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Journal	Bulletin of Tokyo Dental College, 51(1): 1-6
URL	http://hdl.handle.net/10130/1559
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Bull Tokyo Dent Coll (2010) 51(1): 1–6

Original Article

Three-dimensional Observation of Decrease in Pulp Cavity Volume Using Micro-CT: Age-related Change

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Received 2 October, 2009/Accepted for publication 16 November, 2009

Abstract

We investigated three-dimensional decrease in the volume of the pulp chamber caused by age-related secondary dentin formation using micro-CT and evaluated the applicability of the results to evaluation of age taking into account sex, age and tooth type. Decrease was slightly higher in females than in males, and a higher correlation between decrease and aging was observed in females. A comparison between age-groups revealed that decrease progressed between the fifties and sixties in males, and the forties and fifties in females. A stronger correlation between aging and decrease was observed in the mandibular central incisors than in the mandibular second premolars. This correlation was higher than other correlations between sexes and age-groups.

Key words: Pulp chamber—Secondary dentin—Micro-CT—Age estimation—Three-dimensional measurement

Introduction

A decrease in the volume of the pulp cavity by secondary dentin formation is known to occur with age. Numerous quantitative studies using ground sections or radiographs have been performed[6,9]. In forensic science, the size and area of a tooth and pulp cavity are measured on ground sections or radiographs and a regression analysis is performed to determine correlations between the ratios of these values and age. These results are then used to estimate age[3,4,7,10,15]. However, these ground section or radiograph-based methods

Table 1 Age and sex distribution of study sample

Age (year)	Central incisor		Second premolar	
	Male	Female	Male	Female
20–29	9	12	6	4
30–39	19	24	10	7
40–49	15	10	11	11
50–59	10	10	10	10
60–69	9	10	9	12
70–79	11	9	10	10
	73	75	56	54
Total	148		110	

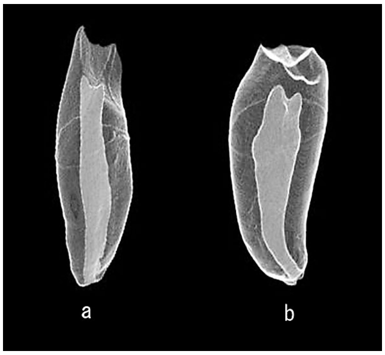

Fig. 1 Settings for volume ratio of pulp cavity to tooth
3D rendered image of pulp chamber and hard tissue morphology excluding enamel.
Volume ratios of pulp cavity to whole tooth excluding the enamel were calculated. (a) Mandibular central incisor; (b) Mandibular second premolar

use only one- or two-dimensional measurements, and do not comprehensively investigate three-dimensional decrease in the pulp chamber caused by age-related formation of secondary dentin.

In recent years, the development of micro-CT has enabled three-dimensional observation[1,11,13] and detailed quantitative evaluation of teeth. Oi *et al.*[14] reported three-dimensional morphological change with age in the pulp chamber of maxillary first premolars by observing and calculating the volume ratio of the pulp chamber and root bifurcation of the root cavity. Iwaka[8] also performed the same research using mandibular first molars as samples. However, these two studies used only a limited number of samples, and only a fraction of the tooth was evaluated fragmentally. Therefore, the effectiveness of three-dimensional measurement using micro-CT remains to be fully utilized. The only three-dimensional evaluations of a decrease in the pulp chamber with age were reported by Aboshi *et al.*[2] and Someda *et al.*[17]. Aboshi *et al.* described an age estimation method based on calculation of pulp/tooth volume ratios for various regions of the mandibular first premolars, and Someda *et al.* reported age estimation based on calculation of pulp/tooth volume ratios between sexes using mandibular central incisors.

In the present study, we performed three-dimensional measurements using micro-CT to determine decrease in the volume of the pulp chamber caused by age-related formation of secondary dentin and evaluated the applicability of the result to evaluation of age taking into account sex, age and tooth type.

Materials and Methods

A total of 148 mandibular central incisors and 110 mandibular second premolars without restorative treatment from patients aged 20–79 years were chosen from the collection stored at the Department of Anatomy in Tokyo Dental College. The age and sex distributions of the samples are shown in Table 1.

Samples were scanned using micro-CT with the HMX225 ACTIS4 under the following conditions: tube voltage, 90 kV; tube current, 60 μA; magnification, $\times$10. Based on sliced image data, three-dimensional structures were obtained using TRI 3D-BON (a three-dimensional structural analysis software) and volumes of the enamel, dentin and pulp chamber were measured.

Based on these measurements, the volume ratios of the pulp chamber to the whole tooth except the enamel were calculated following the method of Someda *et al.*[17] (Fig. 1).

