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IMAGE QUALITY EVALUATION AND PATIENT DOSE ASSESSMENT OF MEDICAL FLUOROSCOPIC X-RAY SYSTEMS: A NATIONAL STUDY

S. Economides, C. J. Hourdakis, N. Kalivas, M. Kalathaki, G. Simantirakis, P. Tritakis, G. Manousaridis, S. Vogiatzi, P. Kipouros, A. Boziari and V. Kamenopoulou
Greek Atomic Energy Commission, P.O. Box 60092, Ag. Paraskevi, 153 10, Greece

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This study presents the results from a survey conducted by the Greek Atomic Energy Commission (GAEC), during the period 1998–2003, in 530 public and private owned fluoroscopic X-ray systems in Greece. Certain operational parameters for conventional and remote control systems were assessed, according to a quality control protocol developed by GAEC on the basis of the current literature. Public (91.5%) and private (81.5%) owned fluoroscopic units exhibit high-contrast resolution values over 1 lp mm^{-1}. Moreover, 88.5 and 87.1% of the fluoroscopic units installed in the public and private sector, respectively, present Maximum Patient Entrance Kerma Rate values lower than 100 mGy min^{-1}. Additionally, 68.3% of the units assessed were found to perform within the acceptance limits. Finally, the third quartile of the Entrance Surface Dose Rate distribution was estimated according to the Dose Reference Level definition and found equal to 35 mGy min^{-1}.

INTRODUCTION

Fluoroscopic techniques are widely utilised in medical diagnosis when functional studies of the human anatomy are required such as those of the digestive tract. During a fluoroscopy examination, the patient is continuously exposed to radiation for screening times, sometimes exceeding 5 min. Additionally, in some cases, a number of radiographs may be required. Therefore, the optimum performance of the X-ray units must be ensured in order to the patient doses to be kept as low as reasonably applicable and practicable, while the best image quality is obtained. For this to be accomplished, well-established quality assurance programmes must be implemented in the procedures of the radiology departments, including quality control, servicing and maintenance of the equipment on a regular basis.

X-ray departments in Greece are subjected to a licensing procedure on a 5 y basis. Prerequisite for the license to be granted is the conformity with the requirements of the current legislation[1]. Therefore, Greek Atomic Energy Commission (GAEC) performs periodical on-site inspections of the radiology departments all over the country. The inspections comprise the assessment of the most important operational parameters of the radiology systems, affecting both the image quality and the doses to the patients as well as control of the main procedures followed during the medical applications[2,3–6]. Additionally, the frequency and the completeness of the periodical quality control tests performed by the Medical Physicists are followed up. The results of GAEC's inspections represent an important index of the X-ray systems performance and they contribute significantly to the optimisation of the radiation protection in the radiology departments.

Moreover, the Greek Radiation Protection Regulations[1] that implement the European Commission directives 96/29 and 97/43[7,8] in the national legislation impose the need for mandatory quality control of radiology systems both at the stage of acceptance of new equipment and on a regular basis. In this aspect and according to its statutory duties and the experience gained during the on-site inspections GAEC issued special protocols for quality control testing of medical radiological equipment[9]. These protocols define in detail all the operational parameters that have to be checked during regular quality control procedures, as well as the respective acceptance limit values. The frequency of the checks strongly depends on the type of the equipment and the operational parameter evaluated, as well as on the relative workload. These protocols are expected to contribute significantly in the homogenisation of the procedures followed by the medical physicists during quality control tests.

This paper presents the results of the analysis of high-contrast resolution and dosimetry measurements performed by GAEC to 530 fluoroscopic units during the period 1998–2003. The systems, either conventional (with the tube under the table) or remote control (with the tube over the table), were installed both in private and public institutions all over in Greece. C-arm type fluoroscopic systems often used in interventional procedures are not included in this survey. The results are compared to

those of a similar study performed by *Hourdakis et al.*[10] during the time period 1995–1997 and the derived conclusions are used as an index for the evaluation of the National Radiation Protection System. Moreover, the third quartile of the Entrance Surface Dose Rate (ESDR) distribution was estimated according to the Dose Reference Level (DRL) definition[11,12].

