Clin Oral Invest (2010) 14:223–231
DOI 10.1007/s00784-009-0285-1

ORIGINAL ARTICLE

The use of high-resolution digital imaging technology for small diameter K-file length determination in endodontics

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Received: 12 March 2009 / Accepted: 5 May 2009 / Published online: 19 May 2009

Abstract To assess the reliability of high resolution intra-oral photostimulable storage phosphor (PSP) and complementary metal-oxide semiconductor (CMOS) imaging systems for working length (WL) assessment of small K-files in narrow and curved root canals. Eleven narrow and curved canals from extracted molars were used as pre-test for sample-size calculation. Nineteen canals from four cadavers were used for endodontic length assessment in the final study. Small K-files (ISO size 6, 8, and 10) were introduced into the canals at prepared length. Digital intra-oral radiographs were obtained using high-resolution Vistascan® PSP plates and Sigma M CMOS active pixel sensor with a DC X-ray tube at 70 kV, 7 mA, and 0.16 s. Both image series were assessed with and without use of a dedicated endodontic filter. Three observers measured WLs for comparison to the gold standards of a digital millimeter ruler. Multiple regression analysis of the dependent measurements revealed no significant influence of imaging sensor (PSP or CMOS, $p=0.34$) and image processing ($p=0.97$). For ISO file size, however, there was a significant difference ($p=0.08$) at a level of 10%. Observers mostly underestimated lengths using PSP but overestimated them on CMOS. Almost all radiographic measurements (96–98%) were within 2-mm deviation, while 71% to 82% deviated within 1 mm. Dedicated filtering and sensor type did not influence the outcome of WL determination of small file sizes when using high-resolution imaging sensors. WL determination with ISO file 6 did show a significant difference compared to ISO 8 and 10 but mostly for deviations <1.5 mm.

Keywords Photostimulable storage phosphor (PSP) plates · CMOS · Endodontics · Working length · Small K-files · Intra-oral radiography

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Introduction

One of the most important steps toward a successful endodontic treatment is the working length (WL) determination. Conventionally, this length is assessed and verified on intra-oral radiographs. Unfortunately, the exact determination of the apical constriction, anatomical variations, and radiographic projection errors remain problematic in this step of the endodontic treatment [1–4]. Therefore, new techniques have been introduced in order to optimize the root canal length measurements. Electronic devices for apex location have proven their usefulness by surpassing the accuracy of conventional film in WL determination [5, 6]. Electronic apex finders run up to 90% accuracy with a ±0.5-mm tolerance for teeth with a normal foramen [3, 4]. However, these devices cannot replace traditional radiographic techniques but are a useful addition in the endodontic treatment [2, 3, 7–11]. Visualization of the K-files and their tips for canal preparation and WL determination remains an important aspect in order to locate the apical constriction and especially not to exceed the apical foramen causing unnecessary instrumentation beyond this point. Furthermore, small file diameters, like ISO size 6, 8, or 10 files, are often required in narrow root canals, like those of molars with curved roots. The combination of the conventional radiographic film technique with a magnifying glass or high-resolution digital radiographic systems is a valuable improvement in this field.

The introduction of digital radiography has been explored because of its many advantages compared to conventional radiographs. Not only is the radiation exposure reduced, but the possibility to digitally enhance the images may bring potential in radiographic diagnosis and interpretation [12–14]. There still seems to be some hesitation when comparing the diagnostic potential of both techniques, and although several studies have found digital sensors to be inferior for root canal assessment than using conventional film [15–19], the resolution of the systems used are often suboptimal or out-of-date, and the ability of digital enhancement is often not explored. Resolution is typically measured in line pairs per millimeter (lp/mm), which is actually an expression of spatial frequency, referring to the ability of the human eye to distinguish all the horizontal and vertical lines and the spaces between them. As a consequence, the higher the line pair, the better the image resolution. The resolution of conventional radiographic films is greater than 14 lp/mm and can even run up to 20 lp/mm [14]. It seems reasonable to assume when looking at the resolution of most filmless digital systems, which usually lie between 7 and 10 l p/mm, that conventional films are able to resolve finer or more detailed structures [14]. However, the human eye can only resolve up to eight to ten lp/mm [14], which makes the use of a magnifying glass for direct emulsion films necessary. In addition, newer digital systems have now reached higher resolution and the same principle should be applied: Using digital enhancement tools will aid in exploring the complete resolving power of digital sensors [20, 21]. The question becomes now: What is the diagnostic power of high resolution digital sensors and of the ability to digitally enhance radiographic images for endodontic length measurements?

