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ORIGINAL ARTICLE

Do upper third molars provide more accurate age estimation in the adult based on the pulp-to-tooth ratio than lower third molars? A cone-beam CT study

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Abstract *Introduction:* Age-at-death estimation is an essential part of the identification process of individuals in many forensic dentistry cases where identity of the individual cannot be resolved by visual recognition or other means. Dental age estimation in adults is more of a challenge as most teeth complete their development by the age of 18 years.

Aim: This study aims at using the mesio-distal (MD) pulp-to-tooth ratio taken at the cervix of upper third molars (UM3) to estimate age at the time of radiographic imaging.

Materials and Methods: A set of 135 Cone-beam computed tomography (CBCT) radiographs of UM3s for a random sample of 135 Jordanian adults (65 females, 70 males; age range = 18–63 years, mean age = 34.4 years, SD = 11.2 years) were used. Both pulp and tooth MD diameters were measured at the cervix. MD pulp-to-tooth ratios for UM3s were correlated with age.

Results: Statistically significant negative moderate correlation was found between the age of the individual and the cervix MD pulp/tooth ratio (r = 0.516). This indicates that only 26.6% of the variation in age can be explained by the cervix MD pulp-to-tooth ratio.

Conclusions: This study concludes that cervix MD pulp-to-tooth ratio of UM3s, although apparently stronger than that of lower M3s (r = 0.361), is not a sufficiently reliable estimator of

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age in adults, and this is perhaps attributed to the greater variability in the time line of third molars development.

1. Introduction

Precise estimation of age-at-death of unidentified persons from their body and/or dental remains is of vital significance in numerous forensic cases. This is especially important when such data is required to assist police science investigators in identifying the person to whom the remains belong (Gupta et al., 2014; Panchbhai, 2011; Verma et al., 2014). Instances of such cases comprise identification of deceased individuals involved in criminal cases and the tremendously disfigured victims of mass catastrophes such as natural disasters, accidents and deadly attacks (Gupta et al., 2014; Verma et al., 2014). Besides, age estimation using teeth is of key significance for age-at-death valuation of human skeletal remains found in archaeological sites (Maber et al., 2006). Additionally, age estimation using teeth can also be done on living individuals, predominantly when the information of birth is absent or doubtful, in many instances including premature births, school attendance, adoption, marriage, immigration, orthodontics, pediatric endocrinology, entitlement for welfare aids, disciplinary judgments, and legal prosecution in cases like rape and abduction (Cameriere et al., 2007; Cameriere et al., 2004; Ciapparelli, 1992; Maber et al., 2006; Masthan, 2009a, b; Whittakar and McDonald, 1989).

Teeth are the most robust parts of the body including the skeleton because of their exceptionally high degree of mineralization, and therefore they are almost unaffected to biological deterioration or destruction by external causes like massive traumas and burns (Babar et al., 2008; Carvalho et al., 2009; Ciapparelli, 1992; Holden et al., 1995; Masthan, 2009a; Tobias, 1991). Also, dental remains occasionally are the sole available source of information on which age assessment can be based particularly when the other body remains are tremendously devastated (Gupta et al., 2014; Verma et al., 2014). Furthermore, the assessment of age on the basis of dental development is normally regarded more precise than the one founded on the growth and maturation of the skeleton, especially during childhood and the adolescence period, because dental development is more genetically controlled and thus is less affected by external factors and internal discrepancies such as illness and hormonal disturbances (Ardakani et al., 2007; Babar et al., 2008; Carvalho et al., 2009; Ciapparelli, 1992; Masthan, 2009a; Willems, 2001).

Age assessment based on teeth during adulthood is a challenge. This is due to the fact that most of the teeth have concluded their formation by the early adult period (Panchbhai, 2011; Verma et al., 2014). Nonetheless, there are several methods commonly employed to achieve this objective. These include Gustafson's method (Gustafson, 1950); methods that rely on the development of third molars, such as Harris and Nortje's method (1984) and by Van Heerden' method (1985); a method that relies on dentin translucency (Lorentsen and Solheim, 1989); Kvaal et al. pulp-to-tooth ratio method (Kvaal et al. 1995); Johnson's method (Willems, 2001); a method based on aspartic acid racemization (Avon, 2004; Ritz-Timme et al., 2000); a method that relies on occlusal wear of teeth (Yun et al., 2007); the coronal pulp cavity index method (Drusini, 2008); and a method that relies on incremental lines of cementum where the accuracy is claimed to be 2–3 years (Aggarwal et al., 2008). Generally speaking, the methods that rely on the development of third molars or on attrition are regarded inconsistent for the estimation of age in the adult. On the other hand, the methods that depend on incremental lines of cementum, the ratios of the pulp to the tooth, occlusal dental wear are regarded consistent, and the most precise ones are those that rely on aspartic acid racemization and dentin translucency (Gupta et al., 2014; Verma et al., 2014).