MATERIALS AND METHODS

GAECs Department of Licensing and Inspections performed performance evaluation tests in 530 conventional and remote control fluoroscopic systems during the time period 1998–2003. Majority of the assessed systems (435) were installed in the private sector, whereas the rest (95) were public owned. The quality control tests comprise measurements of specific operational parameters such as high-contrast spatial resolution, patient entrance surface air-kerma rate and tube filtration. Table 1 presents the assessed fluoroscopic parameters and summarises the main quality control test procedures followed. The type of the instrumentation used to conduct the required measurements is presented in Table 2.

The overall image quality is evaluated with a special homemade phantom (Figure 1). The phantom represents an average sized patient and consists of 45 mm of Al covered by 1.2 mm Cu sheets. It contains several holes of various diameters and regions of different Cu thicknesses from which the performance of fluoroscopic systems can be evaluated, regarding image uniformity, distortion and low-contrast detectability[10].

The value of the Standard Patient Entrance air-Kerma rate (SPEKeR) is used for the assessment of the dose rate at the entrance surface of an average sized patient[12–14]. Measurements of the SPEKeR were performed using the phantom of Figure 1. In each case, an optimal image quality of the phantom was obtained by manually selecting appropriate tube voltage and current values, or by utilising the Automatic Exposure Control (AEC) capability of the systems. The SPEKeR values were recorded by placing a detector of appropriate type (Table 2) either at the radiation entrance surface of the phantom (directional detectors) or at a distance of 5 cm from it (non-directional detectors). Moreover, Maximum Patient Entrance air-Kerma rate (MPEKeR) was measured by selecting the maximum clinical voltage and current values or by placing two additional Cu sheets on the phantom when AEC system was used. Finally, the ESDR values were estimated by multiplying the respective SPEKeR values by an appropriate Back Scatter Factor, taking into account the X-ray tube voltage and filtration[15,16].

The assessment of the high-contrast resolution was carried out either with a lead bar pattern consisting of several groups of line pairs of different spatial frequencies or with a lead wedged shape resolution pattern (Table 2). The selected test tool was attached to the image intensifier input surface and a fluoroscopic exposure was performed with the radiation field covering only the area of interest.

Table 1. A brief description of the test methods used in this survey for the fluoroscopic X-ray systems assessment.

Test	Test method	Acceptance limit
Automatic beam limitation	Simultaneously exposing, for comparison reasons, two loaded cassettes, one placed in the image receptor and a larger one at the table-top. The unexposed area of the first film is checked	1 cm perimetrically
Image uniformity and distortion	Assessing the image of the phantom described in Figure 1	—
Beam filtration	Measuring the aluminium half-value layer (HVL) at a 'true' tube voltage of 80 $\pm$ 2 kV_p, at 200 mA, 100 ms (20 mA s).	$\geq$2.5 mm Al
MPEKeR	Measuring the air kerma rate (mGy min^{-1})[a] at maximum tube voltage and fluoroscopic current.	$\leq$50 m Gy min^{-1} (manual) $\leq$100 mGy min^{-1} (AEC)
High contrast resolution	Measuring the line pairs per mm of the lead bar (or wedge) test pattern, attached to image intensifier face and observed under the conditions of high contrast and low noise	1.0 l p mm^{-1}
2% low contrast detectability	Measuring the diameter of the smallest observable hole of the 2% low contrast resolution aluminium phantom under optimum fluoroscopic conditions	3.0 mm

[a]On the table top, beneath the phantom, 45 cm from the focal spot for classic systems and at 30 cm above table-top, over the phantom, 75 cm from focal spot for telecommander systems.

Table 2. Type and model of the instrumentation used for the assessment of fluoroscopic X-ray systems performance.

