Pulp Chamber Analysis of Primary Molars Using Micro-Computed Tomography: Preliminary Findings

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Purpose: *To determine the three-dimensional (3D) tooth morphology of all primary molars and to identify and consolidate positional factors that could potentially have an effect on tooth preparation.* ***Study design***: *Thirty-one non-carious primary molars were scanned using micro-CT and reconstructed using 3D analysis software. Each pulp horn to its respective cusp tip distance (PHCD) was measured as well as the distances from the pulp chamber to the mesial, distal, lingual and buccal surfaces. One-way ANOVA and post-hoc t-tests were used for data analysis.* ***Results***: *The mesio-buccal and disto-buccal PHCD was significantly shorter than the mesio-lingual and disto-lingual PHCDs in maxillary second primary molars ($P < 0.05$). Mesial, distal and lingual walls were thinner than the buccal walls of mandibular molars while in maxillary molars; the mesial and distal walls were thinner than the palatal and buccal walls ($P < 0.05$).* ***Conclusions***: *First primary molars have thinner tooth structure surrounding the pulp than second primary molars in the same arch with the exception of the buccal walls of all molars and lingual walls of maxillary molars. The mesial and distal walls are thinner than the buccal walls of all molars and lingual walls in maxillary molars.*

Keywords: *primary molars, micro-CT, tooth dimensions*

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INTRODUCTION

Primary teeth are widely reported to have a larger pulp chamber to crown volume ratio than permanent teeth.[1] Enamel and dentin layers are thinner in primary teeth, which means the pulp chamber is closer to the tooth surface. Therefore, there is a higher chance of iatrogenic mechanical exposure of the pulp when preparing primary teeth with deep carious lesions. Following iatrogenic exposure of the pulp in asymptomatic teeth, the clinical courses of action are direct pulp capping, pulpotomy, pulpectomy or extraction.[2,3] This results in higher costs, treatment times and stress for pediatric patients, which is undesirable. Intra-oral radiographs are essential to identify carious lesions and determine pulp chamber location and size.[4] Nevertheless, they are a two-dimensional representation of a three-dimensional (3D) structure and hence do not provide an accurate depiction of tooth morphology. It would therefore be useful to construct 3D images of the primary teeth to better understand their shape, location and size of the pulp chambers.

The majority of the literature involving 3D pulp chamber analysis has been focused on the permanent dentition.[5-8] A variety of methods have been used to analyze the pulp chamber, such as dental radiographs,[4,9] morphometric analysis,[10,11] cone beam computed tomography (CBCT),[9] magnetic resonance imaging (MRI),[9] spiral computed tomography (spiral-CT),[12] and micro-computed tomography (micro-CT).[13-17]

Micro-CT is a non-invasive technique that provides high-resolution three-dimensional imaging. However, because of the high levels of radiation required, analysis can only be performed on extracted teeth. The existing literature on the use of micro-CT to analyze the pulp chambers of primary teeth is limited and what data there are is only for selected molars and mandibular central incisors. Furthermore, three of the five investigations were conducted on teeth extracted from the dried skulls of children from an Indian population.[15-17] Thus, this study aimed to describe the 3D tooth morphology of all primary molars and to identify and consolidate positional factors that could potentially have an effect on tooth preparation.

MATERIALS AND METHOD

Following ethics approval (Human Research Ethics Committee, University of Western Australia; RA/4/1/8639) and consent from the participants, non-carious maxillary and mandibular primary molars were collected from children who attended various dental clinics in Perth, Australia. Teeth extracted as part of their pre-existing treatment plans that were formulated prior to recruitment of participants for this study were collected. Ectopic first permanent molars, resorbing the roots of second primary molars, impacted teeth, dental anomalies, and planned (serial) orthodontic extractions were the main reasons for extractions. The collected teeth were de-identified and stored in a 5 % solution of 'chloramine T' at 4° C. Therefore, it was impossible to ascertain their age gender and other demographic information. Digital photographs were taken of each tooth type. Teeth that were grossly broken down or heavily restored were excluded and a total of 31 non-carious primary molars were selected (11 mandibular first molars, 5 mandibular second molars, 9 maxillary first molars, and 6 maxillary second molars).

