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โครงการวิจัย

ความแม่นยำของเครื่องวัดความยาวคลองรากฟันอิเล็กทรอนิกส์ในฟันน้ำนม

Clinical accuracy of electronic apex locator in primary teeth

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Abstract

Accurate root canal length measurement means adequate bacterial removal, and less trauma to periapical tissues and permanent tooth buds. However, in primary teeth, there is still controversy on how to accurately measure the canal length, especially in the case of severe root resorption. The aim of this study was to evaluate the clinical accuracy of electronic apex locator (EAL) in primary teeth with severe root resorption. Nineteen primary teeth (33 roots) were collected from patients at Pediatric Dental Clinic, Rangsit University. Each root was measured in vivo with an EAL (Root ZX®) at three different levels of display bars; 0.0, 0.5, and 1.0. Then, each tooth was extracted and directly measured to the coronal end of apical foramen under a stereomicroscope. The accuracy from all three groups were analyzed using paired t-test at 95% confidence level. Among the three display bars, the measurement at display bar 0.0 demonstrated the best accuracy at 63.63% within ±0.5 mm, and 90.90% within ±1 mm. The less accurate measurements were at display bar 0.5 (51.61% within ±0.5 mm, 83.87% within ±1 mm) and at display bar 1.0 (36.67% within ±0.5 mm, 76.67% within ±1 mm), respectively. There was no significant difference between the measurement at display bar 0.0 and the direct measurement (P=0.428). EAL measuring at the display bar 0.0 is most accurate in determining the root canal length in primary teeth with severe root resorption.

ชื่อเรื่อง: ความแม่นยำของเครื่องวัดความยาวคลองรากฟันอิเล็กทรอนิกส์ในฟันน้ำนม

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คำสำคัญ: พัลพ์เพคโตมี ฟันน้ำนม เครื่องวัดความยาวคลองรากฟันอิเล็กทรอนิกส์

ลิขสิทธิ์: มหาวิทยาลัยรังสิต

บทคัดย่อ

การหาความยาวรากฟันที่ถูกต้องมีความสำคัญต่อผลสำเร็จในการรักษาคลองรากฟันน้ำนม และช่วยลดการสร้างความเสียหายต่อเนื้อเยื่อบริเวณปลายรากฟันน้ำนมและหน่อฟันแท้ คณะผู้วิจัยจึงได้วัดความยาวรากฟันที่มีการละลาย 33 ราก จากฟันน้ำนม 19 ซี่ ด้วยเครื่องวัดความยาวคลองรากฟันอิเล็กทรอนิกส์ ก่อนการถอนฟัน เพื่อประเมินความแม่นยำในการอ่านค่าที่ตำแหน่งบาร์ 0.0 0.5 และ 1.0 โดยนำค่าที่วัดได้ทั้ง 3 กลุ่ม เปรียบเทียบกับความยาวรากแท้จริงที่วัดด้วยคาลิปเปอร์แบบดิจิตอลผ่านกล้องจุลทรรศน์ชนิดสเตอริโอหลังจากฟันถูกถอนออก และทดสอบทางสถิติแบบ Paired t test ผลศึกษาพบว่า การอ่านค่าเครื่องวัดในตำแหน่งบาร์ 0.0 ให้ความแม่นยำที่มากที่สุด คือ ร้อยละ 63.63 และร้อยละ 90.90 ณ ความคลาดเคลื่อนที่ยอมรับได้ 0.5 และ 1 มิลลิเมตร ตามลำดับ ในขณะที่การอ่านค่าในตำแหน่งบาร์ 0.5 มีความแม่นยำรองลงมา ที่ร้อยละ 51.61 และ ร้อยละ 83.87 ณ ความคลาดเคลื่อนที่ยอมรับได้ 0.5 และ 1 มิลลิเมตร ตามลำดับ และการอ่านค่าในตำแหน่งบาร์ 1.0 ให้ความแม่นยำน้อยที่สุด เพียง ร้อยละ 36.67 และ ร้อยละ 76.67 ณ ความคลาดเคลื่อนที่ยอมรับได้ 0.5 และ 1 มิลลิเมตร ตามลำดับ จึงสามารถสรุปได้ว่า การอ่านค่าเครื่องวัดความยาวคลองรากฟันอิเล็กทรอนิกส์ที่ตำแหน่งบาร์ 0.0 ในรากฟันน้ำนมที่มีการละลายนั้นให้ผลแม่นยำ โดยพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติกับความยาวคลองรากฟันที่แท้จริง (P=0.428) ที่ระดับความเชื่อมั่นร้อยละ 95

Acknowledgement

In search for ways to better dental treatment in children, data must be gather from these amazing young volunteers. Thank to their cooperation and understanding that had developed well beyond their years. There were also dental assistant staffs at RSU pediatric dental clinic who were always helping as much as they could during the entire period of data collection. Deep gratitude and appreciation must be made to Assistant Professor Dr. Nichakant Klinkusoom for providing the access to the stereomicroscope which was essential to this study. Special thanks to Professor La-ongthong Vajrabhaya for your useful suggestion and warm encouragement throughout the project.