A scatter diagram was developed with the X axis as age and the Y axis as volume ratio to

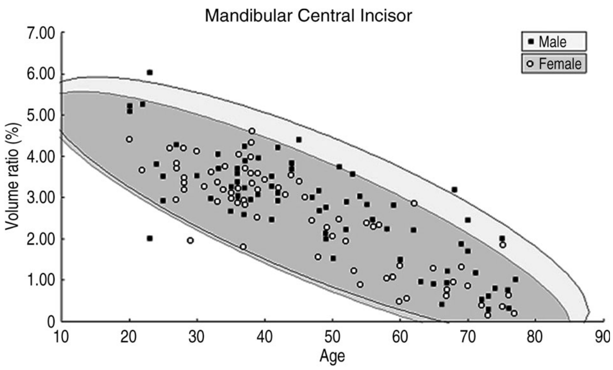

Fig. 2 Relationship between volume ratio of pulp chamber and age in each sex (Mandibular central incisor)

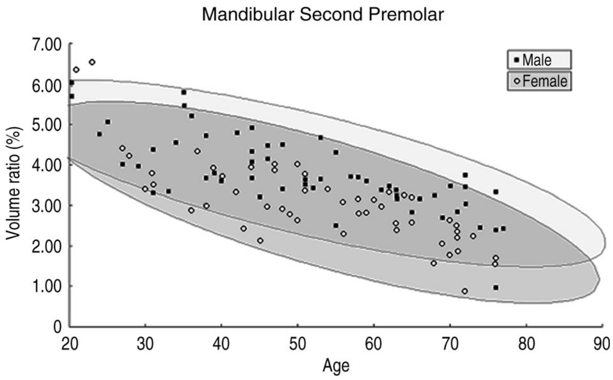

Fig. 3 Relationship between volume ratio of pulp chamber and age in each sex (Mandibular second premolar)

elucidate the correlation between the volume ratio of the pulp chamber and age. A 95% density ellipse was calculated in order to compare the distribution status on a scatter diagram by sex. A regression analysis was performed using volume ratio of the pulp chamber as a dependent variable and age as an independent variable; a determination coefficient R^2 was calculated to assess the degree of correlation between volume ratio of the pulp chamber and age. The average volume ratio of the pulp chamber in each age group (in 10-year age groups) was calculated and a two-way analysis of variance performed to statistically investigate difference between sexes.

Microsoft Excel was used for the statistical analysis.

Results

The relationship between the volume ratio of the pulp chamber and age in each sex was plotted on a scatter diagram (Figs. 2, 3). The 95% density ellipse between sexes overlapped in most areas, but there was a difference in distribution area. The distribution area for females was located slightly lower than that for males.

Table 2 shows the regression coefficient and determination coefficient R^2. Regression

Table 2 Determination coefficient (R^2)

Central incisor		Second premolar	
Male	Female	Male	Female
0.67	0.75	0.56	0.58

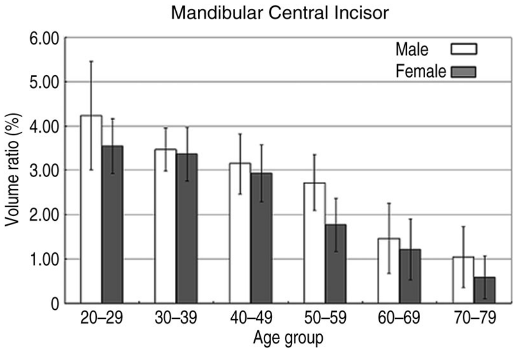

Fig. 4 Average volume ratio of pulp chamber (Mandibular central incisor)

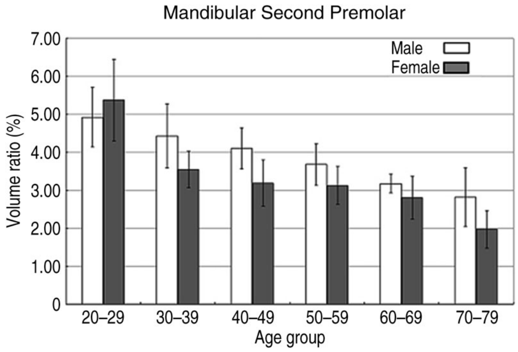

Fig. 5 Average volume ratio of pulp chamber (Mandibular second premolar)

coefficients were significant for all areas and in each sex. The comparison of the accuracy of age estimation using the R^2 of each volume ratio in each region showed the following results: mandibular central incisor (male, $R^2=0.67$; female, $R^2=0.75$) and mandibular second premolar (male, $R^2=0.56$; female, $R^2=0.58$). Females showed a stronger correlation between volume ratio of the pulp chamber and age than males in both teeth (Table 2).

