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# Radiation Doses in Different Digital Radiography Systems: A Comparison of CR and DR

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## Abstract

**Introduction:** This study evaluates radiation doses associated with computed radiography (CR) and digital radiography (DR) systems during radiographic examinations of the chest, shoulder, and pelvis with hips.

**Objective:** The aim of this study was to compare entrance surface doses (ESD) between CR and DR systems and to assess the potential of DR technology for radiation dose optimisation.

**Methods:** The study included 180 participants of both sexes and different ages. ESD was calculated based on data obtained during annual testing of the X-ray equipment performed in 2025. An independent-samples t-test was used to compare CR and DR systems, the Mann–Whitney U test was used to analyse differences between male and female participants, and linear regression analysis was used to assess the association between ESD values obtained with CR and DR systems. Statistical significance was set at $p < 0.05$.

**Results:** The DR system yielded lower mean ESD values in all analysed anatomical regions. Statistically significant differences were found for chest and shoulder examinations, whereas the difference for pelvic examinations was not statistically significant. Linear regression analysis showed no statistically significant linear association between ESD values obtained with CR and DR systems.

**Conclusion:** Under the conditions of this study, the DR system demonstrated lower ESD values than the CR system, particularly for chest and shoulder examinations. The results highlight the importance of proper use of the automatic exposure control (AEC) system and optimisation of exposure parameters to reduce patient exposure to ionising radiation.

**Keywords:** computed radiography, digital radiography, radiation dose, entrance surface dose (ESD), radiation protection

## Introduction

### Digital Radiography

Digital radiography is currently one of the fundamental imaging methods used in everyday radiological practice. The development of digital technologies has significantly changed the way radiographic images are acquired, processed, displayed, and stored, while also enabling their integration into modern information systems. The introduction of digital detectors has created new opportunities to optimise radiographic procedures, particularly regarding the relationship between image quality and patient exposure to ionising radiation (1,2).

Unlike conventional radiography, in which the image is formed using a film-screen system, digital radiographic systems enable electronic acquisition and computer-based processing of image data. Digital images can be processed, displayed, and stored without a physical medium. These capabilities increase the efficiency of the radiological workflow, but also require a systematic approach to controlling exposure parameters and protecting patients from unnecessary radiation exposure (1,2).

In contemporary digital radiography, two systems are commonly distinguished: computed radiography (CR) and digital radiography (DR). Although both systems ultimately produce a digital radiographic image, the mechanisms by which X-rays are converted into an image signal differ substantially. These differences are not only technological they may also affect acquisition efficiency, workflow, detector characteristics, and the relationship between required exposure and resulting image quality (3).

## Computed Radiography (CR)

Computed radiography was one of the first widely implemented digital radiography technologies. CR systems use a photostimulable phosphor plate (PSP) housed within a radiographic cassette. During exposure, X-rays pass through the patient and reach the phosphor plate, where a portion of the X-ray photon energy is stored within its structure. In this way, a latent radiographic image is formed (4,5).

Unlike DR systems, CR technology does not make the digital image immediately available after exposure. Following the examination, the cassette must be transferred to a CR reader, where the phosphor plate is scanned with a laser beam. The energy stored during exposure is released in the form of light, and the resulting signal is converted into an electrical signal, which is subsequently digitised and processed. After reading, the plate is erased and prepared for reuse (5).

This workflow represents an important difference compared with DR technology, as CR involves an additional step between exposure and digital image acquisition. An advantage of CR systems is that they can be implemented with existing radiographic equipment with relatively minor infrastructure modifications, facilitating the gradual transition from conventional film-screen radiography to digital technology. However, cassette handling and the need for image readout prolong the workflow compared with direct digital image acquisition (4,5).

From the perspective of dose optimisation, the characteristics of CR detectors play an important role. The amount of radiation required to obtain an adequate radiographic image depends on the sensitivity of the phosphor plate, exposure parameters, and the method of image signal processing. At the same time, the wide dynamic range of digital systems allows an acceptable image to be obtained over a relatively broad range of exposure levels. Therefore, image quality alone cannot be used to determine whether an optimal amount of radiation was applied during the examination (5).

## Digital Radiography (DR)

Digital radiography represents a technologically advanced approach to radiographic image acquisition. DR systems use flat-panel detectors that enable the near-immediate conversion of information obtained during X-ray exposure into a digital image. Unlike CR systems, there is no need to remove a cassette after exposure or to perform a separate phosphor plate readout procedure (6,7).

Flat-panel detectors can use different technologies for converting X-rays. In indirect conversion, a scintillator layer converts X-ray photons into light, after which photodiodes convert the light signal into an electrical signal. A thin-film transistor (TFT) array reads the electrical signal, then digitises and further processes it in a computer system. This enables rapid acquisition of the digital image and its near-immediate availability to the radiologic technologist and physician (7).