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Yada Anantawat

Head of the research project

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Chapter 1

Introduction

Significance and origin of research topics

The essence of pediatric dental treatment is to deliver a safe, quick, and successful dental procedure, in the hope to embed positive attitude toward dental visits in these young patients. Some dental treatments are simple and short enough for children to maintain their good cooperation. Pulpectomy, however, is not one of those treatments. As if the local anesthesia injection and the access opening in child patients are not difficult enough, the various position and shape of root apex in primary teeth have been problematic when determining the canal root length in the pulpectomy procedure. Clinicians and researchers are trying to find the accurate method of locating these apical foramens in the primary teeth in order to estimate the canal root length, thus the appropriate working length. Currently, clinicians are using radiographs as a primary tool to locate the apical foramen in primary teeth. Limitation was drawn by the fact that radiographs are two-dimensional representatives of the roots. When oblique root resorption occurred or actual apical foramen linguo-facially located, the canal root length could be misread from a radiograph. Drawback of the radiographs consists not only the extra exposure of radiation, but also, the risk from having dental files inside a child's mouth while taking the x-rays. In the early 40s, electronic apex locators (EALs) have been developed to determine the working length of root canals. The early-generation of EALs may be affected significantly by the presence of strong electrolytes, excessive hemorrhage, pus, pulpal tissue, or large apical foramens. Late generations claimed that those factors are less influential, therefore the more accurate measurement could be made. Despite of the widely-use in permanent dentition, EAL's accuracy remains questionable in large apical foramens which are generally found in the constantly-resorbing roots of primary teeth. High accuracy of EALs in primary teeth with different stages of root resorption has been reported in several in vitro studies, However, the result from in vitro studies is not be the best depiction of EALs accuracy in primary teeth because the fundamental principle of EAL is based on a constant electrical resistance value between the file instrument and the oral mucous membrane. Some in vivo studies on EAL accuracy in primary teeth were investigated (Kielbassa et al. 2003), (Bodur et al. 2008), (Odabas et al. 2011), (Wankhade et al. 2013). Their interesting and divergent results had urged the necessity for the more carefully-design in vivo study on this subject.

Objective of research

To evaluate the clinical accuracy of a commonly-used electric apex locator (Root ZX®) in the root canal length determination of the primary teeth.

Research hypothesis

H0: There is no difference between the EAL measurement at display bar 0.0, 0.5, 1.0 and the actual root canal length.

H1: There is a difference between the EAL measurement at display bar 0.0, 0.5, 1.0 and the actual root canal length.

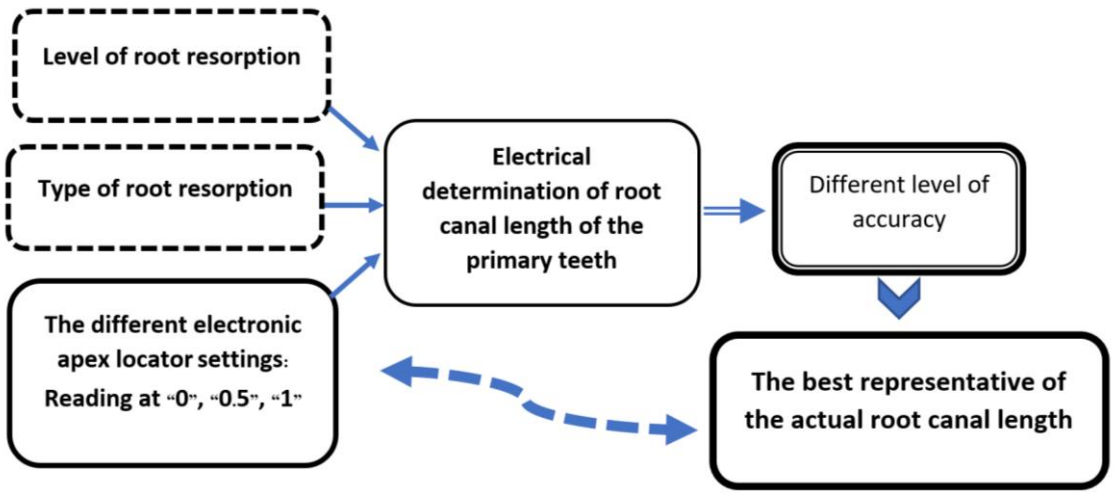
Scope of research

This research studied the measuring technique of root canal length in primary teeth as a part of a dental procedure in pediatric patient, pulpectomy. The root canal measurement from a Root ZX® EAL before the tooth extraction at three different were compared to the direct root canal measurement after the teeth were extracted. All the measurement of canal root length was detailed to the second decimal number of millimeter via a digital caliper.

The study population was the group of young cooperative patients age between 4 to 9 years old whose teeth was scheduled to be extracted during January of 2018 to September of 2018 at the Pediatric dental clinic, College of Dental Medicine, Rangsit University.

The total period of data collecting was 1 year.

Conceptual framework



Expected benefits

1. Dentists would know which EAL setting is the most appropriate determination of root canal length in primary teeth ensuring the treatment success.

