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The nano-hardness and elastic modulus of sound deciduous canine dentin and young premolar dentin—Preliminary study

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The purpose of this study was to compare the nano-hardness and elastic modulus among deciduous and permanent dentin, buccal and lingual sides, incisal, center and cervical areas, and outer, middle and inner layers. Three premolars and three deciduous canines were bucco lingually (BL) sectioned, and three deciduous canines were mesio-distally (MD) sectioned parallel to the long axis at the center of the tooth. Hardness (H), plastic hardness (PH) and Young's modulus (Y) were measured using a nano-indentation tester. The H, PH and Y values from the deciduous canine dentin were significantly lower than those from the premolar dentin at most sites. For deciduous canine dentin, the H and PH values of the MD sectioned dentin were significantly higher than those of the BL sectioned dentin in many layers of many areas. Generally deciduous canine dentin had H, PH and Y values that decreased from outer toward the inner layers and significant differences were obtained among the layers in many areas. For MD sectioned deciduous canine and BD sectioned premolar dentin, the H, PH and Y values of the cervical area were significantly lower than those of the incisal and center areas in many layers. It is possible that optimum bonding may require different treatments for deciduous and permanent dentin and perhaps also for different intratooth locations.

1. Introduction

The structure and properties of dentin vary with intratooth location [1]. Permeability increases, and bond strength often decreases in deeper dentin [2–5]. Bond strength to dentin is dependent on dentin depth, hardness and mineral content [5]. Regional differences in shear strength have been shown for permanent coronal dentin [6, 7]. Hardness of permanent dentin has been shown to decrease with depth and was inversely correlated with dentin tubule density [8], although Kinney *et al.* [9] showed that much of the decrese could be a result of changes in the intertubular dentin with distance from the pulp. Information on deciduous dentin biomechanical properties is not available, although substantial differences in its structure have been reported [10] and there is limited information that suggests deciduous dentin may have a lower mineral content [11].

Matching the properties of restorative materials to the properties of teeth may be important to enhance the longevity of the restorations. As a consequence, baseline mechanical property data of teeth are required. This knowledge is also important to help clinicians understand how these tissues react under clinical conditions as well as to help predict the behaviour of the tooth/restoration interface. Improved resin bonding yields strong bonds to enamel with excellent sealing ability [12]. However, the resin-dentin seal is much less reliable. One possible reason for the unreliability of the resin-dentin seal might be local variations in the mechanical properties of dentin. Although permanent tooth dentin has been studied extensively, the microstructure of dentin in deciduous teeth has received only limited attention [10]. A better understanding of dentin in deciduous teeth is needed to improve dentin bonding methods and make dental restorations more effective and successful.

The hardness and elasticity of fully mineralized permanent dentin have been reported in many studies [9–21]. Recently, nano-indentation has been used for

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measurement of the hardness and Young's modulus of materials on a submicroscopic scale [22–27]. The nano-indentation technique has several advantages for hardness determination over conventional microhardness methods such as Vickers and Knoop hardness. This technique has the ability to produce small indentations under small loads and can measure both the hardness and the elastic modulus of materials. The range in hardness of sound permanent dentin is broad, from 0.2 to 0.8 GPa (1 MPa = 10.2 kgf/cm^2, 1 GPa = 101.93675 kgf/mm^2) [9, 15, 16, 18]. Young's modulus of sound permanent dentin ranges from about 10–25 GPa [9, 13, 14, 17–21, 28].

Several studies of the hardness of deciduous dentin have been reported [29–35] including two studies using a nano-indentation tester [27, 35] and showed considerable variation in the properties. Knoop hardness values for sound deciduous dentin ranged from 35 to 60 KHN depending on location within the tooth [31].

The elastic properties of dentin are important for understanding the mechanical properties of calcified tissue in general, and for understanding alterations in the mechanical response of dentin due to caries, sclerosis, aging, and bonding procedures. Mahoney *et al.* [27] measured the hardness and elastic modulus of sound maxillary deciduous molar dentin using a nano-indentation tester. However, they used both sound and carious teeth in their samples, and calculated the mixed data. They did not evaluate variations with depth or location of the dentin. Hosoya and Marshall [35] compared the hardness and elastic modulus of carious and sound deciduous canine dentin. They reported that hardness and elastic modulus for deciduous canine teeth with carious lesions showed markedly lower mechanical properties than sound deciduous dentin.