The immediate availability of images represents one of the major advantages of DR systems. It enables faster assessment of technical image quality, a more efficient workflow, and easier integration with digital systems for image storage and distribution. Digital image processing also allows adjustment of image display, including changes in contrast and visualisation of individual anatomical structures, without the need for repeated exposure (2,6).

However, the technological advantages of DR systems do not by themselves mean that every radiographic examination will be performed with a lower radiation dose. DR technology may provide a more favourable relationship between image quality and dose, but the actual dose also depends on the protocol, automatic exposure control, patient positioning, exposure parameters, and detector characteristics (6,7). Therefore, comparisons of CR and DR systems should be based on actual use conditions rather than solely on technological differences between detectors.

## Detective Quantum Efficiency and the Relationship Between Image Quality and Dose

One important parameter used to describe digital detector efficiency is detective quantum efficiency (DQE). DQE describes the ability of a detector to convert incident X-ray radiation into useful image information while minimising signal loss and noise. A higher DQE value generally indicates more efficient use of incident radiation to produce a diagnostically useful image (8).

DQE therefore represents an important technological factor when considering the relationship between image quality and dose. However, DQE does not independently determine the patient's overall radiation exposure. The actual amount of radiation is also influenced by X-ray beam energy, exposure parameters, detector design, image processing, automatic exposure control, imaging geometry, and the patient's anatomical characteristics (7,8).

Therefore, when comparing CR and DR technologies, it is necessary to distinguish the detector's potential efficiency from the patient's actual radiation exposure in clinical practice. This distinction is one reason quantitative dose assessment is important in evaluating digital radiographic systems (8).

## Optimisation of Radiographic Procedures and the *Dose Creep* Phenomenon

Patient protection from ionising radiation is based on the ALARA principle (As Low As Reasonably Achievable), according to which radiation exposure should be maintained at the lowest reasonably achievable level that allows a diagnostically acceptable image to be obtained. In radiography, the goal of optimisation is not simply to apply the lowest possible dose, but rather to achieve an appropriate balance between patient exposure and the image quality required for diagnosis (9).

Patient exposure is influenced by several interrelated factors. The most important include X-ray tube voltage (kV), tube current–time product (mAs), source-to-image distance (SID), filtration, collimation, detector characteristics, and the use of the automatic exposure control (AEC) system. Proper application of these factors enables standardisation of radiographic procedures and reduces unnecessary variations in patient exposure (4,9).

A particular challenge in digital radiography is the phenomenon known as *dose creep*. Digital detectors have a wide dynamic range, making it possible to obtain a diagnostically acceptable image at different exposure levels. Unlike

film-screen systems, in which excessive or insufficient exposure is relatively clearly manifested through changes in optical density, digital systems use image processing that can maintain an acceptable image appearance even when the amount of radiation applied increases (4,9).

*Dose creep* therefore refers to the gradual increase in exposure values over time, often intended to ensure sufficient image quality. Such increases may remain undetected if exposure is not systematically monitored. In the long term, this may lead to an unnecessary increase in patient dose without a corresponding diagnostic benefit (4,9).

Therefore, quality control of digital radiography systems should not focus exclusively on visual assessment of image quality. It is important to monitor exposure parameters and, whenever possible, use objective dosimetric indicators. Such an approach enables deviations from typical values to be identified and provides a basis for optimising radiographic protocols (4,9).

### Assessment of Patient Exposure: DAP and ESD

Quantitative assessment of patient exposure is an important component of optimisation programs in radiology. Various dosimetric indicators can be used for this purpose, depending on the type of radiological procedure and the technical capabilities of the radiographic equipment (10,11).

One important dosimetric indicator is DAP (Dose Area Product). DAP represents the product of radiation dose and the irradiated field area. In this way, it combines information on radiation dose and the size of the irradiated area. Therefore, DAP can be useful for monitoring patient exposure, comparing different radiographic procedures, and evaluating protocol optimisation (10,11). An important property of DAP is that it is independent of the distance between the radiation source and the patient.

DAP can be determined using a DAP meter integrated into the radiographic system, allowing the value to be obtained for an individual exposure. However, its use depends on the equipment's technical capabilities and the availability of an appropriate measuring system. When DAP measurement is not available, patient exposure can be estimated by calculating the entrance surface dose (ESD) based on the X-ray tube output and the actual exposure parameters (11,12).