2. The child patients could have a shorter and more comfortable chair time during pulpectomy.

Chapter 2

Literature review

Pulpectomy is a dental treatment for primary teeth with diagnosis of irreversible pulpitits or pulp necrosis. There are several steps in pulpectomy procedure, including the step of root canal length and working length determination. The main principle of pulpectomy is to eliminate the bacteria and infectious dental pulp tissue inside the tooth, and place antibacterial filling material inside the root canal (Casamassimo et al, 2012). In order to do so, the dentist must determine the length of each root canals before starting eliminating the bacteria and infectious tissue.

The root canal anatomy of primary teeth is varied, and the root is usually present with an open apex because the physical root resorption of a primary tooth starts almost immediately once the root formation is completed. There is also the deposition of secondary dentin inside the root canals causing the variations and alterations in the number and size of the root canals, as well as many small connecting branches or fins between the facial and lingual aspect of the canals. The deposited secondary dentin and the physical root resorption can reconfigure the root canal system continuously.

Anterior primary teeth normally have one root and one canal and the variation is not as much as in posterior primary molars. According to the literature, a primary maxillary molar may have two to four roots. The most common variant is the three-rooted which includes distobuccal root, mesiobuccal root, and palatal root. The number of root canals in primary maxillary molars varies due to several reports of multiple-canals in one root, with mesiobuccal root being mostly reported. In a primary mandibular molar, the number of roots can be one to three roots, with the two-rooted variant being the most common (mesial root and distal root). The mesial root of a primary mandibular molar normally has two root canals with some exceptional cases of one or three root canals. The distal root in a mandibular molar usually has one or two root canals (Ahmed, 2013). Beside the physiological root resorption and the deposited secondary dentin, the pathological root resorption as a consequent from the pulp and/ or periodontal inflammation can also complicate the anatomy of the root canals in primary teeth.

Steps in pulpectomy include access opening, root canal length determination, root canal preparation, and root canal filling. The access from occlusal surface to pulp chamber can be made, using the carbide bur no. 330 or the diamond flat-end cylinder bur. The remaining overhang of dentin from the roof of pulp chamber can be removed with a high-speed diamond round bur. Then, after the

removal of the coronal pulpal tissue, a 10-size or 15-size endodontic file is often used to identify the canal orifices. Care must be taken in these steps not to perforate the pulpal floor. Next step is measuring the root canal length to determine the working length which will be 0.5 to 1 mm shorter than the root canal length. This is a crucial step because, with this step, the extent of the root canal area that will be cleaned, prepared, and filled with antibacterial medication is determined. American association of Endodontic 2003 defined working length as "the distance from a coronal reference point to the point at which the canal preparation and filling should terminate". The placement of root canal instruments, irrigation, and filling materials should not be beyond the apical foramen to avoid possible damage to the permanent tooth bud underneath the primary tooth. The root canal length, therefore, should be precisely determined to deliver a successful and safe pulpectomy. There are a few methods currently used to determine the root canal length. The most traditional one is the radiographic method.

The radiographic method can be done in two fashions. The first is the use of the initial periapical radiograph taken prior to the access opening of the tooth digital. A digital film is adjusted into the patient's mouth to expose the tooth of interest using a "paralleling technique". Then the film is processed, and the root length will be measured in the computer software. The estimated root length is, then, substracted with 0.5 - 2 millimeters depending on the clinician's judgement on the degree of the root resorption. The final length is referred to as the working length. Another fashion includes an extra radiograph taken after the access opening and a 15-or-20-size endodontic file is inserted in each canal at the trail length (the measurement from the initial periapical radiograph). When the second radiograph is obtained, the final working length will be determined. Although it was reported that the location of the root apex could be accurately located radiographically, the precise position of the apical foramen cannot be measured when the foramen is located facially or lingually. Possible distortions and mistakes in the working length determination can occur because the image produced from the radiograph is a two-dimensional representation of a three-dimensional tooth structure. It is also very difficult to have a poor cooperative child taking an intraoral radiograph with small, long, and pointy instrument inside her/his teeth. Majority of the x-ray technique used in children is bisecting angulation rather than paralleling. A report showed that working length determined by the bisecting angle technique, either correctly or incorrectly angulated, was less accurate than the paralleling technique (Forsberg, 1987). With regard to these limitations, the

radiographic method is still in doubt to be the most appropriate way to estimate the accurate working length of primary teeth.

The second method is the tactile sensation. This is the quickest method to find the working length since this technique does not require any extra equipment. An endodontic file corresponding to the size of the root canal is introduced until the apical constrictor is felt by the clinician through manual tactile sensation. The readings are then recorded. However, the technique to determine working length should be based on scientific data and should be reproducible by any clinicians. This method relies very much on operator's experience and personal skill. The tactile sensation method also has other disadvantages, including pain and discomfort from the patients during the canal sensation, and the difficulty in sensing the apical constrictor in the canal with open apex or root resorption. This method when compared with X-ray and EAL in primary teeth does not produce the most reliable results (Wankhade et al., 2013).