The two main digital intra-oral systems are the solid state sensors—charged coupled device (CCD) or complementary metal-oxide semiconductors (CMOS)—and photostimulable storage phosphor (PSP) plates. The latter were introduced in 1983 as a new X-ray detector system [22]. The PSP plates are reusable image detectors, which store a latent image when exposed to ionizing radiation. The image is obtained indirectly compared to the direct solid-state sensors after read out through a red laser light scanner, which causes blue photostimulated luminescent photons to be emitted. The most recently introduced high-resolution PSP systems, like the VistaScan Perio PSP (Dürr Dental GmbH & Co. KG, Bietigheim-Bissingen, Germany), are able to deliver high-quality digital images at 16 bits and a theoretical scan resolution of 40 lp/mm. However, current plates only run op to a resolution of 20 lp/mm but give the high scan resolution that brings even more potential for future plates. For the direct solid-state systems, new technology has brought theoretical resolutions up to 26.5 lp/mm like the Sigma M active pixel CMOS sensor (Instrumentarium Dental, Tuusula, Finland). In addition, each individual active pixel of this CMOS contains both a photodetector and an amplifier, which consumes far less power than passive pixel CCD systems and decreases manufacturing costs. In combination with the possibility of digital enhancement (the accompanying processing software provides many tools for endodontic viewing conditions), these high resolutions bring potential in more accurate view of small K-file tips.

Up to the present, scientific literature has reported some ambiguous results when comparing conventional to digital modalities for WL determination, especially when using small K-files. Previous reports show inferior [15–19] or similar and better [23–28] accuracy of digital systems to conventional WL assessment, depending on the modality used and the size of the K-files. However, inferior accuracy is mostly seen in older research. Sanderink et al. [19] found that digital sensor systems are unacceptably inferior to film images when size 10 K-files were used in assessing root canal length. Still, no differences were found by Vandre et al [25] when using a range from size 8 up to 20 files. For this same range in file sizes, Piepenbring et al. [21] found that the larger the file size, the less the deviation from the known lengths. One study from Friedlander et al. [18] considered the small ISO size 6 K-files and showed that the acuity to perceive fine endodontic files and periapical lesions was significantly diminished by using PSP scanned at six lp/mm resolution compared to conventional radiographs. Unfortunately, there has been limited research on high-resolution digital sensors and the detection of small ISO size 6 K-files.

The overall aim of our study was therefore to investigate the accuracy of a high-resolution indirect digital radiographic system (PSP) and a high-resolution direct imaging system (CMOS) for detection of small K-file (ISO size 6, 8, and 10) length in narrow and curved canals. The influence of dedicated endodontic filtering on the detection of the different file sizes is also assessed.

Materials and methods

Pre-test: Sample-size determination

Endodontic K-file length measurements of 11 narrow and curved canals of extracted mandibular molars were assessed in a first experiment. ISO size 6, 8, and 10 K-files (Dentsply International, Tulsa, OK, USA) were placed into the canals until the tip of the file was visible at the apical foramen. Both a direct method using an endodontic millimeter ruler and an indirect method on digital PSP images (VistaScan Perio, Dürr Dental GmbH & Co. KG, Bietigheim-Bissingen, Germany) using the accompanying software's (DBSWIN) measurement tools were used for K-file length determination.

The direct method consisted of measuring the K-file WLs with an electronic ruler in order to provide the reference or gold standard. For the indirect method, PSP plates (3×4 cm) were erased by exposure to white light, light-protected with standard covers, and subsequently, bucco-lingual radiographs were taken for all specimens with each of the three size type K-files. The PSP plates were exposed to an intra-oral X-ray tube (Trophy IRIX 70 CCX Kodak Dental Systems, Marne-La-Vallée, Paris, France) with 70 kV, 8 mA, and at 0.1-s exposure time. A wax matrix, containing the teeth imprints, was used in the standardized protocol in order to maintain the same projection images for all exposures. Finally, all PSP plates were scanned at 20 lp/mm resolution, in 30 s, using the VistaScan scanner. The resulting digital images were processed on-screen by an Endo filter of Dürr DBSWIN imaging processing software (see Fig. 1). All images were subsequently exported and saved in tagged image file format (TIFF) for assessment in a random order with the Emago Advanced v.3.5.2 software (Oral Diagnostic Systems, ACTA, Amsterdam) on a desktop with 1,024×768 display resolution and 32-bit color depth of the monitor.