Property variations in a single tooth could be larger than previously reported, but no report has compared the nano-hardness and elasticity of sound deciduous dentin and permanent dentin as a function of depth or location. Such a comparison is important since most bonding treatments are evaluated using permanent teeth, and the results are assumed to apply for deciduous teeth. Since peritubular dentin and tubules contribute little to the overall elastic properties [19], major differences with tooth type or intratooth location should be dependent on variations in the intertubule dentin. Thus the purpose of this work was to determine regional variations with intratooth location for deciduous intertubular dentin, and to compare these variations with those seen in permanent teeth. We suggest the hypothesis that deciduous teeth show broad variations in hardness and elastic modulus of the intertubular dentin, and have values that are significantly reduced from those seen in permanent teeth.

2. Materials and methods

2.1. Sample teeth

Six sound deciduous canines (4 maxillary and 2 mandibular) and three sound young maxillary first premolars that were relatively easy to obtain in the pediatric dental clinic were used. The deciduous teeth were extracted by eruption of the succedaneous permanent tooth or orthodontic treatment, and the premolar teeth were extracted as required for orthodontic treatment from Japanese children. The teeth were stored in 4 °C physiologic saline solution soon after extraction or exfoliation. The age of the patients ranged from 7 years 7 months to 10 years 8 months for deciduous canines, and 10 years to 10 years 6 months for premolars. Informed consent was obtained from parents and patients for collecting the teeth.

2.2. Specimen preparation

The three maxillary premolars and three deciduous canines (two mandibular and one maxillary) were bucco-lingually or labio-lingually (BL or LaL) sectioned, and three maxillary deciduous canines were mesio-distally (MD) sectioned parallel to the long axis through the center of the tooth. Sectioning was done using low-speed saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA) with a circular diamond blade and copious filtered water.

After sectioning, specimens were polished on wet silicon carbide paper using grit sizes of 600, 800, 1000 and 1200. Final polishing was carried out on felt cloth using 3, 1, 0.3 and 0.05 μm-size aluminum oxide suspensions (Baikalox, Baikowski International Co., Charlotte, NC, USA). Optical photomicrographs of the polished specimens were taken with a microscope (Olympus SZH, Olympus Co., Tokyo, Japan). The sectioned and polished specimens were stored in 4 °C distilled water until the measurement and dried in room air prior to study.

2.3. Nano-indentation test

Cyanoacrylate (Bond Aron Alpha, Konishi Co., Tokyo, Japan) was applied on small areas of the enamel on the specimen, and then the specimen was fixed on a flat glass plate to stabilize the specimen surface and to orient the surface parallel to the stage of the nano-indentation tester (ENT-1100, Elionix Co., Tokyo, Japan). The ENT-1100 is a depth sensing computer controlled instrument and has a Berkovich indentor, a three-sided pyramid diamond probe. The instrument was enclosed in an isolation chamber with a temperature controller and placed on an ALD anti-vibration isolator in order to minimize influences of environmental conditions such as the room temperature, floor-vibration and noise. The temperature in the chamber was 26 °C. The loading control system was powered by electromagnetic force with available load ranges from 10 mgf to 100 gf. The position of indentation was programmed and the indents were observed with a CCD camera attached to the tester.