The last method is using the electronic apex locator or EAL. The electronic method for root length determination was first investigated by Custer in 1918. Its functionality was based upon the fact that the electrical conductivity of the tissue outside the root apex is greater than the conductivity inside assuming that the canal is either dry or filled with nonconductive fluid. Years later, Dr. Sunada discovered a specific value of electrical resistance that indicated when the tip of endodontic instrument had reached the periodontal tissue at the apical foramen. Regardless of the patient's age, type or shape of teeth and diameter of root canals, the electrical resistance between the instrument and the oral mucous membrane when the instrument reached apical foramen is approximately 6.5 kΩ (Sunada, 1962). The periodontal tissue beyond the root apex is a conductor of electric current, while dentin, tissue, and fluid inside the root canal are the resistive material (insulator). When the endodontic file inserted inside the root canal begins to reach the apical foramen, the electrical resistance between the tip of the file and the apical portion of the canal decreases due to the decrease of the effective length of the insulator inside the canal.

Consequently, the first generation of electric apex locator was resistance-based. Since then, the development of EAL continues and a generation of EAL using two-frequency altering electrical current and the impedance ratio was introduced. The impedance is the total amount of opposition to an altering electrical current (AC). In the circuit that has both resistors and capacitors, like the condition of root canals, the value of impedance depends on the resistance values of its resistors and

the reactance values of its capacitors. In other words, the impedance of the root canal depends on many parameters and is not the same in different canals.

The Root ZX® (J. Morita Co., Kyoto, Japan) is an EAL that uses impedance ratio method. This method works on the different sine wave frequencies of same type of electrolytes by two electric currents. It comprises two sine waves with a high and a low frequency (f_H and f_L respectively). The impedance of the model is measured at each frequency, and the position of the file is determined from the ratio between these two impedances ($Z(f_H)/Z(f_L)$). The capacitance of root canal increases as the file reach the apical area but the quotient of the impedances reduces decrease as the file reach the apical area. The ratio of different frequencies has definitive values, meaning the ratio will not change even with the different electrolytes in the canal. Studies reported that there was no statistical difference between the ability of the Root ZX® to determine the canal length in roots with vital pulps versus those with necrotic pulps and/or various irrigants (Dunlap et al., 1998; Nekoofar et al., 2006). The Root ZX® has been tested for accuracy. A study showed that when a potential error of ±0.5 mm from the 'foramen' was accepted as a clinically tolerable range, the Root ZX® was able to locate the 'foramen' in 96.2% of cases despite the presence of sodium hypochlorite, blood, water, local anesthetic, and pulpal tissues (Shabahang, Goon, and Gluskin, 1996). While in 2004, Hoer & Attin has reported the probability of determining the apical foramen was between 81 and 82.4% of cases. (Hoer and Attin, 2004). Root ZX give a good performance when using a smaller file compare to the diameter of root canal with NaOCl solution. But if the canal contained blood, serum or pus, it was suggested to use file that fit well to the canal (Ngyungen et al., 1996).

The study on EAL accuracy in primary teeth has been investigated for years. In primary tooth, there are several studies on the accuracy of EALs in primary teeth. One study had tested the accuracy of Root ZX® compare with the radiographic method and the result showed no significant difference between the EAL method and the radiographic method (Katz et al., 1996). Others have conducted the *in vitro* studies to test the effect of root resorption on the accuracy of electric apex locator in primary teeth. Their investigations have reported that the electric apex locator gave an accurate result in primary teeth both with and without root resorption (Mente et al., 2002; Tosun et al., 2008; Angwaravong and Panitvisai, 2009). However, there are limited numbers of *in vivo* studies. A few studies have also investigated different brand of EAL, such as Joypex 5 (Wankhade et al., 2013), Dentaport ZX (Chougule, Padmanabhan, and Mandal, 2012), and Propex (Patino-Marin et al., 2011), but the most commonly-used in primary teeth was Root ZX and Root ZX II by Morita Japan.

Regarding the study of Root ZX, the level of accuracy still varied in both *in vitro* and *in vivo* studies (Srirath, 2005; Mello-Mouraet al., 2010). Investigators reported and recommended the necessity for further clinical studies. The following table listed all of the *in vivo* studies of Root ZX's accuracy in primary teeth (Table 1).

Table 1: Review of in vivo studies performed in primary teeth for root canal length determination using Root ZX®.

