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Root canal instrumentation efficacy of non-fused and fused primary molar roots: a micro-computed tomography study

O. Dalzell¹ · S. Mohd Ariffin⁵ · C. J. Patrick⁶ · R. Hardiman³ · D. J. Manton^{1,4} · P. Parashos² · S. Rajan¹

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Abstract

Purpose Pulpectomy may be indicated in restorable primary teeth exhibiting irreversible pulpitis or pulpal necrosis. The purpose of this study was to compare the cleaning and shaping efficacy of NiTi systems (Reciproc[®] Blue and MTwo[®]) with manual stainless-steel instrumentation in primary molars using micro-CT analysis.

Methods Fifty-seven maxillary second primary molars were scanned using micro-CT. Teeth with three divergent roots were divided randomly ($n = 15$) according to instrument type (K file, MTwo[®], and Reciproc[®] Blue). Teeth with root fusion were instrumented manually as a separate group ($n = 12$). Pre- and post-instrumentation micro-CT images were superimposed, and the instrumentation area (IA) and procedural complications were recorded.

Results No statistically significant differences in IA between file systems was observed in the non-fused teeth. The mean IA of fused roots was significantly lower than in the non-fused distobuccal ($p = 0.003$) and palatal ($p < 0.001$) roots. The root segment had a significant effect on IA ($p < 0.001$) and the highest mean IA was observed in the apical third. Manual instrumentation had fewer procedural complications compared with rotary systems.

Conclusion No differences were determined in the cleaning and shaping effectiveness of all systems in non-fused teeth. Uninstrumented areas ($> 60\%$) occurred in both non-fused and fused primary teeth with fewer procedural complications observed after manual instrumentation.

Keywords Micro-computed tomography · Primary teeth · Pulpectomy · Root canal preparation · Rotary systems

Introduction

Pulpectomy treatment aims to maintain a primary tooth in a functional non-pathological state until natural exfoliation, to avoid pain, recurrent infection and premature extraction (AAPD 2016; Smail-Faugeron et al. 2018). This is achieved through the removal of necrotic pulp tissues, infected dentine, cleaning and shaping of the root canals, root filling with a biological material with a sound coronal seal and restoration (Smail-Faugeron et al. 2018; Hulsmann et al. 2005). The overall mechanical cleaning efficacy may be compromised in primary molars due to the complexity of root canal anatomy and frequent inaccessible intricate accessory canals (Vertucci 2005; Fumes et al. 2014; Ozcan et al. 2016). Anatomical variations such as flared curved roots, root fusion and continuous dentine deposition and physiological root resorption may compromise success of endodontic treatment in primary teeth (Cleghorn et al. 2012; Fumes et al. 2014).

The success of endodontic therapy of primary teeth requires a thorough understanding of primary tooth root

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canal anatomy. As variation in root canal morphology influence the preparation and the overall success of pulpectomy treatment, the classification of root canal morphology is important (Cleghorn et al. 2012; Fumes et al. 2014). Currently there is no validated classification system for primary tooth root canal morphology (Ahmed et al. 2018). The Vertucci classification system is well established classification for permanent teeth that categorises the root canal configurations into eight types (Types I–VIII) (Vertucci 2005). This system has been used for primary tooth root canal morphology studies (Ozcan et al. 2016). A newer classification, Ahmad index, is promising for primary teeth as able to classify roots and canal configurations more accurately (Ahmed et al. 2018). Traditional methodologies investigating root canal morphology and instrumentation efficacy have included: radiographical assessment (da Silva et al. 2018), the Indian ink removal method (Weiger et al. 2002; Ramazani et al. 2016), and intracanal impressions using polyvinyl siloxane (Crespo et al. 2008; Nagaratna et al. 2006). These techniques, however, often only yield two-dimensional information and/or are invasive in nature. Researchers are now utilising new non-destructive and reproducible techniques to view root canal morphology in three dimensions including cone beam computer tomography (CBCT) (da Silva et al. 2018; Pathak 2016) and micro-computed tomography (micro-CT) (Esentürk et al. 2019; da Silva et al. 2018; Kaya et al. 2017; Hidalgo et al. 2017).