K-file lengths were measured on the bucco-lingual radiographs by a panel of three observers, all specialized dentists in either endodontics or oral radiology, following the curvature of the canals. The acquired data was tested for normality and outliers. No inter-observer effect was found ($p>0.05$), which allowed averaging the observer data. The absolute differences of the observer and the gold standard measurements were then compared through a one-way analysis of variance test using SPSS v13.0 statistical software (SPSS Inc., Chicago, IL, USA). WL assessment on the bucco-lingual images showed no significant differences ($p=0.669$) for the three K-file size types (ISO 10 vs. ISO 8, ISO 8 vs. ISO 6, and ISO 10 vs. ISO 6). Standard deviation was 0.49, 0.53, and 0.61 for, respectively, ISO 10, 8, and 6 (See Fig. 2). Sample-size calculation with a hypothesized difference of 0.5 mm to be biologically significant revealed a sample size of 19.

Cadaver study

Nineteen narrow and curved canals from molars of four cadaver jaws were used for the study. The formalin-fixed cadaver jaws were obtained with permission and ethical approval from the Department of Anatomy at the Catholic University of Leuven, Belgium. After locating the canal orifices with a round bur on a high-speed handpiece under irrigation, the orifices were accessed using a stainless steel K-file of size 10 and further widened using Gates Glidden drills on a slow-speed handpiece. All canals were manually prepared with size 10, 8, and 6 K- or K-Flexofiles (Dentsply International, PA, USA) and intermittently irrigated with a 2.5% NaOCl solution. WL was verified using the Sigma M CMOS sensor (Instrumentarium Dental, Tuusula, Finland) and set either at the apical foramen or within 1 mm of the latter for blinding the observers from the small file-size endings. A digital caliper was used to determine the WL of all canals and served as the gold standard. ISO file 10, 8 and 6 K-files were then successively inserted into the canals at the gold standard WL. A standardized exposure setup was created for acquiring the digital radiographs. The cadavers were cut in their respective left and right halves and horizontally fixed on steps of approximately 2 cm at both ends of each half. This allowed for proper insertion of the digital sensors under the jaws, parallel to the alveolar process of the molar regions. The tube head of a Minray DC X-ray tube (Soredex, Tuusula, Finland) was positioned perpendicular to the horizontally positioned sensor plane and was operated at 70 kV, 7 mA, and 0.16 s. The PSP plates (Vistascan Perio, Dürr Dental GmbH & Co. KG, Bietigheim-Bissingen, Germany) and Sigma M CMOS with active pixel technology (Instrumentarium Dental, Tuusula, Finland) were used to acquire digital images of the ISO size 10, 8, and 6 files at WL. For PSP, the imaging plates were scanned at 20 lp/mm resolution and further processed with a dedicated endodontic filter in the Dürr DBSWIN image processing software. The CMOS images were processed in the Instrumentarium Cliniview image processing software with a sharpening filter. For both digital imaging modalities, processed as well as unprocessed images were exported into 24-color bitmap files for further analyses.

All images were blinded for observer assessment and imported into the Emago advanced v3.5.2 image processing software for WL measurements. Three experienced observers, graduate dentists, and one specialized in oral radiology independently measured file lengths on the blinded PSP and CMOS and filtered and unfiltered images (see Fig. 3),

