Three-dimensional observation of pulp cavities in the maxillary first premolar tooth using micro-CT

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Abstract

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Aim To observe three-dimensional morphological changes with age in the pulp cavities of maxillary first premolar teeth.

Methodology The specimens used in this study were 10 maxillary first premolar teeth (five males and five females) obtained from patients in three age groups, namely in their twenties (20s), forties (40s) and sixties (60s). Each specimen was imaged by a micro-CT to reconstruct the three-dimensional structure. Then, using the reconstructed images, the morphological characteristics of the pulp cavity, the volume ratio at the horn region, the floor region and the overall region of the pulp chamber and the diameters of the buccal and lingual orifices of the root canals were compared between the three age groups.

Results The mesio-distal widths and the heights of the pulp cavity decreased with age. The volume ratio and the diameter of the root canal orifices also decreased. The decrease in volume was not constant but showed a large decrease between the 20s and the 40s, compared to those of 40s to 60s.

Conclusions Morphological features of the pulp cavity of maxillary first premolar teeth in different age groups were observed three dimensionally using micro-CT. Decreases in pulp cavity size and shape with age were clarified using a three-dimensional technique.

Keywords: maxillary first premolar, micro-CT, morpho-metrical changes with age, pulp cavity, root canal orifices, three-dimensional observation.

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Introduction

Three-dimensional methods, which make possible observations from arbitrary viewpoints, are replacing two-dimensional methods for the morphological study of dental pulp cavities. Usually three-dimensional observation has been performed by reconstructing the image based on tracings of the contours from serial cross sections of the specimen. However, this method is problematical in that the specimens have to be destroyed to prepare the cross sections and accurate images cannot be obtained because of the slice thickness.

Micro-CT has been used to observe the structure of bone (Huiskes *et al.* 1987, van Rietbergen *et al.* 1998, Hara *et al.* 2002), but to date, there are few studies on teeth. One study on the morphological and quantitative changes of maxillary second deciduous molars with age using micro-CT has been reported by Suto *et al.* (2002).

It is known that the pulp cavities show complicated morphological changes owing to the addition of secondary dentine with age. This can make root canal treatment more difficult in older patients.

In this study, morphological changes of the pulp cavities with age were three dimensionally observed in maxillary first premolar teeth using a micro-CT. In addition, changes in the volume ratio and diameter of the orifices of root canals, which are difficult to assess by two-dimensional observation methods, were measured.

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Materials and methods

The specimens were all maxillary first premolar teeth with two root canals, which had been collected in the Department of Anatomy, Tokyo Dental College, along

with the record of the patients' age at the time of extraction. Each specimen had no tooth substance defect or caries, and tooth attrition was limited to enamel. Based on the patients' age at extraction, the specimens were classified into three age groups, namely in their twenties (20s), forties (40s) and sixties (60s). Specimens in each age group consisted of 10 teeth (five males and five females). The mean age of each group was 25.5, 46.1 and 65.6 years, respectively.

Micro-CT was taken under the conditions of tube voltage 55 kV, tube current 90 μA, and slice thickness 16.5 μm, setting the tooth axis of the specimen orthogonal to the micro-CT specimen stage. The tooth axis was determined following the method reported by Fujita (1949).

With regard to each sliced image obtained by micro-CT, elimination of noise and contrast adjustment were performed according to the method described by Shibuya *et al.* (2000), using photo-retouching software (PHOTOSHOP 6.0, Adobe Inc, San Jose, CA, USA). Thereafter, three-dimensional images were reconstructed from the sliced images, using three-dimensional reconstruction software (VOX BLAST, Vaytek Inc, Los Angeles, CA, USA).

The reconstructed three-dimensional images in each age group were used to examine the items mentioned below.

Morphological characteristics of the reconstructed three-dimensional images

First, five points were determined by dividing equally into four the height between the deepest point of the dentino-enamel junction and the root apex. Then, five planes orthogonal to the tooth axis passing through these points were established (Fig. 1A). Among the four areas made by adjacent planes, the first and the second nearest areas to the occlusal surface always involved the horn of the pulp chamber and the floor of the pulp chamber in all specimens, respectively. Therefore, these two regions were determined as the areas of interest in this study and they were designated as the horn region of the pulp chamber (Fig. 1A, a) and the floor region of the pulp chamber (Fig. 1A, b).

