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PAPER

ODONTOLOGY

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Age-Related Changes in Pulp Cavity of Incisors as a Determinant for Forensic Age Identification

ABSTRACT: To find a simple and convenient method for age identification upon age-related pulp cavity narrowing, the mesiodistal diameters of the cervical pulp chamber, the middle and terminal parts of the root canal of the pulp cavity of 620 incisors were measured on radiographs taken *in situ* in 80 Chinese aged from 15 to 80. It was shown that the three mesiodistal diameters significantly decreased in a negative linear relationship with age ($-0.4233 \leq r \geq -0.8465$) in all incisors, but the narrowing velocity of the cervical pulp chamber and the middle part of the root canal in the maxillary incisors ($b = -0.02$ mm) was faster than that in the mandibular incisors ($b = -0.01$ mm). Accordingly, a mathematical model describing the ages as a function of any one of the three mesiodistal diameters of the pulp cavity was deduced, which would be useful for age identification in forensic medicine or archaeology.

KEYWORDS: forensic science, dental pulp cavity, age-related changes, age identification, incisor, dental radiography

Age identification of living or dead individuals is an important aspect of forensic sciences. Most of the techniques reported in literature for age estimation are based on the tooth because it is the hardest structure in the human body which undergoes age-related physiological changes throughout life and shows the best resistance against postmortem alterations caused by humidity, high temperature, microbial activities, and mechanical forces.

The pulp cavity is the central hollow of a tooth consisting of the pulp chamber in the dental crown and cervix, and the root canal in the dental root. It contains the fibrovascular dental pulp composed of connective tissue, blood vessels, nerves, and lymphatics. The pulp cavity is lined throughout by the odontoblasts capable of depositing the dentin on the inner aspect of the wall of the cavity (1–3). It is well documented that after tooth eruption, the volume of the pulp cavity gradually decreases with age because of the secondary dentin deposition in the pulp cavity wall (4–7). Therefore, the morphological changes in the pulp cavity or/and in dentin accumulation serve as one of the most promising predictors for age estimation. Since Gustafson (8) first reported the characteristics of six age-related changes including the narrowing of the pulp cavity, numerous investigations have been made for the same purpose using various techniques such as visual examination by microscope (9–12), dental radiography (13–18) and micro- or cone-beam computed tomography (CT) analysis in 3D (19–21). Among these techniques, only the images of dental radiography and cone-beam CT can be obtained from living individuals without tooth extraction; and in comparison with the cone-beam CT, the dental radiography is a convenient, simpler, and much less expensive method for a legal medical expert to use practically in various situations.

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By measuring 620 incisors on X-ray photographs taken from 80 healthy Chinese with different ages, the present study provided detailed quantitative data about the morphological changes in the human incisor pulp cavity with age. This information would be a very useful reference for root canal therapy (22–25) clinically and for age identification of the skeletal remains in archaeology and forensic medicine.

Materials and Methods

A preanalysis test showed that there were no significant differences between the measured values of teeth from the male and the female in the same age groups. Consequently, in the present study, the data in the same age group were from both sexes.

A total of 620 incisors were measured on radiographs taken in 80 healthy local residents (15–80 years old with integrated dentition and good occlusion) from the mid-southern part of China. The age and gender distribution of the investigated persons is shown in Table 1. Each incisor was radiographed *in situ*. To ensure that mesiodistal plane of the tooth is parallel to the film, the dental film (30×40 mm; Meisheng Med Sci Tech CO, Fujian, China) was directly put on the lingual aspect of the tooth. The X-tube was situated at right angles to the long axis of the tooth with a distance of 50 mm from the film. The graphs were developed according to the standard protocol provided by the manufacturer and scanned with a film scanner. The measuring was performed by one person on the amplified digital images of the dental films with image analysis software (Scion Image B402, Scion Corporation, Frederick, MD) after calibration with a rediograph taken from a standard 1 cm metal bar. The mesiodistal diameters of different parts of the pulp cavity were measured at three selected levels: the mesiodistal diameter of the cervical pulp chamber at the cementoenamel junction, the mesiodistal diameter of the middle part of the root canal at 1/2 distance from the cementoenamel junction to the root apex, and the

mesiodistal diameter of the terminal part of the root canal at the level of 0.5 mm apart the apex (Fig. 1*A*). The data were statistically analyzed by ANOVA with scientific statistic software (SigmaStat 3.5; Systat Software Inc., Chicago, IL). If the differences between the means of the mesiodistal diameters were found significantly important among different age groups, a correlation analysis was performed to analyze the relationship between the average values of the diameters and the corresponding ages. To test for reproducibility of the measurements, 10 radiographs were randomly selected and remeasured by the same observer. A paired *t*-test showed that there were no significant differences between the first and the repeated measurements.