There are two forms of physiologic dentin: primary dentin that is secreted prior to completion of root formation, and secondary dentin that is deposited subsequently and continues to be secreted in smaller increments throughout life (Panchbhai, 2011). Both of these forms are secreted in the direction of the tooth center and, thus, leading to a gradual reduction in the size of the tooth pulp. The quantity of secondary dentin formed was found to be positively correlated with age (Bodecker, 1925). It has been argued that age has greater influence on secondary dentin formation than attrition or irritation because more secondary dentin is normally secreted on the floor of the pulp chamber of the tooth crown than on its roof (Drusini, 2008). Therefore, it is assumed that age can be consistently assessed on the basis of the ratio between the total thickness of dentin and the diameter of the pulp at the corresponding cross sectional level of the tooth.

The general agreement in the field of forensic odontology is that in order to achieve the most accurate age estimates is to employ as many reliable methods and techniques of dental age estimation as applicable to the case in question (Gupta et al., 2014; Panchbhai, 2011; Verma et al., 2014). There are no previous published studies about the use of pulp-to-tooth ratio of upper third molars in estimating the age of the individual. Therefore, the authors believe that this method would be a useful supplement to the existing methods of dental age estimation.

The current study aims at assessing the reliability of age estimation in the adult on the basis of ratio between the diameters of the pulp and the tooth at the cervix of upper third molars (UM3), similar to our previous study that utilized lower third molars for this purpose (Alsoleihat et al., 2017).

2. Materials and methods

The present study used a random sample attained in 2016 consisting of 135 selected cone beam computed tomography (CBCT) radiographic images of upper third molar teeth of 135 adult Jordanians (65 females and 70 males) who sought clinical treatment at the Dental section of the Jordan Univer-

sity Hospital. These CBCT images were taken for therapeutic purposes and not for the sake of this research. All CBCT scans were taken using mode I: 0.2 mm voxel size. It is essential in studies assessing the association between age and reduction in the size of the pulp to ensure that the used sample encompasses individuals from a wide spectrum of socio-economic background so as to optimize the representativeness of the used sample for the target population. This is because of the possibility that the lower socioeconomic classes may show developmental patterns, including dental development and dentine formation, which are different from the upper classes.

The age range of the selected individual of the sample was between 18 and 63 years (SD = 11.2) and the mean age was 34.4 years. All selected individuals were subjected to the following selection criteria: (1) healthy without any history of severe diseases that might have adverse impact on dental development, (2) no anomalous development, such as ectodermal dysostosis, craniofacial clefts or syndromes, and (3) and having un-erupted upper third molars or erupted ones but not in occlusion, having normal morphology, and do not show signs of caries or attrition. Upper third molars that are in occlusion were not included in the study sample as it is not yet addressed whether the rate of secondary dentine formation varies when the tooth becomes functional. Medical and dental accounts for the participants were checked to strengthen the accurateness of the inclusion criteria. The participants voluntarily elect to take part in the study. Informed written consent was attained from each participant. The necessary ethical approval for this kind of research was sought from and granted by the Ethical Committee of Jordan University hospital/University of Jordan before starting this study.

All selected upper third molar images were cross-sectioned at the cervix level (crown-root junction). At this level, the mesio-distal (MD) diameter of the tooth and the MD diameter of the pulp were measured for each tooth image using a computer program that is compatible the Cone beam CT program (ONDEMAND software). For each tooth image, the proportion between these two diameters was computed. The measured MD diameter of the tooth was defined as the maximum distance between the mesial and distal peripheries of cervical cross-section of the tooth image. Similarly, the MD pulp diameter was defined as the maximum distance between the mesial and distal peripheries of the pulp taken at the same cross-sectional level. All of the measurements taken were rounded to the closest 0.01 mm.

