Root Canall Length Determination: An *in vivo* assessment of the CDR® intraoral radiographic system

Određivanje dužine korijenskog kanala: procjena CDR® intraoralnog radiografskog sustava *in vivo*

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Summary

The Computed Dental Radiolography System® (CDR: Schick Technologies, Long Island City, NY) is a CCD-based digital intraoral radiographic device which possesses a measurement software algorithm that can be adjusted with respect to an object of known dimension. This "calibration" algorithm was compared to the CDR® preset mode and analog film using 30 root canals in vivo. The three measurement methods differed significantly from each other for 40% of the canals sampled. Two of the three differed significantly for 50% of canals. No difference existed between the methods for 10% of the canals.

Estimates of tooth length using the calibrated mode differed from those obtained using a conventional radiographic technique by an average of 1.2 mm, while those using the calibrated mode differed by 1.9 mm. The 1.2 mm average for the calibrated CDR® was judged to be an acceptable degree of clinical error for most root canal procedures and indicates that the calibration function of the CDR® system should be used when measuring endodontic working lengths. The results demonstrated that calibration to a 15 mm probe when using the Schick CDR® system is more consistent with a comparable measurement, if film is used as the "gold standard", than are measurements of the tooth length using the CDR® without calibration.

Key words: *dental radiography, digital image processing, endodontics, measurement algorithm*

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Introduction

An important aspect of clinical endodontics is the establishment of accurate root canal working lengths. Such measurements are necessary to delimit the required endodontic preparation and where the apical stop is to be established. The root canal working length is the operator imposed limitation preventig over instrumentation of the root canal space, which could cause trauma to the periapical tissues. Furthermore, it permits the dentist or endodontist to confine the filling materials to the internal anatomy of the tooth root. The intraoral radiograph has proven to be the most reliable means of achieving these goals (1). Endodontic therapy prognosis has been correlated to the length of the root canal filling (2). Histologic analyses have shown endodontics is most successful if instruments, chemicals and obturating materials are confined to the root canal space (3,4).

Generally, canal working lengths for conventional endodontics are obtained using an endodontic file inserted to a known length into the canal as a reference and imaging using a conventional radiograph. A magnification factor of approximately 10% (or 2 mm) is usually factored due to the geometric divergence of the x-ray beam. A decrease of 3 mm should leave the initial instrument placement short of the actual length and it has been demonstrated that endodontic fillings which end slightly short of the apex have excellent prognosis (5-7). Files smaller than size 15 are not used to measure the working length because their fine tips are difficult to see on conventional periapical radiographs (5).

In the past decade, digital imaging has become available (8,9). Most of the digital intraoral systems utilize a charge-soupled device (CCD). Such sensors have greater sensitivity to radiation than intraoral film, reducing the needed radiation exposure to the patient (8,9). They also permit electronic filtering software-based enhancements in density, contrast, gamma, edge detection among other functions. Digital rediography also allows almost instant image display without the need for chemical processing.

One of the latests CCD systems for intraoral radiographiy is CDR® (Computed Dental Radiography®) from Schick Technologies, Long Island City, NY, USA (10). This system, includes a measurement algorithm that can be used in its default mode or can be calibrated to an object of known reference length such as an endodontic instrument.

The objective of this study was to investigate root canal length determinstions using the CDR®, both with and without calibration, in comparison to conventional D-speed dental radiographic file (Ultra Speed, Eastman Kodak, Rochester, NY). The reproducibility of measurements was determined for each modality tested by utilizing a panel of endodontists.

Materials and methods

The study population comprised a presenting sample of 30 dental patients (8 male and 22 female) ranging in age from 18-80 years. These patients were referred for endodontic treatment. Following a thorough clinical examination, patients found to be in need of root canal treatment were invited to participate. Pregnancy was grounds for exclusion from the study as additional radiographic exposures were a requirement of this investigation. All participants completed an informed consent agreement in addition to that used routinely for all patients.

Four periapical radiographs were made as part of the conventional endodontic evaluation and therapy for each slelcted volunteer. These included an initial diagnostic view, a working length estimation radiograph, an endodontic filling cone-fit evaluation, and a radiograph upon completion. Two additional exposures were added for each patient using the Schick CDR®: one with a size 15 or 20 K-type® endodontic file (Kerr Manufacturing, Romulus, Michigan, USA) at the full working length as estimated by conventional radiography; one with a size 40 or 60 K-type® file inserted only 15 mm into the canal. All images were exposed using a direct current/constant potential x-ray generator (Intrex®: SS White, Holmdel, New Jersey, USA) operating at 70 kVcp and 10 mA. Exposure times varied depending on the tooth location.

