Age estimation by Gustafson method and its modifications.

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Abstract : *Estimation of the human age is a procedure adopted by anthropologists, archaeologists and forensic scientists. Different factors have been used for age estimation but none has withstood the test of time for adults above 25 years. Since 1950 the gustafson method is used by many researcher, in its original form or after its modification to estimate age of a person using teeth. We reviewed such studies on age estimation which used the gustafson method or its modifcation to calculate the age from teeth of the person. Also we reviewed the development and modification of Gustafson's method and various new formulae derived by the different researcher over the time.*

Keywords : Age estimation, Age from teeth, Gustafson method, Physiological changes in teeth

INTRODUCTION

Estimation of the human age is a procedure adopted by anthropologists, archaeologists and forensic scientists. Different factors have been used for age estimation but none has withstood the test of time for adults above 25 years[1].

Teeth in many ways form a unique part of human body e.g. they are most durable and resilient part of the skeleton. "Forensic Odontology is a branch of odontology which deals with the proper handling and examination of dental evidence and with proper evaluation and presentation of dental finding in the interest of justice"[2]. Amoedo, who has been called the father of Forensic Odontology incorparate many of the concepts of dental identification of the bazaar fire into the text, " L'Art Dentaire en Medecine Legale", published in French in 1898[3]. It has now been clearly established that dental evidence can be invaluable in personal identification and criminalistics. In the eyes of most law enforcements agencies and courts, it is valid and reliable method, ranking favourably with other methods of comparison such as fingerprints and blood grouping procedures[4].

Although, Forensic Odontology is a relatively small specialty, has been utilized for many years especially in establishing identity. The first reported crime in the history of mankind was solved when bite marks were discovered in the remains of the forbidden fruit in the Garden of Eden and identified as those of the Adam and Eve[3].

At no time during life of an individual is a tooth unit static. It is constantly undergoing changes of one sort or another e.g. eruption, tilting or even lateral movement through jaw. The epithelium of mouth on crown of teeth also moves rootwards. Other changes which are appreciable with increasing age are attrition, peridontal disease, deposition of secondary dentine, root translucency, cementum apposition, root resorption, color changes and increase in root roughness. By taking in consideration these secondary changes in teeth with advancing age various studies were done to estimate the age of an individual. Such research has resulted in multifactorial methods that help in age estimation.

The amount of abrasion of enamel tissue, the shrinkage of pulp tissue, and the apposition of cementum tissue layers around the root structure was found to be in direct proportion with dental aging[6].

From the teeth along with the estimation of age, the social status of the deceased persons may be found out from the dental restorations of the dental remains, and also may be aproximately dated. In 900 BC, inlays of jade and turquise were made for the purpose of decoration in Mayan culture[7].

In this, we have reviewed various studies on age estimation using teeth and various changes occuring in teeth with age since 1950. Also we reviewed the development and modification of Gustafson's method and the various new formulae derived by the different researcher over the time.

Gustafson's method

Gustafson in 1950[8] was first to note the morphological changes in the structure of teeth that can help in age estimation of an individual. These were attrition, periodontosis, secondary dentition, cementum apposition, root translucency and root resorption. Teeth were grinded using two carborundum, rough and other

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smooth. On microscopic examination, he awarded a score of 0-3 based upon visual severity of changes and estimated age. Scores were calculated and they plotted graph of known age Vs score calculated and regression equation was deduced. The regression formula derived from his observation was: Y – 3.52 X + 8.88 (X = Total Score and Y = Estimated Age). Gustafson established that the difference between calculated age and real age would not exceed +/-3.6 years in 33% of cases, +/- 7.3 years in 4.5%cases, +/-9.1 years in 1% of cases and +/- 10.9 years in 0.3% cases.

Various studies done later using Gustafson method or its modification: Bang and Ramm in 1970[9] used one physiological factor i.e. root dentine transparency in their study and recorded that this change with the age can be used for age estimation. They found a mean error of estimation of ± 4.7 years in 58% cases and ± 10 years in 79% of subjects.

Johanson[10] in 1970 also used same six criteria as used by Gustafson but instead of 0-3 he used seven bands to each factor and found that error was less as compared to previous studies.