Test equipment	Type/model
Electrometer	1. Radcal 2025 Radiation Monitor 2. Dosimeter Corp. America 1015 X-ray Monitor
Ionisation chamber	Radcal 20 × 5–3, 10 × 5–6
High-voltage, loading time, air-kerma measuring instrument	1. Victoreen 4000 X-ray test device 2. RTI Electronics AB PMX-III R/CT
Aluminium filters	RMI Model 115A & 116
Lead high contrast test pattern	1. PTW Type 1-83, 23 2. RMI mesh test tool
2% low contrast detectability aluminium test tool	RMI
Copper sheets	Thickness of 0.5, 1.0 mm
Phantom of Figure 1	Details presented in the legend of Figure 1

The image produced was observed on an appropriate monitor under high-contrast, low-noise conditions. The tube voltage and current values were adjusted either automatically or manually at 50 kVp and 0.5 mA, respectively.

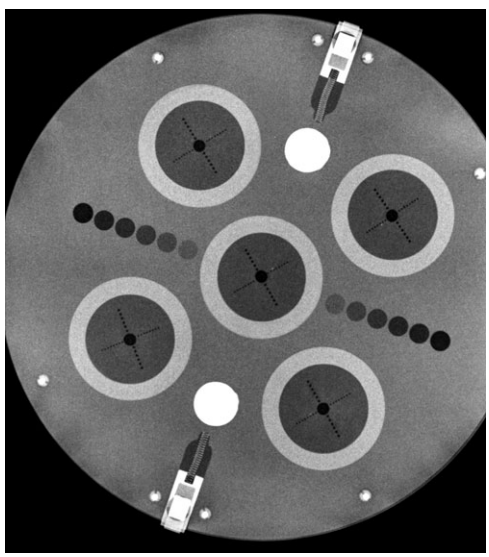

Figure 1. An image of the phantom used for the assessment of the image quality as well as of the standard fluoroscopic air-kerma rate. The phantom corresponds to an average sized patient and consists of 45 mm of Al covered by 1.2 mm Cu sheets.

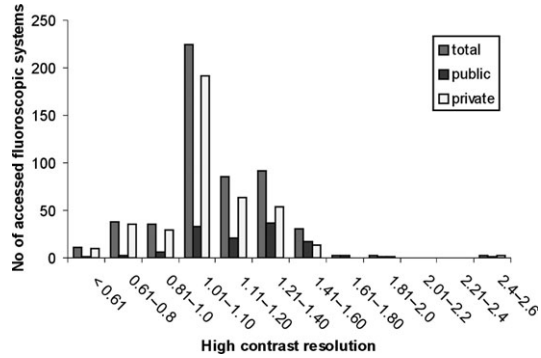

Figure 2. Distribution of image intensifier systems with respect to high-contrast resolution, expressed in line pairs per millimter.

Low-contrast spatial resolution was evaluated under 'standard' fluoroscopic conditions, by using the test tool reported in Table 2. The phantom consists of an aluminium sheet having holes with diameters of 7, 5, 3 and 1.5 mm placed between two aluminium plates, 2 cm thickness each. Room lights were kept dimmed while monitor brightness and contrast were adjusted in order an optimal image to be obtained. Finally image uniformity and distortion were qualitatively evaluated by using the phantom shown in Figure 1.

RESULTS AND DISCUSSION

The results of the collected data analysis are shown graphically in Figures 2–8. The survey showed discrepancies in the performance of fluoroscopic X-ray systems, mainly due to different operational

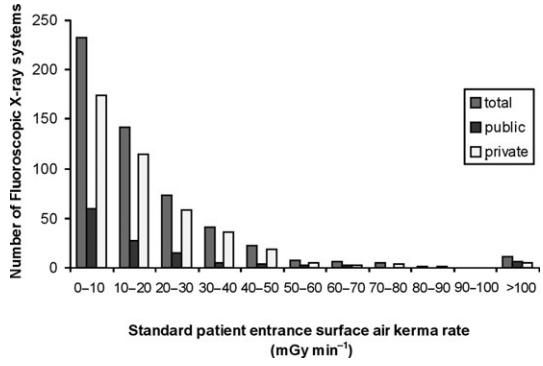

Figure 3. Distribution of the assessed fluoroscopic X-ray systems, with respect to the SPEKeR values, measured using the phantom of Figure 1.