Studies/Year	EAL	Tooth	N (roots)	Apical reference point	Accuracy	
					Without Resorption	With Resorption
Kielbassa et al. 2003	Root ZX	All primary teeth	105	Not specified	± 1mm = 65.6%,	± 1mm = 63%,
Ghaemmaghami et al. 2008	Root ZX	Primary incisors	150	"0.5" reading	± 0 mm = 65% ± 0.5mm = 95%	
Beltrame et al. 2011	Root ZX	Primary molars	30	"0.0" reading	±0.5mm = 69%, ± 1mm = 92%,	±0.5mm = 65% ± 1mm = 94%,
Odabas et al. 2011	Root ZX	Primary molars	46	"1" reading	±0.5mm = 79.16%, ± 1mm = 95.82%,	±0.5mm = 63.63% ± 1mm = 86.35%,
Patino-Marin et al. 2011	Root ZX	All primary teeth	61	"0.0" reading	No significant difference from the actual root length, but the percentage was not reported.	
Kumar et al. 2016	Root ZX mini	All primary teeth	41	"0.5" reading	± 0.5mm = 95.1%, ± 1mm = 100%	

An *in vivo* experiment in 2003 reported a good performance of Root ZX in primary teeth (Kielbassa et al., 2003). Another *in vivo* study, conducted in 2008, reported that 65% of the root canal length measured *in vivo* was equaled to the length measured *in vitro* by a standard ruler (Ghaemmaghami, Eberle, and Duperon, 2008). The study also indicated no significant difference between the tooth with and without gingival fistula. The Root ZX apex locator was accurate in determining *in vivo* and *ex vivo* the canal root length ±1 mm in primary molar teeth in over 90% of roots regardless of the presence of root resorption (Beltrame et al., 2011). Another *in vivo* study reported the accuracy of Root ZX was 86.35% within ± 1 mm (Odabas et al., 2011), whereas the latest *in vivo* study of Kumar et al. in 2016 reported up to 95.1% of accuracy within the acceptable range of ±0.5 mm, and a 100% of accuracy within the acceptable range of ± 1 mm (Kumar et al., 2016).

However, these investigations did not follow the same criterion of the apical reference point of EAL. For example, the studies of Ghaemmaghami et al. 2008 and Kumar et al. 2016 read the measurement at “0.5” bar while the studies of Beltrame et al. 2011 and Patino-Marin et al. 2011 read at “0” or “Apex” bar, and the study of Odabas et al. 2011 read at “1” bar. The variety of measurement technique led to the unstandardized of the study method, and perhaps led to the existed conflicting results both *in vitro* and *in vivo* studies. In conclusion, the *in vivo* information about the accuracy of EAL in primary teeth is still very limited, and further investigations are needed.

Chapter 3

Methodology

1. Population and sample size

The sample size was calculated using the below formula and the standard deviation from a prior study of Odabas et al. in 2011. 'Z' was the value obtained from a statistics table using 95% confidence interval: z=1.96, 'σ' was substituted with 0.42, the standard deviation from a previous study (OdabaŞ et al, 2011), and 'd' was the acceptable standard error of the mean, estimated as 0.30 mm. The sample size calculated was 30 root canals.

$$n_o = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{d^2}$$

2. Equipment and materials used in the research

-	Apex locator (Root ZX mini)	3 units
-	Dental exam instruments (explorers, mouth mirror, tweezers)	5 sets
-	Extraction forceps for primary teeth	5 pairs
-	Stainless steel dental syringe	5 syringes
-	Digital X-ray machine	1 unit
-	Stereomicroscope	1 unit
-	Canon EOS 1300D (Rebel T6)	1 unit
-	Canon EF 100mm f/2.8 Macro USM with Macro Ring Lite Flash	1 set
-	XCP periapical view for children	1 set
-	Digital caliper	1 unit
-	Intraoral mirror set (size S and M)	1 set
-	Dental retractors (for children)	1 set
-	Digital X-ray film size 0	2 films
-	Digital X-ray size 0 barrier envelopes	50 envelopes
-	K-file #010 and #015 (with rubber stop)	10 boxes
-	Sterile paper points	20 boxes
-	Sterile cotton pellet	1 piece
-	Glass plate with cover	5 sets
-	Irrigation needle # 25 x 1"	3 boxes

- Plastic syringe 5 ml — 50 units
- High speed D8 bur — 20 burs
- High speed diamond flat end cylinder bur no.010 — 20 burs
- High speed diamond round bur no.010 — 20 burs
- High speed diamond round bur no.012 — 20 burs
- Storage boxes for K-files — 4 boxes
- Sponge — 2 sheets
- Storage bottle — 50 bottles
- 70% Alcohol 450 ml — 2 bottles
- 0.2% Thymol solution 500 ml — 1 bottles
- Normal saline solution 1,000 ml — 2 bottles

3. Data collection

Healthy child patients at the Pediatric dental clinic, College of Dental Medicine, Rangsit University will be asked for participation in the study if the patients are indicated for an extraction of one or more primary teeth. After the procedure is explained and the patient have signed the consent form, the primary tooth will be measured for root canal length before extraction. Patients with systemic disorder and/or uncooperative behavior will be excluded from the study. The exclusion criteria for the sample teeth will consist of the teeth with large gingival abscess or severe mobility, the teeth that their pulpal tissue cannot be completely anesthetized, and the teeth that cannot be properly isolated with rubber dam. The inclusion and exclusion criteria are listed in table 2.

