PATIENT DOSES AND IMAGE QUALITY IN CHEST RADIOGRAPHY: THE INFLUENCE OF DIFFERENT BEAM QUALITIES

by

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A simple method of assessing optimal X-ray beam quality in respect to patient exposure and image quality in chest screen-film radiography is presented here. Different beam qualities were generated by the use of various combinations of tube voltages (70 kV to 110 kV) and Al and Cu filter thicknesses. Patient doses were assessed by kerma-area product measurements. Simultaneously, image quality was evaluated by a twofold method: a clinical study applying European quality criteria for the radiographic technique of image on image of 126 patients and a multifunctional home-made dosimetric phantom with embedded test objects. The quantification of image quality criteria yields a simpler method of optimizing image quality and patient dose relationships. Modifications of radiographic practice, based on image quality assessment and dose measurements, resulted in significant dose reductions and preservation of image quality. Through the use of harder beam quality, dose reduction of up to a value of factor 3 were observed, compared to the doses from previously used radiographic techniques, implying that sufficient image quality does not necessarily imply higher doses. As a result of the optimization process, an optimal radiographic technique was suggested.

Key words: chest radiography, optimization, dose, image quality

INTRODUCTION

The optimization of image quality *vs*. patient dose is an important task in medical imaging. The effective use of ionising radiation in diagnostic radiology involves the interplay of three factors: image quality, radiographic technique, and patient dose. The maximal validity of optimization has to be based on clinical images.

Based on the data of the frequency of radiological examinations worldwide, chest radiography is one of the most frequent examination techniques, with an overall contribution of above 30%. It is also demanding (both in the physical and technical sense) because of significant variations in tissue densities and thicknesses falling in the X-ray beam. Typically, chest radiography is performed in a posterior-anterior (PA) projection, using the chest wall stand [1].

Previous results have pointed out significant variations in patient doses during chest radiography as a consequence of differences in examination techniques and radiological practice [2, 3]. In Serbia, patient dose variation up to a factor of 8 has been reported, while preliminary diagnostic reference level (*DRL*) has been set to 0.8 mGy [1, 2]. The *DRL* has been selected as a third quartile of the dose distribution from seven randomly selected general hospitals. This value is significantly higher then the European *DRL*, which is 0.3 mGy, highlighting the need for the optimisation of practice [4].

A range of techniques has been developed in screen-film chest radiography because of the technical difficulties in imaging and wide variation of tissue densities. These techniques can differ in tube potential selection, method of scatter reduction and exposure settings. The application level of available methods

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for balancing dose and image quality varies significantly among hospitals worldwide.

The enhancement of beam filtration is a well established method of dose reduction in diagnostic radiology [5]. The "hard-beam" technique is also recommended in European Guidelines on Quality Criteria for Diagnostic Radiographic Images [6]. Contrary to this, radiographic practice in Serbia is mostly based on the application on the "soft-beam" technique. This is partially related to limited technical capabilities of imaging equipment and image receptors [2, 7].

MATERIALS AND METHODS

Simultaneous measurement of patient dose levels and image quality assessment is used for investigating the possibilities of dose reduction and maintainance of image quality.

A simple method for assessing the optimal X-ray beam quality in respect to patient exposure and image quality in chest screen-film radiography is presented here. The beam qualities were generated by the use of various combinations of tube voltages (70 kV to 110 kV) and Al and Cu filter thicknesses. The patient dose was assessed by kerma-area product (*KAP*) measurement. Simultaneously, image quality was evaluated by a twofold method: a clinical study applying the European quality criteria for the radiographic technique of image on image of 126 patients and by use of a multifunctional home-made dosimetric phantom with embedded test objects.

The survey was conducted in a local hospital realizing more than 60 000 images annually and representing a typical Serbian practice. A total of 126 patients of average body mass 72 ± 11 kg were divided into six groups. At least 10 adult patients were followed for each beam quality.

A conventional X-ray unit, TOP-X-HF (Innomed, Budapest, Hungary), with a high-frequency generator, 150 kV X-ray tube with two focal spots (1.2/0.6 mm) and an anti-scattering grid (grid ratio 7:1) was used for the study. As an image receptor, a film-screen combination of the speed class 400 was used. The unit was not equipped with an Automatic Exposure Control setting. Quality control tests were performed on the unit prior to the study. A standard protocol was used [8]. The unit met the stated criteria, with the exception of low beam filtration.

KAP was measured using the transmission ionising chamber KERMAX-Plus (Wellhofer, Scanditronix, Sweden). Prior to these measurements, the calibration of the *KAP* meter was performed by a solid-state dosimeter, the Barracuda R-100 (RTI Electronic AB, Göteborg, Sweden) and screenless film. For organ and effective dose assessment, a NRPB-SR 262 set of conversion coefficients from *KAP* to the organ dose was used [9].