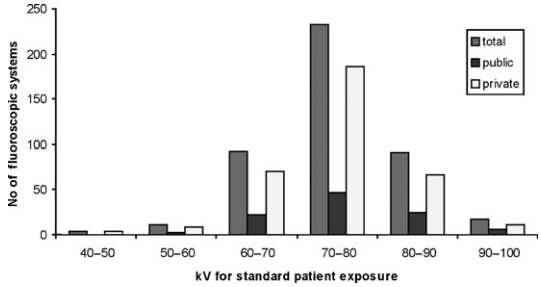

Figure 4. Distribution of the assessed fluoroscopic X-ray systems, with respect to the kilovolt applied during standard fluoroscopic air-kerma rate measurements using the phantom of Figure 1.

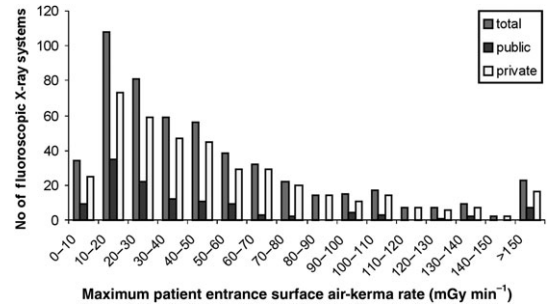

Figure 6. Distribution of the assessed fluoroscopic X-ray systems, with respect to the MPEKeR values, measured using the phantom of Figure 1.

characteristics or different AEC system adjustments among them. Furthermore, some of the discrepancies observed were due to the fluoroscopic systems' malfunction.

Performance characteristics of fluoroscopic systems

Image quality

In Figure 2, the distribution of the measured high-contrast resolution values is shown. Majority of the assessed fluoroscopic systems exhibit high-contrast resolution values above 1.0 l p mm^{-1}, with most frequently observed value that of 1.1 lp mm^{-1}. Moreover, the distribution of high-contrast resolution values for systems installed both in the public and the private sectors is demonstrated. The percentage of the public owned fluoroscopic systems with high-resolution values above the acceptance limit is 91.9%, whereas for the private sector is 81.5%.

As far as 2% low-contrast detectability values are concerned, in the vast majority of the fluoroscopic systems examined the 3 mm diameter hole of the test tool was clearly visible. No differences between public and private owned fluoroscopic systems were found.

The totality of fluoroscopic systems inspected can be considered acceptable regarding image uniformity and distortion, since no gross non-uniformities and artefacts were observed. However, some units

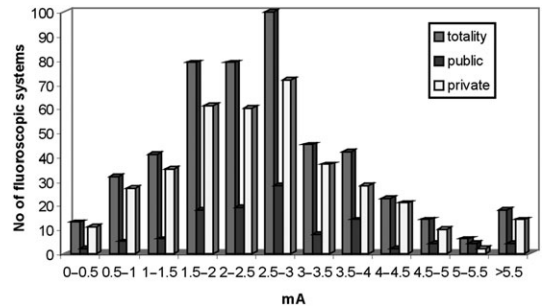

Figure 7. Distribution of the assessed fluoroscopic X-ray systems, with respect to the mA values applied during SPEKeR measurements using the phantom of Figure 1.

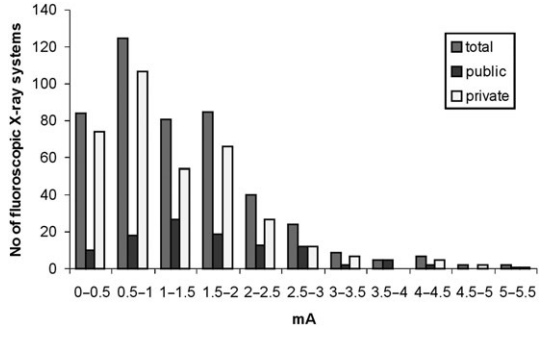

Figure 5. Distribution of the assessed fluoroscopic X-ray systems, with respect to the milliampere applied during standard fluoroscopic air-kerma rate measurements using the phantom of Figure 1.