Table 2: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
1. Healthy and cooperative child patients 2. Child patient age around 4-9 years old 3. Indicated for dental extraction (Ex. Un-restorable tooth, prolong retention, orthodontic plan)	1. Severe mobility 2. Large gingival abscess 3. Pulp obliteration, Pulp stones 4. Incomplete anesthetized pulp tissue 5. Cannot be isolated with rubber dam 6. Patients with systemic disorder and/or uncooperative behavior 7. Root fracture during the extraction

All of the root canal measurement has been done by one operator, but the data collected each time had recorded by a different operator under a random code for each tooth sample. The study has done with a single blinded method. After the patients and/or their legal guardian read and sign the

consent form, the following procedure would be performed. The participant has required to be presented for the study only once on the day of the dental extraction.

A preoperative periapical radiograph of each tooth has been taken for diagnosis and root identification along with its level of resorption. After the radiographic examination, the participant had been prepared for a local anesthesia injection using a cartridge of 2% Mepivacaine with epinephrine 1: 100,000. At least one dental assistant was necessary in this procedure. After the tooth was anesthetized and isolated with rubber dam, a horizontal preparation has been done using a high-speed D8 bur across the entire occlusal surface to create the stable reference point. Then, the operator began access opening and removed the remaining pulpal tissue. The root canals irrigated with normal saline solution and excessive moisture has been removed with sterile cotton pellet and paper point.

The *in vivo* root canal measurement at three different EAL settings: The root canal length measured using an endodontic K-file attached to an electric apex locator (Root ZX mini, Morita Japan). The measurement has been done three times for each canal and at each EAL settings; display bar "0", "0.5", and "1" with the total of nine times for each canal. The mean value from triple EAL readings at display bar "0" was gathered as the data marked as group 0, at display bar "0.5" as the data marked as group 0.5, and at display bar "1" as the data marked as group 1. The position of rubber stop on occlusal reference point was recorded with an intraoral photograph at each root reading. Later, the K-file used in each measurement was measured with a digital caliper. The measurement of EAL reading at bar "0", "0.5", and "1" was recorded.

The direct measurement of actual root canal length: Tooth extraction has been performed after the in vivo measurement of root canal length. After extraction, the root has been examined along with the preoperative radiograph to confirm no significant root fracture. The tooth has been immersed in 5.25% sodium hypochlorite for an hour then stored in 0.2% Thymol solution. The extracted tooth was brought under a stereomicroscope and measured for the actual root canal length. The same size endodontic K-file used in the in vivo measurement was inserted inside the canal with the rubber stop stable at the position on the tooth occlusal surface, the tip of the K-file was extended until it was seen at the apical foramen or that it reached the coronal part of apical foramen. The direct measurement was photographically recorded with the adapted camera (Canon® EOS 1300D (Rebel T6)). Then, the K-file was removed from the canal and brought to measure its length from its tip to the rubber stop using the digital caliper. The actual root canal length was compared to data from the in vivo root canal measurement.

4. Data analysis

For the analysis, the percentages of accuracy within 0.5 mm and within 1 mm from the actual root canal length of each EAL readings (bar “0”, “0.5”, and “1”) was reported, along with the percentages of overestimated root canal length (> 1 mm) and the percentages of underestimated root canal length (> 1 mm) from each EAL readings (bar “0”, “0.5”, and “1”). The data was also analyzed using paired t-test analysis (SPSS 24.0) to determine the statistical difference (P-value) from the actual root canal length in each group.

Chapter 4

Results

Every volunteer had shown good co-operative behavior during EAL measurement *in vivo*. The demographic data of the studied samples is shown in Table 3. The root samples were collected from 7 primary incisors (36.84%), 2 primary canines (10.53%), and 10 primary molars (52.63%). The roots most frequency examined were from male patient (51.52%), and maxillary arch (60.6%). Eighty-eight percent of the root samples had at least 1/3 root resorption.

Table 3: Demographic data

Variables	Frequency N (%)
Teeth (N=19)	Incisors: 7 (36.84%) Canines: 2 (10.53%) Molars: 10 (52.63%)
Roots (N=33)	Single: 9 (30.3%) Mesial: 11 (30.3%) Distal: 9 (30.3%) Palatal: 4 (9.09%)
Sex (N=33)	Female: 16 (48.48%) Male: 17 (51.52%)
Arch (N=33)	Maxillary: 20 (60.6%) Mandibular: 13 (39.4%)
Resorption (N=33)	More than 1/3: 29 (88%) Less than 1/3: 4 (12%)

The difference between EAL measurements and actual root canal length were used to evaluate the accuracy of EAL. The distribution of differences between EAL measurements and actual lengths (acceptable range of ± 0.5 mm and ± 1 mm) was illustrated in Table 4.

Table 4: **Distribution of differences between the EAL and actual lengths (acceptable range of ± 0.5 mm and ± 1 mm).**

EAL measurement		Display bar 0.0 (n = 33)	Display bar 0.5 (n = 31[a])	Display bar 1.0 (n = 30[b])
Underestimate	more than 1 mm	1 (3.03%)	5 (16.13%)	7 (23.33%)
	0.5 to 1mm**	5 (15.15%)	7 (22.58%)	10 (33.33%)
	0 to 0.5 mm*, **	8 (24.24%)	13 (41.93%)	6 (20%)
Overestimate	0 to 0.5 mm*, **	13 (39.39%)	3 (9.68%)	5 (16.67%)
	0.5 to 1 mm**	4 (12.12%)	3 (9.68%)	2 (6.67%)
	more than 1 mm	2 (6.06%)	-	-

*The accuracy of EAL measurement within 0.5 mm was displayed in orange boxes.

