for valid clinical reasons (periodontal disease, malocclusion/orthodontic treatment, and caries). Carious teeth were included in the sample contingent to roots being unaffected macroscopically by disease. The extracted teeth were thoroughly cleaned and soft tissue remnants removed from the root surface with a scalpel. Teeth were preserved in 10% formalin and mounted in autopolymerizing acrylic for sectioning by a Leica SP 1600 hard-tissue microtome. While acrylic may have a tendency to affect translucency length, the teeth were mounted <48 h before sectioning and probably had negligible impact on dentinal translucency. Mounted teeth were sectioned longitudinally to 250 µm in the buccolingual plane, as close as possible to the central axis of the tooth. The sections were coded to ensure blind assessment of translucency length.

Translucency length was measured in accordance with the description given by Bang and Ramm [16]. However, in contrast to their manual caliper-based method, we used a semi-automatic digital approach. The method employed commercially available computer hardware and software, the details of which have been reported elsewhere [21]. Briefly, tooth sections were placed adjacent to an ABFO no. 2 reference scale on a flat-bed scanner and scanned under a resolution of 600 dpi. Scanned images were imported into Adobe Photoshop 7 image-editing software program for measuring translucency length. For convenience in measuring, Photoshop's in-built "guides" were placed at the apical (TA) and coronal extent (TC) of translucency and length between the guides measured using Photoshop's in-built measure tool (Fig. 1). Note that the junction between translucent and non-translucent zones on the labial/buccal and lingual sides is depicted as a relatively even horizontal line in Fig. 1. If this is not so, Bang and Ramm [16] recommend separate measurements of translucency on the two sides. This would necessitate placement of two guides to represent the labial/buccal and lingual aspects of the coronal extent of translucency. The distances between the coronal and apical guide on each side are measured separately and their average taken. Measurements obtained were accurate to 0.1 mm and were repeated by a second examiner on all 100 sections; measurements were also made by this examiner on 40 randomly selected tooth sections. Using SPSS 10.0 statistical program, paired t test was run to assess inter- and intra-observer differences.

Age was calculated using tooth-specific regression equations developed by Bang and Ramm [16]. In addition, formulae for dentinal translucency length derived in other populations [15, 22, 23] were also applied to the Indian sample and the age calculated. Furthermore, we developed regression formulae (using the SPSS 10.0 program) from raw data (i.e., chronological age and corresponding translucency lengths) published for other samples [18, 24] and applied these also for estimating age in Indians. It must be noted that the method of translucency measurement in some of these studies [15, 24] had minor variations compared to Bang and Ramm's method [16]. The intention, however, was to assess diverse translucency length formulae vis-à-vis Bang and Ramm's formulae [16]. Tooth sections were decoded and actual age ascertained. The difference between actual and estimated age was tabulated using Microsoft

Table 1 Distribution of tooth sections across age groups, sex, and tooth type

Age group (years)	Sections (n)	Sex		Tooth type		
		M	F	Incisors	Canines	Premolars
19–30	19	4	15	10	–	9
31–40	20	12	8	9	6	5
41–50	18	8	10	3	6	9
51–60	18	10	8	4	5	9
>60	25	15	10	11	4	10
Σ	100	49	51	37	21	42