With respect to the morphological features of the pulp cavity in those regions, the horn region of the pulp chamber was observed from the direction of the mesio-buccal occlusal margin angle (Fig. 2a), and the floor region of the pulp chamber was observed from the mesial direction and from the root apical direction (Fig. 2b1,b2). Additionally, the root canal orifices were observed from the root apical direction (Fig. 2c), by cross sectioning the reconstructed image of the floor of the pulp chamber on the plane (Fig. 1A, c) orthogonal to the tooth axis passing the lowest point of the floor of the pulp chamber.

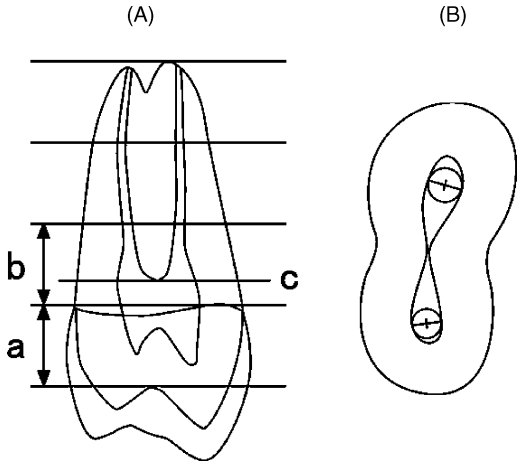

Figure 1 (A) The area of interest: a, the horn region of the pulp chamber; b, the floor region of the pulp chamber; and c, plane of passing the lowest point of the floor of the pulp chamber. (B) Diameter of the root canal orifice.

These reconstructed images were compared between age groups, and morphological changes with age were observed.

Volume ratio of the pulp cavity

The ratio of the volume of the pulp chamber to the volume of the whole tooth without enamel in each region of interest mentioned above was measured. In addition, the ratio of the volume of the overall region of the pulp chamber to the volume of the whole tooth without enamel was also calculated. Furthermore, morphological changes with age were observed. Statistical significant differences of the results were examined in three age groups using ANOVA with Fisher's Protected Least Significant Difference (PLSD) test.

Diameter of the root canal orifice

On the surface of the cross-sectional plane (Fig. 1A, c), the maximized circle within the root canal was drawn using ADOBE PHOTOSHOP software, and the diameter of the circle was measured (Fig. 1B). Furthermore, morphological changes with age were observed. Statistical significant differences in the buccal and lingual root canal orifices of three age groups were examined using ANOVA with Fisher's PLSD test.

Results

Visible findings of morphological characteristics in the reconstructed three-dimensional images

The horn region of the pulp chamber

The horn region of the pulp chamber (Fig. 2a) showed that mesio-distal width and its height were the largest in the specimens from patients in their 20s and decreased with age. The buccal and lingual tips of the horn of the pulp chamber became more round with age.

The floor region of the pulp chamber

The floor region of the pulp chamber from the mesial direction (Fig. 2b1) indicated that the bucco-lingual widths of both the buccal and lingual root canals were the largest in the specimens from patients in their 20s and smallest in their 60s. The furcation area changed from V-shape to U-shape with age.

Observation of the floor region of the pulp chamber from the root apical direction (Fig. 2b2) revealed that the sliced surface of both the buccal and lingual root canals were the largest in the specimens from patients in their 20s and then decreased with age.

The root canal orifices

The root canal orifice in the specimens from patients in their 20s were found to be wider mesio-distally than those in their 40s and 60s (Fig. 2c); the diameter of described circles reduced with age.

Volume ratio of the pulp cavity

The volume ratios of the specimens in their 20s, 40s and 60s were 8.73 ± 1.32, 5.18 ± 0.78 and $3.43 \pm 0.62\%$ in the horn region, 11.64 ± 1.87, 7.08 ± 1.24 and $4.61 \pm 0.83\%$ in the floor region, and 5.78 ± 0.90, 3.25 ± 0.51 and $2.29 \pm 0.48\%$ in the overall region of the pulp cavity, respectively (Fig. 3).