Conventionally, primary tooth pulpectomy instrumentation has been conducted using manual stainless-steel files and is well documented in the literature (Kaya et al. 2017; Manchanda et al. 2020; Panchal et al. 2019). Reportedly, the use of rotary NiTi instrument systems has equivalent cleaning efficiency, clinical and radiographic success and less post-operative pain in comparison with manual instrumentation (Manchanda et al. 2020; Panchal et al. 2019). Primary molar teeth have fine, flared curved roots to accommodate the developing permanent tooth germ and canal cleaning and shaping studies have evaluated procedural errors with the systems used (Manker et al. 2019; Esentürk et al. 2019; Hidalgo et al. 2017). The ability to clean and shape complex root canal systems with minimal procedural errors such as canal transportation, over-instrumentation, instrument fracture or strip-perforation is an important consideration in primary teeth, especially in those undergoing physiological root resorption (Fumes et al. 2014; El Hachem et al. 2019). The favourable biological outcome of the pulpectomy treatment is dependent on an aseptic operation field and effective debridement, shaping and concomitant chemical disinfection of the root canal system.

Only four studies to date have specifically focused on the assessment of biomechanical preparation in primary teeth using micro-CT (Esentürk et al. 2019; da Silva et al. 2018; Kaya et al. 2017; Hidalgo et al. 2017). The purpose of the

present micro-CT study was to evaluate qualitatively and quantitatively the cleaning and shaping efficacy of NiTi rotary systems; Reciproc® Blue (VDW, Munich, Germany) and MTwo® (VDW, Munich, Germany), with manual stainless-steel instrumentation in primary molars. This study aimed to compare (a) cleaning and shaping effectiveness in the non-fused roots between systems (b) cleaning and shaping effectiveness of manual instrumentation in non-fused and fused roots and (c) qualitative analysis of procedural errors between systems in non-fused and fused roots.

Materials and methods

Specimen collection

Ethical approval was obtained from Human Research Ethics Committee of the University of Melbourne (HREC ID: 1647645). Informed consent was obtained from caregivers/legal guardians prior to collection of maxillary second primary molars from children undergoing routine dental care under general anaesthesia at the Royal Dental Hospital of Melbourne. Suitable teeth were obtained from healthy children with no history of pulp pathosis, canal calcification, no evident root defects or anomalous morphology and a minimum of two-thirds root length remaining. Specimens were collected, deidentified, assigned a unique code, cleaned to remove adherent hard and soft tissues and then stored in 0.4% aqueous thymol solution (Sigma-Aldrich, MO, USA) at room temperature.

Pre-instrumentation micro-CT procedures

Pre-instrumentation scanning was undertaken using a Sky-scan™ 1172 micro-CT system (Bruker, Kontich, Belgium). Each tooth was mounted moist in a plastic specimen container and placed on the scanning platform. The micro-CT scans had a pixel size of 9.87 µm, and based on the 3D models, each root canal configuration was qualitatively classified according to the Vertucci judgement criteria (Vertucci 2005), based on consensus (OD, SM and SR) (Table 1).

Root canal instrumentation

There were three groups in the non-fused root category. As per the paediatric pulpectomy guidelines, canals for all groups were prepared up to size #25 (AAPD 2016). Group 1 consisted of manual stainless-steel K-files. Root canal instrumentation was performed with 21 mm K-files using a crown-down technique to ISO size #2. In Group 2; the MTwo®, a conventional rotary system was used where root canal instrumentation was performed using 21 mm MTwo® instruments in the following sequence was 10/0.04, 15/0.05,

Table 1 Vertucci's Classification. Adapted from Vertucci (2005)

Type	Description
A single canal from pulp chamber to the canal terminus
I	

Table 1 (continued)

Type	Description
Two separate canals leaving the chamber, but converge short of the canal terminus to form a single canal

Table 1 (continued)

Type	Description
A single canal that divides into two within the root and subsequently converge to a single canal near the canal terminus

Table 1 (continued)

Type	Description
Two distinct canals from pulp chamber to the canal terminus

IV

Table 1 (continued)

Type	Description
A single canal leaving the chamber and dividing into two separate canals at the canal terminus

Table 1 (continued)

Type	Description
Two separate canals leaving the pulp chamber, merging in the body of the root, and dividing again into two distinct canals short of the canal terminus

Table 1 (continued)

Type	Description
A single canal that divides, merges and exits into two distinct canals short of the canal terminus