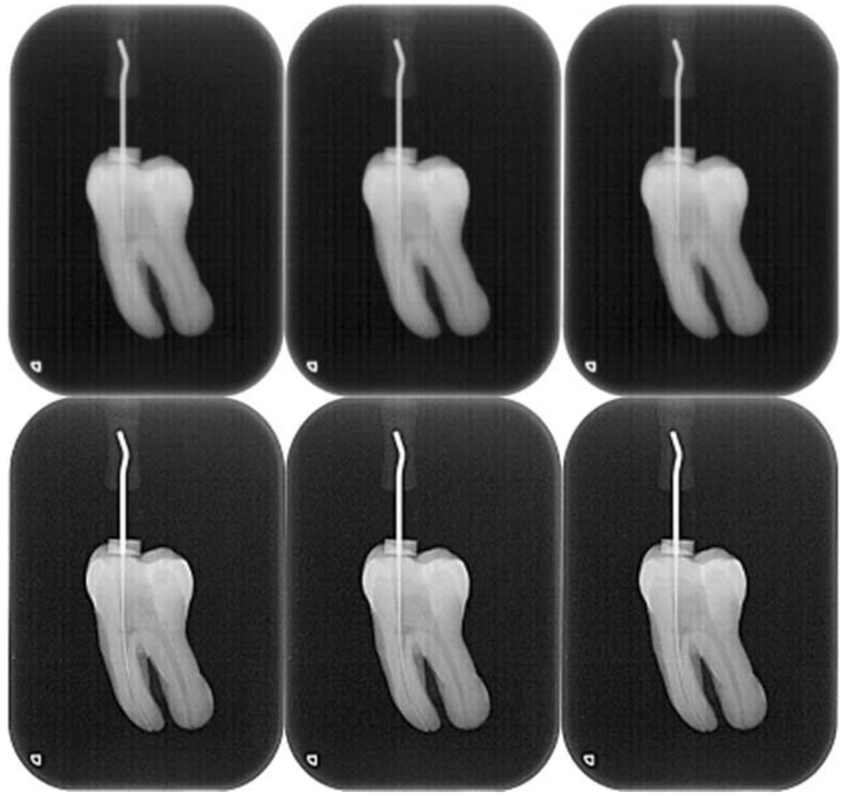

Fig. 1 Bucco-lingual PSP radiographs of an extracted mandibular first molar as pre-test for sample-size calculation. The images from left to right show ISO size 6, 8, and 10 K-files, inserted into the mesio-buccal canal for working length measurements. The upper row consists of the raw images and the lower one of images processed with an *Endo* filter

using a step-wise measuring method by clicking and following the curvature of the files. All measurements were compared to the gold standard, being the direct file measurements using the digital caliper, by calculating the absolute differences. A 15% repeat of measures was done at an interval of 1 week, with a high reliability among observers (interval of 0.667–0.874 with 95% confidence and a single-measure intraclass correlation coefficient of 0.786). The absolute differences of the three observers were then averaged for further calculations. The WL measurements were used as the dependent variable in a multiple regression analysis with ISO file size (6, 8, and 10), digital sensor (PSP and CMOS) and the use of a dedicated filter (unprocessed or processed) as independent variables. The level of significance was set at 5%. All statistical analyses were carried out using SPSS v.13.0. statistical software (SPSS Inc., Chicago, USA) and MedCalc v.9.3.2 (MedCalc Software bvba, Mariakerke, Belgium).

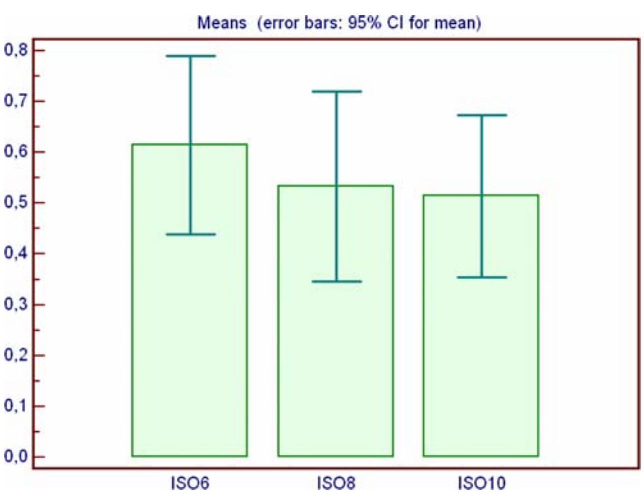

Fig. 2 The absolute differences of the PSP measurements from the gold standard or clinical working length ones show mean deviations of 0.61, 0.53, and 0.49 mm for, respectively, ISO size 6, 8, and 10 K-files. Although the one-way analysis of variance analysis revealed no significant difference between the three file sizes, we see that the means and 95% coincidence intervals (CI) point towards larger deviations for smaller file sizes

Results

Descriptive statistics of the absolute differences of the grouped data show deviations from 0.01 to 2.54 mm from the gold standard (see Table 1). The standard deviation (SD) for all variables is consistent, and only a very small difference is SD is seen for PSP (SD=0.52) vs. CMOS (SD=0.50) or unprocessed (SD=0.53) versus processed images (SD=0.50).