ESD represents the estimated radiation dose at the entrance surface of the patient's body. Its determination may take into account the X-ray tube output, tube voltage, mAs value, the distance from the focal spot to the patient's surface, and the contribution of backscattered radiation. This assessment method is particularly useful in retrospective studies because it estimates exposure from already available data without additional patient exposure to ionising radiation (2,11).

In this study, ESD was selected as the primary dosimetric indicator for comparing the CR and DR systems. Its use enables the estimated dose to be related to the specific exposure parameters used during clinical radiographic examinations. This provides a quantitative basis for comparing the two technologies under actual working conditions (2,12).

It is important to emphasise that ESD is not determined solely by the type of detector. The resulting value reflects the interaction of several factors, including the characteristics of the CR and DR systems, the selected exposure parameters, AEC, imaging geometry, and individual patient characteristics (9,12). Therefore, any difference between the CR and DR systems should be interpreted as a difference under the conditions of their specific clinical application rather than as an isolated effect of the detector technology itself.

Comparison of ESD values between different digital systems can therefore provide valuable insight into the potential for optimisation of radiographic procedures. Such comparisons are particularly relevant when combined with an analysis of exposure parameters and system characteristics, as this enables identification of areas where protocols could be further optimised without compromising diagnostic image quality (9,12).

### Aim of the Study

The aim of this study was to compare entrance surface dose (ESD) values between CR and DR systems during standard radiographic examinations of the chest, shoulder, and pelvis with hips, and to determine whether statistically significant differences in ESD values exist between the two technologies. Additionally, differences in ESD values according to sex and the association between ESD values obtained with the CR and DR systems were analysed.

## Participants and Methods

### Participants

The study was a retrospective analysis of data collected at Health Centre Zagreb East. The study included data from patients who underwent standard radiographic examinations using CR and DR systems as part of routine clinical practice.

Three anatomical regions were analysed: the chest, shoulder, and pelvis with hip joints. For each anatomical region, 30 examinations using the CR system and 30 using the DR system were analysed, resulting in a total of 180 examinations. The CR group consisted of 90 participants, as did the DR group.

The distribution of participants according to sex was as follows: for chest examinations, the CR group included 16 male and 14 female subjects, while the DR group included 13 male and 17 female subjects. For shoulder examinations, both groups included 14 male and 16 female subjects. For pelvic examinations, the CR group included 13 male and 17 female subjects, while the DR group included 10 male and 20 female subjects (Table 1).

Table 1. Distribution of participants according to anatomical region, digital system, and sex

| Anatomical region | System | n | Male | Female |
|---|---|---|---|---|
| Chest | CR | 30 | 16 | 14 |
| Chest | DR | 30 | 13 | 17 |
| Shoulder | CR | 30 | 14 | 16 |
| Shoulder | DR | 30 | 14 | 16 |
| Pelvis | CR | 30 | 13 | 17 |
| Pelvis | DR | 30 | 10 | 20 |

The inclusion criterion was the availability of complete data required for analysis and ESD calculation. The analysis included data on X-ray tube voltage, mAs values, SID, anatomical region, and parameters required to determine the tube output.

The study was conducted as a retrospective analysis of existing data, without additional patient exposure to ionising radiation for research purposes. The data were processed while ensuring anonymity and confidentiality. The study was approved by the Ethics Committee of the Health Centre Zagreb East under reference number 01-1069-1/25.

## Data Collection and Processing

The data used in this study were collected from the PACS of the Health Centre Zagreb East and entered into structured Excel spreadsheets. For each examination included in the analysis, the X-ray tube voltage (kV), tube current–time product (mAs), SID, type of radiographic examination, and data required for the calculation of ESD were recorded.

Prior to statistical analysis, the data were reviewed and organised according to anatomical region and the radiographic system used. The CR and DR systems were compared under routine clinical conditions using the same radiographic equipment.

## X-ray Equipment and Digital Systems

Radiographic examinations were performed using a Siemens MULTIX Top radiographic system (Siemens Healthineers, Erlangen, Germany). The system was equipped with automatic exposure control (AEC).

For chest and pelvic examinations, the lateral AEC chambers were used, whereas the central AEC chamber was used for shoulder examinations. The AEC settings were 1 for CR chest examinations, 2.5 for CR shoulder and pelvic examinations, 0 for DR chest examinations, and 1 for DR shoulder and pelvic examinations.

For CR examinations, cassettes with photostimulable phosphor plates were used and read using the KODAK DirectView CR975 system. After exposure, the signal stored in the phosphor plate was read by laser stimulation, producing a signal that was converted into a digital record.

For DR examinations, an AGFA XD 17 flat-panel digital detector with the MUSICA image-processing system was used. The detector uses a scintillator layer to convert X-ray radiation into a light signal, photodiodes to convert light into an electrical signal, and a TFT array to read the signal. The resulting electrical signal is digitised and processed by the image-processing system.

