JURNAL KESEHATAN BUDI LUHUR
Published By: STIKes Budi Luhur Cimahi
P-ISSN: 1978-8479
E-ISSN: 2581-0111

The Quality of Digital Radiography Images of The Sacrum Is Influenced by X-Ray Exposure Factors

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ABSTRACT

Digital radiography of the sacrum requires precise adjustments of exposure parameters (kV, mA, time) to produce high-quality images while minimizing radiation exposure. This study aims to investigate how these exposure factors affect the quality of sacral images and to recommend optimal settings that align with radiation safety principles such as ALARA. By reviewing the existing literature, it was found that the modification of exposure parameters (kV, mA, time) in digital radiography is essential for achieving optimal image quality while minimizing radiation exposure. The exposure index (EI) serves as an indirect measure of the dose absorbed by the detector, thereby facilitating the implementation of the ALARA principles. Properly orienting the AEC chamber can reduce radiation dose by up to 44% without compromising image quality. Tube voltage and current adjustment enhances image contrast and sharpness. Nonetheless, inconsistent exposure methods and dependence on presets can still lead to dose creep. It is essential to train radiographers, adjust equipment settings, and set Diagnostic Reference Levels (DRLs) to enhance imaging quality and ensure patient safety. In digital radiography, factors such as tube voltage (kV), tube current (mA), and exposure time (s/mAs) significantly affect image quality and patient radiation dose. Adjusting exposure settings according to patient characteristics and exam objectives enhances image quality and reduces radiation exposure, particularly in sensitive areas like the sacrum. Technologies such as Exposure Index (EI), Automatic Exposure Control (AEC), and image analysis software facilitate an objective method that follows the ALARA principle, ensuring patient safety while optimizing diagnostic outcomes.

Keywords: digital radiography (DR), sacrum, radiation dose, exposure index, personalised optimization

Correspondence:	How to cite:
Edwin Suharlim Universitas Yarsi Pratama Email address edwinsuharlim@yarsipratama.ac.id	Suharlim, E., Kusmiati, E., Sugandi, E. S., & Pratama, A., & Hamidah, M. A. (2026). The quality of digital radiography images of the sacrum is influenced by x-ray exposure factors. *Jurnal Kesehatan Budi Luhur: Jurnal Ilmu-Ilmu Kesehatan Masyarakat, Keperawatan, dan Kebidanan, 19*(1), 210–218. https://doi.org/10.62817/jkbl.v19i1.433

INTRODUCTION

Medical imaging using digital radiography (DR) has become one of the primary modalities for diagnosing various clinical conditions, including spinal examinations such as sacral radiography. Radiographic evaluation of the sacrum plays an important role in detecting fractures, degenerative changes, inflammatory conditions, and sacroiliac joint pathology. However, accurate diagnosis highly depends on the quality of the radiographic image produced. One of the most critical determinants of image quality in radiography is the selection of exposure factors.

Exposure factors consist of tube voltage (kV), tube current (mA), and exposure time (s), which together determine both image quality and patient radiation dose (Rasad, 2005). Proper adjustment of these parameters can produce optimal radiographic contrast and spatial resolution, allowing clear differentiation between anatomical structures with varying tissue densities (Dhahryan & Azam, 2009). Conversely, inappropriate exposure selection may result in images with insufficient contrast or penetration, potentially obscuring clinically significant findings.

Clinically, sacral radiography presents a particular diagnostic challenge due to the complex anatomy of the sacrum and its overlap with surrounding pelvic structures. Several studies have reported a relatively high false-negative rate in conventional pelvic radiography for detecting sacral and pelvic abnormalities. Schicho et al. reported that approximately 21.7% of pelvic fractures were initially missed on standard radiographic examinations, highlighting the critical importance of producing high-quality diagnostic images to avoid misinterpretation and delayed diagnosis. This finding emphasizes that suboptimal image quality in sacral imaging may directly compromise clinical decision-making.

At the same time, sacral radiography involves irradiation of radiosensitive organs located within the pelvic region, including the colon, gonads, and urinary bladder. According to the International Commission on Radiological Protection (ICRP) Publication 103 (ICRP, 2007), these organs have relatively high tissue weighting factors, indicating increased sensitivity to ionizing radiation. Due to the anatomical location of the sacrum, these organs cannot be adequately protected using gonadal shielding during sacral radiographic examinations. Therefore, achieving a balance between sufficient image quality and radiation dose optimization is particularly critical in sacral imaging.