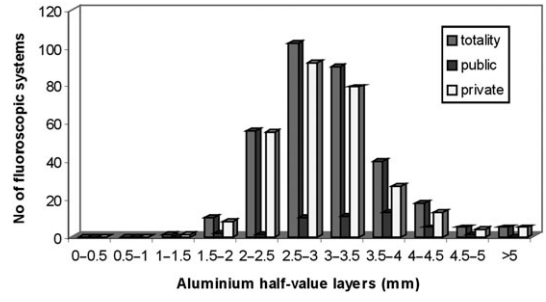

Figure 8. Distribution of the assessed fluoroscopic systems, with respect to the HVL values of the X-ray tubes measured at 80 kVp.

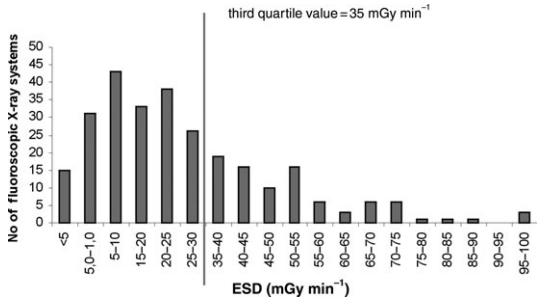

Figure 9. Distribution of the ESD rate values for the assessed fluoroscopic X-ray systems.

showed a small distortion in the periphery of the field of view. For the vast majority of the systems checked, all the internal structures of the phantom imaged were visible. Image quality for larger patient examinations was usually poorer, since the exposure parameters utilised, yielded more noisy images. In the case of manual exposures, the operational, 'standard' parameters (kVp, mA) were selected so that the structures of the phantom could be clearly distinguished at the monitor.

Patient dose assessment

Figure 3 show the distribution of SPEKeR values for systems installed both in the public and the private sectors. Although, there are discrepancies in the distribution of these values, however, the majority of them lie below 40 mGy min^{-1}. The higher values can be attributed to a drift of the image intensifier performance due to aging. Additionally, Figures 4 and 5 show the distribution of tube high voltage (kV) and current (mA) values recorded during standard patient examinations. The majority of tube current values range from 0.5 to 2.0 mA, whereas the tube high voltage range from 70 to 80 kVp. MPEKeR values for fluoroscopic systems are shown in Figure 6. Public (11.5%) and private (12.9%) owned units, respectively, present MPEKeR values higher than 100 mGy min^{-1}. The distributions of the respective mA values are demonstrated in Figure 7.

In order to calculate the ESDR, the Half Value Layer (HVL) values of the fluoroscopic X-ray tubes were measured at 80 kVp (Figure 8). Moreover, the HVL values were related to the corresponding X-ray tube total filtration values with the use of appropriate tables[16]. A backscatter factor (BSF) was calculated for each kilovolt and total filtration combination[15]. The ESDR values for each examination derived from the corresponding SPEKeR value by multiplying it with the respective BSF value were in the range 0.15–272.0 mGy min^{-1}. The distribution of the ESDR values lying below 100 mGy min^{-1} is demonstrated in Figure 9. The third quartile of the relative distribution was estimated according to the DRL definition[11] and found equal to 35 mGy min^{-1}. This value is higher than DRL values recommended by the International Atomic Energy Agency (IAEA), but lower than those recommended by the Foods and Drugs Administration (FDA), the American Association of Physics and Medicine (AAPM) and UK[12] (Table 3). Moreover, it can be utilised as a performance indicator for the appropriate calibration and adjustment of fluoroscopic systems, thus leading to a further reduction of patient doses. However, for the establishment of a national DRL for each fluoroscopic examination type, both reference values of Dose Air Product (DAP) and exposure time are required[12–14]. This procedure is in progress and the relative DRL values are expected to be established in the near future.