**The accuracy of EAL measurement within 1 mm was displayed in both orange and blue boxes.

[a, b] Some roots could not be measured by EAL at displayed bar 0.5 and 1.0 due to the level of resorption

At display bar 0.0, the accuracy of EAL measurements were 63.63% and 90.90% within ±0.5 and ±1 mm, respectively, and the mean difference was 0.07 mm with a standard deviation of 0.53 mm. At display bar 0.5, the accuracy of EAL measurements were 51.61% and 83.87% within ±0.5 and ±1 mm, respectively, and the mean difference was -0.36 mm with a standard deviation of 0.60 mm. At display bar 1.0, the accuracy of EAL measurements were 36.67% and 76.67% within ±0.5 and ±1 mm, respectively, and the mean difference was -0.56 mm with a standard deviation of 0.71 mm.

The paired *t* test comparison of the difference between EAL measurement at bar 0.0 and the actual root canal length indicated no significant difference (P = 0.428). On the contrary, significant difference was strongly indicated when compared actual length to EAL measurement at bar 0.5 and 1.0 (P = 0.002 and 0.000 respectively). The mean difference and standard deviation between the different EAL measurements and the actual length was demonstrated in Table 5.

Table 5: **Mean difference and standard deviation between the different EAL measurements and the actual length**

EAL measurement	Mean Difference * (mm)	SD (mm)	Outbound (mm)		*P*-value [a] (2-tailed)
			Under	Over	
At display bar 0.0	0.07	0.53	-1.08	1.14	0.428
At display bar 0.5	-0.36	0.60	-1.43	0.88	0.002
At display bar 1.0	-0.56	0.71	-2.11	0.91	0.000

* Minus sign indicates measurements shorter than the actual root canal length.

[a] Paired t test analysis (SPSS version 24)

Chapter 5

Discussion and conclusion

Discussion

The determination of root canal length is an important beginning of successful pulpectomy. Several studies had shown the electronic apex locator to be the most accurate method for determining the root canal length. The accuracy of Root ZX® was found to be 86% while the accuracy of radiography was found to be 76% (Bahrololoomi et al, 2015). A coincide result from an *in vitro* study of Angwarawong and Panitvisai also concluded the more precise root canal measurement was at EAL display bar 0.0 or APEX rather than at display bar 0.5 (Angwaravong and Panitvisai, 2009). In an *in vivo* study of Kumar, the highest percentage of accurate working length measurements within ±0.5 mm was for Root ZX® (95.1 %), followed by radiovisiography (75.6 %) and conventional radiography (75.6 %), but the method of comparison was done between the EAL reading at display bar 0.5 and the values obtained after subtracting actual root canal length by 0.5 mm (Kumar et al., 2016). Interestingly, the *in vivo* study of Odabas reported the same exact percentage of Root ZX®'s accuracy in resorbed root canal of primary teeth as the percentage of accuracy from this study, 63.63% (within ± 0.5 mm), but the procedure was done by comparing the EAL root canal measurement at display bar 1 to the actual length subtracted with 1 mm and on 22 roots with resorption (Odabas et al., 2011). The studies that performed a similar comparison as our study were the study of Beltrame et al. and the study of Patiño-Marín et al. They compared the EAL reading at display bar 0.0 and the actual root canal length (measurement to the apical foramen) using Root ZX®. Beltrame et al. reported the EAL precision of 69% (within ± 0.5 mm) from 17 resorbed roots of primary teeth, comparing to our study which reported the EAL precision of 63.63% (within ± 0.5 mm) from 33 resorbed roots (Beltrame et al., 2011). Patiño-Marín et al. evaluated the accuracy in sixty-one root canals and reported the most accurate method of determining the length of the root canals in primary teeth was the Root ZX® (ICC=0.72), followed by the ProPex (ICC=0.70), and the conventional radiography (ICC=0.67) (Patiño-Marin et al., 2011). For the accuracy of EAL in resorbed or non-resorbed roots, both Beltrame and Odabas concluded that no significant difference between the resorbed and non-resorbed root canals measured using the Root ZX®.

According to the Root ZX® manufacturer (Morita, Japan), measuring mark at display bar 0.5 indicates that the tip of the file is in or very near the apical constriction, while at display bar 0.0

indicates that the file tip has reached the apical foramen. The manufacturer suggested that the working length can be calculated by subtracting 0.5 to 1.0 mm from the length measured at display bar 0.5, but the different approach may be applied depending on each individual tooth. They also stated that, when measured the root canal with large apical foramen, the results would show shorter measurement than the actual length. To that, results from this study revealed some level accuracy even when the EAL was used in teeth with large apical foramen. When the reading was made at display bar 0.5 or 0.0 in 33 resorbed roots of primary teeth, accuracy was 83 – 90 % within 1 mm, and the error could result in both a shorter measurement or the longer measurement than the actual length (Bar 0.0: -1.08 to 1.14 mm, Bar 0.5: -1.43 to 0.88 mm).