Fig. 1 shows a load vs. displacement curve in the measurement process. Values of hardness (H), plastic hardness (PH) and Young's modulus were calculated according to the Equations (1)–(3) respectively following the index of Elionix Company that was

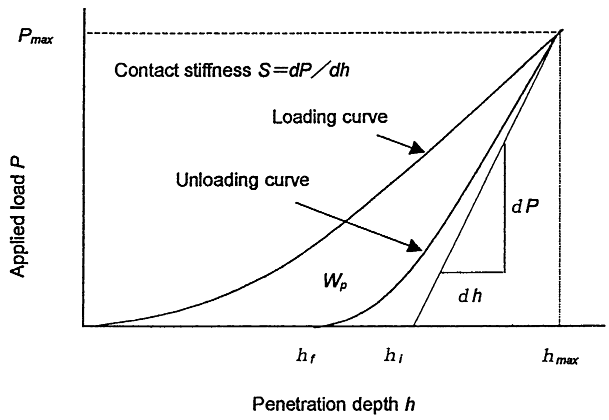

Figure 1 A schematic representation of load versus displacement curve. The quantities shown are P_{max}: maximum applied load; h_{max}: the indenter displacement at maximum load; h_f: the final depth of the contact impression after unloading; h_i: intercept depth determined from extrapolation to zero load of the tangent to the initial portion of the unloading curve near maximum force; dp/dh: contact stiffness or slope of the tangent obtained from the first part to 30% at the beginning of the unloading of the load vs. displacement curve.

modified from the method reported by Oliver and Pharr [36].

$$\mathrm{H} = 3.7926 \times 10^{-2}\left(P_{\max}/h_{\max}^2\right) \quad (1)$$

$$\mathrm{PH} = 3.7926 \times 10^{-2}\left(P_{\max}/h_1^2\right) \quad (2)$$

$$\mathrm{Y} = 1.81092 \times 10^{-3}\,(1/h_1)\,(\mathrm{d}p/\mathrm{d}h) \quad (3)$$

in which P_{max} is the maximum applied load, h_{max} is the indenter displacement at maximum load, h_1 is the intercept depth based on extrapolation of the contact stiffness and dp/dh is the contact stiffness or slope of the tangent that was obtained from fitting the first part to 30% at the beginning of the unloading or down curve of the load vs. displacement curve. Hardness (H) is calculated from indenter displacement at maximum load that includes both plastic and elastic deformation of sample. Plastic hardness (PH) is calculated based only on the plastic deformation of sample and corresponds to Vicker's hardness. Thus compared to the PH, the H includes the elastic element of test samples and therefore generally has a smaller value.

The prepared surfaces were divided into incisal, center and cervical areas. Then, each area was divided into outer, middle and inner layers (see Fig. 4). Ten indentations at intervals of 10 μm in each of the subdivided regions were made perpendicular to the outline of the dentinoenamel junction (DEJ) using a load of 1 gf for 1 s. The positions of indentations were as follows: the first point of the outer layer was made at 10 μm beneath the DEJ; the first point of the middle layer was made midway from the DEJ to the pulp chamber wall; and the last point of the inner layer was made in dentin close to the pulp chamber wall. Indentations were observed using a microscope with a CCD camera attached to the tester under 700× magnification. Some of the indentations were also observed using a scanning electron microscope (SEM ERA-8800 FE, Elionix Co., Tokyo, Japan). Irregular or unclear shaped indentations, and any indentations contacting the dentinal tubule or the peritubular dentin were removed from the data. Therefore all of the selected indentations were in intertubule dentin.

All data was statistically analyzed using ANOVA subsequent to Fisher's PLSD at $p < 0.05$.

3. Results

3.1. Deciduous canine vs. premolar

Table I and Figs. 2–4 compare the average hardness (H), plastic hardness (PH) and Young's modulus (Y) between deciduous canines and premolars. The H and PH of deciduous canines were significantly lower than those of premolars in many layers of many areas.

Comparing the buccal (labial) and lingual sides in the same area among the different layers, the H, PH and Y showed (Figs. 2 and 3): (1) the incisal area for deciduous canines had significantly higher values in the outer layer than those of the other layers, but for premolars, the middle layer values were the highest. (2) the center area of deciduous canines decreased significantly for H and PH inward from outer to middle and middle to inner layer, while the elastic modulus (Y) of the inner layer was significantly lower than the other layers. For premolars, the H, PH and Y of the outer layer were significantly lower than those of the middle and inner layers; and (3) in the cervical area of deciduous canines, all values of the inner layer were significantly lower than those of the outer and middle layers, but premolars had H, PH and Y of the outer layer that were significantly lower than the middle and inner layers.