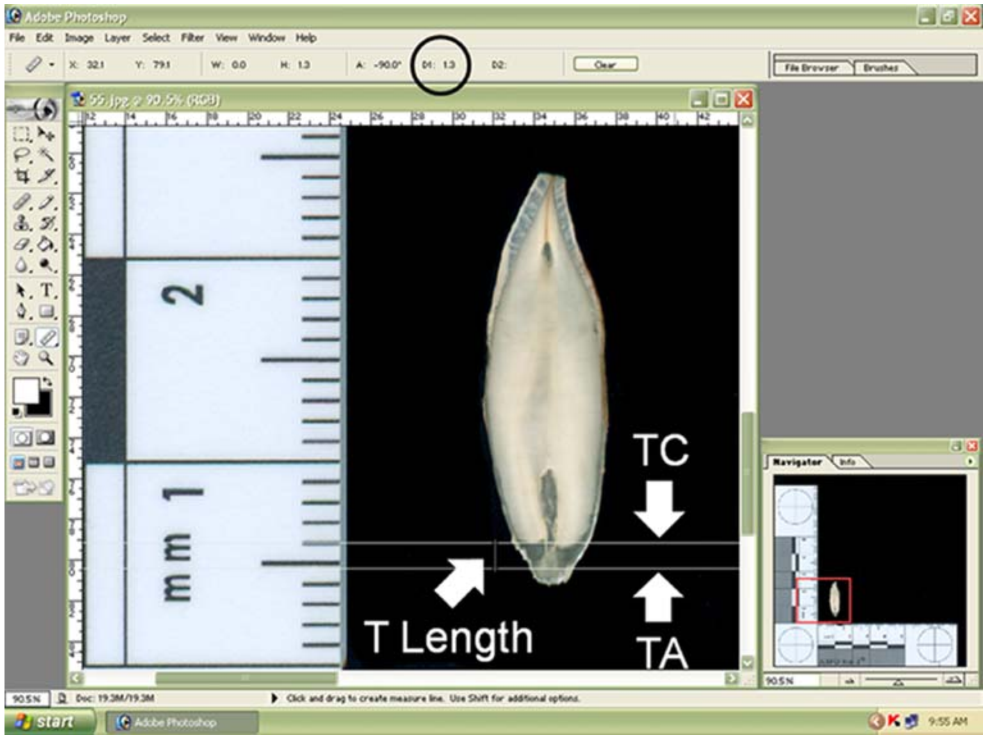

Fig. 1 Once the scanned image is imported to Photoshop, the in-built ruler is activated along the edges of the image (View> Rulers, or Ctrl+R, or Command+R). Guides are placed by clicking on the ruler and dragging on to the coronal (TC) and apical (TA) extent of translucency. Using the measure tool on the toolbox, a line is drawn between the guides to obtain the translucency length (T Length). This length (in mm) may be viewed in the options bar (*encircled*)

Office 2007 Excel spreadsheet. This difference or 'error' was compared between the methods and to those reported in the original study [16] in two aspects:

1. Mean absolute error (MAE), which is the average of the absolute values of the error
2. Number/percentage of estimates with errors <±10 years.

MAE is the average magnitude of error in a set of predictions and has been used as a measure of accuracy of age estimation methods [25], while an error <±10 years is considered as "acceptable" in forensic age estimation [17] and is the range given most often in forensic age estimation and also the error usually associated with age at death assessments [26].

In the event that the MAE and errors <±10 years using Bang and Ramm's formulae in the present sample is recognizably inferior to that in the original study [16] and also if the age estimates obtained in Indians using the other formulae [15, 18, 22–24] are substandard to those obtained using Bang and Ramm's equations, linear and quadratic regression formulae for Indians will be developed (applying the SPSS 10.0 program). The Indian formulae will be applied to a control sample to ascertain whether population-specific formulae enhance age prediction.

Results

Repeat measurements showed minimal intra- and inter-observer differences, which were statistically insignificant (Table 2). Application of the different formulae on Indians showed that Bang and Ramm's equations yielded the best age estimates (Table 3). However, age estimates on the Indian sample using Bang and Ramm's formulae revealed a larger MAE compared to the original study (Table 3), also fewer estimates had errors <±10 years. Considering the wide variations, regression analysis was performed to obtain formulae suitable for the Indian sample. The coefficients and regression equations are presented in Table 4. Figure 2 depicts the linear and quadratic regression lines and the relationship between individual measurements and age. The relationship was statistically significant for both types of regression analyses but higher for quadratic regression (Table 4).

Efficacy of the Indian formulae in estimating age vis-à-vis Bang and Ramm's formulae was tested on a control group (n=18), which included incisors, canines, and premolars from both jaws. The teeth were derived from 18 subjects in the age group 21–70 years (mean=51.22). Since translucency length in these sections was ≤9 mm, the quadratic regression equation only was applied (in accordance with Bang and Ramm's [16] approach). The Indian

Table 2 Paired *t* test evaluating intra- and inter-observer variation in measuring translucency length

Examination	*n*	*t* Value	*p* Value
Intra-observer	40	−0.172	0.87
Inter-observer	100	−1.796	0.08

Table 3 Age estimation outcomes in the Indian sample (n=100) using diverse formulae as well as results in the original study

Formulae applied	MAE (years)	Errors<±10years
Bang and Ramm [16]	11.12	56% (56/100 cases)
Miles [15]	13.31	44% (44/100 cases)
Olze et al. [18]	12.57	46% (46/100 cases)
Valenzuela et al. [22]	11.78	41% (41/100 cases)
Brkic et al. [23]	14.04	39% (39/100 cases)
Foti et al. [24]	12.57	46% (46/100 cases)
Original Norwegian results [16]	6.47	79.2% (19/24 cases)

formula produced more age estimates with smaller errors and with a lower MAE (Table 5).