Preliminary, image quality was assessed by two experienced radiologists using "European Guidelines on Quality Criteria for Diagnostic Radiographic Images" [5]. For chest PA radiography, six image quality criteria related to the positioning and visualisation of anatomical details were evaluated. The criteria being:

- symmetrical reproduction of the thorax, as shown by the central position of the spinous process between the medial ends of the clavicles,
- medial border of the scapulae outside the lung fields,
- visually sharp reproduction of the vascular pattern of the whole lung, particularly the peripheral vessels,
- visualisation of the spine through the heart shadow,
- visually sharp reproduction of the borders of the heart and aorta, and
- visually sharp reproduction of the diaphragm and lateral costo-phrenic angles.

The image criteria score (*ICS*) for each image was calculated by using the following expression [10]:

$$ICS \quad \frac{S_{o,i,c}}{N_o N_i N_c} \qquad (1)$$

where the summation was performed according to the number of observers (*o*), images (*i*), and criteria (*c*) used; N_o being the number of observers, N_i the number of images, and N_c the number of criteria applied. Each of the criteria for a particular image, as given in European guidelines, was assessed as 0, 1, or 2, *i. e.*, not fulfilled, partially fulfilled, or fulfilled.

The optical density (*OD*) of the reference points of the image was measured by means of a transmission densitometer, Lullus 1.21, (Wellhofer, Scanditronix, Schwarzenbruck, Germany). The contrast was calculated as a difference in *OD* of representative points of the image [10].

RESULTS AND DISCUSSION

The characteristics of X-ray beams used for chest PA radiography are given in tab. 1.

Individual characteristics of patients, number of images per group and basic exposure parameters are given in tab. 2. The correlation of the contrast regarding the OD of images in the lung region are given in fig. 1. The results of patient dose assessment in terms of the kerma-area product and effective dose assessment are presented in tab. 3.

Calculation results pertaining to the criteria score and measured values of the OD of the images in the regions of the lungs, heart and ribs, are given in tab. 4. It should also be noted that the assessments of both radiologists on image quality and film acceptability were found to be similar.

Table 1. Characteristics of X-ray beams for various thicknesses and types of filters: total filtration, half-value layer (*HVL*), effective energy (ε_{eff}), and radiation output

Spectrum	Total filtration	*HVL* [mm Al]	ε_{eff} [keV]	Radiation output at 80 kV [Gy/mAs]
A0	2.5 mm Al	2.7	42.5	65.2
A1	3.2 mm Al	3.1	43.8	51.1
A2	3.5 mm Al	3.1	44.3	47.6
A3	3.9 mm Al	3.5	44.9	48.6
A4	3.5 mm Al + 0.1 mm Cu	4.7	48.4	30.4
A5	2.5 mm Al + 0.2 mm Cu	5.3	50.4	19.42

Table 2. Individual characteristics of patients, body mass indexes (*BMI*) and basic exposure parameters for chest PA radiography for various beam qualities

Spectrum	*N*	*m* [kg]	*BMI*	*U* [kV]	*Q* [mAs]
A0	20	76 14	25 4	48 4	46 5
A1	21	70 ± 12	25 4	69 5	5 1
A2	31	72 ± 13	24 3	67 4	5 1
A3	18	70 8	24 4	68 4	5 1
A4	18	72 7	26 3	69 3	5 1
A5	18	71 8	24 3	71 4	5 1

Figure 1 contains the comparison between *OD* in the lung region, *ICS*, and patient doses for different beam qualities. The interdependence of presented parameters has demonstrated a significant potential for dose reduction by use of harder beam qualities in chest PA radiography. In parallel, sufficient image quality is maintained. In spite of the decrease in OD in the lung region for a heavy filtered beam (0.2 mm Cu), the *ICS* value, which is a consequence of the observer's individual preferences, remains constant.

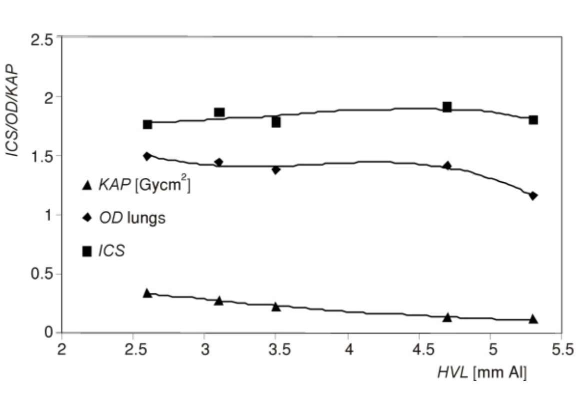

Figure 1. Comparison between OD in the lung region, *ICS*, and patient doses for different beam qualities

Table 3. Mean values, standard deviation, minimum and maximum of *KAP* for different beam qualities, followed by the effective dose (*E*) estimates

