RESEARCH

Length of endodontic files measured in digital radiographs with and without noise-suppression filters: an *ex-vivo* study

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Objectives: The aim of this study is to evaluate if theoretically possible edge shifts induced by noise-suppression filters potentially occur on objects found in digital radiographs. Most manufacturers carry out noise-suppression filtering of their images before they are displayed to the user. It is not usually possible for the user to disrupt the function of the filters. The use of these filters can lead to deletion of small image structures.

Methods: K-files (ISO size 06, 08, 10 and 15) were placed in the root canals of 6 human teeth located in cadaver jaw segments. File tip positions were measured on original and filtered digital images by three observers. The file position was marked on each filtered image and compared with the unfiltered ones.

Results: The 5×5 pixel-sized median and mean filters caused the largest underestimation of measured lengths between -7.87 pixels and -10.8 pixels ($-306.93 \mu\text{m}$ and $-421.2 \mu\text{m}$). Maximum standard deviation for length differences was found for the calculated position (= gold standard) and the original unfiltered images with 13.31 pixels. The standard deviation found for the 5×5 mean and median filter was 7.62 pixels and 8.68 pixels.

Conclusion: Different studies showed that noise-suppression filters can induce edge shifts in diagnostic radiographs. The high standard deviations found for length differences between the defined gold-standard and the original images indicate that theoretical edge shifts may not be clinically relevant for length measurements of endodontic files.

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Introduction

Since charge-coupled device (CCD) and complementary metal oxide semiconductor (CMOS) sensors produce a high amount of noise, different image processing schemes have been developed to improve image quality.¹ These include white balance, noise removal and several other undocumented image processing steps. With the CMOS technique, more transistors and circuit elements can be integrated on smaller areas. Therefore, it is possible to add control and processing units to the sensor circuitry in order to obtain a fully integrated image acquiring and processing system.² Fast implementations of median filters

and convolution algorithms are feasible on simple hardware (without using floating point units), which can outperform noise suppression filters based upon fast Fourier transform.^{3,4} Therefore, it has to be suspected that onboard processing on modern sensors modifies image quality substantially. This study was conducted to investigate if such algorithms can affect relevant structures in digital dental radiographs. For medical imaging, an extremely high signal-to-noise ratio (SNR) is considered as essential for clinical diagnosis and resolution is considered less critical.⁵

Possible sensor resolutions calculated upon the number of pixels per square millimetre often differ tremendously from the resolution seen during testing.⁶ A causative factor for this discrepancy between theoretical possible spatial resolution and actually assessed image quality can be seen in pre-processing. Examples are the so-called pixel binning and noise removal.^{7,8} Pixel

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binning combines the levels of four or more adjacent pixels of a sensor and writes them into a single pixel of an image. This allows charges from adjacent pixels to be combined and offers benefits in faster read-out speeds and improved SNR ratios, albeit at the expense of reduced spatial resolution. Another example is noise removal. Noise removal is usually acquired by means of convolution filters (spatial filtering) or rank filters.^{9–11} Several studies stated that digital image processing can influence image quality negatively. Davies demonstrated that size and shape distortions can result from the use of median filters. The same phenomena were stated for convolution filters like the commonly used arithmetic mean and Gaussian filters.^{12–14}

The aim of this study is to evaluate if theoretically possible edge shifts induced by noise-suppression filters potentially occur on objects found in digital radiographs. In this study digital radiographs were further processed in order to assess position changes between small but reproducibly identifiable landmarks.

Materials and methods

Two mandible half-sections with gingival soft tissues attached were obtained from human cadavers and stored in a 10% formaldehyde solution at room temperature throughout the study. Premolar and canine teeth were carefully extracted and apical amalgam fillings were applied to create a defined apical stop. Access preparations were made in all tooth crowns using a diamond bur in a high-speed handpiece with water spray. Canal orifices were located and 25 mm ISO size 06, 08, 10 and 15 stainless-steel K-files (Kerr, Ballaigues, Switzerland) were used to initially instrument the canals, followed by irrigation with 3% sodium hypochlorite and confirmation of a smooth glide path through the canal with a size 25 K-file. The file was positioned to the working length determined by the apical filling and pulled out for a random length after placement of a silicon marker on the tooth's coronal surface. An optical bench was used to allow for a constant spatial relationship among the Heliodont DS X-ray source (Sirona Dental Systems, Bensheim, Germany), the cadaver specimen and the image-recording surface of the Sirona Sidexis Full-Size CCD Sensor (Sirona Dental Systems, Bensheim, Germany) (Figure 2). The source-to-receptor distance was 250 mm and specimen-to-receptor distance was 20 mm. The specimens were exposed for 0.08 s with 60 kV and 7 mA heat current. According to the manufacturer, the physical pixel size of the system is 19.5 µm. However, resolution is calculated downwards to a pixel size of 39 µm owing to pixel binning, which is applied automatically by the proprietary software. The software offers no possibility to deactivate the automatic binning. Images were saved with the proprietary Sidexis XG software (Sidexis neXt Generation 2.4, Sirona Dental Systems, Bensheim, Germany) as standard bitmaps.

