Physica Medica 64 (2019) 238–244

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Technical note

The impact of image processing algorithms on digital radiography of patients with metalic hip implants

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ARTICLE INFO

Keywords:
Digital radiography
Image quality
Image artifacts
Image processing algorithms

ABSTRACT

Objective: To investigate the impact of image processing algorithms on image quality of digital radiographs. This study was motivated from a case of a patient with metallic hip implant, where the anatomy around the implant was misrepresented, due to failure of the processing algorithm.

Materials & methods: A quality control phantom was imaged using a digital radiographic unit and the standard examination protocol for Pelvis anteroposterior (AP) projection. The original image was reprocessed with all available selections of Diamond View, which is a processing algorithm for optimizing image quality of different anatomic regions. The same procedure was repeated for two other examination protocols, Femur AP and Hip AP, which differ in terms of harmonization kernel and gain, and look up table settings. The whole procedure was repeated with a Pb strip, 2 cm wide and 3 mm thick, positioned close to the right phantom edge, in order to simulate a metallic hip implant.

Using ImageJ a number of regions of interest (ROIs) were positioned on the phantom images and the impact of processing parameters on certain image characteristics and image quality indices was evaluated.

Results: Processing parameters have a strong impact on image characteristics, but in terms of image quality, differences between images with and without the implant are small. Exception is the regions in the vicinity of the implant, where larger differences, that could affect diagnosis, were observed.

Conclusion: In case of doubt, additional processing with settings which minimize the risk of anatomic misrepresentation should be used.

1. Introduction

Computed radiography (CR) and digital radiography (DR) are gradually replacing film-screen radiography all around the developed world. The main advantages of CR and DR systems are the wide dynamic range and the processing capabilities that digital imaging systems offer [1–3]. These may facilitate the diagnosis, especially when used in conjunction with picture and archiving communication systems (PACS) and the image interpretation is performed on medical grade monitors of diagnostic workstations, instead of viewing printed films on viewing boxes. In digital systems, the images are automatically adjusted for latitude and contrast, for window level and width (WL, WW), however, additional local or global fine tuning of window settings, as well as, digital magnification can be used to further facilitate diagnosis. The software of many diagnostic workstations also offer filters for noise reduction, edge enhancement, etc.

Depending on the examination type, processing algorithm settings which pronounce the anatomic details of interest should be used, in order to optimize image quality and facilitate diagnosis. Usually, manufacturers offer a number of preset examination protocols, including predetermined processing algorithm parameters, which are supposed to be optimum for each specific examination type. In case that the image quality obtained doesn't allow the radiologist to make a confident diagnosis, even when using all available image processing tools in the diagnostic workstation, then reprocessing of the original image using alternative processing settings may be considered.

It should be clarified that the full range of imaging processing capabilities is available only in the acquisition workstation and only when the original image is available. In most CR and DR systems an old examination can be reopened, a copy of the original image can be created and this copy can be reprocessed using another processing protocol. If the original image is deleted after is sent to the PACS, major

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https://doi.org/10.1016/j.ejmp.2019.07.015
Received 16 February 2019; Received in revised form 25 May 2019; Accepted 17 July 2019
Available online 02 August 2019

reprocessing can no longer be applied when the deleted image is imported back in the acquisition workstation from the PACS.

A case where the use of the standard examination protocol processing parameter settings resulted in an image which misrepresented the actual anatomy and lead initially to wrong diagnosis, was observed in our radiology department. This was a Pelvis anteroposterior (AP) radiograph of a patient with metallic hip implant. Motivated by this incident, in this study we investigated the impact of the image processing algorithms used in digital radiography on image characteristics and image quality, with focus on patients with metallic implants.

2. Materials and methods

The study was performed using the digital X-ray unit installed in our hospital (Axiom Aristos MX, Siemens, Erlangen, Germany). The digital detector is an a-Si Flat panel with CsI scintillator, with size 43 cm × 43 cm, image matrix 3 k × 3 k × 16 bit, and pixel size 143 μm.

This unit is equipped with a digital control console, incorporating preset anatomic protocols and automatic exposure control (AEC) system. Depending on the examination protocol selection, the respective image detector and AEC chamber set are automatically activated (in the chest stand or the horizontal table), as well as, the collimation, filtration and tube potential settings. In each examination protocol there are also stored a number of parameters which are related to the image processing algorithms (referred to as preprocessing) and which are used to produce the digital image that is presented on the acquisition workstation screen. One of these is Diamond View, which is a processing algorithm for optimizing image quality of different anatomic regions.

The clinical case that motivated this study is shown in Fig. 1. It is a Pelvis AP radiograph of a patient with a hip implant, that was acquired with the Pelvis examination protocol, Diamond View setting number 6 (designated for the pelvis anatomic region), tube potential 81 kV, tube load 27.5 mAs and exposure index (EXI) equal to 453. In this radiograph it can be seen (black arrow position) that the bone appears broken at the top of the left hip and to the left of the implant.