Pillai and Bhaskar[4] in 1974 studied 83 anterior teeth collected from 59 cases (36 males and 23 females) and recorded physiological changes in tooth with age and comparison of these changes in males to that in females. Score was calculated and they plotted graph of known age Vs score and regression equation was deduced Y= 5.34 X – 4.08. They also found that the six factors used by Gustafson were age related variable but there was no significant relation with the sex of the person. They found that chewing habits exposed the teeth and surrounding tissue for degenerative changes thus giving rise to higher point value although study proved that whether vegetarian or non-vegetarian doesn't seem to influence the age changes in and around teeth.

Vlcek[11] in 1977 used modification of Gustafson's method in estimating individual age according to the state of teeth in prehistoric bone material. Four markers were ascertained on thick sagittal section of single root teeth in pre-historical material: Degree of dental abrasion (Attrition), Secondary dentine deposition, cementum apposition and dental apex resorption, with score ranging from 0-3 points. By using this method he estimated the ages of Czech rulers from their dental remains with range of +/- 3 years. His modification made possible for anthropologist and Forensic experts to use histological section of Gustafson section in estimating the age both in pre-historical and in recent bone material.

Maples[12] in 1978 improved multiple regression analysis in improvement of age estimation from adult human teeth. He found that not only the estimates were more precise but also involving fewer variables used in Gustafson's method, decreased the probability of observer error. He found that there was consistent evidence that the second molar was the best to use for histological aging techniques. The reduction in variables to just secondary dentine and root transparency has also resulted in technique that can be used with some confidence in populations other than the one sampled.

Maples and Rice[13] in 1979 found that although Gustafson's method was a significant contribution to forensic identification but many statistical errors were present in the published articles. It was improved and new formula was found using multiple regression techniques. Formula derived was Y = 4.26 X + 13.45 (X = Total Score and Y = Estimated Age), (r = 0.912) and value of error as +/-7.03 years.

Solheim and Sundnes[14] in 1980 compared methods of Gustafson's, Bang and Ramm, Miles, Johanson and Dalitz in addition to visual examination of un-sectioned teeth. They calculated the mean error as well as standard error for estimating age by noting the factors in the teeth changing with age. They found that all methods resulted in largest number of over estimates of age were in teeth from persons below 40 years and that too in teeth from males. They also found that there was overestimate of age by these methods when the teeth taken into consideration are from maxilla or extracted from corpses. Underestimation of age from these formulas was found in the case of teeth from persons above 50 years.

Whittaker[15] in 1982 reviewed various method of age estimation and found that beyond young adulthood the age estimation becomes difficult. They found that Gustafson's method was quite satisfactory in estimation. It was suggested that most sensitive indicator of age estimation is the degree of development of translucent dentine at the apex.

Singh and Mukerjee[16] in 1985 used same Gustafson's six criterias of secondary changes in the in elderly person and conducted study using one central incisor, one canine and one premolar in total of 150 cases out of which 114 males and 36 females. So, in all 450 teeth were studied. They ranked these factors 0 to 3 score and calculated the age using this score. In 61.3% of total cases studied the error came out to be 4 years, 27.3% cases error was 5-7 years and in 11.4% cases error came above 7 years. The regression equation computed by was Y = 6.26 X – 6 (where X = Total Score and Y = Estimated Age). They found that error in estimation using this study was found +/- 4.9 years as compared to +/- 3.63 years from Gustafson's method.

Solheim[17] in 1989 studied the apical translucent zone in 1000 human teeth. For each type of tooth, excluding molars, the size of the apical translucency was estimated according to the scoring methods of Gustafson, Dalitz & Johanson. The lengths of the translucent zones were measured on moist and then on dry teeth, both un-sectioned and sectioned, while the areas were measured on dry sectioned teeth only. Statistical analyses using the SPSS package in a Cyber computer indicated a symmetric distribution of the translucent zone in left and right teeth. The extent of the translucency showed little variation from one type of tooth to another. The length of the translucent zone measured on un-sectioned teeth demonstrated in most types the closest relation to age. Multiple regression analyses, including more than one method of measuring the size of the translucent zone, resulted in formulas showing a high correlation with age (from 0.68 to 0.86). Slightly larger translucent areas were found in teeth from males, in darker teeth and in teeth with increased thickness of the cementum. The increase in the translucent zone with advancing age was found to be almost linear and was not affected by periodontal destruction.