Micro-CT scanning

The micro-CT system (Sky scan 1176, Bruker-micro CT, Kontich, Belgium) consists of imaging apparatus and an attached dedicated computer to perform the calculations. The main imaging apparatus consisted of an X-ray generator and a 360˚ rotating specimen stage and a detector. For photographing, the tooth specimens were scanned using the following specifications; tube voltage 80 kV, tube current 309 μA, 18 μm resolution, 400 μm copper and 500 μm aluminium, 300 milli-second exposure time, 0.7˚ rotation step over 180˚ rotation, and frame averaging 2. A flat field correction was performed prior to each scan.

3D reconstruction

The steps involved in CBCT reconstruction includes two stages namely, (i) acquisition, where the image data is collected, and (ii) reconstruction, which involves processing image relations and recombining slices to create a 3D volume. The 3D reconstruction was performed using 282 two-dimensional images and a modified Feldkamp (FDK) cone-beam algorithm with the following parameters, BMP file format, ring artefact reduction of 8, and beam-hardening correction of 30% (NRecon, Version 1.7.1.0, Bruker-micro CT, Kontich, Belgium). Due to its practicality and power of the approach, the FDK algorithm is commonly used to reconstruct images with little data loss, and effectively parallelize to an extent. Fundamentally, it converts the CBCT image reconstruction problem into the fan-beam reconstruction problem, using a circular focal point trajectory but using a cone-beam coordinate system. Nonetheless, an additional dimension 'z' is added to represent the third dimension of the cone-beam projection. The main determinant of a weighting function for this algorithm is the length from the detector to the focal point, D, which is an important variable to note. 3D viewing software was used to help identify the different types of teeth (CT Vox, Version 3.3.0 r1403, Bruker-micro CT, Kontich, Belgium) – see Figure 1.

Different colors were used to represent the pulp chamber, dentin, and enamel in the reconstructed 3D images. The enamel and dentin were rendered transparent and the pulp chambers were observed from various aspects to view the positional relationship between the crown contour and the pulp chambers in three-dimensions (CTVol, Version 2.3.2.0, Bruker-micro CT, Kontich, Belgium) – see Figure 2.

Quantitative shape analysis

To investigate the tooth structure thickness at the pulp horns, morphological analysis was performed to measure the distance between each pulp horn and the respective cusp tip using Data Viewer (Version 1.5.3.4, Bruker-micro CT, Kontich, Belgium). The enamel and dentin thicknesses were also measured (Figure 3).

To investigate tooth structure thickness at the mesial, distal, buccal and lingual walls; morphological analysis was performed and a consistent plane where the pulp horns first coalesced was identified across all teeth (Figure 3). Using Data Viewer (Version 1.5.3.4, Bruker-micro CT, Kontich, Belgium), three measurements were taken from the pulp chamber to the different surfaces of the tooth and the mean was taken to estimate wall thickness.

Data analysis

Mean PHCD and wall thickness values were calculated for each tooth type. One-way ANOVA (P-value set to <0.05) was conducted and where statistical significance was found, post-hoc t-tests were performed (P-value set to <0.05).

RESULTS

Comparison of PHCD's within tooth type

No significant difference was found in PHCD for mandibular first and second primary molars and the maxillary first primary molars. However, PHCD was significantly different between the different cusps within the maxillary second primary molars. The mesio-buccal PHCD (3.3 mm) was significantly shorter ($P < 0.05$) than the mesio-lingual (3.8 mm) and disto-lingual (4.12 mm) dimensions. The disto-buccal PHCD (3.6 mm) was also significantly shorter than the disto-lingual ($P < 0.05$) distance (Table 1).

Comparison of PHCD's across tooth type

Furthermore, the PHCDs were significantly shorter in primary first molars than the primary second molars ($P < 0.05$). The average enamel thickness for all molars was 0.4 mm (SD ± 0.20) while average dentin thickness, was 2.8 mm (SD ± 0.50).