Within a given layer values among the different areas showed: (1) in the outer layer for deciduous canines, all values were the lowest in the cervical area, while premolars had cervical values that were significantly lower than those of both the incisal and center areas; (2) in the middle layer, no significant difference was found for different areas of the deciduous canines, but for premolars, the H and PH of the cervical area were significantly lower than those of the incisal and center areas; (3) in the inner layers for deciduous canines, the H, PH and Y significantly decreased in the order incisal, center and cervical areas, but for premolars, the H, PH and Y of the center area were significantly higher than the other areas.

Comparing values of the incisal, center and cervical areas in the same layer between the buccal (labial) and lingual sides (Figs. 2 and 3), H and PH values for the buccal side of premolars in the outer and middle layers were significantly higher than those of the lingual side, but in the inner layer, H, PH and Y of the buccal side were significantly lower than those of the lingual side. For deciduous canines, PH and Y of the labial side were significantly higher than those of the lingual side.

3.2. Labio-lingual side vs. mesio-distal side

Table II compares the mechanical properties of the LaL sectioned and MD sectioned deciduous canines. For deciduous canines, the H and PH of the MD sectioned teeth were significantly higher than those of the LaL sectioned teeth in many layers of many areas.

TABLE I Comparison of hardness, plastic hardness and Young's modulus between sound deciduous canine dentin and premolar dentin (Unit: kgf/mm^2)

Area	Side	Layer	Deciduous(D) Permanent(P)	Hardness mean (S.D.)	Plastic hardness mean (S.D.)	Young's modulus mean (S.D.)	Number of measuring points
Incisal	Buccal	Outer	D	51.9 (9.9)	65.7 (14.8)	2315 (323)	30
	(Labial)		P	58.5 (7.0)*	79.1 (9.1)*	2196 (376)	30
		Middle	D	45.0 (12.3)	64.0 (15.4)	2172 (357)	30
			P	69.2 (10.5)*	95.7 (13.5)*	2493 (484)*	30
		Inner	D	42.6 (13.6)	52.7 (19.3)	2123 (495)	30
			P	53.5 (10.6)*	69.6 (14.5)*	2211 (464)	30
	Lingual	Outer	D	52.4 (10.8)	64.5 (14.4)	2501 (489)	30
			P	53.9 (8.3)	69.4 (9.6)	2280 (187)	30
		Middle	D	43.1 (8.9)	52.1 (12.2)	2196 (311)	30
			P	59.1 (13.3)*	78.3 (23.2)*	2407 (144)*	30
		Inner	D	38.6 (8.8)	45.4 (11.8)	2284 (285)	10
			P	58.9 (4.8)*	77.0 (6.8)*	2395 (311)	28
Center	Buccal	Outer	D	54.7 (7.2)	69.9 (10.7)	2260 (312)	30
	(Labial)		P	57.3 (11.0)	76.1 (14.8)	2212 (418)	30
		Middle	D	50.6 (17.8)	63.5 (24.3)	2374 (547)	30
			P	65.6 (6.8)*	89.0 (11.0)*	2438 (212)	30
		Inner	D	35.2 (11.3)	42.9 (15.7)	1764 (345)	30
			P	61.1 (21.1)*	75.8 (19.8)*	2381 (459)*	30
	Lingual	Outer	D	56.0 (14.1)	69.8 (18.7)	2575 (583)*	30
			P	54.5 (6.6)	70.6 (9.5)	2232 (196)	29
		Middle	D	46.0 (14.6)	56.1 (19.6)	2274 (528)	30
			P	64.5 (8.3)*	84.4 (18.2)*	2621 (158)*	30
		Inner	D	29.6 (6.7)	35.1 (8.5)	1588 (296)	30
			P	71.9 (11.9)*	96.1 (18.4)*	2771 (316)*	30
Cervical	Buccal	Outter	D	45.3 (8.2)	55.3 (10.6)	2238 (392)*	30
	(Labial)		P	48.8 (8.6)	63.3 (13.0)*	2027 (289)	30
		Middle	D	44.6 (11.8)	54.2 (16.5)	2189 (508)	30
			P	55.6 (6.2)*	70.5 (9.2)*	2467 (354)*	30
		Inner	D	26.8 (8.3)	31.2 (11.0)	1547 (251)	30
			P	53.2 (13.9)*	75.1 (23.2)*	1886 (468)*	30
	Lingual	Outer	D	52.7 (12.6)*	65.7 (17.1)*	2418 (435)*	29
			P	39.0 (8.8)	47.0 (12.0)	2001 (288)	30
		Middle	D	46.8 (8.2)	57.8 (10.7)	2194 (360)	30
			P	54.3 (10.6)*	68.8 (16.3)*	2420 (191)*	30
		Inner	D	23.9 (5.0)	27.8 (6.6)	1400 (173)	30
			P	58.4 (13.1)*	77.6 (21.2)*	2013 (272)*	30