All of the measurements were taken by one well-trained observer to avoid inaccuracies caused by inter-observer dissimilarities. Moreover, all of the measured variables in the current study were re-measured by the same observer. Intra-observer reliability for the measurements was assessed using the SPSS Intra-class Correlation Coefficient (ICC) statistic which assesses the degree of association between the two measurement sessions.

The data were analyzed using the SPSS (SPSS, Version 17.0, Inc., Chicago, IL). Pearson's correlation coefficient test was used to evaluate the strength of association between the following variables: (1) age of the individual, and (2) the ratio between MD pulp and tooth diameters at the tooth cervix. According to Cicchetti (1994), Pearson's correlation coefficient values in the range of 0–0.39 were considered weak, 0.40–0.59 moderate, 0.60–0.74 strong, and 0.75–1 very strong correlation. Correlations were regarded as significant statistically if the respective p-values were less than 0.05.

The CBTC images used in the current study are kept at the School of Dentistry of the University of Jordan.

3. Results

The ICC between the two measurement sessions for the two variables used in the current study, MD diameter of the tooth and MD diameter of the pulp, was found to be respectively 0.91 ($p = 0.000$) and 0.93 ($p = 0.000$). This demonstrates that the intra-observer differences are negligible and insignificant statistically for both variables considered.

A moderate negative and statistically significant correlation was found between the age of the individual and the ratio between the pulp and the tooth MD diameters of the UM3 cervix ($r = 0.516$, $p = 0.000$). Therefore, UM3 MD pulp-to-tooth ratio at the cervix can statistically significantly predict the age of individual. Nonetheless, the age of individual explains only 26.6% of the variability in UM3 MD pulp-to-tooth ratio at the cervix. The correlation coefficient for UM3s was statistically significantly greater than the one previously found for LM3s (Table 1).

4. Discussion

The Dental section of the Jordan University Hospital is one of the key referral centers for complex dental management including third molar teeth extraction in Amman which is the capital city of Jordan. According to the 2015 Population and Housing Census conducted by the Department of Statistics in Jordan, Amman is the most populated city in Jordan, where about half the Jordanian populace resides. This census, also, showed that a large percentage of the inhabitants of Amman originated from other geographic areas of Jordan. Despite the fact that the dental treatment at this center is comparatively costly, it is available to all referred patients irrespective of their socio-economic level. This is largely because most of the costs of such dental care are funded by a variety of medical insurance types. Even those who are not covered by any type of such insurance are sponsored by the Royal Exemption Support Scheme. Accordingly, even the disadvantaged people in Amman have accessibility to this affordable dental treatment. Therefore, the authors consider the sample adequately representative of central Jordan.

The cervix of the tooth was selected in this study since the thickness of both enamel and cementum is almost negligible at this level. Consequently, the diameter of the tooth at the cervi-

Table 1 Comparison between upper and lower third molars in term of age prediction based on Pulp-to-Tooth Ratio taken at cervix.

	Upper third molars	Lower third molars	P-value
Number of subjects	135	155	–
Age range (years)	18–63	18–58	–
Mean age ± SD (years)	34.4 ± 11.2	28.2 ± 10.0	0.00[a]
Correlation coefficient	0.516	0.361	0.05[a]

[a] Statistically significant at the 0.05 provability level (2-tailed).

cal level is almost equivalent the total thickness of dentin plus the diameter of the pulp.

In general, it is agreed on within the arena of forensic odontology that the most valid age estimates can only be accomplished by employing a multifactorial methodology, which means using as many reliable techniques and methods of dental age estimation as pertinent to the particular case (Gupta et al., 2014; Panchbhai, 2011; Verma et al., 2014).

Also, it is well recognized that tooth development exhibits differences not only between individuals of diverse regional groups but also between individuals of the same population (Achary and Sivapathasundharan, 2009; Ciapparelli, 1992; Kuritai et al., 2007; Olze et al., 2005). Consequently, it is advised that any dental age estimation method, even the most consistent ones, ought to be used for the same population or regional group of origin, and this is to minimize the possible under- or overestimation of age (Achary and Sivapathasundharan, 2009; Ciapparelli, 1992; Kuritai et al., 2007; Olze et al., 2005). In this context, we emphasize that age estimation for forensic purposes, in contrast to age estimation for clinical purposes, needs to be of optimum accurateness, since possible under- or overestimation of age may result in an injustice (Ardakani et al., 2007; Ciapparelli, 1992; Karjodkar, 2009; Panchbhai, 2011). Therefore, forensic age estimation mandates the following requirements: taking proper radiographic images and samples from the individual considered, the careful choice of the proper method of age estimation relies on the understanding of the method and its appropriateness to the individual considered, as well as understanding and acquiescence of the legal requirements (Ciapparelli, 1992; Panchbhai, 2011). In this regard it is vital in the present method to control for tooth angulation as it may impact the MD distance at the cervix of the tooth and the pulp. Therefore, it is important to use the proximal contact points as reference guide in the vertical plane to determine the MD plane of measurement at the cervix of the tooth and the pulp. In other words, the MD plane of cervical measurement should be parallel to the MD plane passing through the mesial and distal contact points of the tooth.