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Figure 1. Three-dimensional reconstructions of primary molars which assisted in identifying teeth and visualizing anatomy. (a) maxillary first primary molar, (b) mandibular first primary molar, (c) maxillary second primary molar, (d) mandibular second primary molar.

B: buccal, M: Mesial, O: occlusal, D: Distal, L: Lingual

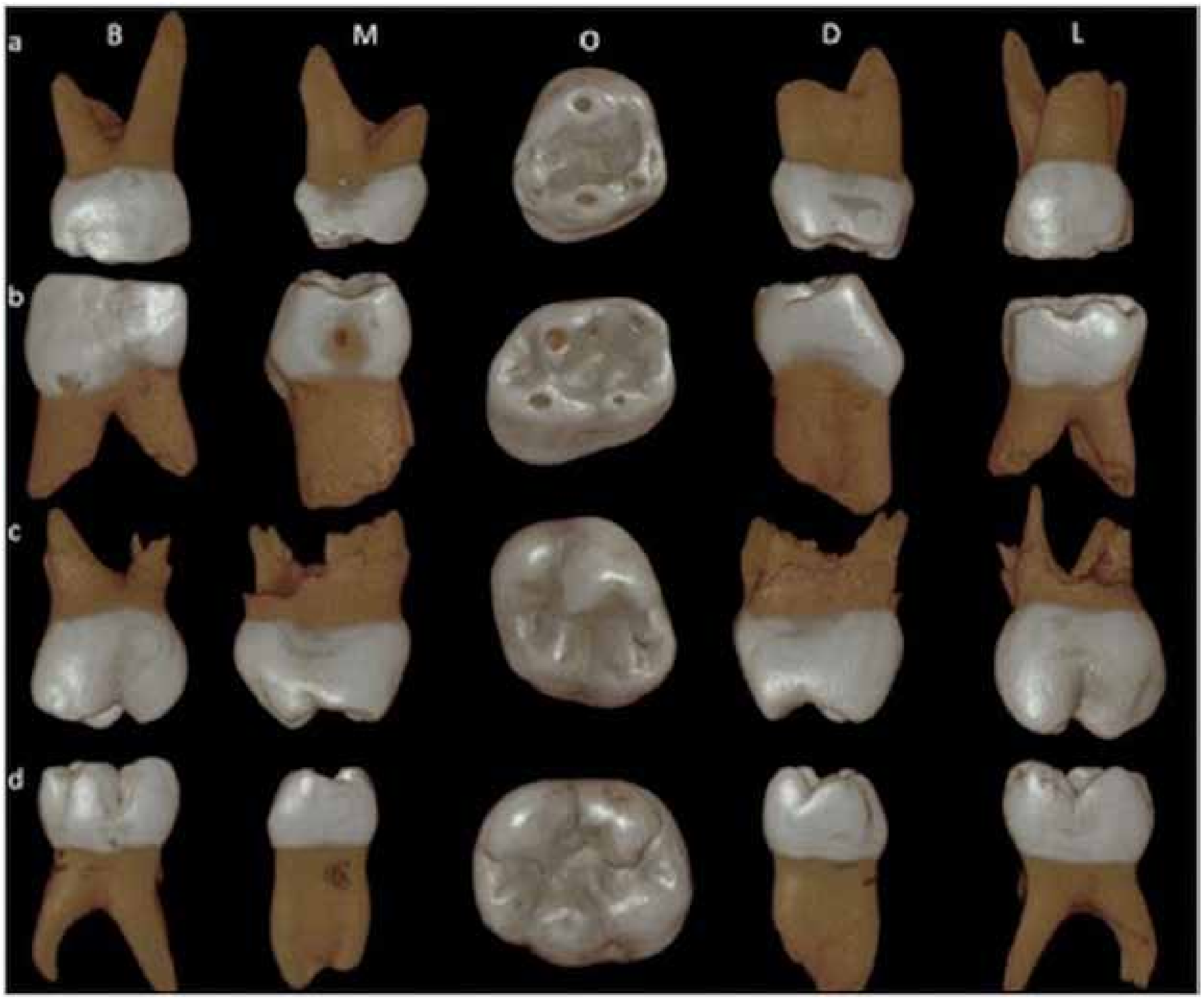

Figure 2. Three-dimensional reconstruction of a mandibular second primary molar. Enamel is represented in white, dentin is represented in yellow, and pulp tissue is represented in red. The pulp horn to cusp