## Technical Imaging Conditions

For chest examinations, an X-ray tube voltage of 125 kV and an SID of 180 cm were used. For shoulder examinations, a tube voltage of 66 kV and an SID of 100 cm were used, whereas pelvic examinations were performed at 77 kV and an SID of 115 cm.

The mAs value was determined automatically using AEC. Thus, the analysis included the actual exposure parameters used during the clinical examinations.

## Determination of Tube Output and Calculation of Entrance Surface Dose

Since the entire study is based on the assessment of entrance surface dose, the calculation procedure represents a central component of the methodology.

For the calculation of ESD, X-ray tube output data obtained during the routine annual testing of the equipment in 2025 were used. Measurements were performed at different X-ray tube voltage values in discrete increments of 10 kV. Tube output was measured at a tube loading of 20 mAs and a distance of 107 cm between the focal spot and the detector of the measuring device (13).

Since the tube voltage values used in the clinical examinations did not necessarily correspond to the directly measured values, interpolation was used for intermediate values. The relationship between tube output and X-ray tube voltage was described using a second-order polynomial:

where y represents air kerma expressed in mGy and x represents X-ray tube voltage expressed in kV.

$$y=0.0001x^2-0.0004x-0.1086$$

The following formula was used to calculate ESD (13):

$$ESD\ (\text{mGy}) = B \bullet (0{,}0001\text{KV}^2 - 0{,}0004\text{KV} - 0{,}1086) \bullet \left[\frac{107}{SID-30}\right]^2 \bullet \frac{\text{mAs}}{20}$$

In the formula, ESD represents the entrance surface dose expressed in mGy. B represents the backscatter factor for diagnostic X-ray beam qualities, and a value of B = 1.4 was used in this study. The backscatter factor (B) was set to 1.4 in accordance with the recommended values provided in the IAEA literature for diagnostic X-ray beams (2). The polynomial in parentheses represents the estimated tube output, i.e., air kerma, at the corresponding X-ray tube voltage. SID represents the distance from the X-ray tube focal spot to the detector, expressed in centimetres, while mAs represents the actual tube current–time product used during each examination.

The formula uses a reference distance of 107 cm, corresponding to the distance at which the tube output measurements were performed, and a reference tube loading of 20 mAs. The distance factor allows the tube output to be adjusted to the actual geometry of the clinical examination according to the inverse square law.

The term SID − 30 uses a value of 30 cm to represent the assumed average body thickness, which is subtracted from the SID to estimate the distance from the X-ray tube focal spot to the patient's surface. This way, the resulting value refers to the estimated dose at the patient's surface rather than the distance to the detector.

Multiplying the interpolated tube output by the backscatter factor provides an estimate of the dose at the patient's surface, including the contribution of backscattered radiation. Correcting for distance and the mAs value yields the final estimated ESD for each individual examination.

Application of the described formula enabled ESD to be calculated for each radiographic examination included in the analysis based on the actual exposure parameters. The obtained values represent estimates of ESD because a uniform approximation of body thickness of 30 cm was

used for all subjects, while tube output was determined based on previous measurements of the X-ray equipment.

### Statistical Analysis

Descriptive and inferential statistical methods were used for data analysis. An independent-samples t-test was used to compare ESD values between the CR and DR systems, while the homogeneity of variances was assessed using the F-test.

The Mann–Whitney U test was used to compare ESD values between male and female subjects. The association between ESD values obtained with the CR and DR systems was analysed using linear regression analysis.

Results were presented as the mean, standard deviation, and 95% confidence interval. The level of statistical significance was set at $p < 0.05$. Statistical analyses were performed using MedCalc.

## Results

A total of 180 radiographic examinations were analysed, with 30 examinations for each anatomical region performed using the CR system and 30 using the DR system. ESD values were analysed for chest, shoulder, and pelvic examinations. The technical imaging conditions were defined according to clinical protocols, with the mAs value automatically determined using AEC.

### Chest

The mean ESD was 0.1273 mGy for the CR system and 0.07851 mGy for the DR system. The difference between the mean values was 0.04884 mGy, with a lower mean ESD observed for the DR system (Figure 1).