The multiple regression equation revealed no significant influence of the independent variables sensor (PSP or CMOS), dedicated filtering (processed or unprocessed), and

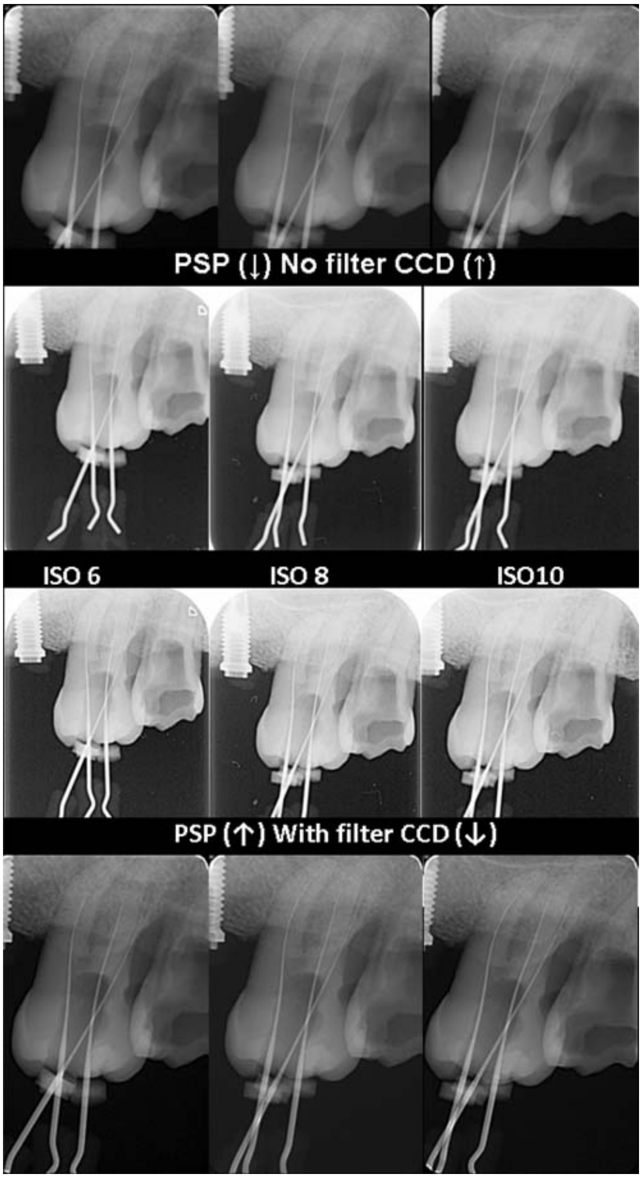

Fig. 3 Bucco-lingual PSP and CCD radiographs of a cadaver maxillary first molar. The images from left to right show ISO size 6, 8, and 10 K-files, inserted into the mesial, distal, and palatal canals for working length measurements. The upper two rows consist of the unprocessed images and the lower two of images processed with a dedicated filter

ISO file size (6, 8, and 10) on the WL measurements at a significance level of 5% ($p>0.05$, see Table 2). However, the small p value of ISO file size ($p=0.08$) does show a significant difference when setting the significance level at 10%. Figure 4 shows the bar charts with mean deviations of WL estimation for the different file sizes using both PSP and CMOS images. It can be seen that the deviations increase when smaller file sizes are used for both PSP and CMOS, which in turn do not show any significant difference ($p=0.3428$). The box-and-whisker plot in Fig. 5 represents the WL estimations using the different ISO file size on unprocessed and processed images. Again, the tendency to smaller deviations for larger file sizes is seen, however, plots for unprocessed and processed images show no significant difference ($p=0.9753$). A paired sample t test of the independent variable ISO size file revealed a significant difference between ISO file size 6–8 ($p=0.034$) and ISO file size 6–10 ($p=0.010$; see Table 3).

When looking at the exact difference for assessment of over- and underestimations in WL determination, it can be seen that observers mostly underestimate the WL on PSP images and overestimate it on CMOS images (see Table 4). For PSP, WL assessment of ISO file size 6, 8, and 10 were underestimated in, respectively, 73.69, 63.16, and 71.06% of the cases compared to 23.68%, 15.79%, and 15.79% for the CMOS system.

When considering a clinically acceptable deviation smaller than 0.5 mm from the actual length (AL), only 42.11%, 40.79%, and 47.37% of the 50% of all radiographic measurements for, respectively, ISO 6, 8, and 10 were found to be within this limit. However, when expanding this range to 1 mm, 71.05% ISO 6, 77.63% ISO 8, and 82.89% of ISO 10 measurements were within this limit (see Fig. 6). Almost all cases (96.05–98.69%) were within 2-mm deviations.