distance was measured from the pulp horns to their respective cusp tips; the dimensions was 2a + 2b. Dentin thickness in the primary molar cusp was ascertained by measuring the pulp horn to dentin tip distances (2b).

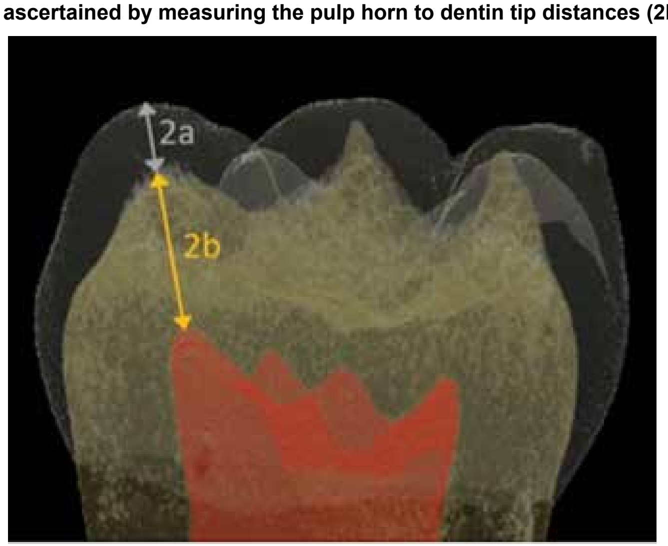

Figure 3. Topographical slices of a mandibular first primary molar in the coronal plane. (A) apical limit of pulp chamber, (B) tip of mesio-buccal pulp horn, (C) coronal limit of dentin, and (D) cusp tips. Topographical slice of a mandibular second primary molar in the coronal plane. (E) reproducible plane where all pulp horns coalesce, and (F) average wall thickness.