*Significant difference at $p < 0.05$.

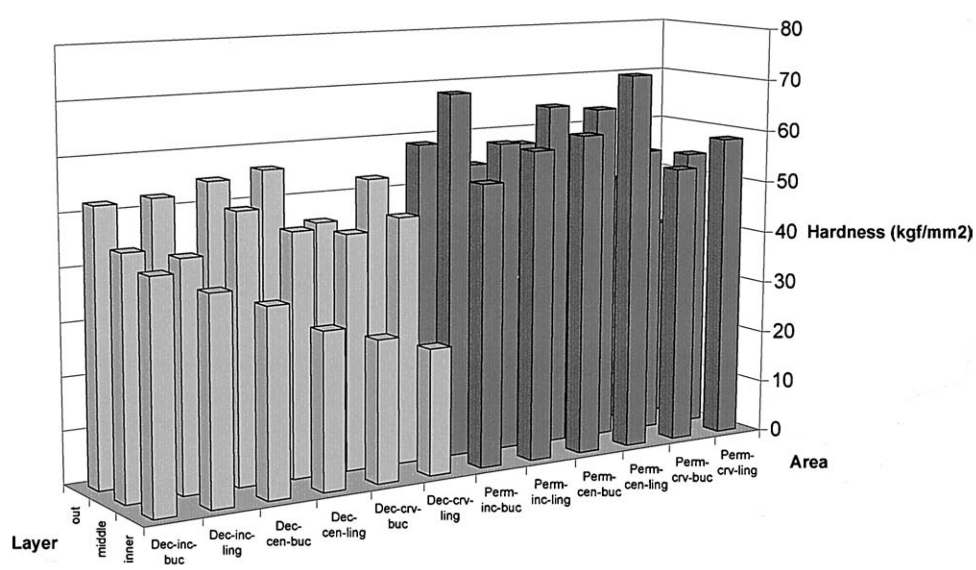

Figure 2 Average hardness values of bucco-lingually sectioned sound deciduous canine dentin and young premolar dentin (Dec: deciduous dentin, Perm: permanent dentin, inc: incisal area, cen: center area, crv: cervical area, buc: buccal side, ling: lingual side).