However, after an initial wrong diagnosis, it was noticed that the tissues around the thighs were missing. The tissues could not appear on the image despite all the window adjustments tried in the PACS workstation. Since feedback was available from a previous conventional X-ray film, the radiologist was confident that the anatomy has been misrepresented and the patient was not recalled to repeat the examination.

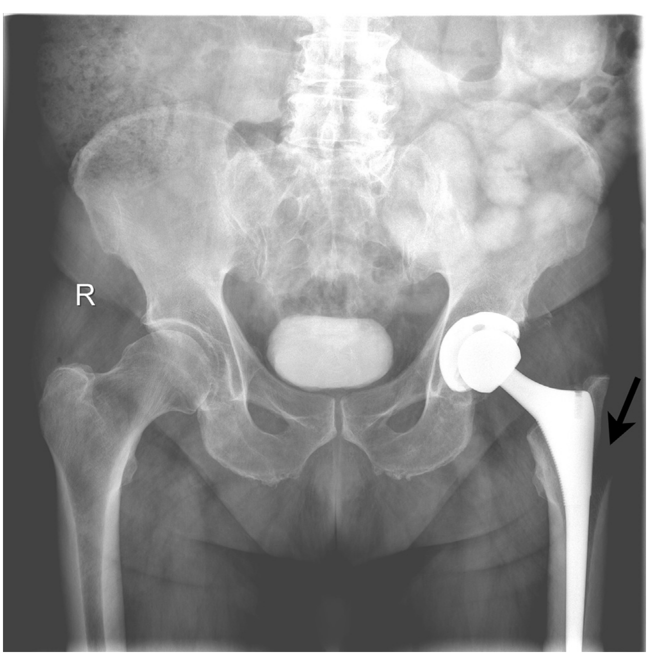

Fig. 1. The clinical case which motivated this study is presented. It is a Pelvis AP radiograph where the bone at the top of the left hip and to the left of the implant appears broken.

Unfortunately, this incident was reported to the Medical Physics Department a few days after, when the original image has been deleted (due to the heavy workload images are deleted every week after they have been sent to a local PACS workstation). The image was retrieved from the PACS workstation and was imported back to the acquisition workstation, where it was verified that major reprocessing was no longer feasible. However, it was seen that the mean Pixel Value (henceforth referred to as PV) and standard deviation (PVSD) of regions of interest (ROI) positioned close to the outer edges of both hips were all 0. It was thus evident that these areas were saturated-like and therefore the anatomy has been clipped. Since the exposure factors used and the exposure index were normal compared to data obtained in the context of a diagnostic reference level survey (for a sample of 30 Pelvis AP radiographs, the mean values of tube potential, tube load and exposure index were respectively 81 kV, 12.8 mAs and EXI = 400), the cause of this saturation was attributed to an occasional failure of the processing algorithm.

To investigate the impact of processing algorithms the Primus L Test phantom was used, which is designed for quality checks at digital and conventional radiographic and fluoroscopic X-ray units according to DIN 6868-4, 2007 [4]. The phantom is a 300 × 300 mm plate that includes among others, a 1 cm spaced grid (for the evaluation of geometric distortion), a 16-step copper stepwedge with detail contrast objects of 4 mm diameter and depth 2.5 mm in PMMA (for the evaluation of the contrast resolution in each step of the copper step wedge) and 8 detail contrast objects with a diameter of 10 mm and variable depth 0.4–4 mm (for the determination of low contrast resolution).

For obtaining the phantom images, the following procedure was followed. The Primus L phantom was positioned on the horizontal table and the 25 mm Al pre-attenuator that accompanies the phantom, was inserted in the tube collimator rails, in order to produce altogether an attenuation similar to the Pelvis of an adult patient. The Pelvis AP examination protocol was used and a radiation field of about 32 cm × 32 cm covering the whole plate up to the Aluminum frame of the phantom was set, using the standard focus-image distance (FID) of 115 cm. The phantom was radiographed using the preset tube potential of 81 kV with the AEC system activated and the resulting tube load (19.5 mAs) and exposure index values (EXI = 461) were recorded.

Using 81 kV and the closest manual mAs value available (20 mAs), in order to avoid any variations that could be due to AEC reproducibility, the exposure was repeated to acquire the first image of the series. Then successive copies of this image were created by changing the Diamond View settings. Thus, one image for each one of the available selections of Diamond View was created for the Pelvis AP examination protocol.

The same procedure was repeated for two other examination protocols used for examinations in the vicinity of the pelvis region, Hip AP and Femur AP, which differ from the Pelvis AP in terms of harmonization kernel and gain, and look up table (LUT) settings, keeping the phantom position, field size, kV and mAs constant. In this way, two more image series were created (Femur, Hip). With the lead strip positioned on the phantom and using the same procedure as before, the respective image series with the simulated implant were created (Pelvis implant, Femur implant and Hip implant). In total 120 digital images were created.