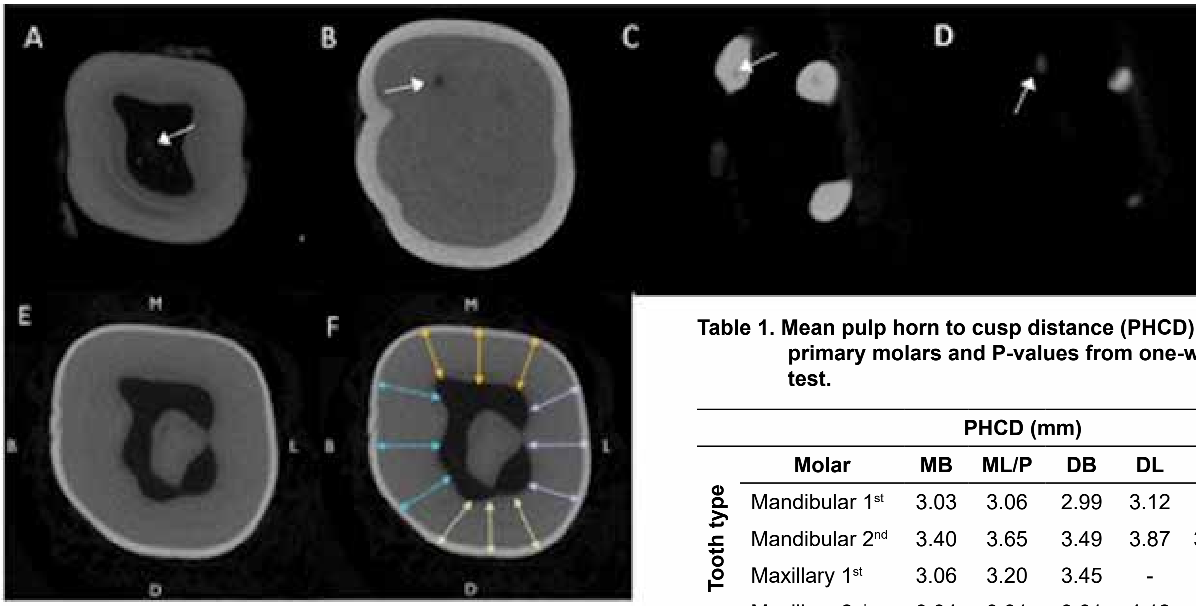

Table 1. Mean pulp horn to cusp distance (PHCD) values in primary molars and P-values from one-way ANOVA test.

	PHCD (mm)						
	Molar	MB	ML/P	DB	DL	D	*P*-value
Tooth type	Mandibular 1st	3.03	3.06	2.99	3.12	-	0.97
	Mandibular 2nd	3.40	3.65	3.49	3.87	3.67	0.35
	Maxillary 1st	3.06	3.20	3.45	-	-	0.62
	Maxillary 2nd	3.34	3.81	3.61	4.12	-	<0.05*

MB, mesio-buccal; ML, mesio-lingual; P, palatal; DB, disto-buccal; DL, disto-lingual; D, distal; *indicates statistical significance

Comparison of pulp to tooth surface distance within tooth type

Significant differences were found in wall thicknesses within each primary tooth type (Table 2). In the mandibular first and second primary molars, the buccal wall was significantly thicker than the mesial, distal and lingual walls ($P < 0.05$). In the maxillary first and second primary molars, both the buccal and lingual walls were significantly thicker than the mesial and distal walls ($P < 0.05$). However, no significant difference was evident between the buccal and lingual wall thicknesses within the maxillary primary molars.

Comparison of pulp to tooth surface distance across tooth type

There were significant differences found in the wall thicknesses of the primary molars. Mandibular second primary molars had significantly thicker mesial, distal and lingual walls than the mandibular first primary molars ($P < 0.05$). They also had significantly thicker mesial and distal walls than those found in the maxillary first primary molars ($P < 0.05$). The maxillary second primary molars exhibited thicker mesial, distal and lingual walls than both the maxillary and mandibular first molars ($P < 0.05$) also it was found that there was no significant difference in the buccal wall thicknesses across all tooth types. Furthermore, maxillary primary molars were found to have significantly thicker lingual walls than those of the mandibular primary molars ($P < 0.05$)–see Figure 4.

Table 2. Mean pulp wall distance (PWD) values in molars and p-values from one-way ANOVA test.

	PWD (mm)					
	Molar	M	B	D	L	P-value
Tooth type	Mandibular 1st	1.62	2.24	1.56	1.68	<0.05*
	Mandibular 2nd	1.93	2.40	1.99	2.07	<0.05*
	Maxillary 1st	1.67	2.25	1.70	2.28	<0.05*
	Maxillary 2nd	2.03	2.35	2.11	2.53	<0.05*
	p-value	<0.05*	0.16	<0.05*	<0.05*	

M, mesial wall; B, buccal wall; D, distal wall; L, lingual wall; *indicates statistical significant

DISCUSSION

The occlusal surfaces of first primary molars were found to be thinner than those of the second primary molars. Furthermore, in the maxillary second primary molars, tooth structure over the mesio-buccal cusp was found to be thinner than the disto-buccal, disto-lingual and mesio-lingual cusps. This suggests that when removing tooth structure during cavity or crown preparation of first primary molars or in the region of the mesio-buccal cusp of the maxillary second primary molars, clinicians should be aware of the proximity of the pulp chamber because of the increased risk of pulpal exposure.

