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DIGITIZING RADIOGRAPHIC FILMS: A SIMPLE WAY TO EVALUATE INDIRECT DIGITAL IMAGES

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ABSTRACT

Objectives: This study applied a simple method to evaluate the performance of three digital devices (two scanners and one digital camera) using the reproducibility of pixel values attributed to the same radiographic image. Methods: Using the same capture parameters, a radiographic image was repeatedly digitized in order to determine the variability of pixel values given to the image throughout the digitization process. One coefficient value was obtained and was called pixel value reproducibility. Results: A significant difference in pixel values was observed among the three devices for the digitized images (ANOVA, $p<0.00001$). There was significant pixel value variability at the same digitization conditions for one scanner and the digital camera. Conclusions: Digital devices may assign pixel values differently in consecutive digitization depending on the optical density of the radiographic image and the equipment. The pixel value reproducibility was not satisfactory as tested for two devices. It is maybe advisable knowing the digitization variations regarding pixel values whenever using digital radiography images in longitudinal clinical examinations.

Uniterms: Digital image; Radiographic image; Charge-coupled device; Digital camera; Scanner.

INTRODUCTION

The radiographic image is converted into pixel values during the digitization process, which is used by the computer to build the digital image[1,2,5,7]. The digitization process varies from device to device and this was evaluated by several studies using different methodologies[3,4,6,8]. Nevertheless, the digitization may suffer variations even when the same digital equipment is used throughout time. This aspect may be important once digital image is used in clinical evaluation of patients.

The present study was based on the hypothesis that, using a simple method, it is possible to evaluate the digitization process in terms of the reproducibility of the pixel value given by a digital device in different captures. So that, it is possible to evaluate if a device used to capture an image can be trusted in subsequent digitizations or in other words, if the equipment is given the same pixel value information continuously throughout the captures (reproducibility). The reproducibility of the pixel values may be important whenever using a quantitative image analysis in longitudinal clinical studies.

MATERIAL AND METHODS

A ten-step exposure on an occlusal film (Insight, Kodak, Rochester) was obtained with a sensitometer (Dual-Flashing, Nuclear Associates, USA). The film was then processed by standardized temperature-time method. This radiography was digitized repeatedly and consecutively without intervals (using the same capture parameters) ten times using two scanners (HP 4c/T and HP 5370C, Hewlett-Packard Co., USA) and a Nikon Coolpix 990 (Japan) digital camera. The capture parameters were 600 dpi for the two scanners and the images stored in TIF format. The digital camera was set to a maximum resolution of 2048 x 1360 pixels and the image stored in TIF format (300 dpi). The images were captured using 8 bits.

Calculations of the Pixel value Reproducibility (PR)

The occlusal film was digitized ten times under identical conditions by all devices in order to determine the reproducibility of the pixel values assigned to the same grayscale steps[3]. After digitization, the mean pixel values (M1 to M10) were obtained using the ImageJ software (NIH, USA). The histogram tool measured an area of 17,000 pixels for each step in every image. The calculation applied to the PR was (largest difference/mean)*100. The largest difference was chosen between the largest value obtained from the difference between mean pixel value of the ten images minus the smallest pixel value (of the ten images) and the largest pixel value (of the ten images) minus the mean of the ten images. The smallest and the largest pixel values were obtained after ten consecutive digitizations of the radiographic step image. The mean pixel value was obtained from the ten images captured consecutively. Step 1 was the whitest and step 10 the blackest.

RESULTS

The following Tables 1, 2 and 3 discriminate the pixel value obtained for each device in every digitization (PV1 to PV10) and the mean (M) obtained from all captures.

Figure 1 shows the pixel value reproducibility (PR) calculated for every device.

Statistical analysis

ANOVA was applied to compare the mean pixel (M) values among the different devices after logarithmic transformation of values. The difference was statistically significant among the devices ($p<0.00001$). The Tukey test showed that the differences were found to be statistically significant from step 1 to step 10 ($p<0.05$) for all devices. However, no difference between the HP 5370C scanner and the digital camera was observed for steps 7, 8 and 9.