Discussion

Bang and Ramm's [16] description of estimating age from translucency length is one of the most comprehensive on the topic and assessed >900 teeth from 265 subjects. Both intact and sectioned teeth were used with no apparent differences in terms of correlation to age; however, it was observed that sections offered better detail for examination [16], which influenced its use in this study. Furthermore, there were sufficient numbers of different tooth types, which allowed for construction of tooth-specific formulae. The preceding features of their study, e.g., (1) detailed methodology, (2) large sample size, and (3) tooth-specific formulae, prompted us to apply the method to estimate age in Indians.

Repeat measurements revealed insignificant differences within and between examiners (Table 2). This indicates not only that translucency length is amenable to multiple observations across examiners but also that the digital approach used in this study is conducive to repeat assessment. Bang and Ramm's formulae gave better age estimates than the formulae derived from other studies (Table 3). The formulae in some of these studies were developed from comparatively small samples (n, ~30–70) [18, 22, 24] which were not always well distributed across different age groups (e.g., [24]). In contrast, Bang and Ramm's [16] tooth-specific formulae were developed from a large sample that was well distributed across diverse age groups, which probably contributed to better results. Hence, Bang and Ramm's formulae appear to be more suitable for age prediction in Indians.

However, the MAE obtained using Bang and Ramm's formulae in Indians was close to twice that of the original study (Table 3) and the percentage of "acceptable" errors (i.e., errors<±10 years) was also considerably lower than in the original Norwegian sample (Table 3). This is in contrast to previous reports, e.g., in another Norwegian sample, 76% of age estimates had errors <±10 years while the mean error reached 4.74 years [17]; in a German sample, estimates with errors <±10 years was 70%, and the MAE was 7.3 years [18]. In a South American sample, mean error was relatively higher at 8.77 years [19] but still lower than ours. These figures suggest that Bang and Ramm's formulae may not be as useful in Indians as it is on other populations. Hence, regression analyses were performed to derive new Indian formulae. Applying the Indian formulae on the 100 sections produced an MAE of 10.2 years, while 61% of age estimates had errors <±10 years, which is an improvement over Bang and Ramm's formulae. However, since the formulae were derived on the same 100 sections, the age estimates therein can be construed as being biased. Hence, the utility of the Indian formulae in age assessment and their potential advantage over Bang and Ramm's formulae was tested in a control group.

Applying the Indian formula in the test sample produced a comparatively lower MAE (~8 years) as well as more age estimates with smaller errors (Table 5). Therefore, the Indian formula estimates age better, albeit marginally. Solheim and Sundnes [17] considered errors <±10 years as "acceptable" in forensic age estimation, and Solheim and Vonen [27] recently stated that variations of approximately ±10 years are normal for most dental age estimation methods. Schmeling et al. [13] have categorized age estimation methods that produce mean errors of 6–8 years as "moderately good," and the MAE obtained using the Indian formula can also be considered as such (Table 5). These

Table 4 Coefficients and formulae derived from regression analyses

Regression analysis	n	r/multiple r	Regression equation/formula
Linear regression	100	0.55*	$Age = 35.5619 + (3.4828 \times T)$
Quadratic regression	100	0.60*	$Age = 29.9074 + (7.4507 \times T) + (-0.4369 \times T^2)$

*$p<0.001$

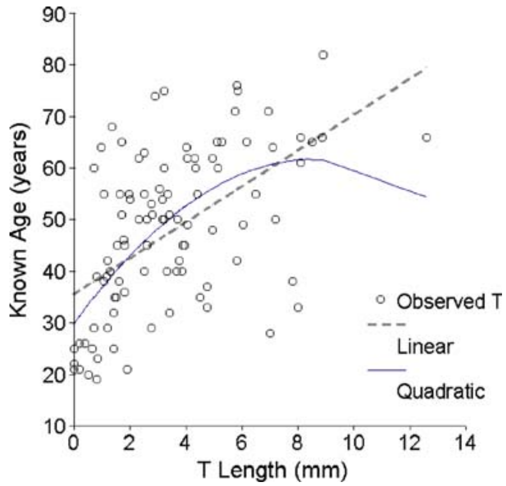

Fig. 2 Scatter plot showing correlation of translucency length to age and the linear and quadratic regression lines