For conventional radiography, ANSI speed D direct emulsion film in double film packets was utilized (Ultra-Speed®: Eastman Kodak, Rochester, New York, USA). Films were processed manually using fresh GBX processing chemistry (Eastman Kodak, Rochester, New York, USA). The radiograph nearest to the incoming x-ray beam were placed in sequential film mounts and coded by number only in order to provide anonymity for the participating patients. The second radiograph was placed in the patient's chart in each case.

The Schick CDR® was installed on an IBM compatible 486 DX2 computer (CompuAdd, Austin, Texas, USA) and the MS-DOS® (microsoft Corporation: Redmont, Washington, USA) version of the CDR® software was utilized for the initial image acquisition in this study. The largest (i.e. No. 2) size sensor was employed throughout. Images were recorded both in the patient's record and also exported for display in a numbered sequence, guarding anonymity for the patients, for display and measurement using the WINDOWS® (Microsoft Corporation: Redmond, Washington, USA) version of the CDR® software.

From the presenting sample of 30 patients, 30 canals were selected randomly from the treated teeth for evaluation.. This was to ensure independence of the measurement inputs. Of the conventional radiographs, only the estimated working length exposures were selected for measurement. Both CDR® images for each patient were utilized for separate and independent evaluations. Eight endodontists, three Oral and Maxillofacial Radiologists and one Prosthodontist acted independently as observers. Viewing of films and of digital images were made under standardized subdued ambient lighting conditions. Including a one third re-reading of images for intra operator consistency measurements over time, a total of 120 images were read, 40 per sitting in three sittings. For conventional radiographs, the observers were informed of the actual file length and were asked whether the length of the file accurately depicted the length of the root. If an observer felt that the file did not accurately deepict the correrct root length, s/he was asked to estimate the discrepanca. For CDR® images, root lengths were determined using the mouse driven measurement algorithm both with and without calibration. Calibration was achieved using the images of the size 40 or 60 files placed to 15 mm in the canal and performed in each case by the first author prior to measurement estimates of the root length being performed by the observers. The calibration error for the first author was determined from the mean of five separate calibration measurements. The average mean calibration error was determined to be 0.21 mm and ranged between 0.09 and 0.46 mm. To achieve statistical counterbalancing, the twelve observers were divided into groups of four, each group performing the length measurements for the three modalities in a different sequence. For intra-observer consistency assessments, two weeks after the initial measurements had been performed for the 30 canals each observer was asked to re-measure 10 of the canals using all three procedures. These were the first 10 canals that had been presented in the former evaluations and were the same for all observers.

For statistical analysis a 2-way ANOVA was performed with multiple comparison using Tukeys Honestly Significant Difference Tests because of the pairwise design where n is the same for all groups (11). The *a priori* alpha was set at $p<0.05$. Tooth lengths with both the calibrated and the uncalibrated CDR® images were compared for each measured canal against the estimates of length from the conventional radiographs. "Clinical significance" between the measurements modalities were estimated after rounding each canal mean length determination to the nearest mm. Uncalibrated versus calibrated CDR®, uncalibrated CDR® versus conventional periapical radiographs and calibrated CDR® versus the use of conventional periapical radiographs were studied and the differences were averaged for each comparison.

Results

Evaluation of the combined sample: Statistically significant differences were present betweeen all three measurements for 12 of 30 canals (40%). For six of 30 canals (20%), the uncalibrated CDR® method was statistically significantly different from the other two methods, and in the same proportion (20%) conventional radiographs differed significantly from the two CDR® measurement methods. The calibrated CDR® technique differed significantly from the other two measuring modalities for three canals (10%). For three canals (10%), no statistically significant differences were found between any of the measurement evaluation methods.

Posterior maxillary teeth: For the 13 posterior maxillary canals sampled, differences between groups were present. Both uncalibrated CDR® images were significantly different ($p<0.05$) from the calibrated CDR® image estimates in 10 of these. Uncalibrated CDR® image estimated canal length were significantly different ($p<0.05$) from conventional radiographic assessed canal lengths for 11 posterior maxillary teeth. Calibrated CDR® image canal lenght estimates differed significantly ($p<0.05$) from convetionsl radiographic assessments for 10 of the posterior maxillary teeth. (See Figure 1 and Table 1).