Discussion

Our main objective was to investigate the accuracy of digital measurements for endodontic ultrafine instruments with high-resolution digital systems. ISO size 6 K-files are often necessary for instrumentation of very fine canals,

Table 1 Descriptive statistics (in mm) of the independent variables imaging system, image processing, and ISO file size

	PSP	CCD	No filter	Filter	ISO6	ISO8	ISO10
Sample-size	114	114	114	114	76	76	76
Minimum	0.013	0.017	0.013	0.017	0.050	0.017	0.013
Maximum	2.537	2.303	2.537	2.270	2.537	2.137	2.103
Mean	0.646	0.710	0.679	0.677	0.759	0.661	0.614
Standard deviation	0.524	0.503	0.530	0.499	0.569	0.475	0.489

The means and standard deviations (SD) are comparable for most groups. ISO file size 6 shows the largest deviation

Table 2 Multiple regression equation at a 5% significance level with WL measurements as the dependent variable

Multiple regression				
Independent variable	Coefficient	SE	*t*	*p* value
S	0.065	0.068	0.951	0.343
F	−0.002	0.068	−0.031	0.975
ISO	−0.072	0.042	−1.739	0.083

The equation outcome reveals no significant influence of sensor (S) or dedicated filtering (F) but reveals a starting influence of the file size (ISO). The file size thus shows a significance on the model at 10% ($p<0.1$).

which can be even harder to access if sharp curvature of the root is present. Since the diameter of such small K-file tips is 0.06 mm for ISO size 6, 0.08 mm for ISO size 8, and 0.10 mm for ISO size 10, the minimum resolutions needed to accurately display the structures are 16.67 lp/mm for ISO size 6, 12.5 lp/mm for ISO size 8, and 10 lp/mm for ISO size10, respectively. It is therefore crucial to employ the latest technology or sensors that allow perceiving this resolution. Both imaging modalities used in this study deliver an actual resolution of 20 lp/mm. This implies that the length of the K-files used for this experiment should be entirely visible. However, the measured lengths may differ from one another because of the bucco-lingual root curvature, which is not taken into account on a two-dimensional radiograph.

A significant difference was found for the WL assessment of ISO size 6 files compared to ISO size 8 and 10. However, this is especially true for deviations smaller than 1.5 mm since 97.35% of measurements are within a 2-mm deviation. Only one other study reports such small file sizes, although they only assess visibility of the files and not the lengths [18]. The latter results show that ISO file 6 size tips are perceived less clear on digital images than on conventional radiographs, although resolution was only six lp/mm compared to the high-resolution 20 lp/mm used in our study. Most recent research does show a comparable or even greater accuracy of digital sensors vs. conventional film for endodontic WL assessment. Radel et al. [28] found digital length assessment more accurate than conventional film. Vandre et al. [25] reported no significant difference between conventional and digital solid state or PSP systems in determining the file lengths. We therefore opted not to compare to conventional film, since our main objective was namely the accuracy of WL with small file size and high-resolution sensors. The descriptive statistics show small deviations (min–max of 0.01–2.54 with SD=0.57) when assessing WL on high-resolution imaging systems for the small file sizes. These deviations are similar [20, 21, 28] or smaller than other studies [27] where conventional and digital acquisition

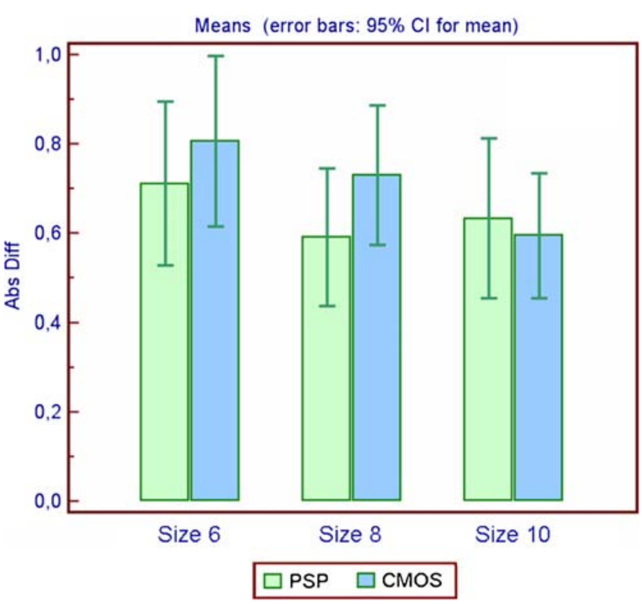

Fig. 4 Bar chart with error bars at 95% confidence interval (CI) for the mean of the absolute differences. The WL measurements of ISO file size 6, 8, and 10 show a mean difference of, respectively, 0.71, 0.59, and 0.63 for PSP and 0.81, 0.73, and 0.59 for CMOS. The means and deviations become larger for smaller file sizes