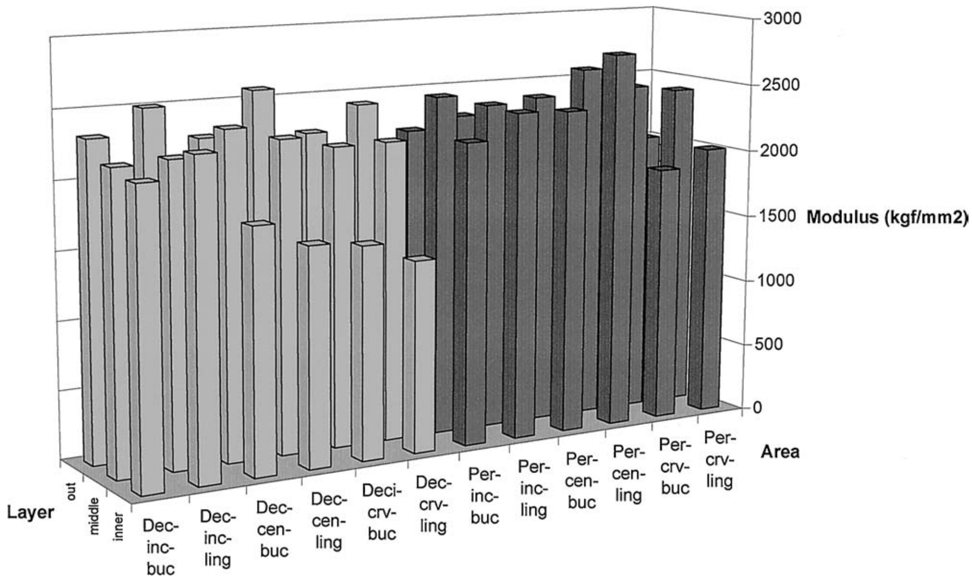

Figure 3 Average Young's modulus of bucco-lingually sectioned sound deciduous canine dentin and young premolar dentin (Dec: deciduous dentin, Perm: permanent dentin, inc: incisal area, cen: center area, crv: cervical area, buc: buccal side, ling: lingual side).

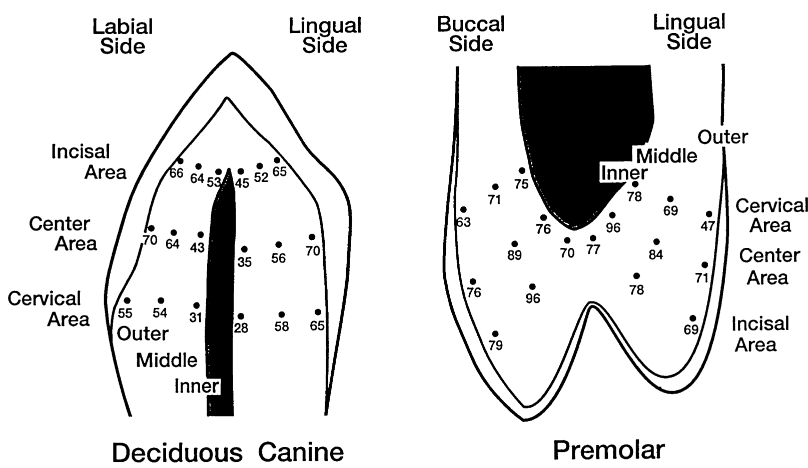

Figure 4 Average plastic hardness as a function of intratooth location in bucco-lingually sectioned sound deciduous canine dentin compared with similar areas in young premolar dentin.

TABLE II Hardness, plastic hardness and Young's modulus between labio-lingually (LaL) sectioned and mesio-distally (MD) sectioned sound deciduous canine dentin (Unit: kgf/mm^2)

Area	Layer	Direction of sectioning	Hardness mean (S.D.)	Plastic hardness mean (S.D.)	Young's modules mean (S.D)	Number of measuring points
Incisal	Outer	LaL	52.1(10.3)	65.1(14.5)	2408(421)	60
		MD	61.8(8.2)*	72.3(12.9)*	2611(374)*	60
	Middle	LaL	44.0(10.7)	54.1(15.6)	2184(332)	60
		MD	57.9(14.1)*	75.6(19.9)*	2538(431)*	60
	Inner	LaL	41.3(12.2)	50.2(17.3)	2176(438)	40
		MD	40.8(10.9)	50.7(14.8)	1961(370)*	60
Center	Outer	LaL	55.4(11.1)	69.8(15.1)	2468(476)	60
		MD	56.8(11.2)	71.2(15.6)	2439(389)	59
	Middle	LaL	48.3(16.3)	59.8(22.2)	2323(535)	60
		MD	55.9(12.1)	70.9(17.3)	2431(368)	58
	Inner	LaL	32.3(9.6)	39.0(13.1)	1676(331)	60
		MD	35.9(10.5)*	44.8(14.7)*	1708(349)	60
Cervical	Outer	LaL	49.0(11.1)	60.4(15.0)	2326(420)	59
		MD	56.3(6.2)	75.9(11.2)	2248(339)	60
	Middle	LaL	45.7(10.2)	56.0(13.9)	2191(436)	60
		MD	48.2(11.9)	59.9(18.1)	2239(308)	60
	Inner	LaL	25.3(7.0)	29.5(9.2)	1473(226)	60
		MD	31.2(9.4)*	37.1(13.6)*	1572(268)	60

*Significant difference at $p < 0.05$.