Santini, Land and Raab[18] in 1990 measured the amount of tooth wear (one of the factors used by Gustafson) using the Brothwell chart based on the Miles method of ageing. They evaluated the accuracy of simple ordinal scoring in recording tooth wear and ageing skulls. A group of Chinese skulls of known age at death was used. The age range was from 16 to 60 years. A single score per molar tooth was used to record occlusal wear. The data were analyzed by regression methods using BMDP statistical software. The results showed that molar tooth wear continues throughout the life of the individual. The first molar teeth wear significantly more quickly than do second molar teeth. Use of a simple ordinal score method for recording wear gives an inaccurate estimate of an individual skull's age at death with a very wide 95% confidence interval.

Solheim[19] in 1990 examined various ways of measuring cementum thickness, studied its relationship with age, and considered what contribution this factor offered in methods for age estimation. The amount of dental cementum apposition was studied in 1000 teeth, excluding molars, from a Caucasian population. Cementum thickness was estimated according to the scoring methods suggested by Gustafson and by Johanson. In addition, the width of the cementum was measured at the apex and also at approximately one third of the root length from the apex. Statistical analyses using the SPSS package in a Cyber computer indicated a symmetric left/right distribution of cementum thickness. The sum of the cementum thickness on vestibular and lingual surfaces, measured at one third of the root length from the apex, showed the strongest correlation with age (r = 0.40 to 0.65). A reduced rate of cementum apposition was observed in the elderly. Also, maxillary teeth had more cementum on the lingual than on the vestibular surfaces. A tendency was noted for less cementum to occur in women than in men and on teeth removed from deceased persons or extracted for pathologic reasons. Correlation coefficients indicated that, for at least some types of teeth, the cementum thickness might give a significant contribution to statistical methods of age assessment.

Drusini, Calliari and Volpe[20] in 1991 studied root dentine transparency (RDT) was used to estimate the ages of human subjects from 152 intact teeth. Teeth were from 134 subjects, both historical and recent, of known age and sex. Instead of only visual method of scoring done in Gustason's method, they measured RDT by two techniques: 1) computerized densito-metric analysis and 2) vernier caliper. Age estimations based on computerized densito-metric analysis were no more accurate than were those determined by caliper measurement; both give a predictive success of +/- 5 years in about 45-48% of cases for premolars. The television-based digitization system has some disadvantages: It is expensive, not portable, and requires some training to use. However, it furnishes a more standardized method, a rapid graphic illustration of the results, and an immediate storage of statistical information for future use.

Richards and Millar[21] in 1991 studied the teeth wear scores only (ratios of exposed dentin to total crown area). They calculated from dental casts of Australian Aboriginal subjects of known age from three populations. Linear regression equations relating attrition scores to age were derived. They also found that differences in morphology between anterior and posterior teeth are reflected in a linear relationship between attrition scores and age for anterior teeth but a logarithmic relationship for posterior teeth. Correlations between age and attrition range from less than 0.40 for third molars (where differences in the eruption and occlusion of the teeth resulted in different patterns of wear) to greater than 0.80 for the premolars and first molars. Because of the generally high correlations between age and attrition, they found that it is possible to estimate age from the extent of tooth wear with confidence limits of the order of +/- 10 years.

Xu et al[22] in 1991 took 317 upper and lower third molars randomly and divided into working and control samples and used to estimate chorological age employing a method which combined multiple regression analysis of data from Gustafson's method and Maples's scoring system, direct morphological measurement obtained with Kontron image analysis system and logarithmic data transformation. The standard errors of estimate were 2.4-6.8 years in the working sample and 1.9-7.5 years when the derived formulae were tested on control sample, respectively. Compared to previous studies, the method provides a smaller standard error of age estimate from single molar teeth.