The grey values of the images were represented on an 8-bit file. According to the manufacturer's information, bitmaps are exported with the same number of pixels as present in the memory after 2×2 binning. Image size was 676×872 pixels. Pixel size was 39 µm.

Altogether, 60 original radiographs were evaluated. For this study, we chose the most common noise-suppression filters which are popular in today's imaging software; a mean filter with a 3×3 pixel-sized kernel (mean 3×3), a mean filter with a 5×5 pixel-sized kernel (mean 5×5), two median filters in 3×3 pixel and 5×5 pixel-sized kernels (median 3×3 , median 5×5) and three 3×3 pixel-sized Gaussian filters with standard deviations of 0.4, 0.8 and 1.2, respectively (Gaussian $3 \times 3/0.4$, Gaussian $3 \times 3/0.8$, Gaussian $3 \times 3/1.2$). The filters were embedded in a special filtering programmed with Borland C-Builder 6.0 (Borland GmbH, Langen, Germany) according to the methods described by Myler and Weeks.¹⁵ This software allowed automatic image processing of whole folders of images sequentially as defined by an initial study protocol file. A Dell LCD Screen 2001 FP (Dell Inc, Roundrock, Texas) was used as a viewing device with a resolution of 1600×1200 pixels. Neither contrast and brightness adaptation nor image sharpening was allowed since contrast adaptation is done automatically by Sidexis.¹⁶

The position of the file tip was determined in the original radiographs. The required landmark points of the file were assessed by manual landmark identification with the mouse-driven cursor in the evaluation software programmed with Borland C-Builder 6.0 (Borland GmbH, Langen, Germany). An advantage of this software was that all images can be inspected sequentially in a random order while measurements are recorded simultaneously into Excel files. The exact position of the file tip on the radiographs was determined by measuring the length between the silicon marker and the coronal surface by sampling the mouse-driven cursor co-ordinates, where $P_1(x_1, y_1)$ denotes the central border point of the silicon marker, and $P_2(x_2, y_2)$ denotes the border of the coronal surface in the midline of the endodontic file (K-file). With these co-ordinates, the length l between marker and coronal surface was calculated using the Euclidean distance:

$$l = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

This length was applied on the images between the apical amalgam stop in the direction of the file tip's position to gain its true co-ordinates (Figure 1). The evaluation software created a line with the calculated length. The user marked the line's base (starting point) at the visible end of the amalgam stop (apical filling) on the images by the mouse-driven cursor. Then it was possible to apply the calculated line in the direction of the file tip on the image to gain its true position. The tip near the co-ordinate of this line was saved as the true position of the file tip in the images. It corresponded to the visible

Figure 1 Determination of the file tip's true position: $P_1(x_1, y_1)$ denotes the central border point of the silicon marker; $P_2(x_2, y_2)$ denotes the border of the coronal surface in the midline of the file. The length l between marker and coronal surface was calculated using the Euclidian distance between P_1 and P_2

file tip in all 60 original radiographs. The three observers (all with more than 5 years experience in endodontic treatment) marked the visible file tips once in the original and filtered images in a random order, using the mouse-driven cursor. The average differences between the marked positions and the defined true file positions and their mean values, median values and standard deviations were calculated using SPSS 17 (SPSS Inc, Chicago, IL). Differences between the file-tip positions were calculated by subtraction of the file-tip positions found in filtered images from the positions found in the original images. In order to assess observer reliability, the intraclass correlation coefficient (ICC) was calculated for the measurement in the original images of three observers for all endodontic files.^{17,18}

Results

The observers were able to define the position of every file tip exactly in the original images; mean differences between determined real positions and positions

Figure 2 Optical bench (a), with holding space for different intraoral sensors (b) and X-ray machine in position (c)