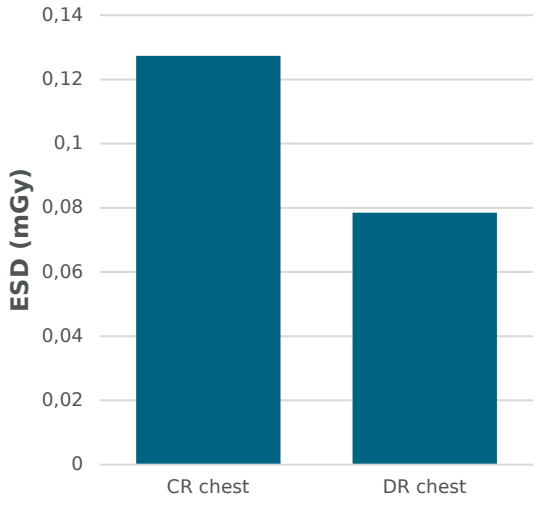



**Figure 1.** Graphical presentation of entrance surface dose (ESD, mGy) values for CR and DR chest radiography.

The **95% confidence interval** ranged from 0.1099 to 0.1448 mGy for CR and from 0.06801 to 0.08900 mGy for DR. The t-test showed a statistically significant difference ($t = 4.0908$; $df = 58$; $p < 0.0001$). The mean ESD value for the DR system was approximately **38.3% lower** than that for the CR system.

The F-test showed a statistically significant difference in variances between the groups ($p = 0.008$). Linear regression analysis showed a low association between ESD values ($R^2 = 0.06158$), and the regression model was not statistically significant ($p = 0.186$).

No statistically significant difference according to sex was found in the CR group. Among men ($n = 16$), the median ESD was 0.120 mGy, whereas among women ($n = 14$), it was 0.100 mGy ($U = 68.50$; $Z = 1.826$; $p = 0.0679$).

In the DR group, 13 men and 17 women were included in the analysis. The median ESD among men was 0.090 mGy, while among women it was 0.060 mGy. The Mann–Whitney U test showed a statistically significant difference ($U = 37.50$; $Z = 3.062$; $p = 0.0022$), with men having higher ESD values than women.

### Shoulder

For shoulder examinations, the mean ESD was 0.8776 mGy for the CR system and 0.6752 mGy for the DR system (Figure 2). The difference between the mean values was 0.2024 mGy.

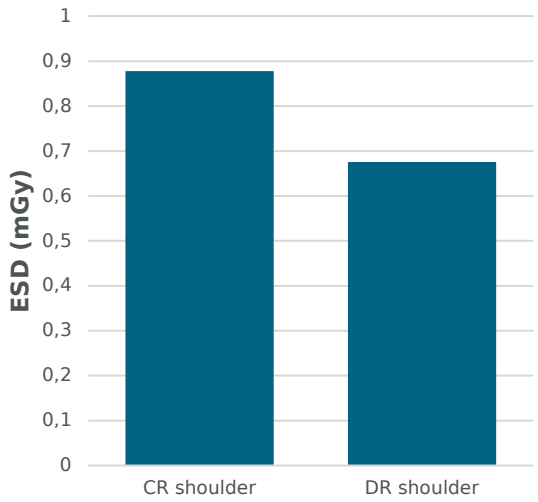



**Figure 2.** Graphical presentation of entrance surface dose (ESD, mGy) values for CR and DR shoulder radiography.

The **95% confidence interval** ranged from 0.7642 to 0.9910 mGy for CR and from 0.5550 to 0.7954 mGy for the DR system. The t-test showed a statistically significant difference ($t = -2.505$; $df = 58$; $p = 0.0151$).

The F-test showed no statistically significant difference in variances ($p = 0.753$). Linear regression analysis showed a very low association between ESD values ($R^2 = 0.01567$), and the regression model was not statistically significant ($p = 0.510$).

Analysis according to sex showed no statistically significant differences. In the CR group, the median ESD was 0.835 mGy in men and 0.774 mGy in women ($p = 0.5741$). In the DR group, the median ESD was 0.663 mGy in men and 0.516 mGy in women ($p = 0.2979$).

### Pelvis

For pelvic examinations, the mean ESD was 2.0021 mGy for the CR system and 1.5578 mGy for the DR system (Figure 3). The difference between the mean values was 0.4444 mGy.

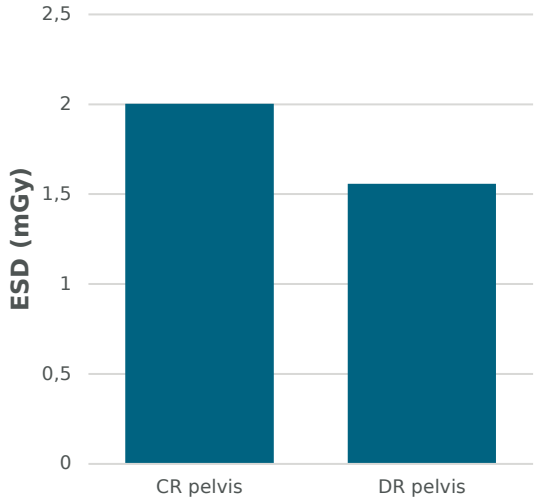



**Figure 3.** Graphical presentation of entrance surface dose (ESD, mGy) values for CR and DR pelvic radiography.

The 95% confidence interval ranged from 1.5871 to 2.4171 mGy for CR and from 1.3040 to 1.8115 mGy for DR. The difference was not statistically significant ($t = -1.868$; $df = 58$; $p = 0.0668$). The F-test showed a statistically significant difference in variances ($p = 0.010$).