Using the ImageJ (version 1.51j8) free software, a number of ROIs were positioned on certain regions of the phantom images, as shown in Fig. 2. In order to enable the automatic measurement of PV and PVSD in all these ROIs, in-home built macros for ImageJ were used and the results were exported in spreadsheets for further analysis. Using the results of these measurements, the impact of the processing parameters

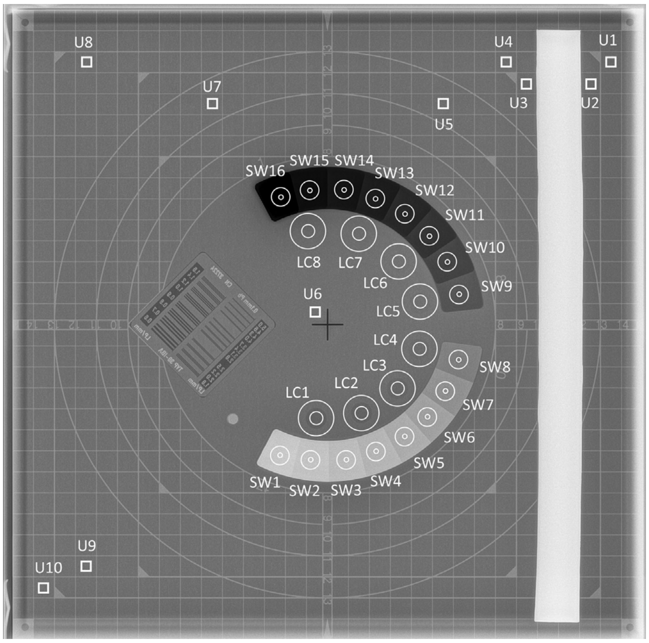

Fig. 2. The position of the ROIs that were set on a radiograph with the implant are shown. (a) U1-U10 are the square ROIs that were positioned on the uniform areas of the image to evaluate the uniformity of PVs and the PVSD. (b) SW1-SW16 are the circular ROI sets, one small within the hole and one larger extending beyond the hole, that were positioned on the Copper stepwedge to evaluate the image latitude and contrast in different levels of attenuation. (c) LC1-LC8 are the circular ROI sets, one small within the hole and one larger extending beyond the hole, that were positioned on the low contrast detail areas to evaluate the low contrast in the average level of attenuation.

on image characteristics and image quality indices was evaluated.

All the parameters relevant to the examination protocol, the processing algorithms settings, the exposure factors and the geometrical set-up used for each radiograph, are automatically stored in the DICOM header of each digital radiographic image. A free software called DICOM Info Extractor [5], was used to read the DVD-rom where all the phantom images were stored. The DICOM Info Extractor was customized to read all DICOM tags which are relevant with this study. A brief description of these tags was found in the DICOM Conformance Statement of the specific unit. These data were extracted and stored in a spreadsheet for further reference.

3. Results

From the DICOM data extracted, it was seen that for all images the exact value of tube load was 20.28 mAs. The EXI was 445 for Pelvis and Femur series and 447 for Hip series, while for Implant Pelvis and Implant Hip was 446 and for implant Femur 445. It was therefore documented that the processing algorithms had practically no effect on EXI.

In Fig. 3 the PVs of U1-U10 ROIs for the digital radiographs of the Primus L phantom acquired with the 3 different examination protocols with and without the implant, and reprocessed with all the available Diamond View settings are shown. There are some basic points that need to be noted. First, image areas which correspond to detector areas exposed in lower radiation levels appear white and present larger PV than the areas which were exposed to higher radiation levels and appear black. Thus, PV is proportional to brightness and inversely proportional to incident radiation. Second, in almost all profiles, the PV of U1 ROI, which is close to the radiation field edge (penumbra) is the lowest compared to the PVs of the ROIs U2 to U10 and indicates the first of the 10 ROIs PV measurements performed in each digital image. Third, with the exception of ROIs U1 to U4 which are positioned around the implant, for ROIs U5 to U10, the PV values in the images with the implant are larger than the respective values in the images without the implant. A PV peak shown in some regions of the profiles correspond to the ROI U6, which is located close to the phantom center.

In Fig. 3 it can be also seen that for the majority of Diamond View settings the PV of Pelvis and Hip profiles are similar and larger than the respective PVs of the Femur profiles. It is therefore apparent, that processing algorithm settings have a strong effect on the images regarding the PVs. This however, does not document any impact on the image quality of the image. The impact of processing algorithms on image quality can be seen when comparing the PVs of ROIs U1 to U4 and especially U2 and U3 with and without the implant, with the rest ROIs (U5-U10), as the presence of the implant introduces a decrease of the PVs in the vicinity of the implant compared to the rest uniform areas of the radiograph.

This is exhibited in Figs. 4 and 5, where the variation of 2 contrast indices (CI-1 and CI-2) with the processing algorithms is shown. CI-1 was defined as the PV difference among the mean PV of ROIs U5-U10 and the maximum PV of ROIs U2 and U3, divided by the mean PV of ROIs U5-U10 and expressed as percent. The ROIs U2 and U3 are at 0.5 cm to the right and to the left respectively of the implant edges. The CI-2 factor was defined similarly for the difference of mean(U5-U10) and max(U1, U4) PVs. The ROIs U1 and U4 are at 1.5 cm to the right and to the left respectively of the implant edges. Since, all these areas are normally expected to have the same PV, a large CI value denotes large non-uniformity and vice versa and therefore CI-1 and CI-2 serve as image quality indices.