Mesio-distally sectioned deciduous canines showed that in all areas, the inner layer had significantly lower H, PH and Y than those of the outer and middle layers. Cervically, the H and PH of the middle layer were significantly lower than those of the outer layer. All the mechanical properties of the cervical area were significantly lower than the incisal and center areas, except for the PH of the outer layer. H values of the inner layer were lower, and Y of all the layers showed significantly decreased values in the order: incisal, center and cervical.

Comparing the combined values of the mesial and distal sides from all areas in the same layer, the distal side showed significantly higher values than that of the mesial side for H and Y in the outer and middle layers, and for the PH in the middle layer.

4. Discussion

There have been no previous reports using a nanoindentation technique to compare the hardness and elasticity of intertubular dentin at different intratooth locations for both deciduous and permanent teeth. Therefore, in spite of the small number of the sample teeth, the data obtained in this study is useful since it demonstrated important differences between deciduous dentin and permanent dentin. Previous reports have suggested wide variations in the basic mechanical properties of dentin. Some of this variation may be as result of the use of techniques such as microhardness that result in averaged values that include contributions from the tubules, peritubular dentin and intertubular dentin. Since the quality of each dentin component might vary with location, this could contribute to the wide range of values. However work by Kinney *et al.* [9] indicated that much of the variation in permanent teeth could be due to differences in intertubular dentin, rather than peritubular dentin. In this work we used a nanoindentation technique that allowed measurement of the intertubular dentin alone. Since resin adhesion to dentin is currently believed to rely on the impregnation of resin into a superficially decalcified dentin zone [37], and peritubular dentin is largely removed in this zone, intertubular dentin comprises the largest and most important component of the dentin for bonding procedures. Thus it was of interest to determine how intertubular dentin mechanical properties vary between teeth of the primary and permanent dentitions, as well as the range of values that might be obtained with intratooth location.

Hardness and plastic hardness values from this study (Tables I and II and Figs. 2 and 4) varied with locations and were lower than that for deciduous molars (0.9 GPa or 94 kgf/mm^2) reported by Mahony *et al.* [27], but were in good agreement with the previous studies of sound permanent dentin [9, 15, 16, 18]. Hardness (H) is calculated from indenter displacement at maximum load that includes both plastic and elastic deformation of dentin. Plastic hardness (PH) is calculated based only on the plastic deformation of dentin and corresponds to Vicker's hardness. Variations in H and PH were almost the same for all layers and areas. In this study, Young's modulus of the deciduous canine dentin ranged from 1400 to 2701 kgf/mm^2 depending on location and the values (Tables I and II and Fig. 3) were in good agreement with the previous study for deciduous molar dentin (19.89 GPa or 2029 kgf/mm^2) [27] and previous studies of sound permanent dentin [9, 13, 14, 17–21, 28]. Maxillary first premolar dentin values were in good agreement with the previous studies of sound permanent dentin [9, 15, 16, 18] but lower than that for maxillary first premolar reported by Akimoto *et al.* [25] (Table I and Figs. 2 and 4). Young's modulus of the maxillary first premolar were also higher than that for the report by Akimoto *et al.* [25] and slightly higher than those for the previous studies of sound permanent dentin [9, 13, 14, 17–21] (Table I and Fig. 3).

Kinney *et al.* [9] reported that there was a nearly four-fold decrease in the hardness of the intertubular dentin between the DEJ and pulp areas, while values for peritubular dentin did not change. Deciduous and permanent dentin measured with a conventional microhardness tester have shown higher hardness values for peripheral dentin than central dentin, and the hardness of pulpal dentin was the lowest [29, 31–34]. Meredith *et al.* [20] and Hosoya *et al.* [33–35] reported that the hardness of dentin decreased with distance from the dentinoenamel junction, while Pashley *et al.* [16] reported a highly significant inverse correlation between dentin microhardness and tubule numerical density that increases with depth, but this could be due to changes in the hardness of the intertubular dentin, and not just the increase in the number density of tubules [9].