VII

Table 1 (continued)

Type	Description
Three distinct canals from the pulp chamber to the canal terminus

VIII

20/0.06 and 25/0.06 to full working length. With Mtwo®, a crown-down technique was used with a brushing motion to help advance the file automatically from the crown towards the apex, with the instrument cutting on both penetration and laterally. In Group 3; the newer Reciproc® Blue, a single system using the reciprocation technique, was used. The root canal instrumentation was performed using a single reciprocating Reciproc® Blue R25 file. A limited pecking motion without withdrawing the instrument fully out of the canal or a brushing motion against the walls of wide canals is recommended. Mtwo® and Reciproc® Blue were used as both instruments had the same overall flute and cross-sectional design and were from different generations. Group 4 consisted of teeth with fused roots and were instrumented using the technique based on the most favourable instrumentation outcomes from the non-fused roots using manual stainless-steel K-files. Root canal instrumentation was performed as per Group 1. A 06 K-file was then inserted passively to find further pathways within the isthmus and additional cleaning

using an in-and-out and brushing motion towards the isthmus area of the fused canal.

Post-instrumentation micro-CT procedures and analysis

On completion of the root canal preparation, teeth were rescanned using the same parameters outlined for the pre-instrumentation micro-CT scanning. Superimposition of the pre- and post-instrumentation reconstructed images was completed using the co-registration tool in DataViewer software (version 1.5.0, Bruker, Kontich, Belgium). Separate 3D models were constructed for the pre-instrumented (grey) and post-instrumented (red) root canal system for each tooth and subsequently superimposed and co-registered. CTVol software (version 2.2.3.0, Bruker, Kontich, Belgium) enabled qualitative comparison of the matched 3D root canal models. Two-dimensional qualitative and quantitative analysis of the root was carried out with CTAn (version 1.13.5.1

Bruker, Kontich, Belgium). The root canals were assessed blinded at three levels (coronal, middle and apical) using the pre- and post-instrumentation superimposed cross-sectional images. Quantitative analysis of the instrumented and uninstrumented region was evaluated by comparing the circumferential preparation at each root level using 2D cross-sectional images (Figs. 1 and 2C–E) (Weiger et al. 2002). Procedural complications were observed using qualitative analysis and categorised based on consensus (OD, SM and SR). Canal transportation was assessed by establishing a simple qualitative observation index where canal transportation was considered if more than 50% of the instrumentation occurred beyond the original root canal. Any discontinuity of the root section border was considered as perforation (Hulsmann et al. 2005). Instrumentation that resulted in an increased risk of perforation with no obvious discontinuity on the border of the section was also reported (Fig. 3).

Statistical analysis

Statistical analysis was undertaken for the data obtained using R software (version 3.6.3 for Windows; R Foundation for Statistical Computing, Vienna, Austria). Linear mixed effects models were used to assess the effects of potential explanatory variables on the percentage IA. An initial model considered the effects of file type, root and segment on teeth with non-fused roots. A second model considered the effects of root and segment, comparing teeth with and without fused roots, instrumented with the K-files. Two final models considered the effect of Vertucci classification, root and segment on teeth with and without fused roots. Tooth and root were included as nested random effects in all models.

Fig. 1 Quantitative analysis of the instrumented and uninstrumented region. Reproduced from Weiger et al. (2002). A cross-section of the root canal pre- and post-instrumentation (dotted line). For each level, the following parameters were obtained: (1) the perimeter of the pre-instrumented root canal outline (I_{orig}) and (2) the length of the original root canal outline that was prepared (I_{prep}). The ratios I_{prep}/I_{orig} were calculated and subjected to further analysis. A value of $I_{prep}/I_{orig} = 1$ (=100%) indicated the instrumented perimeter where dentine removal in all root canal walls took place while a value of 0 indicated that the uninstrumented perimeter (no dentine removal had occurred)

All hypothesis tests used Satterthwaite degrees of freedom. Fisher's Exact Test was used to assess association between root type, Vertucci classification and procedural errors.