Lamendin[23] et al in 1992 proposed a technique to study single rooted tooth. It is based on measurement of two dental features instead of six: periodontosis height times 100/root height (P) and Transparency of the root height times 100/ root height (T). Their sample consisted of 135 males, 73 females, 198 whites and 10 blacks. The sample ranged from 22 years to 90 years. By using formula (A =0.18 x P + 0.42 x T + 25.53, where A =Age in years, P = Periodontosis X 100/root height and T= Translucency height X 100/root height), they were able to calculate the age at death with an error between the actual age and calculated age, of +/- 10 years on their working sample and +/-8 years on a forensic control sample. A comparison of the Gustafson's method and Lamendin methods on the control sample of 39 teeth, resulted in the advantage of the latter considering the mean error on the estimation (14.2 +/- 3.4 years versus 8.9 +/- 2.2 for Lamendin).

Solheim[24] in 1992 also studied that recession of the periodontal ligament has been used as one of several indicators of age in Gustafson's method for age estimation. In a sample of 1000 teeth the relationship between age and periodontal recession was studied for each type of tooth. Only a weak correlation was found, the least weak being for premolars. The mean of the periodontal recession measured in mm showed approximately the same correlation as when assessed by scoring systems. Logarithmic transformation of the mean of the recession resulted in a stronger correlation with age. The use of tooth age rather than individual age did not have the same effect. Periodontal recession tended to be more rapid in males than in females. The correlation of reason for extraction with periodontal recession was not found to be significant. He found that periodontal recession was not sufficiently accurate to be used as a sole indicator of age. However, in multiple regression methods for age estimation it contributes significantly to the age equation, especially for premolars.

Kwak and Kim[25] in 1993 studied 157 extracted teeth. 73 of the teeth originated from males and 84 from females from age groups 12 to 79 years. The correlation coefficient of each Gustafson's criteria in relation to age was carried. Age estimation were performed on 157 teeth according to the method by Gustafson's method and by use of multiple regression, as used by Johanson. After evaluating the six criteria of Gustafson by multiple regression computer analysis, two prediction formulas and standard deviations were compared with each other. They found the following result:

i) Six Gustafson's criteria had strong correlation with age except root resorption and correlation coefficient were r = 0.79 (transparent dentine), r = 0.72 (secondary dentine), r = 0.69 (peridontal change), r = 0.63 (Attrition), r = 0.39 (root resorption).

ii) The age estimation formula by Gustafson's method was calculated as follows: Y = 3.52X + 8.88, r = 0.87, r^2 = 0.76, SD = 8.18, F = 483.56 and $p < 0.01$. The age estimation formula by multiple regression was calculated as follows: Y = 6.37 T +4.63 P + 2.70 S + 2.40 C + 3.08 A + 1.34 R + 8.57, r = 0.89, r^2 = 0.78, SD = 7.82, F = 91.62 and $p < 0.01$. Durbin-Watson Coefficient = 1.09.

iii) In comparison of two estimation formulas, the formula by multiple regression, the method of Johanson (SD = 7.82), was found to be slightly more reliable than Gustafson's method (SD = 8.18).

iv) It was reaffirmed that Gustafson's six criteria could be independent variable in multiple regression analysis.

Solheim[26] in 1993 found that there were several shortcomings in previous studies due to smallness of the material and improvements of the methods were desirable and seemed possible. As a contribution to such improvement various age related changes were studied in a material of 1000 teeth. For each type of change the kind of measurement most strongly related to age was chosen, and a multiple regression analysis was run with age as the dependent variable, using SPSS/PC+ statistical program. Statistically significant formulae were calculated for each type of tooth excluding molars. Because the sex of a deceased body may be unknown and the tooth colour influenced by changes after death, separate formulae excluding these factors were calculated. For the calculated formulae the Pearson correlation (tau) varied from 0.76 in mandibular second premolars (SEX and COLOUR excluded), to 0.91 for maxillary central incisors; a rather promising result compared with other methods. In addition, the inter-correlations between the age-related factors were calculated after control for the effect of age. In some types of teeth, but not in all, some of the factors displayed significant inter-correlation.