Several studies on the accuracy of EAL in primary teeth have been done, but none have ever compared the clinical accuracy at each display readings. Different display readings were performed across different *in vivo* studies. Many chose to read the measurement at display bar 0.0 (Ghaemmaghami et al, 2008; Odabas et al., 2011; Patiño-Marin et al., 2011). Others used the reading of EAL at display bar 0.5 (Srirath, 2005; Kumar et al., 2016). Some read the measurement at display bar 1.0 (Kielbassa et al., 2003; Leonardo et al., 2008). Three different display-bar readings were directly compared in this current study, and the result supported the reading at display bar 0.0 as the closest measurement of the actual root canal length in resorbed roots of primary teeth. As the EAL reading at display bar 0.5 is generally used in permanent dentition, dentists often choose the same measuring mark, bar 0.5, for primary dentition, therefore the particular result from this study should be underlined. However, if the root canal length is being measured in a patient with bleeding disorder, one may reconsider setting the EAL measuring mark at display bar 0.5, due to its less tendency and less distance to over instrumentation, but still with 83.87% accuracy within 1 mm.

The high accuracy of EAL reading at display bar 0.0 from this study demonstrated the EAL efficiency even in cases of severe root resorption. We understood the limitation of this study from the lacking of root samples with no root resorption. Since dental extraction had always been the last option in the treatment plan, the majority of our tooth samples came with extensive periapical lesion and a substantial degree of root resorption. Some intriguing patterns of root resorption collected from this study are shown in figure 1.

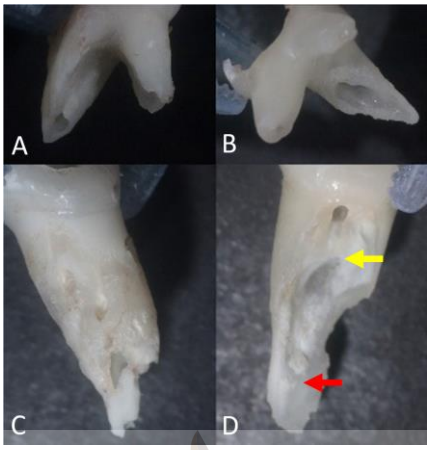


Figure 1: Large apical foramens (A & B) and multiple openings (C & D) commonly found in the roots of primary tooth. A substantial distance between the coronal part (yellow arrow) and the apical part (red arrow) of the foramen was also shown.

Pulpectomy of primary teeth with extensive root resorption could result in poor prognosis. Choosing poor-prognosis pulpectomy over dental extraction may be preferable in some situations, for example, the absence of the succedaneous tooth buds, the patients with a bleeding disorder, and the necrotic second primary molars in primary dentition stage (unerupted first permanent molars). This data can be useful for dental practitioners who are facing those dilemmas.

Upon the data collecting process, we found some interesting points regarding the use of EAL. First, the root canals must contain the least amount of pulpal tissue, blood, or saliva. Therefore, the intracanal bleeding must be stopped before each EAL root canal measurement. The required time for EAL root canal measurement in a single root primary tooth is usually less than 3 minutes in this study, but it would take a longer period of time when there was significant bleeding inside the root canal.

Aside from the accuracy, the success of pulpectomy in pediatric patients also relies on time-efficient technique. The rotary system in pulpectomy of primary teeth was introduced and proven to yield the same quality of root canal filling as manual instrumentation. In the study of Mokhtari et al., the *in vivo* accuracy of the combined use of Root ZX® and rotary system in primary teeth was investigated (Mokhtari, Shirazi, and Ebrahimi, 2017). Based on the total of 80 primary molars in 4-6-year-old children, the result indicated no difference between the accuracy of the new combined method and the conventional method of pulpectomy. However, significantly less time was required during the instrumentation with the rotary system. This time-efficient new method may become the next chapter of this research series. The long-term prognosis of pulpectomies with the use of EAL and/or rotary system should also be investigated.

Conclusion

The electronic apex locator was most accurate in determining the root canal length of primary teeth when the reading was done at display bar 0.0 or at the ‘APEX’.

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Appendix

Data collection form

SAMPLE No.....

ชื่อ.....นามสกุล.....HN.....อายุ.....

วันที่ทำการวัด(ว/ด/ป).....Operator.....Assistant.....

วันที่ทำการถอน(ว/ด/ป).....Operator.....Assistant.....

ฟันซี่.....

Root	Root resorption	Reference point	File number	EAL (0.0)	EAL (0.5)	EAL (1.0)

Root	Root resorption	Reference point	File number	EAL (0.0)	EAL (0.5)	EAL (1.0)

Root	Root resorption	Reference point	File number	EAL (0.0)	EAL (0.5)	EAL (1.0)

Root	Root resorption	Reference point	File number	EAL (0.0)	EAL (0.5)	EAL (1.0)

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