Advances in digital radiography technology offer improved image processing capabilities, wider dynamic range, and enhanced contrast resolution. However, these advantages may also mask exposure errors, potentially leading to unnecessary radiation dose escalation if exposure parameters are not carefully optimized. Consequently, the application of radiation protection principles, such as the As Low as Reasonably Achievable (ALARA), is essential to ensure patient safety without compromising diagnostic image quality.

This study focuses on identifying and analyzing exposure factors that influence the quality of digital radiography images of the sacrum. Furthermore, it explores strategies to minimize patient radiation dose while maintaining adequate diagnostic quality. The aim of this study is to analyze exposure parameters affecting sacral X-ray imaging, outline relevant radiation safety principles, and formulate evidence-based recommendations for optimal exposure settings in sacral radiography in accordance with established radiation protection standards.

METHOD

This study employed a literature review design to analyze scientific evidence related to the influence of X-ray exposure factors on image quality and radiation dose in sacral radiography.

The review focused on identifying exposure optimization strategies that balance diagnostic image quality and radiation protection principles.

Data were collected from several electronic databases, including Google Scholar, PubMed, ScienceDirect, and Neliti. The search process used combinations of relevant keywords such as “digital radiography,” “exposure factors,” “radiation dose,” “image quality,” “sacrum,” and “pelvic radiography.”

Literature Selection Criteria

The literature selection process followed predefined inclusion and exclusion criteria to ensure relevance and consistency. Articles published between 2011 and 2023 were included to reflect contemporary digital radiography technology and current radiation protection standards. Both English and Indonesian language articles were considered to capture international and regional research.

Inclusion criteria were as follows: (1) original research articles evaluating exposure factors such as tube voltage (kV), tube current (mA), exposure time, Exposure Index (EI), or Automated Exposure Control (AEC); (2) studies assessing image quality and/or patient radiation dose in digital radiography or computed radiography systems; and (3) studies relevant to sacral or pelvic imaging, or those providing principles directly applicable to sacral radiography.

Exclusion criteria included: (1) studies focusing exclusively on non-skeletal imaging; (2) research involving advanced imaging modalities such as computed tomography (CT) or magnetic resonance imaging (MRI); (3) review articles without primary data; and (4) studies lacking quantitative or qualitative assessment of exposure parameters.

Based on these criteria, a total of 13 relevant national and international articles were selected for final analysis.

Data Analysis

Data analysis was conducted descriptively by synthesizing findings from the selected studies. Key variables extracted included exposure parameters (kV, mAs, exposure time), image quality indicators, radiation dose metrics, and optimization strategies. The results were compared and interpreted narratively to identify consistent patterns and evidence-based recommendations for optimizing sacral radiography in accordance with radiation protection principles.

RESULT

Tabel 1. Summary of Studies on Exposure Factors, Image Quality, and Dose Optimization in Digital Radiography Relevant to Sacral Imaging

Author (Year)	Imaging System & Focus	Exposure Factors Evaluated	Main Findings	Relevance to Sacral Imaging
Seibert & Morin (2011)	DR (general)	Exposure Index (EI), kV, mAs	EI reflects detector exposure and	Important for dose control in dense sacral anatomy

			helps monitor dose creep	
Manning-Stanley et al. (2012)	DR – Pelvic phantom	AEC chamber orientation, kV	Ca-AEC reduced dose up to 44% with acceptable image quality	Highly applicable for sacral/pelvic imaging
Fadden et al. (2018)	CR & DR (Europe)	Exposure practices, DRLs	Large variation in exposure techniques and DRL awareness	Highlights need for protocol standardization
Sparzinanda et al. (2018)	CR – Phantom study	kV (60–80), mAs (20–30)	Low kV and optimized mAs improved contrast and sharpness	Supports low kV technique for sacral detail
Lewis et al. (2019)	DR – Clinical data	EI variation	Significant EI variability indicates dose creep risk	Reinforces EI monitoring in sacral DR
Welarathna et al. (2022)	DR – Adult patients	KAP, DRLs	DRLs reduce dose variation and improve protection	Basis for sacral DR dose benchmarking

Seibert and Morin (2011) reported that, according to international standards developed by the International Electrotechnical Commission (IEC) and the American Association of Physicists in Medicine (AAPM), the Exposure Index (EI) does not directly represent the radiation dose received by the patient, but rather provides a linear estimate of the radiation exposure incident on the image receptor. The implementation of a standardized EI was shown to support more consistent adjustment of exposure parameters, including kVp, mAs, and exposure time, among radiographers.

The use of EI as a feedback tool supports the ALADAIP principle (As Low as Diagnostically Achievable being Indication-oriented and Patient-specific), emphasizing the importance of tailoring exposure according to clinical indication and patient characteristics. This approach is particularly relevant for sacral imaging, which is susceptible to exposure inaccuracies due to anatomical complexity, and allows improvement of diagnostic image quality without increasing unnecessary radiation risk.