Tomaru et al[27] in 1993 estimated the age using attritions of lower incisors. Using the Amano's method, they took records of tooth attritions in the planted state of 83 subjects whose ages ranged from 14 to 76 years. A positive correlation-ship was found to exist between the tooth attrition index and the actual age, allowing establishing the following formula which graphically shows a straight line: $Y = 8.50X + 26.073$ ($r = 0.607$), where X is the mean attrition indexes of lower incisors and Y is the estimated age.

Kvaal and Solheim[28] in 1994 studied age related changes in 452 extracted, un-sectioned incisor, canines and premolars. The length of the apical translucent zone and extent of the periodontal retraction were measured on the teeth while pulp length and width as well as root length and width were measured on the radiographs and the ratios between the root and pulp measurements calculated. For all types of teeth significant, negative Pearson's correlation coefficients were found between the age and the ratios between the pulp and the root width. It was also found that there is correlation between age and length of apical translucent zone but the correlation was weaker than expected while the correlation of age with peridontal retraction was significant in maxillary premolars. The correlation coefficient ranged between $r = 0.48$ to $r = 0.90$ between chronological age and calculated age, using formulae from this multiple regression study. The strongest correlation coefficient was found for the premolars.

Lampe and Roetzscher[29] in 1994 examined 350 teeth of living and /or dead males and females from Heidelberg area, Germany. Using Gustafson's method they estimated the age of these individual, graded all the six factors in similar way with score of 0-3 and then using the regression curve and plotting the score in the graph they calculated the age. They found almost similar result as that found by Gustafson.

Li and Ji[30] in 1995 studied permanent molars and changes occurring with the age i.e. attrition. A total of 633 teeth, including first and second molars of both the jaws, were collected from 57 cadavers and 54 modern dry skulls in northern china. The attrition of the molars was noted and new graduation method (ASA method) was established. Six new equations for the estimation of age were obtained by means of regression analysis. They found maximum error was 4.53 years. The results showed that this Average stage of Attrition (ASA) method can or do reflect the attrition of whole occlusal surface more objectively than some method using only one cusp of the tooth.

Lucy, Pollard and Roberts[31] in 1995 study sample included 53 teeth from 33 individuals obtained from the Oral Surgery Department, St. Luke's Hospital, Bradford. Ages were then calculated using the Maples and Rice (1979) revised version of Gustafson's regression line, Johanson's multiple regression line, and Bang and Ramm's regression lines. The ages predicted using the formulae given by Gustafson (1950), Johanson (1971) and Bang and Ramm (1970) were separately plotted against the chronological age of the donor at extraction (the known age). They studied first the accuracy of the estimation; defined as how closely the predicted ages corresponded to the known ages. This was measured by the statistic of average absolute deviation (referred to as 'average deviation'), which is the average of the difference in years between the estimated age and the known age (irrespective of sign) across the whole sample. They selected average deviation in preference to standard deviation because it gave a direct estimate of the average difference between 'true' and predicted age. After the study they found that using Gustafson's method mean average deviation was of 4.5 years (i.e. the mean value of the average deviation across all 35 samples) while the quoted standard error is of 5.16 years for Gustafson's method. They also found that Bang and Ramm's method seems to produce a noticeably poorer average deviation of 5.15 years, with the quoted standard error being dependent upon tooth type however Johanson's technique offers a small advantage in terms of both accuracy and precision when measurements from a single root are taken as representing one individual. The maximum differences in the estimated age from multiple roots of the same tooth are 11.4 years using Gustafson's method, 16.7 years by Johanson and 12.9 years by Bang and Ramm. The maximum differences in the age estimates for the same individual using multiple teeth are 13.7, 19.5 and 13.8 years respectively.

Carranza and Ubios[32] in 1996 stated that there is gradual increase in the cementum thickness (one of the factors of Gustafson's method) with the increasing age and there is loose linear relation of this increase with increasing age. Loose relation was due to the reason that the cementum apposition is also effected by other factors like disease condition. They found that normal thickness of cementum at coronal half of root was 16 – 60um (i.e. about the thickness of hair). Thickness of cementum at the apex of the root of the teeth is normally

150 - 200µm. Average thickness of the cementum is 95µm at the age of 20 years and 215µm at 60 years.