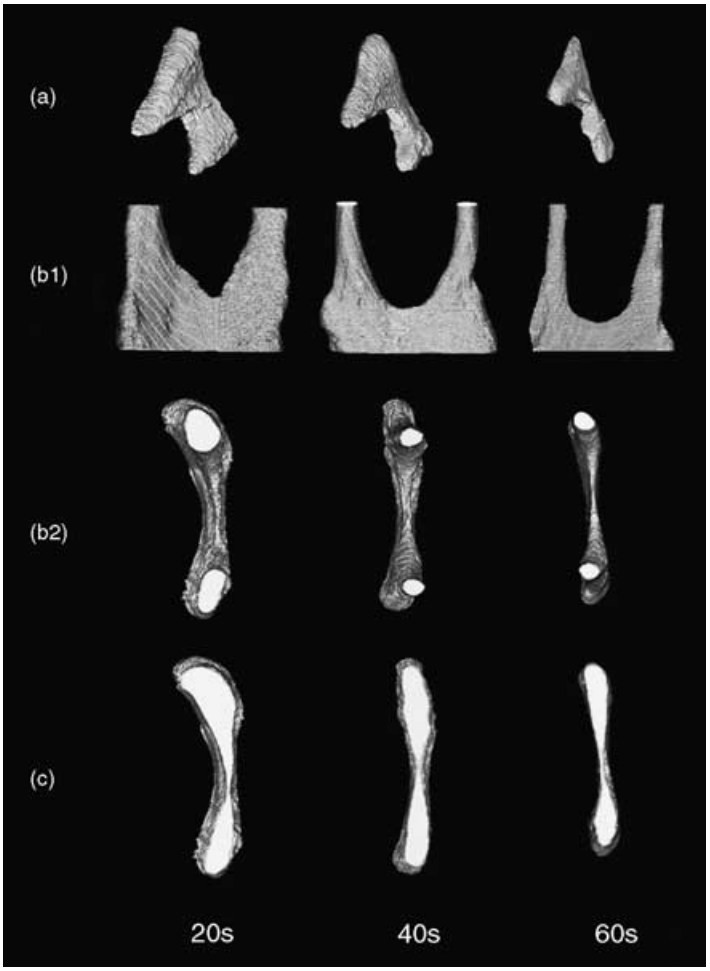

Figure 2 Observation of the reconstructed three-dimensional images: (a), the horn region of the pulp chamber; (b1), the floor region of the pulp chamber (from the mesial direction); (b2), the floor region of the pulp chamber (from the root apical direction); and (c), the root canal orifices.