In Fig. 4 it can be seen that the CI-1 values for the radiographs without the implant are very small (less than ± 2%), with only a few exceptions as for Diamond View selections numbered 0, 8, 9 and 19 where slightly larger values (up to −4%) were observed. On the contrary for the image with the implant the CI values are larger and up to about 19%, for all examination protocols but especially for the Pelvis protocol which presents, for almost all Diamond View settings (except number 18), the larger CI values compared to the respective CI values for Hip and Femur, which are similar to each other. The only Diamond View selection that the CI values are close to 0 for all images with and without the implant is number 12, Extremities.

In Fig. 5 it can be seen that the CI-2 values for the images with the implant are in general smaller than the respective CI-1 values, with the exception of Diamond view settings number 5 and 6 (Pelvis-High Contrast and Pelvis, respectively) where the CI-2 values are larger than CI-1 values. The CI-2 values are larger than 5% only for the Diamond View selections numbered 1, 2, 4, 5 and 6. This denotes that for these selections the effect of the implant on image non-uniformities extends further than for the rest selections.

In Fig. 6 the PV of the outer circular ROIs positioned on the stepwedge (SW1-SW16) are shown, for the radiographs obtained with the Pelvis AP examination protocols, with and without the implant, for Diamond View selections numbered 0, 6, 12 and 14 (for the economy of space the rest settings are not shown in graphs). It can be seen that the PVs are larger in the images with the implant, except for the case of Diamond View 0 (-, i.e. Diamond View off), where there is practically no difference. What is of more interest in Fig. 6, is that for Diamond View selection number 6, the PV for the last 4 steps are zero (in both images with and without the implant), meaning that these steps are indiscernible. In the respective graphs for Hip AP and Femur AP examination protocols (not shown for the economy of space), similar curves were derived. However, the PVs were generally lower, especially for the Femur AP. For both Hip AP and Femur AP, and in both the images with and without the implant, the drop of PVs in the last steps was less steep, compared to Pelvis AP. For example, for Diamond View 6, for Hip AP the PVs were zero for the last 3 steps, while for Femur AP the PV was zero only for the last step. This means that the Pelvis AP examination protocol processing settings (most probably because of the LUT and the gain of the Harmonization) combined with the Diamond

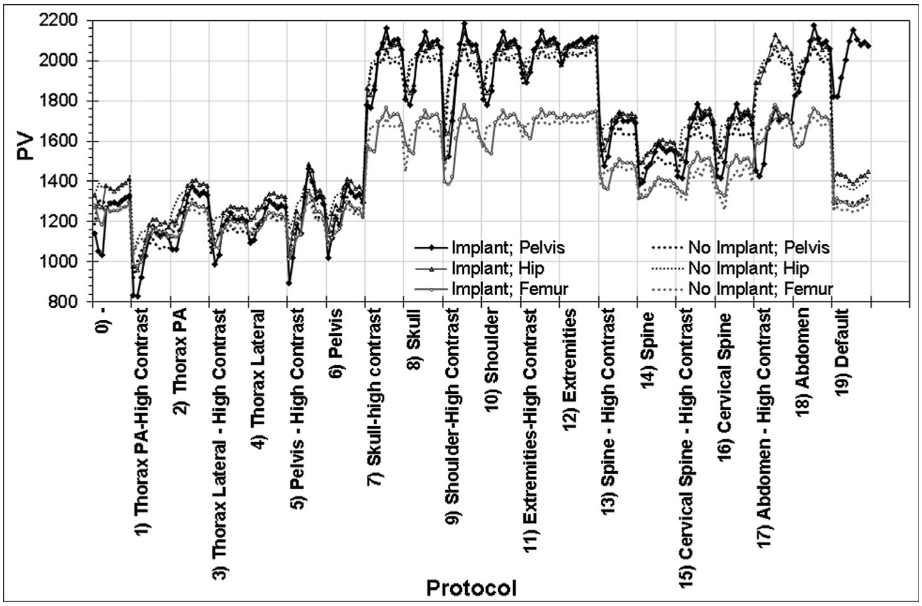

Fig. 3. The PVs of U1-U10 ROIs for the digital radiographs of the Primus L phantom acquired with the 3 different examination protocols with and without the implant, and reprocessed with all the available Diamond View settings are shown.