Gunsolley et al[15] in 1998 did a cross-sectional study of 142 non-smoking subjects and 51 smoking subjects. Subjects could have no more than one tooth with a site of interproximal attachment loss > or =2 mm. Subjects could, however, have attachment loss associated with recession of gums (Periodontosis). For three different methods of summarizing attachment loss measurements at a subject level, including average attachment loss, percentage of teeth with one site of 2 mm of attachment loss, and the percentage of teeth with one site of 5 mm of attachment loss, smoking subjects had approximately twice as much attachment loss than their non-smoking counterparts. Smoking subjects also had significantly greater recession ($P < 0.05$) [0.056 ± 0.017 mm] than non-smoking subjects (0.025 ± 0.005 mm). They found that recession sites occurred primarily on the facial surface of maxillary molars and bicuspids and mandibular central incisors and bicuspids. Their study showed that there is a strong association between smoking and both attachment loss and gum recession in subjects who have minimal or no periodontal disease.

Angyal et al[16] in 2000 examined 42 autopsy cases, aged 18 to 79. After the odontograms were taken, one tooth from each individual was removed from the corpses and examined using both the Gustafson's method and the Johanson's methods for age calculation. The results according to both methods showed a large standard deviation. It suggests the necessity of national database and the reexamination of all of the methods tested on different population samples.

Kim, Kho and Lee[17] in 2000 tested the accuracy of a new scoring system in recording tooth wear for age estimation. Their material consisted of dental stone casts of 383 volunteers who had sound premolars and molars with normal occlusion. The degree of occlusal wear for all premolar and molar teeth was scored with the new system. The high intra- and inter-examiner concordance showed that the new score system was very reliable. The degree of tooth wear showed a significant positive correlation with age in each and every examined tooth of both males and females. Tooth wear scores of males were higher than those of females. Calculating tables for age estimation were designed and the accuracy of age estimation was obtained with the General Linear Models procedures. Their system provided estimation of an individual's age within ± 3 years in 42.4% of males and 49.4% of females, within ± 5 years in 61.8% of males and 63.3% of females. When the subjects were divided into two age groups and data were re-treated, the accuracy of age estimation was increased. Collectively, it was found that new system for scoring tooth wear is a reliable and accurate method for age estimation

Pigno et al[18] in 2001 studied the severity, distribution, and correlations of tooth wear in a sample of Mexican-American and European-American adults drawn from a community-based longitudinal aging study on oral health. The maxillary teeth of 71 subjects enrolled in a longitudinal aging study were assessed using a previously introduced five-point (0 to 4) ordinal scoring system in which each tooth is given a score describing the severity of wear. The tooth wear scores were compared with data concerning demographic factors, functional/para-functional habits, soft drink consumption, and bite force measurements to determine specific correlation with tooth wear. They found that mean wear score for all teeth was 1.50 on the five-point scale. There was a significant difference between the mean wear score of anterior teeth (1.85) and posterior teeth (1.17). Bi-variant analyses detected a moderate degree of correlation between maxillary tooth wear and age and bite force. Maxillary tooth wear was significantly greater in males and in subjects with reported teeth clenching/grinding. Multivariate analyses revealed that age; gender, bite force, self-reported teeth clenching/grinding, and number of daily meals/snacks had significant correlations with maxillary tooth wear.

Selukar, Diwan and Shroff[19] in 2002 conducted study on 77 teeth of known age group out of which 17 were incisors, 9 canines, 33 premolars and 18 were molars. They noted all the six factors of Gustafson's method independently against the age of the tooth. The average was calculated from different index values as Age = [A + D + T + CE] / 4. They found that canines shows more accurate result and their observation suggested that there is significant positive correlation between age of individual and various parameters i.e. attrition, secondary dentine, translucency of root and cementum apposition.