Manning-Stanley et al. (2012) evaluated the effect of phantom orientation and Automated Exposure Control (AEC) chamber selection on radiation dose and image quality in pelvic digital radiography using an anthropomorphic pelvis phantom. Two AEC orientations were compared: cranial-oriented AEC (Cr-AEC) and caudal-oriented AEC (Ca-AEC). All AEC combinations were tested using fixed mAs with variations in source-to-skin distance and tube voltage. Radiation dose was assessed using entrance surface dose (ESD) and effective dose (ED), while image quality was evaluated by two observers using a three-point scoring system across six anatomical regions.

The results demonstrated that changing the phantom orientation from Cr-AEC to Ca-AEC resulted in an average radiation dose reduction of 36.8%, accompanied by only a slight decrease in median image quality score (from 15.5 to 15.0), which remained within acceptable diagnostic limits. In the Ca-AEC configuration, the use of the outer AEC chamber alone achieved dose reductions of up to 44%, whereas the Cr-AEC orientation achieved a maximum reduction of 11% using the central AEC chamber. Only 1.6% of images in the Ca-AEC orientation were rated as unacceptable by one observer, while the majority demonstrated adequate image quality. The study noted that positioning the AEC chamber laterally, where it was not obscured by dense bone structures, resulted in more accurate exposure termination.

Fadden et al. (2017) investigated variations in radiographic knowledge and practices across Europe in chest, abdomen, and pelvis imaging using computed radiography (CR) and digital radiography (DR). Through an online survey involving 17 educational institutions affiliated with the European Federation of Radiographer Societies (EFRS), the study identified substantial variability in radiographer training, exposure parameter selection, and awareness of the ALARA principle and Diagnostic Reference Levels (DRLs). Many radiographers reported reliance on preset exposure techniques with limited adjustment for patient body habitus, highlighting the need for standardized education, protocols, and exposure optimization strategies.

Sparzinanda et al. (2018) examined the influence of exposure factors on radiographic image quality using a mobile X-ray unit and CR system with an air phantom. Exposure parameters included variations in tube voltage (60–80 kV) and mAs (20–30 mAs). Image quality was evaluated using contrast, sharpness, and grayscale histogram analysis via ImageJ software. The study found significant differences in image quality across exposure settings, with low tube voltage (60 kV) combined with appropriate mAs (20 mAs) producing superior contrast and image sharpness. Higher exposure combinations (80 kV and 30 mAs) resulted in darker images with reduced sharpness.

Lewis et al. (2019) conducted a retrospective pilot study to assess exposure technique variation in digital radiography by analyzing EI values from clinical radiographs. The study revealed substantial variability in EI values, with only a limited proportion of images falling within the recommended target range. A significant number of images exhibited EI values indicative of overexposure, suggesting the presence of dose creep. Despite minimal visible degradation in image quality due to digital post-processing, elevated EI values indicated unnecessary radiation exposure, underscoring the importance of monitoring EI as part of exposure optimization.

Welarathna et al. (2022) evaluated the use of Diagnostic Reference Levels (DRLs) as a dose optimization tool by measuring kerma-area product (KAP) values in adult patients undergoing routine projection radiography. The study involved over 400 patients aged 18–87 years and proposed institutional DRLs based on median dose values. The findings demonstrated that DRLs are effective in identifying dose variations and supporting radiation protection practices. The authors emphasized the importance of radiographer training, equipment calibration, and routine audits to maintain dose consistency.

Yufita et al. (2023) analyzed the effect of exposure factors on the optical density of radiographic film images using various tissue-equivalent materials. Exposure parameters included tube voltages ranging from 60 to 85 kV and tube currents between 20 and 32 mA. Optical density measurements obtained using ImageJ software demonstrated that exposure factors significantly influenced image density. The optimal combinations varied with tube current;

however, lower tube voltage settings consistently produced favorable optical density values when appropriately matched with tube current.

DISCUSSION

Exposure factors in digital radiography—including tube voltage (kV), tube current (mA), and exposure time (s/mAs)—play a crucial role in determining image quality and the amount of radiation dose received by the patient. The results of studies from various analyzed literature indicate that suboptimal exposure can directly impact both image quality and the level of radiation exposure received by the patient, which, if not controlled, will contradict the ALARA (As Low as Reasonably Achievable) radiation protection principle.

This principle emphasizes the importance of administering the smallest possible radiation dose to achieve diagnostic goals, without compromising image quality, and adjusting exposure based on clinical needs, patient conditions, and examination objectives.