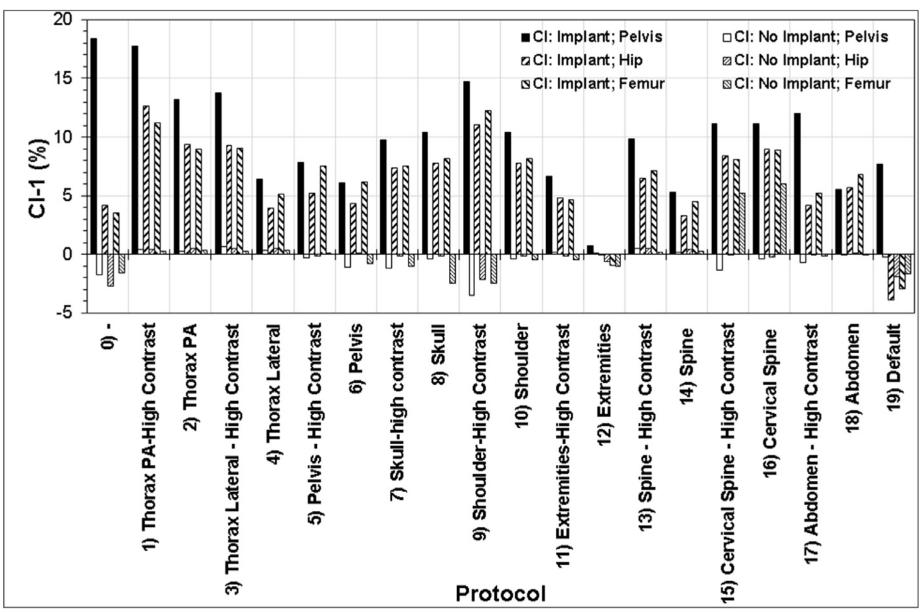

Fig. 4. The CI-1 for the digital radiographs of the Primus L phantom acquired with the 3 different examination protocols with and without the implant, and reprocessed with all the available Diamond View settings are shown.

View 6 (Pelvis), is the least favorable selection for imaging of overexposed areas, since the PVs fall more abruptly compared to other Diamond View selections shown in these figures.

With regard to the CI-SW values (defined as the PV differences between the outer and the inner ROIs SW1-SW16 of the Primus L phantom), no figure is shown for the economy of space and because no definite conclusions could be drawn concerning whether contrast is better in the images with or without the implant. However, it was clear that for the steps that could be discerned, the Pelvis AP protocol presented the best contrast, followed by Hip AP protocol, while the Femur AP presented the lowest CI-SW values.

In Fig. 7 the CI-LC values (defined as the PV differences between the outer and the inner ROIs LC1-LC8 of the Primus L phantom) are shown, for the digital radiographs acquired with all examination protocols and for Diamond View selections number 6 and 12. It can be seen that for the first 6 low contrast details the Pelvis AP and Hip AP presents larger CI-LC values, that is better low contrast, compared to Femur AP. The Diamond View selection number 6 also presents better low contrast than selection number 12. However, for the last 2 low contrast details the situation is not clear. As seen negative CI-LC values appear which means that due to local non-uniformities the PV within the low contrast hole (inner ROI) is larger than this of the outer ROI.

Though in the beginning we considered that local non-uniformities should appear only in clinical images with implant, due to the fact that local non uniformities were also observed in images without implant and were manifested as negative CI-1 and CI-2 values (as shown in Figs. 4 and 5), a fairly large number of Pelvis AP images with and without implant were reviewed for similar artifacts. Though many images of patients with hip implants were found to be free of such obvious artifacts, a patient radiograph without implant was found,

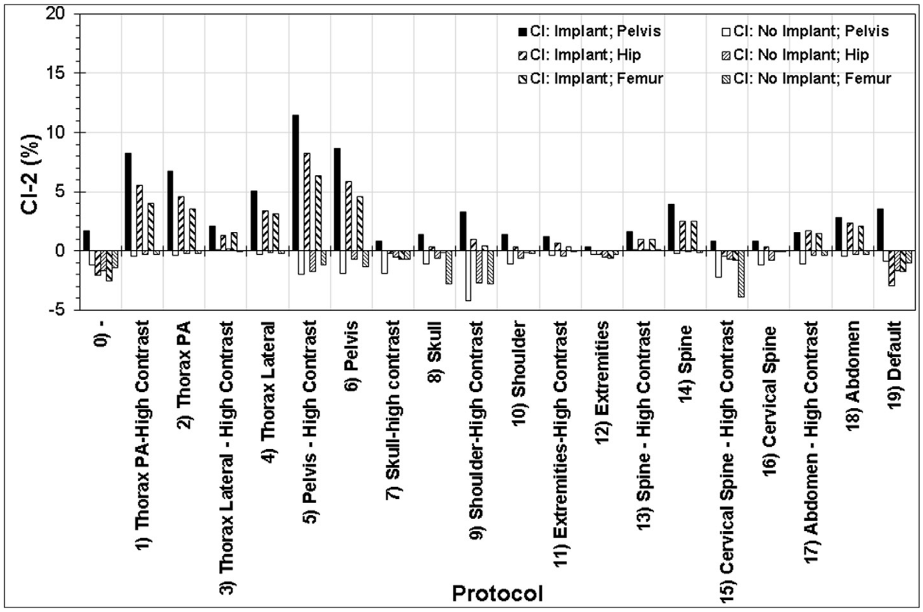

Fig. 5. The CI-2 for the digital radiographs of the Primus L phantom acquired with the 3 different examination protocols with and without the implant, and reprocessed with all the available Diamond View settings are shown.

shown in Fig. 8, where a less obvious artifact was identified. In this Pelvis AP image, though no implant was present, the original protocol's processing settings failed to picture the tissues around the hips and additionally imaged the hips, especially the right, as too radiolucent, creating a suspicion of osteopenia or even osteolysis. This image was reprocessed with Diamond View selections number 0, 6, 12 and 14 and 10 ROIs were set on this image (also shown in Fig. 8), using ImageJ and macros in the same way as for phantom images. The ROI PV measurement results are shown in Fig. 9.