Table 3. Comparison of the DRL values proposed by this study to those recommended by other countries and organisations for standard fluoroscopic procedures[10].

	DRL (mGy min^{-1})
This study	35
UK	50
IAEA	25
FDA	50
AAPM	65

Table 4. Private owned X-ray fluoroscopic systems operating within the relevant acceptance limits.

	No of systems assessed		No of systems in full compliance		% in full compliance	
	This study	Hourdakis *et al.*	This study	Hourdakis *et al.*	This study	Hourdakis *et al.*
Classic	285	221	169	100	59.3	45.2
Telecommander	150	76	117	65	78.0	85.5
Sum	435	297	286	165	65.7	55.5

Table 5. Percentage of acceptable conventional and remote control fluoroscopic systems in terms of high contrast resolution and MPEKeR values.

	Conventional systems (%)	Remote control systems (%)
High contrast resolution	80.0	87.5
MPEKeR	85.8	90.6

Overall performance of fluoroscopic systems

The fluoroscopic units [68.3% (362 out of 530)] assessed were found to be in full compliance with Radiation Protection Regulations. Moreover, the percentages of fluoroscopic units with acceptable performance were 65.7% and 80.0% for the private and public sectors, respectively.

In Table 4, the results concerning private owned fluoroscopic systems are compared to those of a similar study[10] in the performance of fluoroscopic systems in Greece for the period 1995–1997. It is easily deduced that the percentage of systems that are in full compliance with the Radiation Protection Regulations increased from 45.2 to 59.3%. This increase can be attributed to the higher involvement of medical physicists in the quality control of the fluoroscopic systems and the implementation of appropriate quality assurance programmes in public X-ray departments. Moreover, the percentage of the public owned fluoroscopic systems with acceptable performance is 80% (76 out of the 95 systems inspected). This is mainly due to the more frequent quality control tests performed to these systems since in large public hospitals medical physicists are employed on a full time basis.

Finally, a comparison between conventional and remote control fluoroscopic systems was attempted (Table 5). Higher percentage of remote control systems are characterised by an acceptable high contrast resolution and MPEKeR values compared to the conventional ones. This observation is directly related to the age of the fluoroscopic equipment. Conventional systems are in general older installations with second hand image intensifiers and poorer imaging performance.

CONCLUSIONS

From the above analysis, it is deduced that an improvement in the overall performance of fluoroscopic systems in Greece has been achieved. In the private sector, there was a 14.1% increase in the number of systems which are in full compliance with the Radiation Protection Regulations compared to the results of a similar study performed by Hourdakis *et al.*[10]. Fluoroscopic equipment installed in the public sector shows better performance characteristics as a result of the frequent quality control checks performed by the medical physicists employed on a full time basis. However, the situation can be further optimised. For radiology departments, where systems exhibit operational parameter values out of the respective acceptance limits, GAEC proposes certain corrective actions to be taken. After the implementation of the required measures GAEC proceeds in a re-inspection in order to assure the conformance and issue a certificate of compliance. Moreover, quality assurance programmes, routine servicing and maintenance on a regular basis can lead to better fluoroscopic images with reduced patient doses. The establishment of relative DRL values will be essential in the evaluation and the standard fluoroscopic procedures. GAEC has already started the procedure of collecting the required data from medical radiology departments all over the country and the DRL values for each fluoroscopic examination type are expected in the near future. The role of medical physicists with appropriate experience, knowledge and qualifications is also important. Their employment in radiology departments is considered necessary in order to accomplish improved image quality with reduced doses to patients, staff and public. Finally, GAEC has developed new quality control protocols for radiology systems. The implementation of these protocols in the quality assurance programmes of the radiology departments has just started and is expected to contribute to the further optimisation of X-ray system performance and the limitation of patient doses.

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