Results

Fifty-seven extracted maxillary second primary molars met the inclusion criteria. The teeth were collected from children aged 3–8 years (mean 5.5, SD 1.5) consisting of 29 boys (50.9%) and 28 girls (49.1%); comprising 29 right (51.9%) and 28 left molars (49.1%). Twelve (21.1%) teeth had fusion of the disto-buccal and palatal roots, classified as a single canal according to the Vertucci judgement criteria ($n = 24$ roots) (Ozcan et al. 2016). The remaining 45 molars had three separate roots: palatal, mesio-buccal and disto-buccal roots ($n = 135$ roots). The summary of root canal configuration using Vertucci's Classification is tabulated in Table 2. In the pre-instrumentation qualitative analysis (grey), the 3D models showed that there was a wide range of anatomical variation of the shape and number of all the root canals (Fig. 2A). The images of the roots highlight the complexity and variability of the canal systems with additional interconnecting isthmi. The changes in canal shape, identified by superimposition of the 3D un-instrumented canals (grey) and instrumented areas (red), showed an increase in canal shaping in all instrumentation groups (Fig. 2B).

Non-fused roots

Type I was the most prevalent configuration for each instrumentation group (Table 2). Fisher's Exact Test indicated a statistically significant association between Vertucci classification and root type ($p < 0.001$). The mean proportion of IA of teeth based on the root segment, root and file system is summarised in Fig. 4. None of the interaction terms in the mixed model fitted to non-fused teeth were statistically significant. No statistically significant association was found between proportion of IA and instrument used or root type. The overall mean percentage of IA for all three instrumentation groups was 38.0% (95% CI 35.2%, 40.8%). The root level was statistically significantly associated with the IA ($p < 0.001$) and the overall mean IA for the coronal segment was 33.1% (95% CI 29.8%, 36.4%), for the mid segment was 37.7% (95% CI 34.4%, 41.0%) and for the apical segment was 43.2% (95% CI 39.9%, 46.5%) (Fig. 5). The mean IA of the mid segment was 4.7% greater than the coronal segment (95% CI 1.6%, 7.7%; $p = 0.003$). The mean IA of the apical segment was 10.1% greater than the coronal segment (95% CI 7.0%, 13.2%; $p < 0.001$). The mean IA of the apical segment was 5.4% greater than the mid segment (95% CI 2.3%, 8.5%; $p = 0.001$). A separate model indicated no

Fig. 2 Representative 3D reconstructions of the internal and external anatomy of the primary maxillary second molars before and after root canal preparation with Mtwo®, Reciproc Blue® and K-files (non-fused and fused). **A** Preoperative 3D models of the internal root canal

anatomy. **B** Buccal view of superimposed 3D models before (grey) and after (red) root canal preparation. Representative cross-sections of the superimposed root canals before (blue) and after (red) preparation at the coronal (**C**) middle (**D**) and apical (**E**) thirds

Fig. 3 Procedural complications. Root cross-sections of the superimposed pre- and post-instrumentation. Qualitative canal transportation is when instrumentation occurred greater than 50% beyond the original root canal. **A** Is considered canal transportation while **B** is not considered transportation

statistically significant association between proportion of IA and Vertucci classification.

The prevalence of procedural complications was qualitatively observed at the three root levels, based on the method of instrumentation (Table 3). MTwo® had the greatest prevalence of canal transportation (15.5%) followed by Reciproc® Blue (8.9%) and K-files (7.4%). No root perforation was observed, but each instrument method had an occurrence of transportation, risking perforation (Fig. 3A and Table 3). Reciproc® Blue instrument fracture was observed in the apical third of one distobuccal root. There were no statistically significant associations between type of file and procedural complications.

Table 2 Summary of type of root canal configuration using Vertucci's classification according to allocated instrumentation group in non-fused and fused teeth (n =canals)

Vertucci's classification	Non-fused teeth			Fused teeth
	Reciproc® Blue ($n=45$) (%)	Mtwo® ($n=45$) (%)	Manual SS K-files ($n=45$) (%)	Manual SS K-files ($n=24$) (%)
I	30 (66.7%)	30 (66.7%)	32 (71.1%)	2 (8.3%)
II	2 (4.4%)			
III	2 (4.4%)	3 (6.7%)	1 (2.2%)	1 (4.2%)
IV	1 (2.2%)	1 (2.2%)	2 (4.4%)	2 (8.3%)
V	7 (15.6%)	7 (15.6%)	8 (17.8%)	14 (58.3%)
VI			1 (2.2%)	3 (12.5%)
VII	2 (4.4%)	3 (6.7%)		
VIII				1 (4.2%)
Unclassifiable	1 (2.2%)	1 (2.2%)	1 (2.2%)	1 (4.2%)