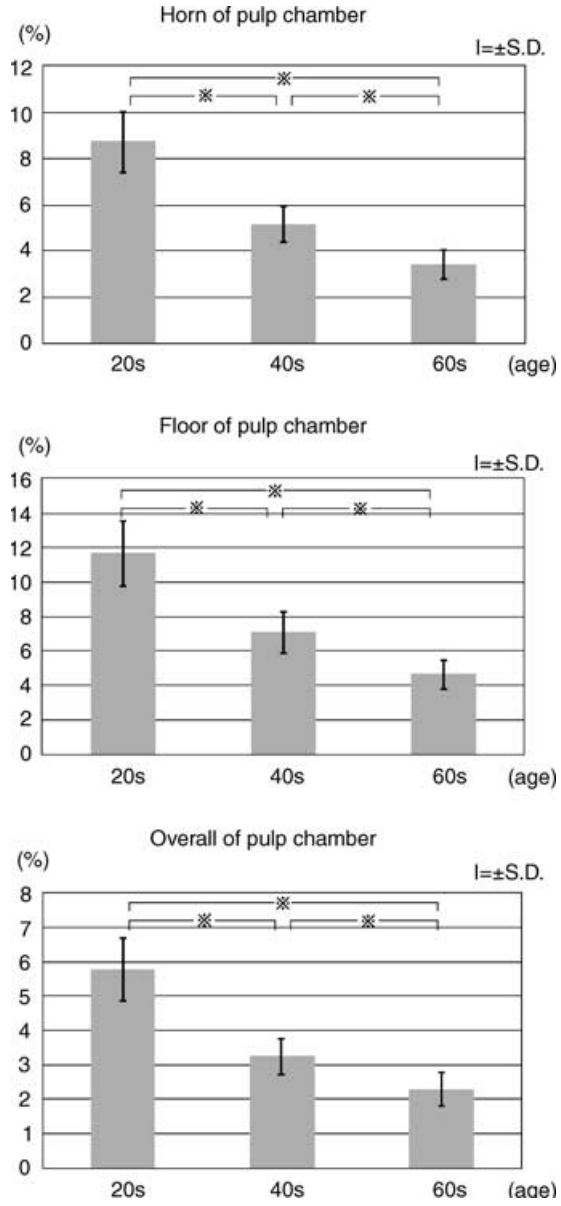

Figure 3 Volume ratio of the pulp cavity (※$P < 0.05$).

Significant differences were noted between the 20s and the 40s, and also between the 40s and the 60s in all the areas of interest ($P < 0.05$).

Diameter of the root canal orifice

The diameters of the root canal orifices of the specimens in their 20s, 40s and 60s were 0.75 ± 0.13, 0.48 ± 0.07 and 0.37 ± 0.08 mm on the buccal side, and 0.79 ± 0.13, 0.51 ± 0.08 and 0.38 ± 0.06 mm on the lingual side, respectively (Fig. 4).

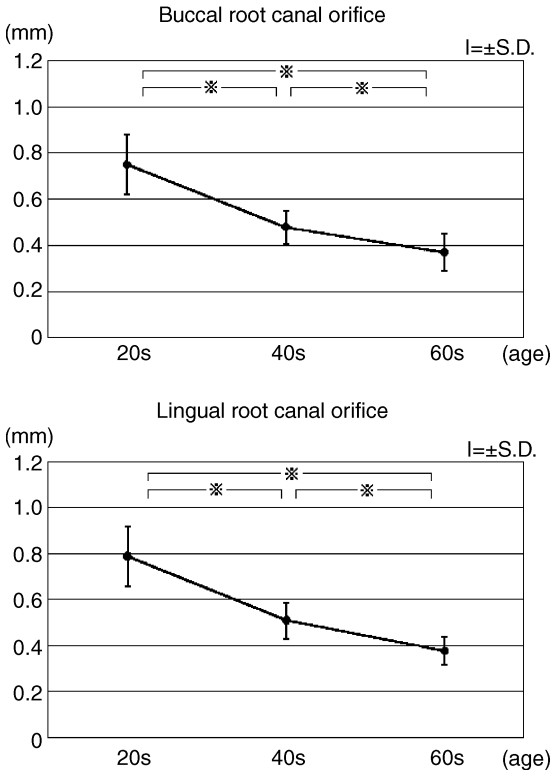

Figure 4 Diameter of the root canal orifice (※$P < 0.05$).

Significant differences were noted between the 20s and the 40s, and also between the 40s and the 60s in the buccal and lingual root canal orifices ($P < 0.05$).

Discussion

Morphological characteristics of the reconstructed three-dimensional images

Berutti (1993), Blašković *et al.* (1995), Lyroudia *et al.* (1997) and Mikrogeorgis *et al.* (1999) made serial tooth cross-sections and traced the contours of the tooth and the pulp cavities in each section. The data were then input into computers to reconstruct three-dimensional images for observation. However, detailed observation was difficult using these methods, as the width of the tooth removed during cross sectioning was 0.5–0.7 mm, making detailed observation difficult. As an alternative method, a micro-CT has been used in the recent years. Shibuya *et al.* (2000) reported that the measurement values obtained by this method were accurate. In this study, the same device was used following their methodology.

Although Dowker *et al.* (1997), Bjørndal *et al.* (1999) and Peters *et al.* (2001) observed the pulp cavities using a micro-CT; changes with age were not reported. Only Suto *et al.* (2002) have described both three-dimensional micro-CT observations of the pulp cavities of maxillary deciduous second molars and their morphological changes with age. They demonstrated that root canal orifices were constricted even in the short period between the deciduous dentition stage and the middle mixed dentition stage. In this study, the constriction of the pulp cavities with age was also confirmed by observing long-term changes in the permanent teeth between the 20s and the 60s.