Valenzuela et al[20] in 2002 studied: (1). Measured parameters that contribute significantly to estimates of dental age, using a combination of classic methods and a computer-assisted image analysis procedure to avoid the bias inherent in observer subjectivity; and (2). Development of new mathematical regression models for age prediction according to postmortem interval. Two different populations were studied. Forty-three permanent teeth (Group I), extracted for valid clinical reasons, were taken from patients 25-79 years of age. The other population group (Group II) was composed of 37 healthy erupted permanent teeth obtained from human skeletal remains (age 22-82 years) with a postmortem interval ranging from 21 to 37 years. Morphologic age-related changes were investigated by measuring variables on intact and half-sectioned teeth. Multiple regression analyses were performed with age as the dependent variable for each sample source. They found that in fresh extracted teeth, the variables that made the greatest contributions to predictions of age were dental attrition, dentin color, and translucency width; the latter measured with a computer-assisted image analysis method. They also found that in teeth from human skeletal remains, the variables that made the greatest contributions to age calculation were cementum apposition, pulp length measured by computer-assisted image analysis, dental attrition, root translucency, and dental color. Thus they recommended use of different regression models to calculate age depending on the postmortem interval.

Morzavi et al[39] in 2003 studied 210 teeth ranging between 25 to 60 years including 185 males and 25 females. By using 0.5 – 1 mm section of tooth, determined attrition, periodontosis, root resorption, secondary dentine deposition, cementum apposition and root translucency. They found that among different mandibular teeth, the sum ranks of the first premolars factors had best correlation with the age and also that the sum of the dental factors presented a better model than each of the factors alone. Correlation coefficient of age with attrition, periodontosis, root resorption, secondary dentine, cementum apposition and root translucency was found 0.394 ($p < 0.001$), 0.384 ($p < 0.001$), 0.169 ($p < 0.014$), 0.522 ($p < 0.001$), 0.251 ($p < 0.001$) and 0.344 ($p < 0.001$), respectively.

Soomer et al[40] in 2003 studied the reliability and validity of eight dental age estimation methods for adults. They took 20 teeth, intact or with superficial filings and taken from 10 males and 10 females (known ages ranging from 14 to 95 years, mean age 47.5 years). They used Johanson's method and computed a formula: Age – 5.14 A + 2.3 S + 4.14 P + 3.17 C + 5.57 R + 8.98 T + 11.02. Other methods they studied were Kvaal and Solheim first formula, Kvaal and Solheim second formula, Solheim's method in-situ teeth, Solheim method for sectioned teeth, Lamendin method, Bang's method for extracted teeth and Bang's method for sectioned teeth. They applied ANOVA and Fisher's PLSD post-hoc analysis (t – test) to compare the mean ages error for each 28 possible pairs of methods. They found that sectioned methods gave a better result and with more precision than that from un-sectioned method. It was also seen that Kvaal's original data gave significantly better regression coefficient for that maxillary premolars teeth. In conclusion, each dental age estimation method presented provides a different combination of accuracy, precision, and procedure and require different equipment.

Singh et al[41] in 2004 evaluated physiological changes in the premolar tooth in 30 cases and the six factors used in Gustafson's method. Each factor was allotted a score of 0–3 depending upon degree of changes in the tooth. Total scores were plotted against the actual age and a regression curve and a regression formula y – 4.6696x + 10.381 was derived (where y – calculated age, x – total score). This formula was used to calculate age and the difference from actual age was studied statistically. A mean difference ± 2.16 years was found between actual and calculated age

Reppien et al[42] in 2006 evaluated the reliability of methods used for forensic dental age estimation. Their study included 51 cases and 7 different methods had been used for dental age estimation, with the Bang/Ramm and the Gustafson/Johanson methods being the most frequently applied. They found that there was good agreement between estimated age interval and factual age at death in 37/51 (72%) of the cases. In eight cases the factual age at death deviated up to +/-5 years from the estimated age, and in six cases by more than 6 years. The average difference between factual age at death and estimated age was 4.5 years. They concluded that forensic odontological age estimates are reliable. However, the implementation of the specific methods may need to be adjusted concerning age ranges.

CONCLUSION

1. Different studies included one or more than one factors used in Gustafson's method.
2. Using same factors, different errors were observed as most of these methods used manual examination while scoring physiological changes.
3. Root translucency is most reliable factor in estimation of age, in most of the studies.
4. Implementation of the specific method for age estimation may be adjusted concerning age ranges.
5. Certain habits like chewing tobacco, pan had effect on certain factors like attrition and periodontosis.
6. Regression formulae derived by various methods showed different standard deviation ranging as less as +/- 3years up to +/- 10 years.

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