Fig. 4 Non-fused teeth mean instrumented area (%)

Fused roots

As the manual instrumentation had the least prevalence of procedural complications in the non-fused roots, specimens with root fusion were instrumented as a separate group with stainless steel K-files: Group 4 ($n=12$). Type V (58.3%) followed by Type VI (12.5%) were the most prevalent canal configurations (Table 2). No statistically significant relationship existed between Vertucci classification and root type in the fused teeth. In the mixed model fitted to fused and non-fused teeth instrumented with stainless steel K-files, the interaction term between root type and root level was not statistically significant, but both root ($p=0.006$) and root level ($p<0.001$) were significantly associated with mean

percentage IA. The overall mean percentage of IA in the fused teeth was 30.8% (95% CI 27.2%, 34.4%) and the mean IA areas for the mesio-buccal and fused palatal disto-buccal roots were 33.5% (95% CI 29.1%, 37.9%) and 28.1% (95% CI 23.8%, 32.6%), respectively. The mean IA of the apical level was 9.5% higher than the coronal level (95% CI 5.7%, 13.3%; $p<0.001$) and 9.1% higher than the mid-level (95% CI 5.3%, 12.9%; $p<0.001$). The mean IA of the mid-level was 0.4% higher than the coronal level (95% CI -3.4%, 4.2%; $p=0.842$).

The comparison of the mean percentage IA for fused and non-fused roots is summarised in Fig. 6. The mean IA of the fused palatal distobuccal root was 9.1% lower than the non-fused distobuccal (95% CI 3.2%, 15.0%; $p=0.003$).

Error bars show 95% confidence interval for mean.

Fig. 5 Non-fused teeth overall mean instrumented area (%)

and 11.4% lower than the non-fused palatal (95% CI 5.5%, 17.3%; $p < 0.001$). Within the fused roots, the mean IA of the mesio-buccal root was 5.3% higher than the fused palatal disto-buccal (95% CI 0.1%, 10.5%; $p = 0.047$). A separate model found no statistically significant association between percentage IA area and Vertucci classification. There was no statistically significant association between type of tooth (fused vs. non-fused) and procedural complications. In regard to procedural complications (Table 3), fused roots showed some canal transportation (8.3%), but no root perforation or instrument fracture was observed.

Discussion

Observations from the present study demonstrate that there is a wide range of anatomical variations of the shape and number of primary molar root canals. At the time the protocol for this project was developed, the Vertucci classification index (Vertucci 2005) was the most established and widely used index adapted for use in primary dentition root canal morphology studies (Ozcan et al. 2016). This index does not include information on the roots, multi-rooted canals and the position of the apical foramen, which limits its practical application, as these will have implications for root canal therapy (Ahmed et al. 2018). Hence, the Ahmed index, which provides information on tooth identification, number of roots and root canal configuration, may be a useful index for root morphology classification for the root canals in the primary dentition in the future (Ahmed et al. 2018). The classification of root canal anatomy is important, as variations in root canal morphology influences preparation outcomes and thus the overall biological outcome of endodontic therapy (Cleghorn et al. 2012; Fumes et al. 2014).

Due to the absence of commercially available instruments that have been manufactured exclusively for primary teeth, rotary instruments for permanent teeth have been investigated in the primary dentition (Manchanda et al. 2020; Panchal et al. 2019). Researchers have favoured rotary instrumentation systems in primary teeth when compared with manual instrumentation (Hidalgo et al. 2017; Kaya et al. 2017; Ramazani et al. 2016; Crespo et al. 2008; Nagaratna et al. 2006; Manker et al. 2019). Rotary NiTi instruments were time- and cost-effective, successful at debriding the uneven walls of primary root canals and produce tapered uniform and predictable obturation consistently (Ramazani et al. 2016; Crespo et al. 2008; Nagaratna et al. 2006;

Table 3 Procedural complications based on the type of instrumentations and procedural errors that were observed at each of the three levels for each root for fused and non-fused teeth