Because the age estimation method of the current study is based on measurements performed on CBCT images, it is regarded more beneficial than the ones based on measurements conducted on histological sections and therefore critiqued for their invasiveness and inappropriateness for age estimation in living individuals and in some dead cases.

Since the sample size of the current study is limited (65 females, 70 males), it was not possible to treat males and females differently. While it may not be possible to identify the sex of a victim from severely damaged skeletal and soft-tissue remains teeth frequently withstand such a damage. Van Heerden (1985) reported no significant differences between sexes in the timing of development of third molars. Moreover, most methods of dental age estimation tend to rule out gender as a delineating factor. Therefore, this may help justify the non-gender specific approach of age estimation presented in the current study. Nevertheless, some age-specific methods have been reported in the literature including those of Nolla (1960), Demirjian et al. (1999), and Solari and Abramovitch (2002).

Based on the value of the correlation coefficient (r = 0.516), the correlation between age and the MD pulp-to-tooth ratio taken at the cervix of the tooth is moderate. Furthermore, the coefficient of determination (R squared = 26.6%) is fairly low and indicates that the pulp/tooth value only explains 26.6% of the age variation. Consequently, age estimation based on this method may be significantly biased. Moreover, it is known that when the absolute value of correlation coefficient is less than 0.9 (based on Bocquet-Appel and Masset (1982), the estimates of age based on equations derived from inverse regression analysis would be significantly affected by the age distribution of reference sample of the study on which the regression was conducted. In general, when the reference sample is dominated by young individuals, as is the case in the present study (average age: 34.4, age range: 18–63 years old), the age-estimation equation tends to underestimate ages while the opposite is true if the reference sample is prevailed by older individuals. The degree of such inaccuracy is dependent on the degree of dissimilarity between the age composition of the reference sample and that of the target population. Besides, it has been noted that age-estimation equations derived from regression analysis tends to underestimate ages in the adult and overestimate them in the Juvenile (Aykroyd et al. 1997). Consequently, it is vital in such cases to clarify the potential inaccuracies and limit the range of use of such a method to certain situations where the likely age range is anticipated to be less than 40 by other methods of age assessment. Nevertheless, if this choice is to undermine the value of such method, another possibility is perhaps a Bayesian approach. Furthermore, if the main problem here is attributed to the greater variability of third molars in their morphology and/or development time line, adopting a tooth type with smaller variation in tooth morphology might be a better option. It is also noteworthy to mention that the results of the present study concur with the those of a previous similar study (Alsoleihat et al., 2017) that utilized lower third molars and found that they were even less indicative (r = 0.361) of age than upper third molars.

In criticism, the authors understand that the sample size in this type of research should be maximized to ensure randomization. Therefore, all CBCT scans available that met the inclusion criteria were included in the study. However, we are restricted by the availability of CBCT scans that are already requested for therapeutic purposes.

5. Conclusions

Since the coefficient of correlation value found in the current study for the upper third molars is intermediate (r = 0.516), and then the MD pulp-to-tooth ratio taken at the cervix of the tooth can only explain about one-quarter (R squared = 26.6%) of the variability in age. This value is not high enough to be recommended for use in forensicodontology, and methods with such values are not in accordance with the *Daubert* standard. Consequently, it was decided that the mesio-distal pulp/tooth value taken at the cervical level of upper third molars is not a sufficiently consistent estimator of age in adults. This is perhaps attributed to the greater variations of third molars in their morphology and/or their development time line. Should these factors be confirmed as the source of the problem, another tooth type with less variation might be worth considering.

Declaration of competing interest

The authors declare no potential conflicts of interest in the present study.

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