The mesial, lingual and distal walls of mandibular first primary molars are thinner than the mandibular second primary molars, while the mesial and distal walls of maxillary first primary molars are thinner than their maxillary counterparts. When preparing first primary molars in these regions, the thinner odontogenic tissues of these tooth surfaces needs to be taken in consideration. Furthermore,

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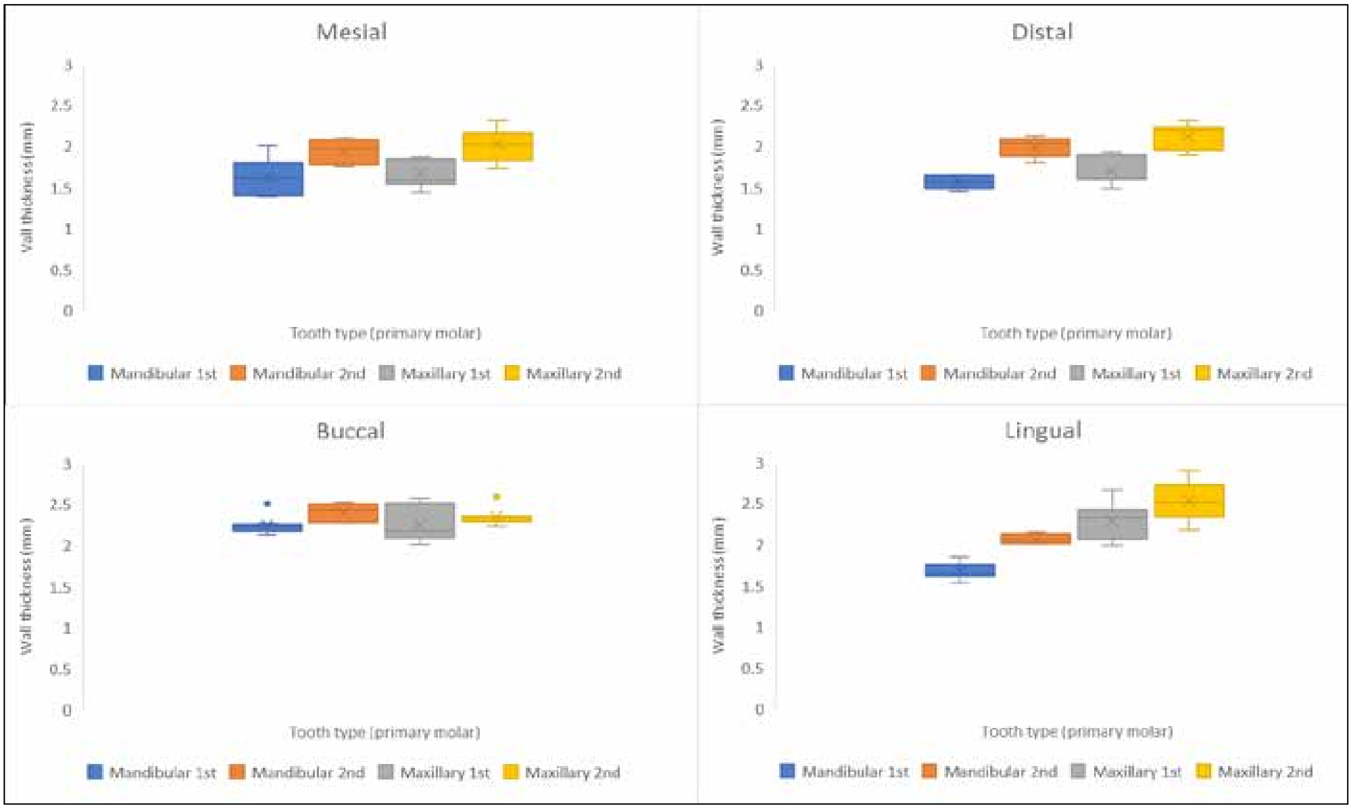
Figure 4. Box and whisker plots of pulp to surface distances of all types of primary molars.



the mesial, distal and lingual walls of mandibular primary molars are thinner than the buccal walls whilst the mesial and distal walls are thinner than the buccal and lingual walls in maxillary primary molars and caution should be observed when preparing these areas.