TABLE 1—*Age and gender distribution of 80 investigated persons.*

Age Groups	Male	Female	Total
15–	6	7	13
26–	8	6	14
36–	8	7	15
46–	7	8	15
56–	6	7	13
66–80	6	4	10
Total	41	39	80

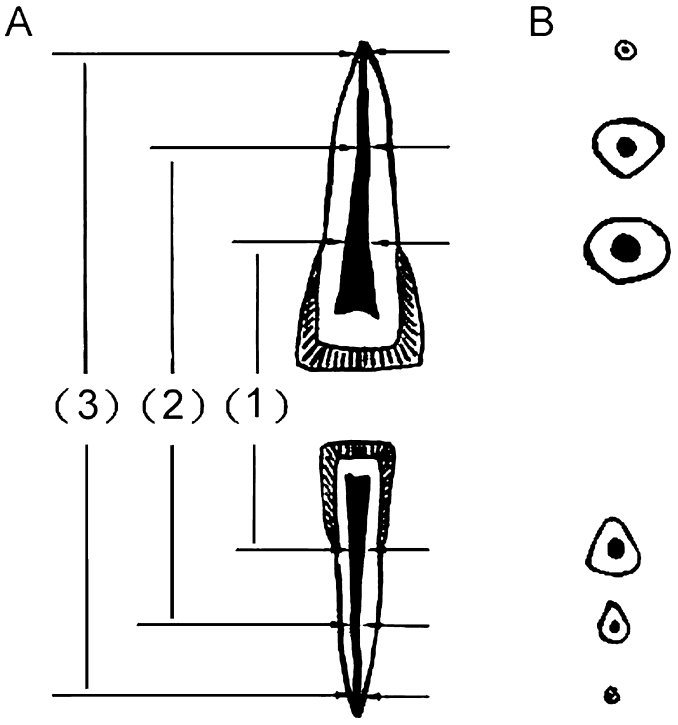

FIG. 1—*Measurements of pulp cavity of human maxillary and mandibular incisors. (A) Mesiodistal diameters of the pulp cavity at three selected levels; (1) mesiodistal diameter of cervical pulp chamber at cementoenamel junction; (2) mesiodistal diameter of middle part of root canal at 1/2 distance from cementoenamel junction to root apex; (3) mesiodistal diameter of terminal part of root canal at the level of 0.5 mm apart the apex. (B) The shape of the transverse sections of pulp cavity at the corresponding levels.*

Results

The average values of three mesiodistal diameters of the pulp cavity of the maxillary and mandibular central and lateral incisors in different age groups are shown in Tables 2–5. For all incisors, the average values of the mesiodistal diameters of three selected parts of pulp cavity were mathematically arranged as the cervical pulp chamber > middle part of root canal > terminal part of root canal, reflecting a long triangular shape of the pulp cavity from the dental cervix to the apex in the mesiodistal plan. The three mesiodistal diameters gradually decreased with age from 15 to 80 years old.

The correlation analysis (Table 6) showed a negative linear relationship ($-0.4233 \leq r \geq -0.8465$) between the changes in average values of the mesiodistal diameters and age. The regression coefficients for the age-related changes in three mesiodistal diameters of the pulp cavity in the maxillary and mandibular incisors were shown in Table 7. Accordingly, a mathematical model to describe the ages (from 15 to 80) as a function of any one of the three mesiodistal diameters of the pulp cavity in ether the maxillary or mandibular incisors was deduced as:

$$Y = 15 + (F - M)/b$$

Here, Y represents the estimated age; F = the average value of one of the three mesiodistal diameters in the age group of 15–; M = the measured value of the corresponding mesiodistal diameter; b = the corresponding regression coefficients.