	KAP [Gycm^2]			
Spectrum	Mean	Min	Max	*E* [Sv]
A0	1.45 0.59	0.69	2.71	100 48
A1	0.34 0.14	0.19	0.75	35 16
A2	0.28 0.09	0.14	0.51	32 12
A3	0.23 0.07	0.12	0.37	29 11
A4	0.14 0.04	0.06	0.23	20 7
A5	0.11 0.05	0.06	0.24	20 15

Table 4. *ICS* and OD in different regions of the chest for different beam qualities

Spectrum	*ICS*	OD_{lung}	OD_{ribs}	OD_{heart}
A0	1.72	1.73 0.35	0.79 0.21	0.23 0.05
A1	1.77	1.50 0.24	0.65 0.15	0.26 0.05
A2	1.87	1.45 0.35	0.69 0.20	0.28 0.07
A3	1.78	1.38 0.31	0.68 0.08	0.31 0.23
A4	1.91	1.47	0.78 0.19	0.32 0.10
A5	1.81	1.16 0.39	0.65 0.21	0.27 0.06

This fact highlights the significance of parallel control of both subjective and objective image quality parameters. While the *ICS* can be related to the subjective assessment of an observer, optimal density shall be 1.2 ± 0.8 [10].

With the results of numerous studies which have pointed out the non-existence of a correlation between physical parameters such as tube voltage, speed class of screen-film combination and methods for the prevention of scattered radiation and patient dose and image quality in mind, *ICS* and OD were assessed in this work. By comparing the values of the kerma-area product, OD and the *ICS* for different beam qualities, it has been concluded that, in this particular case, a total filtration of 3.5 mm Al and 0.1 mm Cu is optimal for chest PA radiography.

From the results presented in the tab. 3, it is apparent that an effective dose does not have the same trend as a kerma-area product. Also, solely by a modification of exposure parameters in group A_0, a dose reduction of a factor 4 value has been achieved. Additionally, with the increase of beam filtration, the dose has been decreased by a factor of 3. Finally, the sample of 126 patients failed to demonstrate a significant correlation among image quality and patient doses. This is in accordance with the findings of other authors [10–12].

The soft beam technique is predominant in chest radiography in Serbian practice. Preference for softer images was used to justify the application of low kV values. Often, operators are not even aware that it is possible to use a hard-beam technique. There was also a degree of non-compliance with a few specific criteria. An outstanding example of this, when chest PA radiography is concerned, are the criteria on the "visualisation of the spine through the heart shadow". By using high kV values, this particular criteria were not fulfilled. However, it appears that this is not critical for overall image quality assessment. It should also be noted that the equipment for the quality control of viewing boxes was not available during the survey.

CONCLUSION

The quantification of image quality criteria yields a simpler method of optimizing image quality and patient dose relationships. Modifications in radiographic practic, based on image quality assessment and dose measurements resulted in a significant reduction of the patient dose while maintaining image quality at the same time. By using harder beam qualities, a patient dose reduction of up to factor 3 was observed, in comparison to the doses from previously used radiographic techniques, implying that sufficient image quality does not always imply higher patient doses. As a result of the optimization process, an optimal radiographic technique can be suggested.

Significant dose savings that did not compromise the diagnostic information were found for some examination types, proving that this simple method is a very efficient dose reduction tool in conventional diagnostic radiology. The usefulness of European quality criteria, too, was demonstrated. Also, the need for staff training is of utmost importance when Serbia is concerned.

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ПАЦИЈЕНТНЕ ДОЗЕ И КВАЛИТЕТ СЛИКЕ У РАДИОГРАФИЈИ ПЛУЋА: УТИЦАЈ КВАЛИТЕТА СНОПА ЗРАЧЕЊА

У раду је приказан једноставан метод за одређивање оптималног квалитета снопа у погледу односа пацијентна доза – квалитет слике у радиографији плућа. Снопови различитог квалитета генерисани су комбинацијама напона рендгенске цеви у опсегу од 70 kV до 110 kV и алуминијумских и бакарних филтара различитих дебљина. Пацијентне дозе одређене су мерењем производа керме и површине. Истовремено, квалитет слике оцењен је на два начина: клиничким испитивањем 126 снимака одраслих пацијената користећи Европске критеријуме за оцену квалитета радиографских слика и применом мултифункционалног дозиметријског фантома са уграђеним алатима за оцену квалитета слике. Квантификација квалитета клиничких слика помоћу дефинисаних критеријума представља једноставнији и ефикаснији начин за оптимизацију односа пацијентних доза и квалитета слике. Модификацијом праксе, користећи резултате оцене квалитета слике и мерења дозе постигнуто је значајно смањење пацијентих доза уз очување квалитета дијагностичке информације. Применом интензивније филтрираних снопова могуће је постићи смањење пацијентих доза до фактора 3, што указује да квалитетна дијагностичка информација не подразумева и повећање пацијентних доза. Као резултат процеса оптимизације предложена је оптимална радиографска техника.

Кључне речи: радиографија плућа, оптимизација, доза, квалитет слике