Table 1 Mean differences found between file lengths in original images and filtered images according to file size (ISO size). The largest changes are found for the bigger arithmetic mean and median filters

	File size														
	6			8			10			15			Total		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Gold standard	3.80	13.31	4.67	0.80	3.52	1.00	2.47	4.32	1.67	0.00	2.32	1.00	1.77	6.88	1.50
Original I															
Original	-0.13	2.66	-0.33	-1.00	3.21	-0.33	-0.13	3.08	-1.33	0.27	1.92	1.67	-0.25	2.58	-0.50
Gaussian 0.4															
Original	-1.07	2.72	-2.00	-0.13	0.56	0.00	0.07	2.2	-0.33	0.47	1.92	0.00	-0.17	1.94	-0.50
Gaussian 0.8															
Original	-3.87	9.74	-3.67	0.33	2.05	0.00	1.00	3.08	-0.67	0.00	0.94	0.67	-0.63	5.18	0.00
Gaussian 1.2															
Original mean	-2.80	1.73	-2.67	-0.67	1.35	-0.67	0.73	2.40	0.00	-0.33	1.33	-0.67	-0.77	2.08	-0.67
3 × 3															
Original mean	-7.87	7.62	-6.67	-1.93	7.19	0.67	0.60	1.94	1.67	-0.27	1.82	0.67	-2.37	6.01	0.50
5 × 5															
Original	-4.33	7.42	-2.00	-0.87	3.10	0.33	-0.27	1.23	-0.33	-0.27	1.44	0.00	-1.43	4.17	0.00
Median 3 × 3															
Original	-10.8	8.68	-12.00	-4.13	9.92	-0.33	0.00	1.72	0.33	-1.27	1.19	-1.33	-4.05	7.47	-1.33
Median 5 × 5															

SD, standard deviation

marked by the observers ranged between 0.00 pixels and 3.80 pixels (0.0 μm and 148.2 μm). The standard deviation found for the smallest file (size 06) was 13.31 pixels. The standard deviation for the bigger files was lower than 3.52 pixels (Table 1). There were only slight differences between the standard deviations (2.32 pixels–4.32 pixels) between identified and true file tips (ISO 08 to ISO 15). The intraobserver reliability between the measurements of the three observers was 0.987 in the original images.

The distribution of the standard deviation for all three observers decreased from a mean distribution of 5.72 pixels for the smaller ISO 06 files to a mean distribution of 1.01 pixels for the ISO 15 files in the original images (Table 2). The mean variation of the observers decreased similarly for the wider file tips' position in the filtered images (Table 2).

Considerable changes between the positions of the file tips between original images and filtered images were mainly found for the smallest files (ISO 06, Table 1). The largest changes in length were found for the filters with bigger kernels. The 5 × 5 pixel-sized median and mean filters caused clinically relevant underestimation of file lengths during evaluation by

the observers. The mean values found are -7.87 pixels (mean 5 × 5) and -10.8 pixels (median 5 × 5) as illustrated in Table 1 (-306.93 μm and -421.2 μm). The smallest length changes were caused by the Gaussian filters (Table 1).

Discussion

This study shows that noise-suppression filters can change fine details found in digital dental radiographs. This can be illustrated by subtraction images (Figure 3). Length changes during evaluation were mainly found for the median and arithmetic mean filters with 5 × 5 pixel-sized filter kernels. This means that the theoretically supposed effects of length changes induced by common noise-suppression filters can actually affect the length of practically relevant image structures which are present in dental radiographs. The 5 × 5 pixel-sized median and mean filters caused significant underestimation of file lengths between -7.87 pixels and -10.8 pixels (-306.93 μm and -421.2 μm). The smallest length changes found in this study were caused by the Gaussian filters (Table 1). The largest length reduction for the

Table 2 The distribution of the standard deviation (SD) for all three observers decreased from mean = 5.72 for the smaller ISO 06 files to mean = 1.01 for the ISO 15 files in the original images

	File size							
	6		8		10		15	
Distribution of standard deviations between rater for the length differences	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Gold standard—original	5.72	1.67	3.46	2.61	2.74	2.51	1.01	0.63
Original—Gaussian 0.4	5.32	3.69	2.62	1.59	4.03	4.87	1.05	0.67
Original—Gaussian 0.8	5.15	4.43	2.25	2.16	4.18	3.43	1.22	1.02
Original—Gaussian 1.2	13.65	13.33	2.36	1.90	3.92	3.74	1.69	0.60
Original—mean 3 × 3	9.90	3.22	2.84	2.52	3.26	2.28	1.91	0.83
Original—mean 5 × 5	13.82	12.46	6.40	6.33	3.06	1.37	1.07	0.48
Original—median 3 × 3	8.13	8.64	2.82	2.21	2.17	1.48	1.54	1.02
Original—median 5 × 5	14.67	10.55	7.02	8.69	2.91	0.86	1.50	1.20