To test the validity of the formula, another 30 central incisor radiographs (not included in the samples used for the correlation analysis) taken from independent individuals (18–58 years old) were measured, and the estimated age calculated by the formula was compared with the real age of the individuals (Table 8). As shown in Table 9, when taking the mesiodistal diameter of the middle part of the root canal as a predictor, the mean error (difference between the estimated and the real ages) was 0.40 with a 95% reliability range of 0.91 year. When taking the mesiodistal diameter of the cervical pulp chamber as a predictor, there was an increased mean error (1.03) with a 95% reliability range of 2.53 years. The increased error appeared mainly in the young individuals (18–25 years old) (Table 8).

Discussion

It is known that under physiological conditions the volume of the pulp cavity gradually decreases with age because of the secondary dentin deposition in the pulp cavity wall (1–3). To investigate the age-related morphological changes in the human incisor pulp cavity, the present study measured the mesiodistal diameters of three

TABLE 2—*Mesiodistal diameters of pulp cavity of maxillary central incisor in different age groups (mm, means ± SD).*

	Age Groups (Years Old)					
Parts of Pulp Cavity	15– (n = 29)	26– (n = 28)	36– (n = 32)	46– (n = 30)	56– (n = 26)	66– (n = 20)
Cervical pulp chamber	2.04 ± 0.37	2.01 ± 0.30*	1.30 ± 0.32*	1.25 ± 0.33*	1.05 ± 0.20*	1.00 ± 0.12*
Middle part of root canal	1.27 ± 0.19	1.20 ± 0.23*	0.89 ± 0.20*	0.60 ± 0.13*	0.54 ± 0.05*	0.41 ± 0.09*
Terminal part of root canal	0.22 ± 0.06	0.18 ± 0.04*	0.14 ± 0.05*	0.08 ± 0.01*	0.07 ± 0.07*	0.07 ± 0.02*

*$p < 0.05$, compare to previous adjacent age group.

TABLE 3—*Mesiodistal diameters of pulp cavity of maxillary lateral incisor in different age groups (mm, means ± SD).*

	Age Groups (Years Old)					
Parts of Pulp Cavity	15– (n = 24)	26– (n = 28)	36– (n = 31)	46– (n = 28)	56– (n = 25)	66– (n = 18)
Cervical pulp chamber	1.72 ± 0.33	1.66 ± 0.31*	1.21 ± 0.18*	0.81 ± 0.24*	0.44 ± 0.20*	0.38 ± 0.05*
Middle part of root canal	1.11 ± 0.23	1.07 ± 0.06*	0.65 ± 0.28*	0.45 ± 0.19*	0.45 ± 0.15*	0.23 ± 0.06*
Terminal part of root canal	0.14 ± 0.06	0.09 ± 0.01*	0.06 ± 0.02*	0.06 ± 0.02*	0.05 ± 0.01*	0.06 ± 0.0018*

*$p < 0.05$, compare to previous adjacent age group.

TABLE 4—*Mesiodistal diameters of pulp cavity of mandibular central incisor in different age groups (mm, means ± SD).*

	Age Groups (Years Old)					
Parts of Pulp Cavity	15– (n = 22)	26– (n = 28)	36– (n = 29)	46– (n = 28)	56– (n = 26)	66– (n = 19)
Cervical pulp chamber	0.85 ± 0.16	0.80 ± 0.15*	0.64 ± 0.11*	0.54 ± 0.13*	0.49 ± 0.11*	0.25 ± 0.07*
Middle part of root canal	0.50 ± 0.12	0.45 ± 0.09*	0.35 ± 0.11*	0.17 ± 0.05*	0.13 ± 0.05*	0.10 ± 0.02*
Terminal part of root canal	0.11 ± 0.03	0.09 ± 0.02*	0.08 ± 0.02*	0.07 ± 0.03*	0.07 ± 0.03*	0.05 ± 0.01*

*$p < 0.05$, compare to previous adjacent age group.