Root	Level	Non-fused teeth												Fused teeth		
		Reciproc® Blue				Mtwo®				Manual SS K-files				Manual SS K-files		
		PAL	MB	DB	T	PAL	MB	DB	T	PAL	MB	DB	T	MB	FPDB	T
Canal transportation	Coronal		1		1		2	1	3				7	1		1
	Mid	1	2	4	7	4	2	6	12	2	1	4	3	2		2
	Apical		2	2	4	2	2	2	6	1	2					
At risk of lateral perforation	Coronal															
	Mid									1		1	2			
	Apical			1	1	1		1	2							
Instrument fracture	Coronal															
	Mid															
	Apical			1	1											
Total					14				23				12			3

Fig. 6 Non-fused vs fused teeth mean instrumented area with manual instrumentation (%)

Hidalgo et al. 2017; Pathak 2016). In the present study, there were no significant differences in shaping and cleaning effectiveness between rotary and manual stainless-steel instrumentation in non-fused teeth—these corroborate previous findings (Azar and Mokhtare 2011), systematic reviews (Panchal et al. 2019) and a recent meta-analysis (Manchanda et al. 2020).

Mtwo® rotary instrumentation has been compared with manual stainless-steel instrumentation in numerous studies. In line with the present results, equivalent cleaning efficiency of Mtwo® rotary instrumentation compared to manual files using the Indian ink method has been reported (Azar et al. 2012; Azar and Mokhtare 2011). Conversely, a similar study by Pathak (2016), reported the cleaning efficiency based on the mean Indian ink scores (0–3) and showed that rotary instruments Mtwo® and WaveOne® had significantly better cleaning efficiency than the K-file in the coronal and middle third of the root canal. All three instrumentation systems were effective at cleaning the apical third of the root (Pathak 2016). The aforementioned studies used Mtwo® up to size 25/0.06 and K-files up to size #25–30 in primary mandibular molars (Azar et al. 2012; Azar and Mokhtare 2011). However, by investigating cleaning efficacy using the Indian ink method, these studies are based on categorical data, which limits the comparability to the present study.

To the authors' knowledge, there are four studies (Esentürk et al. 2019; da Silva et al. 2018; Kaya et al. 2017; Hidalgo et al. 2017) which evaluated the efficacy of manual and rotary instrumentation in primary molar teeth using micro-CT. Esentürk et al. (2019), compared the

instrumentation efficacy of rotary instrumentation systems (OneShape®, Revo-S®) and K-files in primary and permanent maxillary and mandibular molars. In the primary teeth, rotary systems were prepared up to #25/0.06 and K-files prepared with standardised technique to size # 25. Rotary systems exhibited similar shaping efficacy in both the primary and permanent teeth, with significantly better outcomes than the K-files. When the overall effect of root canal instrumentation was compared, primary teeth showed significantly greater uninstrumented areas and less apical transportation than permanent teeth. The majority (76.5%) of the canal surface remained uninstrumented in primary teeth, irrespective of the preparation system (Esentürk et al. 2019). These findings corroborate the present findings, where 62% and 69.2% of the canal surface was still left uninstrumented areas in both non-fused and fused primary teeth, respectively. The convoluted root canal morphology in combination with the use of rotary systems originally developed for permanent teeth, may have contributed to this finding (El Hachem et al. 2019).

Similar to the present study, Hidalgo et al. (2017) used qualitative comparison of the superimposed micro-CT root canal pre- and post-instrumentation images to evaluated K-files, ProTaper Next® and SAF® instrumentation in primary molars. In contrast to the present findings, the authors reported an increased incidence of lateral perforations and apical transportation in the K-file group compared to rotary NiTi (Hidalgo et al. 2017). This observation may have been due to the use of manual instrumentation file size #50, significantly larger than the recommended size for primary

molars (size #25–30) (AAPD 2016). In contrast, in the present study, manual instrumentation up to size #25 file had the least prevalence of qualitative procedural complications compared with the rotary systems. Canal transportation occurs when there is unnecessary removal of healthy dentine beyond the confines of the root canal (Fig. 3) (Huls-mann et al. 2005). This is contraindicated during preparation of primary teeth due to the risk of decreased fracture resistance and potential damage to the succedaneous tooth (Sathorn et al. 2005). Additionally, the flared and curved primary molar roots, often with thin dentine or perforations occurring along the furcation root surfaces may increase the risk of iatrogenic errors during instrumentation (Fumes et al. 2014; El Hachem et al. 2019). There was no significant difference among canal transportation values of MTwo® (15.5%), Reciproc® Blue (8.9%) and K-files (7.4%) in the present study, corroborating previous studies (Esentürk et al. 2019).