Figure 3 Original image and subtracted images showing edge shifts induced by noise-suppression filters. Original and filtered images were subtracted using Image J (Open Source Software, National Institutes of Health, Bethesda, MD, USA). The images were modified in contrast for illustration. The brightness found in subtracted images correlates to grey level changes between original and filtered images

filters with smaller kernels was found for the 3×3 pixel-sized median filter. It is widely accepted that the median filter is edge-preserving and theoretically preserves step edges without blurring. However, in the presence of noise it does blur edges in images and pixels on step-shaped colour change-overs are removed. Owing to their design, median filters remove impulse noise. Impulsive noise generates pixels with grey values not consistent with their local neighbours.¹⁹ A similar effect can be found for fine details, such as small endodontic files or trabecular pattern, since the median filter is applied on all the pixels of the image whether noisy or not. This results in the loss of fine detail.²⁰ The strongest effects on length changes were found for the ISO 06- and ISO 08-sized endodontic files. These findings correspond with the findings drawn by recent studies; noise-suppression filters are said to delete small image structures, depending on the size of these structures and the kernel size and type of filter used. Noise-suppression filters are used to reduce abrupt local changes in images, usually induced by noise. The different algorithms are not capable of differentiating how the local change is induced, either by noise or by a diagnostic relevant structure like a small file tip. However, the high standard deviation found for length differences between the defined gold standard and the original images of 13.31

pixels compared with the standard deviation found for the 5×5 mean and median filter of 7.62 pixels and 8.68 pixels ($-306.93 \mu\text{m}$ and $-421.2 \mu\text{m}$) indicates that the edge shifts may not be of clinical relevance for length measurements with smaller files. However, we have to keep in mind that even the original images were pre-processed.

It has been stated that size 08 and 10 files are not adequate for working-length radiographs because small file tips fade out and are usually not visible.^{21–23} These studies comparing film with digital imaging showed that, in order to discern the tips of endodontic files, one has to start with at least a 10 or 15 reamer or K-file. Compared with the mean distribution given in Table 2, our study completely supports this recommendation. However, since modern sensors offer higher resolution, the use of smaller files might be possible for length measurements, as shown by Vandenberghe *et al.*²⁴ Generally, the accuracy for bigger files is theoretically due to the sampling theorem. For a size 06 file, the tip is 0.06 mm. The thicknesses of the size 08, 10 and 15 files at the tip are given as 0.08 mm, 0.10 mm and 0.15 mm, respectively. According to the Nyquist frequency, the spatial resolution of the system must be equal to twice the spatial frequency of the smallest detail to be detected.^{21,25} Therefore, the theoretical minimum size

of detectable details would be 0.08 mm (assuming a pixel size of 40 μm if 2×2 binning is used). This is approximate to the tip of file size 08. The sensor used in this study delivers a theoretical resolution of 25 line pairs per millimetre (lp/mm) at a pixel size of 19.5 μm , according to the manufacturer. However, 2×2 pixel binning is deployed—a well-known measure to lower radiation doses needed for digital image acquisition.²⁶ According to the manufacturer's information, binning is applied to provide lower radiation doses and smaller image files for easier archiving. Despite the theoretical resolution of 25 lp mm⁻¹, Farman and Farman reported a maximum spatial resolution of < 10 lp mm⁻¹ for this sensor.⁶ In accordance with others, our result supports that file sizes 06, 08 and 10 are not adequate for accurately measuring diagnostic images.^{21–23,27} Except for the smallest files, there was no significant difference between the defined real positions of the file tips and the measured ones in the original images. Endodontic length measurements are reported to be conducted best with a size 15 file using 0° of projection geometry.^{28,29} The tooth's main axis has to be parallel to the receptor plane in this case and centred relative to the central beam. This orientation was provided in this study by using an optical bench to define the relation between image receptor and specimen. Measured objects had no distortions and were magnified equally over all parts visible on the image. Most studies assessing endodontic length measurement use mechanical gauges as the gold standard, but this was not necessary as the visible changes of the file tip positions due to image processing were assessed here.

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