In this study, deciduous canines sectioned either LaL or MD had the highest hardness and elastic modulus in the outer layer, the values of the middle layer were the second highest and the values of the inner layer were the lowest in all areas (Tables I and II and Figs. 2–4). These findings were in good agreement with the Knoop hardness evaluation of deciduous canine dentin by Hosoya *et al.* [33–35]. However, for the premolar dentin, the hardness and elastic modulus of the outer layer were significantly lower than those of the middle and inner layers in many areas, especially for center area (Table I and Figs. 2–4). Lower hardness values, within 100–200 μm from the dentinoenamel junction have been reported [17, 32], probably due to mantle dentin. Since the premolars used in this study were young teeth obtained from the patients aged between 10–11 years, and the outer layer of this study was positioned 10–110 μm beneath the DEJ, the significantly lower values in the outer layer might be due to the influence of the mantle dentin of the young tooth.

In this study, cervical areas for the MD sectioned deciduous canine dentin and the BL sectioned premolar dentin had lower hardness and elastic modulus than those of the incisal and center areas in almost all of the layers (Figs. 2–4). Similarly, for the LaL sectioned deciduous canine dentin, the elastic modulus of the outer layer and the hardness and elastic modulus of the inner layer in the cervical area were significantly lower than those of the incisal and center areas (Fig. 3). Previously, we reported cervical areas under carious lesions were softer and had lower elastic modulus than sound dentin [35]. The lower mechanical properties in the cervical area are probably related to differences in mineral content and could make this area more susceptible to demineralization, either from caries or from etching treatments, and inferior adhesion of resin may be produced in this area.

In this study, only the MD sectioned deciduous canine dentin showed the same results in all of the outer, middle and inner layers. The distal proximal side had significantly higher hardness and elastic modulus values than the mesial proximal side. These differences could be related to the primate space. All of the MD sectioned deciduous canines were maxillary teeth. In the primary dentition, many children have the primate space between deciduous lateral incisor and deciduous canine in the maxilla, and deciduous canine and first deciduous molar in the mandible. Thus it is likely that the distal proximal surface of the maxillary deciduous canines contacted the mesial proximal surface of the first deciduous molar, but a space existed at the mesial proximal side of the deciduous canines. We speculate that the difference in primate space might lead to different abrasion characteristics in these two locations that could have led to the difference in mechanical properties. Abrasion between the adjacent teeth might contribute to the higher hardness of the dentin. In the deciduous canines, the hardness and elastic modulus of the proximal sides were significantly higher than those of the labial and lingual sides (Table II). All of the MD sectioned deciduous canines were maxillary teeth, but two out of three of the LaL sectioned deciduous canines were mandibular teeth. Hardness and elasticity of dentin might differ with tooth type and environmental factors during the time of tooth formation and mineralization. This could account for the considerable difference and variation among the specimens.

Nihei [29] reported that permanent dentin was harder than deciduous dentin and the hardness of permanent dentin increased with the age, but no statistical analysis was done in his study. In this study, the hardness and elastic modulus of the deciduous canine dentin were lower than those of the premolar dentin (Table I and Figs. 2–4). This suggests that there may be substantial difference in the properties of deciduous dentin and permanent dentin [15, 16, 18]. Thus treatments designed based on research on permanent dentin may not be optimized for deciduous dentin. Previous reports [38–40] suggested that deciduous dentin is more susceptible to acid or chemical conditioning treatment, and therefore shorter application times for the dentin conditioner in deciduous dentin may be appropriate. Further study is required to clarify these differences between deciduous and permanent dentin, to determine if different tooth types, or locations yield important differences in their biomechanical properties, and to further understand the precise mechanism of adhesion between dentin and resinous materials. Such information can be utilized to optimize bonding for primary dentin and permanent dentin.

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