support the use of population-specific formulae, in accordance with Ubelaker and Parra's conclusion [19]. Furthermore, since only one Indian linear/quadratic equation exists, it is more convenient to use, as the same formula can be employed irrespective of tooth type, unlike Bang and Ramm's tooth-specific formulae. Valenzuela et al. [22] had also proposed such a "universal formula" for dental age estimation, which they believed was easy to use in forensic cases. While Bang and Ramm's [16] utilization of tooth-based formulae can be perceived as a drawback in terms of convenience of use, they are able to produce estimates that are comparable to that of the Indian formula (Table 5). It has been observed recently that population variations have only a limited effect as far as Bang and Ramm's method is concerned [19]. The use of a large sample and tooth-specific regression formulae are probably responsible for such robustness. As an analogy, one may infer that use of >100 sections and constructing tooth-specific formulae could yield Indian equations with the potential to estimate age even better.

It should also be noted that regression analyses resulted in statistically significant although moderate coefficients (Table 4). The larger coefficient for quadratic regression indicates that a nonlinear/curvilinear relationship exists between translucency length and age (Fig. 2). Such a relationship implies that the progression of translucency with age is not uniform—there is a tendency for it to slow down as age advances, particularly after 60 years. Bang and Ramm [16] made similar observations and believed that most of the root becomes translucent by that age, beyond which further increase in translucency is impeded. Furthermore, it appears that translucency length begins to decrease after ~60 years of age (Fig. 2). This was noted by Bang and Ramm as well [16], who ascribed it to proportionally fewer teeth from older individuals in their sample. Such an explanation, however, may not apply to our sample where >60-year-olds constituted 25% of the subjects (Table 1). Separate regression analysis for this age group showed a positive but weak and statistically insignificant relationship (r=0.14, p=0.49). This indicates that translucency length does not have a tendency to decrease per se but slows down after 60 years, reaffirming that it plateaus in old age. Overall, research attempting to associate dentin translucency length and age must consider quadratic regression besides its linear equivalent, since the former gives a more realistic assessment of the relationship.

Table 5 Errors of age estimation on the control sample (n=18)

Method	MAE (years)	Errors<±10years
Indian formula	8.29	12/18 (66.7%)
Original formulae [16]	8.61	11/18 (61.1%)

Despite the advantage of curve estimation, regression analyses produced only moderate coefficients compared to other studies, particularly European, which suggests that population differences underlie such modest relationships. Among Europeans, the coefficient of Thomas et al., r=0.59 [28], is the only coefficient comparable to ours. Indeed, except for two other observations [22, 24], most studies on Europeans have correlations of 0.70–0.91 [15, 16, 18, 20, 29], which is also reflected in an American sample (r=0.73) [19]. On the other hand, correlations for Indians range from 0.55 in our sample to 0.62 [20] and 0.86 [30]. The latter 2 studies utilized 28 and 25 samples, respectively, originating either from predominantly older [20] or younger age groups [30]. In our sample, a preliminary test on 22 sections mostly from older age groups produced a higher correlation (r= 0.68). Hence, it is plausible that unequal distribution of subjects across different age groups in relatively small samples gives erratic correlation. The 100 sections used in this study is the largest Indian sample examined to date; it includes a reasonably equal distribution of age groups, sex, and tooth type (Table 1) and could serve as a more representative sample of the country. Hence, based on the r/multiple r values obtained in this study (Table 4), one may state that Indians have a moderate correlation of translucency length to age.

It does appear that other Asian samples also exhibit moderate correlation: Whittaker and Bakri [20] report r= 0.66 and 0.61 for Malays and Chinese, respectively. While the number of Asian populations examined is still relatively few and the sample size within each comparatively small, available evidence suggests that Asians, as a whole, have a lower correlation than Europeans and Americans, the reasons for which may be a combination of genetic and environmental effects. Moderate correlation among Asians, in general, and Indians, in particular, may undermine accurate age assessment.

Conclusion

The study revealed that the age determination formulae of Bang and Ramm [16] may not be very suitable for estimating age in Indians, indicating the need to develop population-specific formulae. The Indian formula developed proved better in terms of accuracy as well as a larger number of acceptable estimates. However, the MAE was only marginally better than Bang and Ramm's formulae, probably since these authors used a very large sample and tooth-specific equations for age assessment. To further enhance age prediction using Indian formulae, still larger samples may need to be examined and tooth-specific formulae derived. However, moderate correlation of translucency length to age inherent in Indians may contribute to suboptimal age estimation.

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