A study by Seibert and Morin (2011) highlights the importance of using the Exposure Index (EI) as an indicator of the estimated radiation exposure received by the detector, rather than the patient directly. By applying a standardized Exposure Index (EI), technicians can consistently adjust exposure factors such as kVp, mAs, and exposure time, supporting the ALADAIP principle (As Low as Diagnostically Achievable being Indication-oriented and Patient-specific), which emphasizes dose adjustment based on clinical indications and individual patient characteristics. This approach is highly relevant for anatomy such as the sacrum, which is sensitive to exposure errors.

Manning-Stanley et al. (2012) demonstrated that the orientation settings of the object and the selection of the Automated Exposure Control (AEC) chamber significantly affect the dose magnitude and image quality. The Ca-AEC orientation results in a dose reduction of up to 36.8% compared to Cr-AEC, with minimal image quality degradation and remaining within acceptable diagnostic limits. This shows that exposure configurations should not be default but need to be actively adjusted based on the examined anatomical structure and clinical objectives, supporting the principle of radiation protection optimization.

A study by Eif Sparzinanda et al. (2016) reinforces the importance of exposure settings by showing that the use of low voltage (60 kV) and moderate current (20 mAs) provides the best contrast and image sharpness in a Computed Radiography (CR) system using mobile X-ray. On the other hand, the high exposure combination (80 kV/30 mAs) actually produces darker and less sharp images, and has the potential to cause overexposure. This indicates the need for a balance between image quality and radiation dose to avoid unnecessary dose increases.

Yufita et al. (2023) also found a direct correlation between the combination of exposure factors and optical density in radiographic film images. The optimal combination varies depending on the type of test material representing body tissue, emphasizing that each object requires a specific exposure and cannot be equated between patients or between examinations. This variation underscores the importance of individual and data-driven exposure parameter adjustments, rather than mere habits or fixed protocols.
Overall, from the entire analyzed literature, it can be concluded that optimal exposure settings highly depend on adaptation to patient characteristics, anatomical projections, and the imaging technology used.

Radiation protection principles such as ALARA, ALARP (As Low as Reasonably Practicable), and ALADAIP form the foundation in ensuring that each radiation exposure is kept at a minimal level while still producing images that are adequate for diagnosis. Additionally, the use of supporting technologies such as AEC, monitoring EI values, and analysis software like Image-J provides a more objective data-driven approach in exposure decision-making, rather than relying solely on the subjective experience of technicians. This way, the risk of "dose creep" that often occurs in digital radiography systems can be minimized as much as possible.

The implementation of this principle is crucial, especially in imaging sensitive areas such as the sacrum, to maintain diagnostic quality without compromising patient safety.

CONCLUSION

From the literature review undertaken, it is evident that exposure factors in digital radiography—including tube voltage (kV), tube current (mA), and exposure time (s/mAs)—are vital in influencing the quality of radiographic images of the sacrum and the radiation dose that the patient receives.

This analysis highlights the necessity of these factors in achieving optimal imaging results while reducing radiation exposure to patients. In conclusion, the review emphasizes the critical role of exposure parameters in both image quality and patient safety. Improper exposure settings can not only reduce image quality, such as decreased contrast and sharpness, but also increase the risk of excessive radiation exposure, especially in complex and sensitive areas like the sacrum.

Research indicates that combining low voltage with suitable current levels can yield optimal image quality while reducing radiation exposure. Furthermore, the use of a standardized Exposure Index (EI), the application of Automated Exposure Control (AEC), and the integration of software-driven analysis techniques such as Image-J have demonstrated significant improvements in exposure optimization. Exposure techniques should be customized for each patient, considering their unique characteristics, the goals of the examination, and the complexity of the anatomy being studied. Radiation protection principles such as ALARA, ALADAIP, and ALARP are fundamental in making exposure decisions to ensure patient safety without compromising diagnostic quality.

RECOMMENDATION

According to the findings of the study, it is advisable for radiographers to take a more proactive approach in assessing and modifying exposure parameters tailored to the individual patient's condition and the specific type of projection employed, especially in the case of sacrum imaging, which involves a range of tissue densities. The improvement of support technologies, such as AEC, must consider the orientation and selection of the appropriate camera to reduce the dose while preserving image quality.

Additionally, it is important to implement Exposure Index usage standards in clinical practice to accurately monitor potential overexposure and avoid "dose creep". Local standarization, continuous training, and increased awareness of radiation protection principles are absolutely necessary for all radiographers, including the importance of internal audits and regular calibration of radiographic equipment. These efforts aim to achieve diagnostic imaging that is also safe for patients in accordance with the concept of optimal radiation protection.

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