TABLE 5—*Mesiodistal diameters of pulp cavity of mandibular lateral incisor in different age groups (mm, means ± SD).*

	Age Groups (Years Old)					
Parts of Pulp Cavity	15– (n = 23)	26– (n = 26)	36– (n = 29)	46– (n = 28)	56– (n = 25)	66– (n = 18)
Cervical pulp chamber	1.04 ± 0.15	1.00 ± 0.20*	0.77 ± 0.10*	0.63 ± 0.21*	0.58 ± 0.02*	0.48 ± 0.09*
Middle part of root canal	0.54 ± 0.16	0.48 ± 0.19*	0.38 ± 0.10*	0.20 ± 0.05*	0.20 ± 0.05*	0.18 ± 0.08*
Terminal part of root canal	0.10 ± 0.02	0.09 ± 0.01*	0.06 ± 0.01*	0.05 ± 0.009*	0.05 ± 0.009*	0.05 ± 0.009*

*$p < 0.05$, compare to previous adjacent age group.

TABLE 6—*Correlation coefficients (*r*) between mesiodistal diameters of incisor pulp cavity and age.*

	Parts of Pulp Cavity					
	Cervical Pulp Chamber		Middle Part of Root Canal		Terminal Part of Root Canal	
Tooth Type	r	p	r	p	r	p
Maxillary central incisor	0.6469	<0.01	0.8456	<0.01	0.8083	<0.01
Maxillary lateral incisor	0.6321	<0.01	0.7881	<0.01	0.4775	<0.01
Mandibular central incisor	0.7925	<0.01	0.8249	<0.01	0.4233	<0.01
Mandibular lateral incisor	0.5669	<0.01	0.6082	<0.01	0.4973	<0.01

TABLE 7—*The regression coefficients (*b*) between the change in mesiodistal diameter of incisor pulp cavity and age.*

	Parts of Pulp Cavity		
Tooth Type	Cervical Pulp Chamber (b, mm)	Middle Part of Root Canal (b, mm)	Terminal Part of Root Canal (b, mm)
Maxillary central incisor	−0.02	−0.02	−0.004
Maxillary lateral incisor	−0.02	−0.02	−0.002
Mandibular central incisor	−0.01	−0.01	−0.002
Mandibular lateral incisor	−0.01	−0.01	−0.002

representative parts of the pulp cavity, the cervical part of the pulp chamber, the middle and the terminal parts of the root canal. We did not measure the mesiodistal diameter of the crown pulp chamber, because the crown pulp chamber has a crescent shape in transverse section, which is easy to subject to variation in its width when the mesiodistal plane of the tooth is not parallel to the film. In addition, the reference marks for these three mesiodistal diameters (the cementoenamel junction and the apex) were easy to be clearly recognized on the radiographs, which made the measurements more reliable and repeatable.

As shown in the present study, for all incisors, including the central and the lateral incisors of both maxilla and mandible, the three mesiodistal diameters gradually decreased with age from 15 to 80 years old, indicating an age-related narrowing of the pulp cavity in the mesiodistal plane from the cervical pulp chamber to the terminal part of the root canal. However, the narrowing velocity in different tooth position is unequal. In the maxillary incisors, the decrease in the mesiodistal diameters of the cervical pulp chamber and the middle part of the root canal was about 0.02 mm per year (b = −0.02 mm, see Table 7), which was two fold faster than that in the mandibular incisors. This suggests that the narrowing of the pulp cavity in the maxillary incisors may serve as a more sensitive indicator for age estimation. An unexpected finding in the present study was that in both maxillary and mandibular incisors the terminal part of the root canal had a much slower narrowing velocity (b = −0.002 to −0.004 mm) than the other two parts of the pulp cavity. This probably represents a permanent existence of the apical foramen required to maintain blood and nerve supply for pulp survival.

The methods of age estimation based on the changes in the height and width of teeth and the pulp cavity as measured on radiographs have been reported by numerous investigators (13–17). In these previous studies, the ratios between the tooth and pulp measurements, such as the pulp/tooth length and the pulp/tooth width at the different levels, were calculated and used in the analyses to reduce the

TABLE 8—*A comparison between real and estimated ages of 30 independent individuals.*