The averages ± standard deviations of volume ratio of the pulp chamber in each age group (in 10-year age groups) in each sex were as follows: 1) Mandibular central incisor: 20–29 years old (male = 4.24 ± 1.21, female = 3.55 ± 0.62), 30–39 years old (male = 3.47 ± 0.48, female = 3.36 ± 0.61), 40–49 years old (male = 3.15 ± 0.67, female = 2.94 ± 0.64), 50–59 years old (male = 2.73 ± 0.62, female = 1.77 ± 0.60), 60–69 years old (male = 1.46 ± 0.79, female = 1.22 ± 0.70), 70–79 years old (male = 1.05 ± 0.68, female = 0.58 ± 0.49) (Fig. 4) and 2) Mandibular second premolar: 20–29 years old (male = 4.92 ± 0.78, female = 5.38 ± 1.07), 30–39 years old (male = 4.43 ± 0.84, female = 3.55 ± 0.48), 40–49 years old (male = 4.10 ± 0.54, female = 3.19 ± 0.61), 50–59 years old (male = 3.67 ± 0.54, female = 3.12 ± 0.49), 60–69 years old (male = 3.18 ± 0.24, female = 2.81 ± 0.56), 70–79 years old (male = 2.82 ± 0.76, female = 1.97 ± 0.50) (Fig. 5).

The two-way analysis of variance to determine the average volume ratio of the pulp chamber showed a significant difference in age and sex (Tables 3, 4).

Discussion

The comparison of the narrowing of the pulp chamber due to secondary dentin formation with age between sexes demonstrated a difference in the distribution area on the scatter diagram both in the mandibular central incisors and second premolars. The comparison of the volume ratio average among age groups (in 10-year age groups) also showed a significant difference between sexes. The regression analysis of correlation between aging and decrease in the pulp

Table 3 Results of the two-way variance analysis in mandibular central incisors

Source	Type III square sum	Degrees of freedom	Mean square	F value	Significance probability
Modified model	.011(a)	11	.001	30.599	.000
Section	.052	1	.052	1,667.470	.000
Sex	.001	1	.001	17.162	.000
Age	.010	5	.002	64.039	.000
Sex and age	.000	5	3.637E−05	1.163	.331
Error	.004	136	3.128E−05		
Sum	.081	148			
Modified sum	.015	147			

a: $R^2=.712$ (Adjusted $R^2=.689$)

Table 4 Results of the two-way variance analysis in mandibular second premolars

Source	Type III square sum	Degrees of freedom	Mean square	F value	Significance probability
Modified model	.004(a)	11	.000	14.667	.000
Section	.075	1	.075	2,872.800	.000
Sex	.001	1	.001	24.121	.000
Age	.003	5	.001	23.279	.000
Sex and age	.000	5	3.109E−05	1.191	.319
Error	.003	98	2.611E−05		
Sum	.083	110			
Modified sum	.007	109			

a: $R^2=.622$ (Adjusted $R^2=.580$)

chamber volume showed a stronger correlation in females than in males, suggesting a greater decrease in the pulp chamber in females than in males of the same age.

The comparison between age groups showed progression in the decrease in the pulp chamber volume in the 50–59 year old and 60–69 year old groups in males, and in the 40–49 year old and 50–59 year old groups in females for the mandibular central incisors (Fig. 4). No significant changes were observed in the second premolars.

Someda *et al.*[17] performed a regression analysis for age estimation based on the correlation between aging and decrease in the pulp chamber volume using the mandibular central incisors as samples, and reported that a higher correlation was observed in females than in males. The results of the present study support Someda *et al.*'s results and provide further evidence for a distinct sex difference.

Hietala *et al.*[5] and Silvana *et al.*[16] reported the existence of an estrogen receptor in odontoblasts in human pulp tissue. In addition, Yokose *et al.*[18] reported that estrogen deficiency in ovariectomized rats promoted the substrate synthesis of odontoblasts. These reports suggest that estrogen exerts a strong influence on formation of secondary dentin.

The relationship between aging and decrease in the pulp chamber volume showed a stronger correlation in the mandibular central incisors (male, $R^2=0.67$; female, $R^2=0.75$) than in the mandibular second premolars (male, $R^2=0.56$; female, $R^2=0.58$).

Previous studies on age estimation using pulp/tooth volume ratio showed that statistical correlations were reduced by the morphological diversity of the teeth[7]. The difference seen here in the results between the mandibular central incisors and the second premolars is considered to be due to the fact that the mandibular central incisors have the lowest morphological diversity in all human permanent teeth, whereas the crowns of the mandibular second premolars show morphological diversity[12]. This is also believed to be the reason the difference in decrease in pulp chamber volume in different age groups was not as clear in the second premolars as in the central incisors.

Acknowledgements

We would like to thank Associate Professor Jeremy Williams, Tokyo Dental College, for his assistance with the English of this manuscript.

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