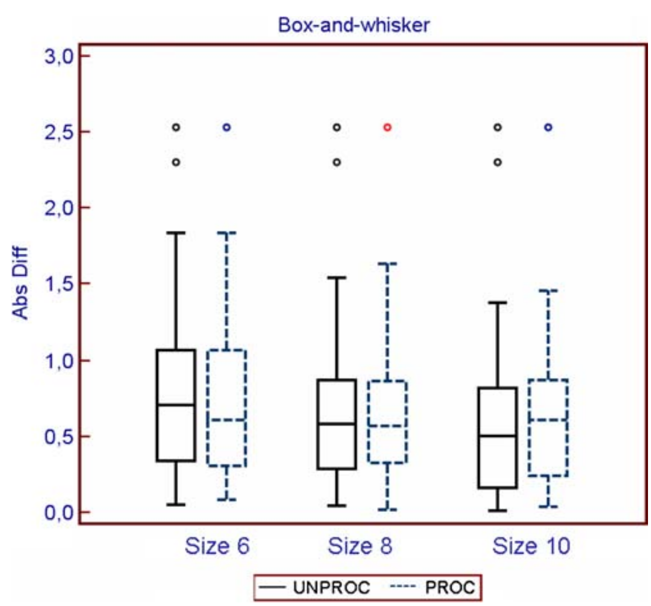

Fig. 5 Box-and-whisker plot depicting the descriptive statistics of the absolute differences, clustered in ISO file size 6, 8, and 10 for processed and unprocessed images. Deviations are minimal for the different file sizes with no apparent difference when using of a dedicated endodontic filter

Table 3 Paired-samples t test of the independent variable ISO file size

Paired samples test

		Paired differences					t	df	Sig. (two-tailed)
		Mean	SD	SE mean	90% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ISO 6–8	0.09802	0.39594	0.04542	0.02239	0.17366	2.158	75	0.034
Pair 2	ISO 6–10	0.14469	0.47720	0.05474	0.05353	0.23585	2.643	75	0.010
Pair 3	ISO 8–10	0.04666	0.38638	0.04432	−0.02715	0.12048	1.053	75	0.296

There is a significant difference for both ISO 6–8 and ISO 6–10 pairs ($p<0.1$).

systems were compared for WL accuracy, even though only small file sizes (ISO 6–10) were used in this study.

No significant difference between assessments of small ISO size 6 K-files and larger ISO size 8 or 10 was found in this research when using a high-resolution PSP or CMOS sensor. Vandre et al. [25] report similar results, with no significant difference between direct and indirect digital systems while using file sizes of ISO 8 to ISO 20. Furthermore, both imaging systems provide an actual resolution of 20 lp/mm, which should depict the same measurement accuracy. In addition, no significant difference was found for unprocessed and processed digital images. This is in contrast with the results of Li et al. [26] and Kal et al. [20], where for the latter study invert, contrast/brightness, and edge enhancement was found to help for ISO size 8, 10, and 15 assessments. They also report that not all processing algorithms show significant differences, which can explain our results. We used a sharpen filter for the CMOS images and a pre-set Endo filter for PSP without using another function. Contrast and brightness processing may have improved the visibility of the file tip, since PSP images were found to be somewhat on the bright side and CMOS images on the dark side by the observers. This does imply that the use of filtering methods varies and needs to be further investigated.

The mean deviations for ISO size 6, 8, and 10 files were 0.76, 0.66, and 0.61 mm. If a 0.5-mm threshold value is considered for clinically acceptable WL determination, only 43.5% of the measurements by our observers were within this limit. This differs from other research conducted by Piepenbring et al. [21] who found 100% of their deviations for file size 20 to 8 within this limit. However, in this research, straight canals were used for length determination, while we measured file lengths on digital images of curved canals. The bucco-lingual curvature may have contributed to a higher deviation rate.