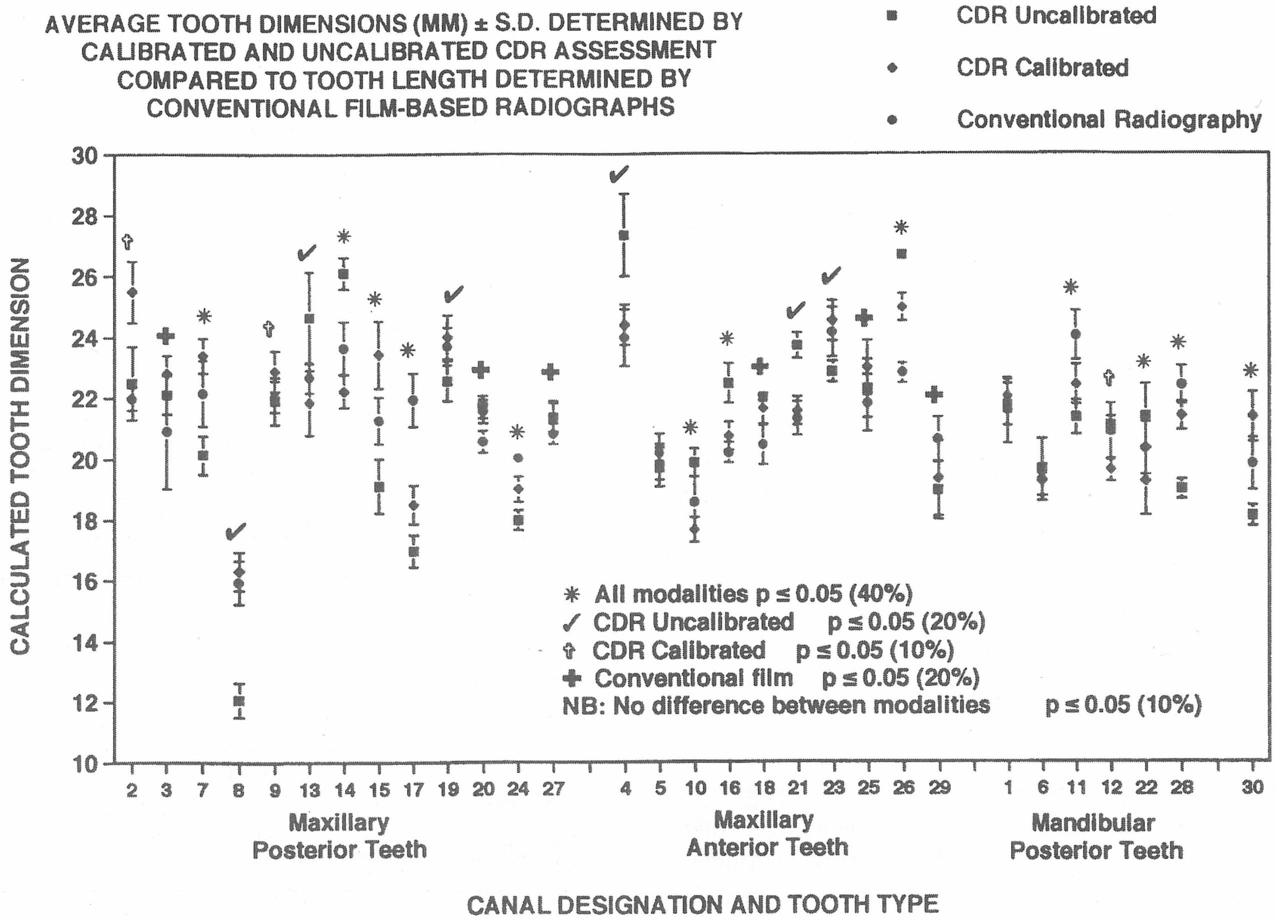

Figure 1.

Slika 1. *Određivanje kanala i oznake zuba*

Anterior maxillary teeth: For the 10 anterior maxillary teeth in this study, significant differences ($p<0.05$) in canal length estimates between uncalibrated and calibrated CDR® images were found for six. Estimates using both the uncalibrated and the calibrated CDR® images differed significantly ($p<0.05$) from those made using conventional radiographic film in nine. (See Figure 1 and Table 2).

Posterior mandibular teeth: Measurements using uncalibrated CDR® images differed significantly ($p<0.05$) from those made using calibrated CDR® images in four of six cases. Measurements form uncalibrated CDR® images differed significantly ($p<0.05$) from those using conventional radiographs in three of the six posterior mandibular root canals studied. Comparing estimates made from calibrated CDR® images to those made from conventional radiographs, significant differences ($p<0.05$) were found for four of six canals measured in posterior mandibular teeth. (See Figure 1 and Table 3).