Linear regression analysis showed a low association ($R^2 = 0.06053$), and the regression model was not statistically significant ($p = 0.190$).

In the CR group, no statistically significant difference by sex was found ($p = 0.3149$). The median ESD was 1.458 mGy in men and 1.911 mGy in women. In the DR group, a statistically significant difference was found ($U = 51.50$; $Z = 2.134$; $p = 0.0328$), with median ESD values of 1.710 mGy in men and 1.257 mGy in women.

### Summary of the results

Across all three analysed anatomical regions, the mean ESD was lower with the DR system, as shown in Table 2 and Figure 4.

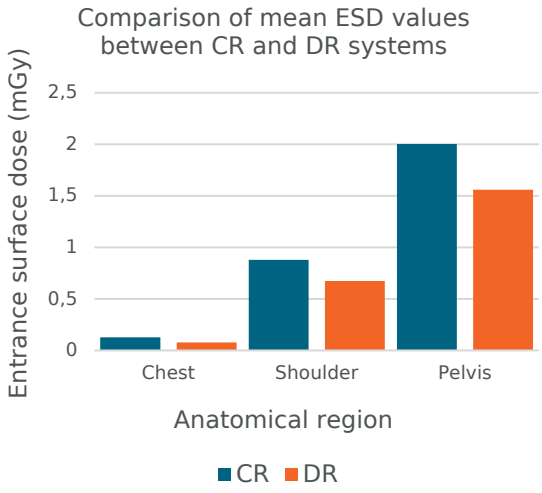



**Figure 4.** Comparison of mean entrance surface dose (ESD) values between CR and DR systems according to anatomical region.

Table 2. Comparison of mean ESD values between CR and DR systems

| Anatomical region | CR ESD (mGy) | DR ESD (mGy) | Difference (mGy) | p |
|---|---|---|---|---|
| Chest | 0.1273 | 0.07851 | 0.04884 | <0.001 |
| Shoulder | 0.8776 | 0.6752 | 0.2024 | 0.0151 |
| Pelvis | 2.0021 | 1.5578 | 0.4444 | 0.0668 |

Statistically significant differences between the CR and DR systems were observed for chest and shoulder examinations, whereas the difference for pelvic examinations was not statistically significant.

## Discussion

The results of this study showed that the DR system had lower mean ESD values than the CR system in all three analysed anatomical regions. Statistically significant differences were observed for chest and shoulder examinations, whereas the difference for pelvic examinations did not reach statistical significance. These findings indicate that, under the clinical conditions analysed, the DR system may be associated with a lower estimated entrance surface dose; however, the observed differences should be considered in the context of the radiographic procedure as a whole.

The largest relative difference was observed for chest examinations. The mean ESD was 0.1273 mGy for the CR system and 0.07851 mGy for the DR system, representing an approximately 38.3% lower value for the DR system. This difference was statistically significant. The examinations were performed at 125 kV and an SID of 180 cm, using the lateral AEC chambers.

The technological characteristics of DR detectors may contribute to more efficient utilisation of X-ray radiation for image formation. However, in this study, it was not possible to isolate the effect of detector technology from other factors. Particular attention should be given to the difference in AEC settings: for chest examinations, the CR system was used with setting 1, whereas the DR system was used with setting 0. Since mAs was determined by AEC, different settings may affect the amount of radiation required to terminate the exposure. Therefore, the observed difference reflects a combination of system characteristics and their specific clinical settings.

A statistically significant difference according to sex was also observed for chest examinations performed with the DR system. Men had a higher median ESD than women. This finding may be associated with differences in body characteristics; however, the exact cause cannot be determined from the retrospectively collected data.

For shoulder examinations, the mean ESD was also significantly lower with the DR system. The difference was 0.2024 mGy. Shoulder examinations were performed at 66 kV and an SID of 100 cm, using the central AEC chamber. The AEC setting was 2.5 for the CR system and 1 for the DR system.

Different AEC settings also represent an important factor in this context. Therefore, the lower ESD value observed with the DR system cannot be attributed solely to

detector type. The result reflects differences between the specific systems used in everyday clinical practice, including their technical and exposure settings.