Table 4 Descriptive statistics of the WL estimations' exact difference with the gold standard for the ISO file sizes and the high-resolution digital imaging systems

	PSP			CMOS		
	ISO 6	ISO 8	ISO 10	ISO 6	ISO 8	ISO 10
Sample-size	38	38	38	38	38	38
Minimum	−0.77	−0.68	−0.78	−1.84	−1.81	−1.41
Maximum	2.54	2.14	2.1	2.3	0.74	1.2
Overestimations (%)	26.31	36.84	28.95	76.32	84.21	84.21
Underestimations (%)	73.69	63.16	71.05	23.68	15.79	15.79

The observers overestimated 30.7% of the WL determinations compared to 69.3% of underestimations on the digital PSP images. On the other hand, when measuring the WL on CMOS images 81.58% were overestimations compared to 19.42% of underestimations

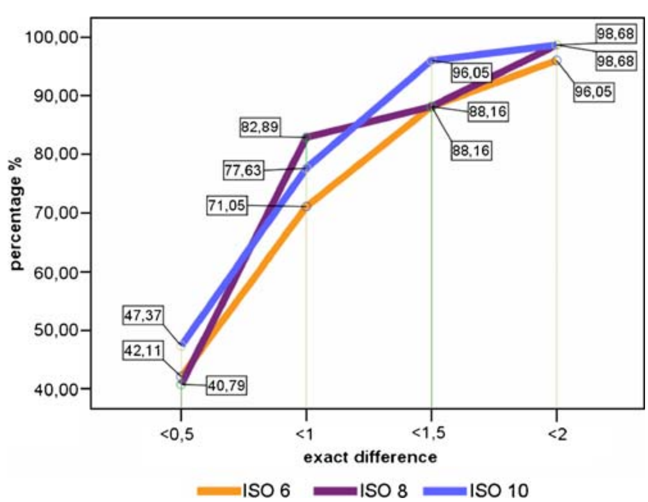

Fig. 6 Line chart showing the percentages of measurements within deviations from the gold standard. For ISO file size 6, 8, and 10, respectively, 42.11%, 40.79%, and 47.37% of the exact differences are smaller than 0.5 mm. If considering a clinically acceptable deviation of 1 mm, this percentage increases to 71.05, 77.63, and 82.89 for respectively ISO 6, 8, and 10

However, the same phenomenon was seen in our results, namely, the larger the file size, the smaller the deviation of the radiographic WL from the AL. On the other hand, Vandre et al. [25] found deviations from 0.65 to 0.98 mm, slightly higher than in this study. Again, this may be explained by the high resolution of the systems used in this study and the impact of rapid technological advancement. It must be noted that electronic WL assessments run up to 90% within this limit. This shows the importance of the complementary use of both methods.

Finally, 69.3% of measurements were underestimated with PSP compared to only 19.42% for CMOS. The latter mostly overestimated the WL, although there is no apparent reason for this. A possible explanation is that small differences could have been obtained by using a standardized image processing software. In the Emago Advanced software, parameters like pixel size need to be given for calibration of measurements. If the pixel size of one of the sensors differs only slightly (for instance a pixel size of 19 or 19.01 μm), this could explain the deviations between PSP and CMOS. When calibrating the sensors, a few measurements were compared in the Emago software and the sensors' accompanying software with no apparent differences. Maybe, it would be more useful to use the sensor's own software, although preprocessing steps can also affect the outcome. More research on dedicated filtering and small file sizes should be conducted, including clinical research with large sample sizes, using the latest high-resolution digital systems.

Conclusion

Dedicated endodontic filtering and sensor type (direct PSP and indirect SMOS) did not influence the outcome of WL determination of ISO file 6, 8, and 10 sizes when using high-resolution imaging sensors. WL determination with ISO file 6 does show a significant difference compared to ISO 8 and 10 but mostly for deviations of <1.5 mm. ISO file size 8 assessments are not significantly different from ISO file size 10 using high-resolution digital imaging systems. Only 43.5% of the WL assessments with small file sizes are within a 0.5-mm deviation, which is inferior to electronic length assessment. Therefore, especially for these small file sizes, radiographic endodontic length assessments should be used in addition to electronic determination.

Acknowledgements I would like to thank Dr. Daniel Leucuta, Faculty of Medicine, Department of Biostatistics and Medical Informatics, Medicine and Pharmacy University, Cluj-Napoca, România, for his help with the statistical analyses.

Conflict of interest The authors declare that they have no conflict of interest

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