	Age Estimation from Mesiodistal Diameter of Cervical Pulp Chamber				Age Estimation from Mesiodistal Diameter of Middle Part of Root Canal		
Cases	Real Ages (*R*)	Measured Mesiodistal Diameter (mm)	Estimated Ages (*E*)	Errors (*R*–*E*)	Measured Mesiodistal Diameter (mm)	Estimated Ages (*E*)	Errors (*R*–*E*)
1	18	2.02	16	+2	1.21	18	0
2	20	2.01	18	+2	1.16	21	−1
3	21	2.01	18	+3	1.14	22	−1
4	21	2.00	17	+4	1.15	21	0
5	22	2.01	18	+4	1.13	22	0
6	24	1.95	20	+4	1.09	24	0
7	24	1.90	22	+2	1.08	25	−1
8	25	1.88	23	+2	1.06	26	−1
9	25	1.86	24	+1	1.07	25	0
10	25	1.84	25	0	1.07	25	0
11	25	1.85	25	0	1.06	26	−1
12	26	1.84	25	−1	1.05	26	0
13	26	1.83	26	0	1.04	27	−1
14	27	1.81	27	0	1.03	27	0
15	27	1.80	27	0	1.04	27	0
16	27	1.82	26	+1	1.03	27	0
17	28	1.80	27	+1	1.01	28	0
18	28	1.79	28	0	1.01	28	0
19	34	1.66	34	0	0.88	35	−1
20	35	1.66	34	+1	0.87	35	0
21	35	1.65	35	0	0.87	35	0
22	37	1.62	36	+1	0.83	37	0
23	37	1.61	37	0	0.82	38	−1
24	37	1.60	37	0	0.83	37	0
25	39	1.57	39	0	0.79	39	0
26	39	1.58	38	+1	0.77	39	0
27	44	1.46	44	0	0.68	45	−1
28	56	1.22	56	0	0.45	56	0
29	57	1.19	58	−1	0.43	57	0
30	58	1.18	58	0	0.41	58	0

*The estimated age was calculated by the formula "$Y = 15 + (F–M)/b$" from measurements of pulp cavity on radiographs of maxillary central incisors.

TABLE 9—*A test for reliability of estimated ages from measurements of different parts of pulp cavity on 30 radiographs of maxillary central incisors.*

Measuring Sites	Mean Errors (Years)	Maximal Errors (Years)	95% Reliability Range (Years)
Cervical pulp chamber	1.03	4	2.53 ($p < 0.05$)
Middle part of root canal	0.40	1	0.91 ($p < 0.05$)

possible variation because of the angulation of the radiographs. In the present study, we chose the mesiodistal diameters of the pulp cavity (rather than the ratio of pulp/root width) at the three levels as the predictors for age estimation. This is because the transverse sections of the cervical pulp chamber and the root canal are near-round, but those of the cervix and the root are oval or near-triangular in shape (as illustrated in Fig. 1*B*). Thus, an angulation of the radiograph may have little to do with the width of the cervical chamber and root canal, but cause a variation in the tooth width at the corresponding level, leading to greater error. As demonstrated by the correlation analysis, a negative linear relationship between the changes in average values of the three mesiodistal diameters and age existed in both maxillary and mandibular incisors. Accordingly, a mathematical model, "$Y = 15 + (F–M)/b$," was deduced, which described the ages (from 15 to 80) as a function of any one of the three mesiodistal diameters of the pulp cavity in either the maxillary or mandibular incisors. This formula would be a useful alternative or complementary tool for age identification of a nameless dead body or skeletal remains in forensic medicine and archaeology. For example, if a digital radiograph of a maxillary central incisor was obtained (it is easy to be taken *in situ* without injury to the dead body), and the mesiodistal diameter (M) of the middle part of the root canal was measured 0.87 mm, the age of the dead person can be estimated by using the formula above, that is:

$$Y = 15 + (F - M)/b = 15 + (1.27 - 0.87)/0.02 = 35.00$$

Here, F is the average mesiodistal diameter of the middle part of the root canal of the maxillary central incisors in age group of 15– (Table 2), and b is its regression coefficient (Table 7). The estimated age of the dead person is about 35 years old.

It is worth noting that the best predictor for age identification using the formula is the measurement of the mesiodistal diameter of the middle part of the root canal. If taking the mesiodistal diameter of the cervical pulp chamber as a predictor, there may be a 2–4 years' underestimate for the real age in the young population (18 to 25 years old).

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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