As seen in Fig. 9, with Diamond View selection number 0 there is a relative symmetry in the PVs positioned on the left and right pelvis and hip regions (ROIs 1–3 and 8–10), thought slightly lower around the right hip. With Diamond View selections number 12 and 14, the PVs of these ROIs are significantly reduced and differences between the left and right hip and the rest of the pelvis are accentuated, but tissues are visible. With the original Diamond View selection number 6, the right hip is strongly distorted, leading to the image quality shown in Fig. 9. It was therefore revealed that occasional failure of the original Diamond View selection number 6, which is used for contrast enhancement, may also occur in patients without implants. Another case of a patient who due to the suspicion of osteolysis was referred by the orthopedicians for a Pelvis CT, which however excluded osteolysis, verified that the preset Pelvis AP processing parameter settings are not always optimal.

4. Discussion

The processing algorithms are designed to manipulate the linear signal response curve of digital detector systems, so as to resemble in a way to the sigmoidal curve of classic screen-film systems. Depending on the radiographed anatomy, the incident air-kerma range on the detector

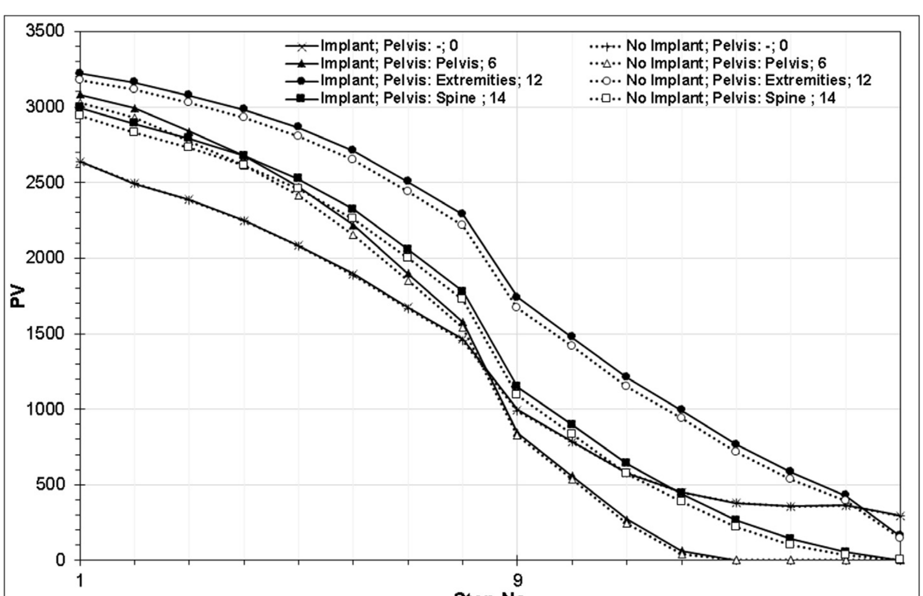

Fig. 6. The PVs of the stepwedge of the Primus L phantom with and without the implant, for the digital radiographs acquired with the Pelvis AP examination protocol and reprocessed with 4 different selections of Diamond View, are shown.

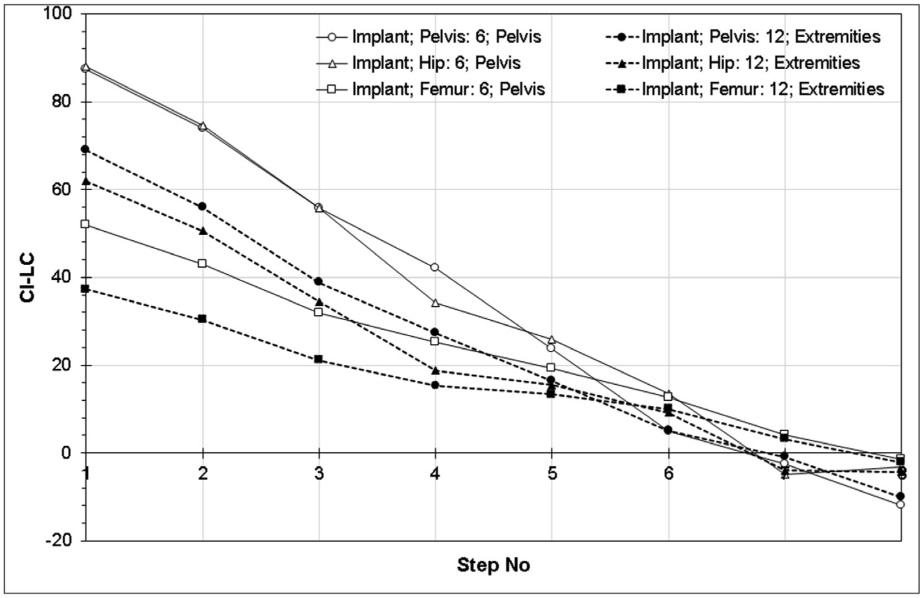

Fig. 7. The PVs differences (CI-LC) between the outer and the inner ROIs LC1-LC8 of the Primus L phantom with the implant are shown, for the digital radiographs acquired with all examination protocols and for Diamond View selections number 6 and 12.