The aim of the present study was to describe the 3D tooth morphology of primary molars and to identify positional factors that could have an effect on tooth preparation. Measuring the tooth structure thickness at various surfaces of the primary molars facilitated determination of the position of the pulp chamber in relation to the surface of the tooth. The proximity of the pulp to these surfaces is an important factor to consider when undertaking tooth preparation.

The PHCD was shorter in the buccal region than in the lingual region of maxillary second primary molars with the shortest distance being between the mesio-buccal PHCD. This is consistent with results from the study by Amano et al[1] that investigated the pulp chambers of maxillary second primary molars using micro-CT. Although no significance difference was found, the average PHCD in mandibular second primary molars was the least over the mesio-buccal pulp horn followed, in order, by the disto-buccal, mesio-lingual, distal, and disto-lingual pulp horns. These findings are in agreement with the study by Ikari et al.[2]

The average values for maxillary primary first and second molar wall thicknesses were comparable to the results found in a previously published study that used light microscopy.[3] The lingual wall measurement however was larger in this study when compared to the previous one. This discrepancy can be explained by the difference in techniques employed in the two studies. Bacchouche and co-workers[10] only took one measurement of the wall thickness for each surface along the line of greatest mesio-distal or bucco-lingual width of the crown, whereas in our study three measurements were taken for each surface and an average value was subsequently calculated.

In a study evaluating primary molar pulp chamber dimensions using bitewing radiographs, the average distance from the buccal cusp tip to the roof of the pulp chamber was found to be larger than the distances found in the current study.[4] This is likely because of the higher resolution achieved with micro-CT, which allows measurements in three dimensions and visualization of fine pulp horn tips. The reliability of intra-oral radiographs in estimating pulp to surface distance is limited by lower resolution and image distortion.

One major limitation of micro-CT is that it cannot be used at the chair side to measure teeth in a patient. The high exposure values and scanning time make it unsuitable to scan teeth *in situ*. Therefore, micro-CT cannot be used to visualize the internal tooth anatomy in patients, nor can it be used to monitor how the pulp chamber changes over time.

Another limitation of the current study was the sample size. It is difficult to obtain non-carious primary molars as they do not warrant extraction unless for orthodontic reasons or with pre-existing dental anomalies and/or disturbances. Although, we allowed a 2-year period for teeth collection we could only collect 31 primary molars. With a greater number of primary molar teeth of each type it would be possible to determine any changes in pulp chamber morphology with age, between genders and across ethnicities. A larger sample size would also minimize error and provide more accurate mean values. Nevertheless, it is very difficult to obtain primary molars without caries and subsequent breakdown.

Future studies that involve micro-CT analysis could include anterior teeth the values of which when combined with the current study should give a comprehensive account of pulpal anatomy within the entire primary dentition. The 3D reconstructions of the teeth can also be analyzed in many different ways. For example, crown to pulp volume can be analyzed, root canal morphology can be visualized, and different mineral densities can be determined.

The values reported in this study will help form reference tables, which can be used to inform clinicians of average tooth structure thicknesses at different surfaces in different tooth types. Measurements made using micro-CT analysis techniques are more accurate than those obtained from chairside radiographs. Information regarding the amount of tooth substance that can be safely removed before causing pulpal exposure may help pediatric dentists avoid pulpal insult when excavating caries or preparing teeth for restorations. Information regarding proximity of the pulp to certain surfaces of the tooth may be useful in the decision-making process when choosing to perform a pulpotomy or minimally invasive treatment.

CONCLUSIONS

First primary molars have thinner tooth structure surrounding the pulp than second primary molars in the same arch with the exception of the buccal walls of all molars and lingual walls of maxillary molars. In the maxillary second primary molars tooth structure is thinnest over the mesio-buccal cusp. Mesial and distal walls are thinner when compared to buccal walls of all primary molars and, the buccal and lingual walls of maxillary primary molars.

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