Anterior mandibular teeth: Only one anterior mandibular tooth was included in the sample. All three modalities differed significantly ($p<0.05$) for this canal. (See Figure 1 and Table 3).

Table 1. *Results of 2-way ANOVA with multiple comparison using Tukey's honestly significant difference test*

Tablica 1. *Rezultati dvostrukog ANOVA puta s višestrukim usporedbama s pomoću Tukeyevog testa značajnosti razlike*

MAXILLARY POSTERIOR TEETH

Canal #	Tooth #	Treatment #1 TG	Mean	Treatment #2 TG	Mean	Treatment #3 TG	Mean
2	14	A	22.5	B	25.51	A	22
3	14	A	22.13	A	22.82	B	20.91
7	3	A	20.15	B	23.43	C	22.16
8	3	A	12.08	B	16.35	B	15.95
9	4	A	21.94	B	22.91	A	22.08
13	14	A	24.68	B	21.88	B	22.7
14	5	A	26.12	B	22.25	C	23.66
15	4	A	19.13	B	23.46	C	21.29
17	3	A	16.99	B	18.51	C	21.95
19	5	A	22.57	B	24.03	B	23.7
20	13	A	21.72	A	21.58	B	20.58
24	5	A	18	B	19	C	20.04
27	5	A	21.38	A	21.4	B	20.83

TG=Tukey grouping: Means with the same letter are *not* significantly different. P<.05

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MAXILLARY ANTERIOR TEETH

Canal #	Tooth #	Treatment #1 TG	Mean	Treatment #2 TG	Mean	Treatment #3 TG	Mean
4	7	A	27.35	B	24.43	B	24
5	7	NO DIFFERENCE		NO DIFFERENCE		NO DIFFERENCE	
10	8	A	19.89	B	17.7	C	18.58
16	8	A	22.49	B	20.76	C	20.2
18	10	A	22.03	A	21.66	B	20.45
21	9	A	23.73	B	21.6	B	21.3
23	10	A	22.87	B	24.55	B	24.16
25	6	A	22.3	A	23	B	21.83
26	8	A	26.7	B	24.97	C	22.83
29	9	A	18.96	A	19.36	B	20.62

TG=Tukey grouping: Means with the same letter are *not* significantly different. P<.05

Table 3. *Results of 2-way ANOVA with multiple comparison using Tukey's honestly significant difference test*

Tablica 3. *Rezultati dvostrukog ANOVA puta s višestrukim usporedbama s pomoću Tukeyevog testa značajnosti razlike*

MAANDIBULAR POSTERIOR TEETH

Canal #	Tooth #	Treatment #1 TG	Mean	Treatment #2 TG	Mean	Treatment #3 TG	Mean
1	29	NO DIFFERENCE		NO DIFFERENCE		NO DIFFERENCE	
6	20	NO DIFFERENCE		NO DIFFERENCE		NO DIFFERENCE	
11	29	A	24.04	B	22.44	C	21.35
12	19	A	21.1	B	19.64	A	20.87
22	19	A	21.4	B	19.26	C	20.33
28	19	A	19	B	21.43	C	22.41

TG=Tukey grouping: Means with the same letter are *not* significantly different. P<.05

MANDIBULAR ANTERIOR TEETH

Canal #	Tooth #	Treatment #1 TG	Mean	Treatment #2 TG	Mean	Treatment #3 TG	Mean
30	25	A	18.13	B	21.39	C	19.83

TG=Tukey grouping: Means with the same letter are *not* significantly different. P<.05

Table 4. *Observer variation*

Tablica 4. *Varijacije promatranja*

	Mean	SD	t-value	2-tail Sig
Treatment #1				
Viewing #1	20.72	0.266	1.39	0.192
Viewing #2	20.61	0.226		
Treatment #2				
Viewing #1	21.42	0.234	-1.32	0.213
Viewing #2	21.54	0.227		
Treatment #3				
Viewing #1	20.54	0.472	-0.88	0.399
Viewing #2	20.67	0.478		

Observer variation: Analysis using the *t-test* for repated canal samples resulted in mean lengths and standard deviations for the 12 observers combined that were extremely close for each of the three treatments (Table 4). For uncalibrated CDR® images the mean length at hte first viewing was 20.72 and for the second viewing 20.61 mm. For calibrated CDR® images the mean length at the first viewing was 21.42 mm and at the second viewing 21.54 mm. For Ultra-Speed® radiographs the mean length at the first viewing was 20.54 mm and at the second viewing 20.67. mm. To ensure that each observer was consistent with the other observers, individual means were calculated. For none of the three measurement treatments did the range of observer means exceed 1 mm. Distribution of variability batween the treatments and the observers demonstrated that the measurement modality accounted for ≥50% of the variability for 20 canals (67%) whereas the observers accounted for ≥50% of the variability for three canals (10%).