No statistically significant differences according to sex were observed for shoulder examinations in either the CR or DR group. Although the median values differed, the observed differences were not statistically significant.

For pelvic examinations, the mean ESD was also lower with the DR system, but the difference was not statistically significant. The mean ESD was 2.0021 mGy for the CR system and 1.5578 mGy for the DR system. The p-value of 0.0668 was close to the significance threshold of 0.05; however, according to the predefined criterion, the result was not considered statistically significant.

In pelvic examinations, a statistically significant difference in variances was observed between the CR and DR groups. The greater variability may be associated with the anatomical characteristics of the region and differences between individual subjects. The pelvis is an anatomical region in which individual differences in body habitus and tissue thickness may have a substantial effect on the required exposure.

The AEC settings also differed between the systems for pelvic examinations. The CR system was used with setting 2.5, whereas the DR system was used with setting 1. Despite the lower mean ESD value observed with the DR system, the variability of the results prevented the difference from reaching statistical significance.

Sex-based analysis showed a statistically significant difference in the DR pelvic group, with men having a higher median ESD than women. No such difference was observed in the CR group. As with chest examinations, this finding may be associated with differences in body characteristics; however, based on the available data, it is not possible to determine their individual contribution.

Linear regression analysis did not show a statistically significant linear association between individual ESD values obtained with the CR and DR systems. The $R^2$ values were low for all three anatomical regions. This indicates that an individual ESD value obtained with one system cannot readily be used to predict the corresponding value obtained with the other system.

This relationship may be explained by the fact that CR and DR systems represent different image acquisition technologies, with different detector characteristics, signal processing methods, and exposure settings. In addition, differences in AEC settings affected the actual exposure conditions. Therefore, comparisons should focus on group-level measures and specific clinical protocols rather than on simple mathematical conversion of individual values.

A particularly important aspect of the study is the role of AEC. Since mAs was determined automatically, AEC settings were directly related to the amount of radiation delivered. Appropriate selection of the AEC chamber, patient positioning, and adequate collimation are therefore important elements of optimisation.

The results also show that DR technology alone does not automatically reduce dose in every clinical situation. If the DR system is improperly configured or unnecessarily high exposure settings are used, the potential advantages of the technology may be diminished. Conversely, a well-optimised CR system may achieve acceptable dose values while maintaining adequate image quality.

Due to the wide dynamic range of digital systems, diagnostically acceptable images can be obtained at different exposure levels. Therefore, an increase in dose is not always immediately apparent through deterioration in image quality. Continuous monitoring of exposure parameters and estimated ESD values may help identify unnecessarily high exposures.

In this study, ESD was calculated based on the X-ray tube output, mAs, and geometric conditions. The advantage of this approach is the possibility of retrospectively assessing radiation dose without additional exposure of patients. At the same time, the method has certain limitations. In particular, the use of an average body thickness of 30 cm should be emphasised, as this does not account for individual differences among patients.

Despite these limitations, the study enables comparison of ESD values under real-world clinical conditions. The results showed lower mean ESD values with the DR system in all analysed anatomical regions, with statistically significant differences observed for chest and shoulder examinations.

The practical significance of these findings lies in the need for continuous optimisation of radiographic protocols. Dose monitoring should be performed together with image quality assessment, as dose reduction itself should not be the goal if it results in a loss of diagnostic image quality. An optimal radiographic procedure requires a balance between the image quality required for diagnosis and the lowest reasonably achievable patient exposure.

## Conclusion

This study compared entrance surface dose values between CR and DR systems during standard radiographic examinations of the chest, shoulder, and pelvis with hips. In all analysed anatomical regions, the mean ESD was lower with the DR system.

The most pronounced difference was observed for chest examinations, where the mean ESD with the DR system was 38.3% lower than that with the CR system, and the difference was statistically significant. A statistically significant difference was also observed for shoulder examinations, whereas the difference for pelvic examinations did not reach statistical significance.

The results show that differences in ESD between CR and DR systems cannot be attributed solely to detector technology. Patient exposure is also influenced by exposure parameters and automatic exposure control settings. In this study, AEC settings differed between the systems; therefore, the results should be interpreted as the combined effect of the technology and the specific clinical protocols used.

Linear regression analysis did not show a statistically significant linear association between individual ESD values obtained with the CR and DR systems. Sex-based analysis showed statistically significant differences in the DR group for chest and pelvic examinations, whereas no statistically significant differences were observed for shoulder examinations.