TABLE 1- Pixel values (PV1 to PV10) of each step, mean (M) and PR obtained for the HP 4c/T scanner

Step	PV1	PV 2	PV 3	PV 4	PV 5	PV 6	PV 7	PV 8	PV 9	PV 10	M	PR
1	4.7	5.7	4.0	4.4	4.9	4.4	5.3	5.7	4.2	4.7	4.8	18.7
2	6.0	7.2	5.5	5.8	5.8	5.5	6.3	7.3	5.6	6.0	6.1	19.6
3	9.3	10.0	8.4	8.6	9.5	8.7	9.3	10.3	8.8	9.3	9.2	11.9
4	13.3	14.8	12.8	13.2	13.9	12.9	13.6	14.5	13.2	13.3	13.5	9.6
5	23.5	25.7	22.9	23.5	23.8	23.1	23.5	24.7	22.8	23.5	23.7	8.4
6	44.3	46.4	43.8	44.4	44.7	43.6	44.1	45.1	43.6	44.3	44.4	4.5
7	83.2	83.9	83.0	82.8	82.9	83.3	83.3	84.4	83.0	83.2	83.3	1.3
8	155.9	156.7	156.0	156.2	154.9	154.5	156.1	155.8	156.1	155.9	155.8	0.6
9	222.2	223.1	222.6	221.9	222.3	221.7	222.9	222.3	222.1	222.2	222.3	0.3
10	248.5	248.9	248.3	248.4	248.4	248.3	248.5	248.4	248.5	248.5	248.5	0.2

TABLE 2- Pixel values (PV1 to PV10) of each step, mean (M) and PR obtained for the HP 5370 scanner

Step	PV1	PV 2	PV 3	PV 4	PV 5	PV 6	PV 7	PV 8	PV 9	PV 10	M	PR
1	34.5	33.5	33.6	33.9	33.3	33.5	33.6	34.0	33.7	34.5	33.8	2
2	33.9	33.6	33.9	33.9	33.3	33.6	33.5	33.6	33.8	33.9	33.7	0.6
3	35.2	34.8	35.0	35.1	34.7	34.9	34.6	34.7	35.2	35.2	34.9	0.8
4	37.0	36.8	37.0	37.1	36.4	36.6	36.9	37.0	37.1	37.0	36.8	1.1
5	41.0	40.7	40.8	41.0	40.3	40.6	40.8	40.9	40.9	41.0	40.8	1.2
6	50.7	50.4	50.4	50.7	50.2	50.4	50.5	50.6	50.8	50.7	50.5	0.6
7	70.9	70.6	70.9	70.9	70.5	70.6	70.8	70.7	70.9	70.9	70.7	0.3
8	115.5	115.6	115.5	115.5	114.8	115.5	115.3	115.3	115.5	115.5	115.4	0.5
9	178.3	178.5	178.8	178.5	178.5	178.7	178.6	178.4	178.7	178.3	178.5	0.1
10	243.6	243.1	243.3	243.5	242.0	242.8	243.5	243.5	243.6	243.6	243.2	0.5

DISCUSSION

One of the major differences among the three devices was in terms of the illumination source, which, unfortunately, cannot be the same since each of the two scanners has its own light source and a light box was used for the digital camera. This fact could explain why the devices attributed different pixel values to each step (Tables 1 to 3), but does not explain the difference in PR for each device.

The digital camera presented a higher PR value than the two scanners (Figure 1), i.e., the values attributed to the same region varied widely among the digitizations themselves.

The larger PR coefficient attributed to the digital camera might have been caused by the maximum capture resolution used which has occupied the entire CCD. The fact of taking the images in rapid succession (consecutively without intervals) may cause the CCD to overheat, increasing the fill-factor error of the device. The Nikon 990 camera possesses a full-frame type CCD that theoretically reaches a fill-factor close to 100%. It is possible that heating of the sensor compromised this characteristic of the device, thus a fact leading to pixel values that reasonably differed between each other. As can been seen in Table 3, comparison between the PV1 (pixel values of the first photograph) and PV10 columns (pixel values of the tenth and last photograph taken) clearly shows that the PV10 values were systematically lower than the PV1 values (except for step 10).

The same reasoning can be applied to the two scanners, with closely similar PV1 and PV10 values being obtained for the two scanners for all steps (Tables 1 and 2), in contrast to the digital camera. The scanners captured consecutive images more consistently.

Comparison of the two scanners showed a higher relative PR for scanner 4c/T, which would be the variance in pixel values attributed to the same region during consecutive