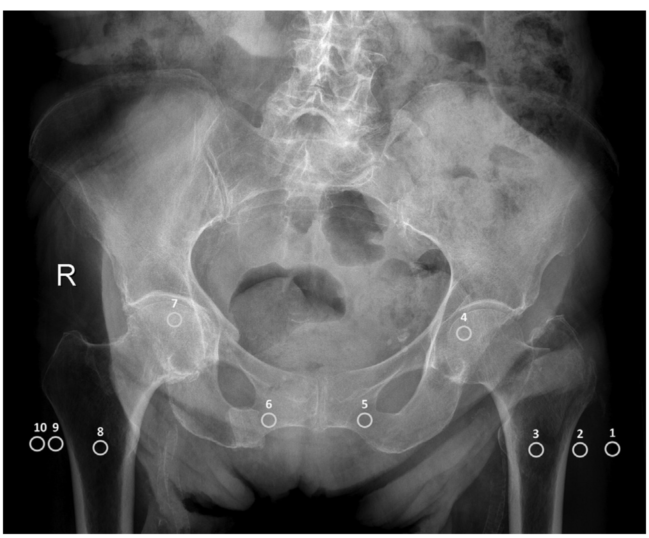

Fig. 8. A Pelvis AP image where the original protocol processing settings failed to picture the tissues around the hips and additionally imaged the hips, especially the right, as too radiolucent, creating the suspicion of osteopenia or even osteolysis. The position of the ROIs that were set on the radiographs for the measurement of PV are shown.

and the radiation contrast, the image signal is manipulated so as to positively affect image quality. This is done by identifying the collimation edges, the overexposed areas which correspond to areas outside the body, so as to end up with the histogram of signal values relevant with diagnostically useful information [1,3]. Using appropriate processing algorithms, some parts of the signal histogram are accentuated and other are suppressed, so as enhance the visibility of the anatomic areas of interest for each particular anatomic region.

Most users will normally use the manufacturer's preset processing algorithms, assuming they are optimal. However, the processing algorithms are usually proprietary and their specifics and impact on the image quality are not available to the user. Thus, if a change is required, this has to be done by trial and error, with or without the participation of an application specialist, and the radiologists should determine the optimal settings according to their professional opinion.

However, in this study it was seen that processing algorithms may also have a negative impact on image quality, as they may introduce non-uniformities and artifacts, which in extreme cases may interfere with diagnosis. Searching the international literature on this subject did not resulted in many articles that address this particular artifact. We found only two articles regarding digital luminescence radiography in patients with prostheses, where it was noted that the high contrast differences at the edge of the metal implant may lead to artifacts, which could result in erroneous interpretation [6,7]. A few additional articles were found regarding artifacts that appear in dental digital radiography due to the presence of metal restorations of teeth [8,9]. It is pointed out that digital processing may produce artifacts that they are hard to recognize and may lead in misdiagnosis. For this reason it was suggested that when in doubt, the raw images (without processing) should be reviewed [8].

According to a very comprehensive article on digital radiography artifacts in veterinary radiographic imaging [10], there are two possible reasons for the artifacts observed in this study in patients with and without a metallic hip implant. The first is the use of a wrong LUT and the second the Uberschwinger or rebound effect. With the specific digital X-ray unit, the raw data of a digital acquisition is 16 bits, but after the LUT is applied during preprocessing, bits beyond the display range are discarded and the image is converted to 12 bits for viewing and storage. In this way the application of the LUT in the preprocessing phase may potentially lead to clipping of anatomic information which cannot be retrieved with any WW and WL adjustments. On the other hand, the Uberschwinger or rebound effect, which is manifested as a black halo around edges like a bone/soft-tissue or an implant/bone interface, can be mistaken for bone loss and is due to contrast and edge enhancement processing algorithms.

There are two approaches to the solution of the problem observed in our study. The first is to maintain the original Pelvis AP protocol settings which provide the best contrast and instruct the radiation technologists to be watchful for the occurrence of such artifacts. In case of doubt, a copy of the image should be made and reprocessed with another processing protocol or Diamond view setting, which does not result in such artifacts (e.g. Extremities). This approach has the problem that relies on the accountability of the various radiation technologists who use this X-ray unit and that the radiologist has to review two images.