Based on these results, the DR system achieved lower mean ESD values than the CR system under the conditions of this study, with statistically significant differences observed for chest and shoulder examinations. The results

emphasise the importance of appropriate AEC settings, standardisation of radiographic protocols, and continuous dose monitoring to optimise patient protection from ionising radiation while maintaining adequate diagnostic image quality.

All data presented in this paper are part of the results of the Master's thesis "Radiation doses on different digital systems in radiology" written at the Faculty of Health Sciences, University of Split (13).

## References


1. Bushberg JT, Seibert JA, Leidholdt EM Jr, Boone JM. *The Essential Physics of Medical Imaging*. 4th ed. Philadelphia: Wolters Kluwer; 2020.
2. International Atomic Energy Agency. *Dosimetry in Diagnostic Radiology: An International Code of Practice*. Technical Reports Series No. 457. Vienna: IAEA; 2007.
3. Carlton RR, Adler AM, Balac V. *Principles of Radiographic Imaging: An Art and A Science*. 6th ed. Boston: Cengage Learning; 2020.
4. 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):6658–6670. doi:10.1118/1.4932623.
5. Sonoda M, Takano M, Miyahara J, Kato H. Computed radiography utilizing scanning laser stimulated luminescence. *Radiology*. 1983;148(3):833-838.
6. Seeram E. *Digital Radiography: Physical Principles and Quality Control*. 2nd ed. Cham: Springer; 2019.
7. Seibert JA. Flat-panel detectors: how much better are they? *Pediatr Radiol*. 2006;36(Suppl 2):173-181.
8. International Electrotechnical Commission. IEC 62220-1-1: Medical electrical equipment – Characteristics of digital X-ray imaging devices – Determination of detective quantum efficiency. Geneva: IEC; 2015.
9. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann ICRP*. 2007;37(2-4):1-332.
10. Lin P-P, Schueler BA, Balter S, Strauss KJ, Wunderle KA, LaFrance MT, et al. Accuracy and calibration of integrated radiation output indicators in diagnostic radiology: a report of the AAPM Imaging Physics Committee Task Group 190. *Med Phys*. 2015;42(12):6815–6829. doi:10.1118/1.4934831.
11. International Atomic Energy Agency. *Diagnostic Radiology Physics: A Handbook for Teachers and Students*. Vienna: International Atomic Energy Agency; 2014.
12. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2020/2021 Report. Volume I*. New York: United Nations; 2022.
13. Bajs G. Doze zračenja na različitim digitalnim sustavima u radiologiji (Master's thesis). Split: University of Split, Faculty of Health Sciences; 2026. (accessed 1 September 2026). Available at: https://repo.ozs.unist.hr/object/ozs:2089/FILE0


# Doze zračenja na različitim digitalnim sustavima u radiologiji: usporedba CR-a i DR-a

## Sažetak


**Uvod:** Ovaj rad analizira doze zračenja na digitalnim radiografskim sustavima računalne radiografije (CR) i direktne digitalne radiografije (DR) pri snimanju pluća, ramena i zdjelice s kukovima.

**Cilj:** Cilj istraživanja bio je usporediti ulazne površinske doze zračenja (ESD) između CR i DR sustava te procijeniti mogućnosti DR tehnologije u optimizaciji doze zračenja.

**Metode:** Istraživanje je provedeno na 180 ispitanika različitog spola i životne dobi. ESD je izračunat na temelju podataka dobivenih godišnjim ispitivanjem rendgenskih uređaja iz 2025. godine. Za usporedbu CR i DR sustava primijenjen je t-test za nezavisne uzorke, za analizu razlika između muškaraca i žena Mann–Whitney U test, a linearna regresijska analiza korištena je za procjenu povezanosti vrijednosti dobivenih na CR i DR sustavima. Statistička značajnost postavljena je na $p < 0,05$.

**Rezultati:** DR sustav ostvario je niže srednje vrijednosti ESD-a u svim analiziranim anatomskim regijama. Statistički značajne razlike utvrđene su kod snimanja pluća i ramena, dok kod zdjelice razlika nije bila statistički značajna. Regresijska analiza nije pokazala značajnu linearnu povezanost između vrijednosti ESD-a dobivenih na CR i DR sustavima.

**Zaključak:** U uvjetima ovog istraživanja DR sustav pokazao je niže vrijednosti ESD-a u odnosu na CR sustav, osobito pri snimanju pluća i ramena. Dobiveni rezultati ističu važnost pravilne primjene AEC sustava i optimizacije ekspozicijskih parametara u cilju smanjenja izloženosti pacijenata ionizirajućem zračenju.



**Ključne riječi:** računalna radiografija, direktna digitalna radiografija, doza zračenja, ulazna površinska doza zračenja (ESD), radiološka zaštita