Instrument fracture is a procedural risk of any endodontic instrumentation and often follows incorrect use or overuse of an endodontic instrument and is most common in the apical third of a root canal (Spili et al. 2005; Parashos and Messer 2006). In the present study, there was one instrument fracture involving Reciproc® Blue in the apical third of a disto-buccal root. While instrument fractures have not been reported in studies on primary teeth, in the permanent dentition its prevalence is reported to range from 1 to 6% with manual instruments and 0.4–5% with rotary NiTi instruments (Spili et al. 2005; Parashos and Messer 2006). Clinical skill is a factor in the risk of rotary NiTi instrument fracture (Parashos and Messer 2006). In summary, factors that may have contributed to the lower prevalence of procedural complications in primary teeth with manual instrumentation compared to rotary, include the use of flexible files up to size #25, ease of use and long experience of using manual instrumentations for careful cleaning and shaping.

Fusion of roots is an anatomical variation occurring between two or more roots (Ordinola-Zapata et al. 2017). The prevalence of fusion between palatal and disto-buccal roots varies in maxillary second primary molars, ranging between 17.2 and 28.6% (Fumes et al. 2014; Ozcan et al. 2016). In the present study, 21.1% of the sample had fusion of the disto-buccal and palatal roots, within the reported prevalence range. As this study has shown, fused roots may have a high incidence of merging canals, isthmi, apical deltas and C-shaped configurations (Fumes et al. 2014; Ozcan et al. 2016). To the authors' knowledge, this is the first study investigating the cleaning and shaping effectiveness in fused primary teeth and demonstrated that teeth with fusion of the disto-buccal and palatal roots were significantly less instrumented (62.0%) than the non-fused teeth (69.2%) roots. Root canal cleaning and shaping procedures of C-shaped canals require modification due to the presence of ribbon-shaped,

narrow communications between the canals that often contain necrotic pulpal tissue. Micro-CT studies in permanent teeth have shown that a large proportion of the root canal surface has remained untouched in C-shaped root canals, regardless of instrumentation technique (Yin et al. 2010; Zhao et al. 2019). Rotary instrumentation yields an uninstrumented root canal surface area between 28.0 and 34.0% (Amoroso-Silva et al. 2017; Zhao et al. 2019), and 41.6% (Yin et al. 2010) for rotary and manual instrumentation, respectively, in permanent teeth. In the present study in primary teeth, uninstrumented area in fused teeth and manual instrumentation was 62.0%. Hence, chemical disinfection is an essential adjunct to mechanical cleaning in assuring optimal microbial decontamination and removal of remnant pulpal tissue in areas inaccessible to mechanical instrumentation (Hidalgo et al. 2017; Kaya et al. 2017; El Hachem et al. 2019).

More studies in fused roots of primary molars using micro-CT technology are needed to evaluate the effectiveness of cleaning and shaping with different endodontic systems. Future considerations may include that the current rotary systems are developed for permanent teeth and need to be adapted to consider the anatomy of primary teeth.

Conclusion

Under the conditions of this study the following can be concluded:

1. Rotary (MTwo®, Reciproc® Blue) and manual instrumentation showed similar instrumentation efficacy in the root canals of non-fused primary molar teeth. Manual instrumentation had a lower prevalence of procedural complications compared with the rotary systems.
2. There was a significantly greater instrumented area in non-fused roots compared with fused roots when the type of instrumentation (manual) was standardised.
3. Regardless of the file system used, uninstrumented areas still existed in both non-fused (62.0%) and fused (69.2%) roots of primary molar teeth.

Author contributions SR, SMA conceived idea. OD, SR, SMA, RH, DJM, PP designed the project. OD and SM collected data and analysis. CJP data analysis. OD, SMA, SR lead the writing. OD, SMA, CJP, SR, RH, DJM, PP approved the final manuscript. This research is the result of two doctoral projects by SMA and OD.

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Declarations

Conflicts of interest All authors deny any conflicts of interest in this study.

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