Reconstructed images of the horn region of the pulp chamber showed decreases in the height of the horn region, and both the buccal and lingual tips of the horn of the pulp chamber were obtuse. Although the lingual tip was more obtuse than the buccal tip, it was speculated that this was because the lingual cusp was the functional cusp, and the amount of the induced secondary dentine was greater in the lingual tip than it was in the buccal tip.

As the floor region of the pulp chamber showed constricted root canals bucco-lingually and an obtuse furcation area with age, it was confirmed that the amount of the secondary dentine was greater in the mesio-distal direction than that in the bucco-lingual direction, and was greater in the root canal area than that in the tip of the furcation area. It was considered that this was because external stimulation was more easily transmitted to the root canal area than to the tip of the furcation area, as the distance from the tooth surface was shorter in the root canal area than that in the tip of the furcation area.

The root canal orifices were constricted mesio-distally with age, and the amount of the secondary dentine was greater in the mesio-distal direction than that in the bucco-lingual direction.

Volume ratio of the pulp cavity

It is apparent that size of the pulp cavity is strongly related to age. Using radiographs, Hirayama & Maeda (1993) and Aboshi *et al.* (2001) reported that constrictive changes in the pulp cavity were more marked in young than in middle-aged patients. As shown in Fig. 3, changes in the volume ratio of the three regions of interest in this study were also more marked between the 20s and the 40s specimens (3.55%) than between the 40s and the 60s specimens (1.75%).

Furthermore, using maxillary deciduous second molars, Suto *et al.* (2002) reported that changes in the volume of the pulp cavity between the deciduous dentition stage and the early mixed dentition stage were larger than those between the early mixed dentition stage and the middle mixed dentition stage. These findings suggested that the amount of secondary dentine in both the deciduous and permanent teeth was larger in the young stage than that in the old stage.

Green (1955) reported that the amount of the secondary dentine was larger in the roof of the pulp chamber than that in the floor of the pulp chamber, whereas Philippas (1961) reported that the amount of the secondary dentine was larger in the floor of the pulp chamber than that in the roof of the pulp chamber. In this study, no differences in the volume ratio among the regions of interest were seen suggesting that no marked differences in the amount of induced secondary dentine were present between the roof of the pulp chamber and the floor of the pulp chamber.

Diameter of the root canal orifice

As one of the methods measuring the size of the root canal, Peters *et al.* (2000) inscribed spheres with various diameters into the root canal model and then measured the diameter of the largest sphere. However, it is difficult to inscribe the spheres near the cutting surface of the root canal. Suto *et al.* (2002) used an alternative method; they drew the circle with the largest diameter at the cutting surface of the root canal. As the diameter of the root canal orifice, which shows the maximum value at the cutting surface, was measured in this study, the latter method was used.

Employing deciduous second molars, Suto *et al.* (2002) reported that changes in the diameter of the mesio-buccal, disto-buccal and lingual root canal orifices between the deciduous dentition stage and the early mixed dentition stage were larger than those between the early mixed dentition stage and the middle mixed dentition stage. Changes in the diameter of the buccal and lingual root canal orifices between the 20s and the 40s specimens were markedly larger than those between the 40s and the 60s specimens (Fig. 4). These findings suggested that the amount of the secondary dentine in both the deciduous and permanent teeth was greater in youth.

Furthermore, almost no differences were noted between the diameter of the buccal root canal orifice and that of the lingual root canal orifice, suggesting that the two root canal orifices developed almost the same changes. It is speculated that this is because there were no marked differences in the transmission of external sti-

mulation from the tooth surface between the two root canal orifices.

Conclusions

1 The mesio-distal and bucco-lingual widths and the height of the pulp cavity at all of the interest areas decreased with age.
2 The volume ratio of the decrease showed a large value from the 20s to the 40s, compared to the ones from the 40s to the 60s in the horn, floor and overall region of pulp chamber.
3 The diameter of the root canal orifices from the 20s to the 40s decreased more than that from the 40s to the 60s in buccal and lingual canals.

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