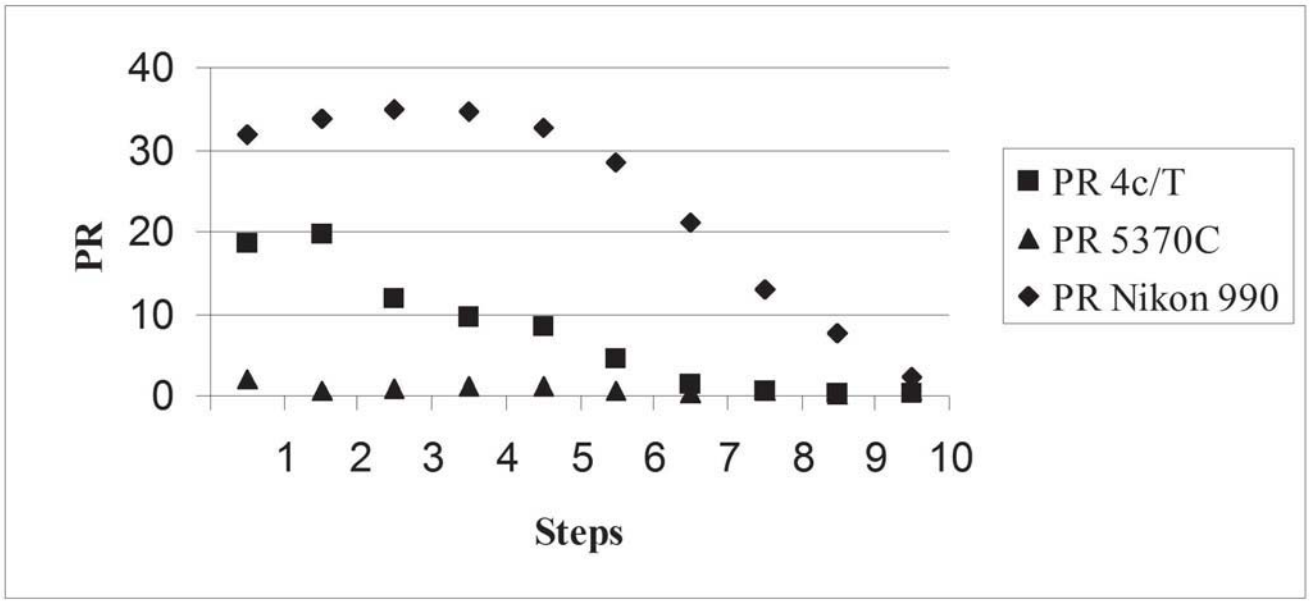

FIGURE 1- Pixel value Reproducibility (PR) values comparison for all devices

TABLE 3- Pixel values (PV1 to PV10) of each step, mean (M) and PR obtained for the Nikon Coolpix 990 digital camera

Step	PV1	PV 2	PV 3	PV 4	PV 5	PV 6	PV 7	PV 8	PV 9	PV 10	M	PR
1	59.3	60.2	57.9	61.8	51.6	46.9	49.0	48.3	49.8	35.5	52.0	31.7
2	57.2	58.5	56.1	60.0	49.7	45.4	46.8	45.7	48.2	33.1	50.0	33.8
3	57.1	58.2	55.6	59.9	49.4	44.5	46.4	45.8	47.6	32.4	49.7	34.8
4	57.2	58.4	55.8	60.0	49.5	44.5	46.3	45.8	47.6	32.5	49.7	34.6
5	60.1	61.2	58.6	62.8	52.4	47.5	49.4	48.8	50.5	35.5	52.7	32.6
6	67.0	67.9	65.4	69.6	59.6	54.7	56.6	56.0	57.8	42.7	59.7	28.4
7	82.4	83.2	80.7	84.7	75.1	70.5	72.3	71.6	73.3	59.3	75.3	21.2
8	118.6	119.2	116.9	120.9	111.9	108.0	109.6	108.9	110.6	97.6	112.2	13
9	182.7	185.8	183.5	187.1	178.7	175.3	176.8	177.3	177.0	165.2	178.9	7.6
10	233.1	241.2	240.5	241.7	239.0	237.8	238.3	239.0	238.5	234.0	238.3	2.2

captures. Also with respect to the pixel reproducibility (PR), the largest differences were observed for steps 1 to 7, i.e., the least dense steps. Figure 1 clearly shows the large decrease in PR from step 1 to step 10 for all devices.

However, the denser steps 8, 9 and 10 showed a lower PR for all devices, either because they captured the values of these areas with relative quality or they were areas much more penetrated by light which led to uniformity in the capture. A decrease in PR was noted between step 6 and step 7. The greatest problem was related to the less dense steps (white), which showed greater pixel variability.

The scanner HP 5370C showed a high pixel reproducibility (low PR coefficients) this equipment could be the best option among the three equipments tested for a longitudinal study (Table 2).

The importance of information about the performance of digital equipments lies exactly in knowing in which regions of the image the device can obtain the best characteristics for the final image. The method applied in this work can be applied either to direct or to indirect digital radiographic images. Inasmuch, variation on the pixel values in consecutive digitization may influence the clinical results mainly based on pixel values, such as healing process studies. It may be advisable to test the digital devices, whether direct or indirect, regarding a variation in pixel value at the same capture conditions prior quantitative image analysis. Usually, it could be assumed that a digital device should attribute the same pixel value as long as the image is kept the same. The results showed that this is not always true. It seems that digital equipment may suffer influences that modify pixel values given to the same image in different digital captures.

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