Clinical significance: For all canals measured, the calibrated CDR® determinations rounded to the nearest mm produced the smallest differences from estimates made using conventional radiographs. Calibration of the CDR® measurement algorithm to an instrument of known length produced results that were close to those made from Ultra Speed® radiographs than did the CDR® without such prior calibration. Nevertheless, the differences in measurement were small and, although statistically significant, probably not "clinically significant".

Discussion

This study demonstrated that the accuracy of the CDR® measurement algorithm is clinically acceptable when compared to Ultra-Speed® intraoral x-ray film. The CDR® system can effect an image with only 10% of the radiation exposure needed for conventional film (10). Furthermore, the use of the CDR® effects an immediate image without chemical processing, a convenient time saving for the busy dental clinic. Images with the CDR® can also be enhanced digitally using a variety of electronic filters to permit better visualization of the structures involved. Such filters permit adjustments in image density, contrast and gamma, including an equalization feature to standardize the appearance of images made within the acceptable exposure range (10). This can avoid the need to repeat a adiographic exposure by providing the means to substantially improve the diagnostic qualities of a suboptimal exposure Hence the provision of an "on-the-screen" measurement algorithm is but one of the many advantages of the CDR®.

Based upon the results in the current report, it is not possible to claim that one modality was clinically superior to the others examined for canal length estiamtions. The standard procedure for measuring the working length for a root canal *in vivo* is conventional radiographic film. The true "gold standard" for the actual length is impossible to ascertain without extracting the tooth and making a direct measurement. Thus, due to practical considerations, for this investigation the "gold standard" needed to be the conventional radiographic evaluation. The canal measurements using pre-calibration of the CDR® to an instrument of known lenght produced closer to those with standard film than did the CDR® measurement algorithm using the default calibration. Statistically, the diferences between the calibrated CDR® measurements and those from conventional film were significant; however, these differences averaged < 1 mm which is in the acceptable range of error for most clinicians.

Conclusions

The CDR® dental radiographic system can be used for endodontic canal length mesurements without the resutls differing more than 1 mm on average from those determined using conventional x-ray film radiographs. Calibration of the CDR® measurement algorithm against an instrument of known length is advocated.

ODREĐIVANJE DUŽINE KORIJENSKOG KANALA: PROCJENA CDR® INTRAORALNOG RADIOGRAFSKOG SUSTAVA in vivo

Sažetak

Sustav "Kompjuterizirane dentalne radiografije" (CDR: Schick Technologies. Long Island City. NY) je na CDD-u zasnovan uređaj za digitalnu intraoralnu radiografiju koji posjeduje "Software-ski algoritam" za mjerenja koji se može prilagoditi prema objektu poznate veličine. Ovaj "kalibracijski" algoritam uspoređen je sa sustavom CDR (kompjutorizirane dentalne radiografije) bez mjernog algoritma i analognim filmom rabeći 30 korijenskih kanala in vivo. Tri postupka mjerenja značajno su se razlikovali u 40% mjerenih korijenskih kanala. Dva od tri postupka razlikovala su se u 50% mjerenih kanala. Nikakve razlike između postupaka nije bilo u 10% mjerenih korijenskih kanala. Procjena duljine zuba korištenjem kalibriranog načina razlikovala se od procjene dobivene konvencionalnom (analognom) radiografskom tehnikom za otprilike 1,2 mm, dok se od digitalnog sustava bez mjernog algoritma razlikovala za prosječno 1,9 mm. Razlika od 1,2 mm za "kalibrirani CDR" se procjenjuje kao prihvatljiva klinička greška za većinu endodontskih postupaka i ukazuje da bi se "kalibracijski sustav CDR-a" trebao rabiti pri mjerenju radne duljine korijenskog kanala. Rezultati ukazuju da je kalibracija sonde do 15 mm kad se rabi Schch-ov CDR sustav postojanija s usporednim mjerenjem ako se film koji se mjeri uzme kao "zlatni standard", nego je mjerenje duljine CDR sustavom bez kalibracije.

Ključne riječi: *dentalna radiografija, digitalizacija slike, endodoncija, algoritam za mjerenje.*

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