The second approach is to modify the standard protocol and adjust

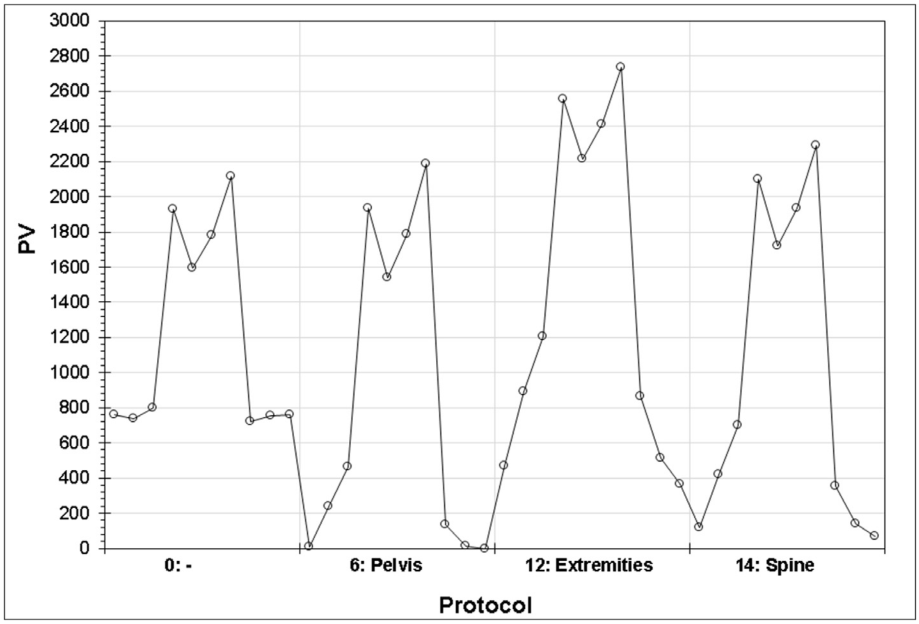

Fig. 9. The PVs of the ROIs 1–10 defined on the Pelvis AP clinical image shown in Fig. 8, for the Pelvis AP examination protocol and Diamond View selections number 0, 6, 12 and 14.

the parameter settings until the best compromise between good contrast and absence of artifacts is found, using the procedure described above. However, since this phantom is not anthropomorphic, the suitability of the settings found with the phantom has to be verified in the clinical practice. This requires the cooperation of medical physicists, radiation technologists and radiologists, until the optimal settings are established.

5. Conclusion

The processing algorithms are designed to positively affect image quality by manipulating the original signal, so as to adjust the latitude and promote contrast, depending on the anatomic region imaged. However, in this study it was seen that they may also have a negative impact on image quality, as they may introduce non-uniformities and artifacts, which in extreme cases may interfere with diagnosis. It was also seen that this negative impact may occur occasionally, for no obvious reason, not only for patients with implant but for patients without implants too.

While in this study a single X-ray digital unit was investigated, based on its results and on the results reported in the limited references found in the literature, it is expected that similar problems may occur in other digital X-ray units as well. The methodology described in this study provides a guide for the investigation on the impact that different processing algorithms may have on image quality. It should be stressed however, that any results found with phantoms, should be always verified using clinical images, which should be evaluated by the radiologists bearing the responsibility of diagnosis.

References

[1] Körner M, Weber CH, Wirth S, Pfeifer KJ, Reiser MF, Treitl M. Advances in digital radiography: physical principles and system overview. Radiographics 2007;27(3):675–86.
[2] AAPM REPORT NO. 93. Testing and quality control of photostimulable storage phosphor imaging systems. Report of AAPM Task Group 10; 2006.
[3] Jones AK, Heintz P, Geiser W, Goldman L, Jerjian K, Martin M, et al. Ongoing quality control in digital radiography: report of AAPM imaging physics committee task group 151. Med Phys 2015;42(11):6658–70.
[4] DIN 6868-4:2007-10. Image quality assurance in diagnostic X-ray departments – Part 4: Constancy testing of medical X-ray equipment for fluoroscopy; 2007.
[5] Tsalafoutas IA, Metallidis SI. A method for calculating the dose length product from CT DICOM images. Br J Radiol 2011;84:236–43.
[6] Wiesmann W, Reiser M, Pauly T, Fiebich M, Bick U, Peters PE. The visualization of metal implants with digital luminescence radiography. [Article in German] Rofo 1990;152(6):687–92.
[7] Krug B, Fischbach R, Herrmann S, Dietlein M, Küpper T, Dölken W, Harnischmacher U. X-ray studies of the peripheral joints: a comparison of digital luminescence radiography (DLR) and film-screen systems. [Article in German] Rofo 1993;158(2):133–40.
[8] Brettle D, Carmichael F. The impact of digital image processing artefacts mimicking pathological features associated with restorations. Br Dent J. 2011;211(4):167–70.
[9] Schweitzer DM, Berg RW. A digital radiographic artifact: a clinical report. J Prosthet Dent. 2010;103(6):326–9.
[10] Drost WT, Reese DJ, Hornof WJ. Digital radiography artifacts. Vet Radiol Ultrasound. 2008;49(1 Suppl 1):S48–56.