*Proc. 2nd Saudi Sci. Conf., Fac. Sci., KAU, 15-17 March 2004, **Part II,*** pp. 113-121 (2005 A.D /1425 A.H.)

Quality Control Procedures for Improving Diagnostic Imaging and Reducing Radiation Exposure to Patients

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ABSTRACT. The main role of the medical physicist in diagnostic imaging is to implement a quality control program that will insure accurate diagnosis of disease and low radiation exposure to the patients and to hospital staff. In many Saudi hospitals little or no quality control is implemented. Simple procedures can be used to reduce the exposure to the patient. Using a patient equivalent phantom and an ionization chamber we can measure the entrance skin exposures for the x-ray settings for the different radiography exams. The measured entrance skin exposures should be compared to the maximum recommended values. The imaging system contrast sensitivity and resolution can also be measured by means of a Contrast-Detail phantom. A Contrast-Detail analysis shows the ability of the imaging system to detect low contrast tumors and small bone fissures. Such quality control procedures will improve the accuracy, the sensitivity and the specificity of diagnostic imaging. This is particularly necessary for early detection of breast cancer which is the highest type of cancer among Saudi women.

Introduction

Reducing patient dose and maintaining the best image quality are the primary objectives of a medical physicist working in the diagnostic Imaging. These objectives are necessary to protect both the patient and technician from excessive dose of ionizing radiation and for increasing the chance of correct diagnosis of disease. Most Saudi hospitals do not have a medical physicist working to achieve these primary objectives. In fact, most hospitals rely on the companies that sold them the equipment to do quality assurance. Needless to say, that there is a conflict of interest when a service engineer evaluates the machine that his or her company sold to the hospital or clinic. Moreover, a service engineer or a technician is not qualified to do the dosimetry and quality control procedures that are mandated by international organizations (such as the IAEA and WHO). In the following paper, simple procedures will be presented to measure and protect patients and technicians from undue exposure to radiation and to evaluate the x-ray image quality.

Methods

Entrance Skin Exposure

The entrance skin exposure is the amount of radiation delivered to the patients skin at the entranee point of the x-ray [1,2]. Since, radiation measurement devices ean't be put just under the skin of patients undergoing x-ray exams, we use a radiation measuring instrument, such as an ionization chamber, with a "phantom" (a plastic sphere or square to represent a body) in the beam to estimate entrance skin exposure (ESE) for various x-ray procedures. The ionization chamber measures the exposure and is used to estimate skin dose.

There are no national or international regulations concerning entrance skin exposure for most diagnostic radiology procedures. However, there are guidelines and recommendations that give the range of reasonable entrance skin exposures. Institutions are not required to comply with the guidelines. However, institutions that want to have the best standard of practice will determine methods to comply with acceptable ESEs. The US food and Drug Admiuistration (FDA) suggests that the potential for injury be noted in the patient's record for any procedure the facility determines could result in a cumulative absorbed dose in a specific area of skin equal to or greater than 1 Gy (100 rad).

The Nationwide Evaluation of x-ray Trends (NEXT) is a U.S. national program conducted annually to measure the x-ray exposure that a standard patient receives for selected x-ray examinations [1]. This program is conducted jointly by the Conference of Radiation Control Program Directors (CRCPD), in association of state and local radiation control agencies, and the Food and Drug Administration (FDA) Center for Devices and Radiological Health. The NEXT reports give some reasonable entrance skin exposures for some Radiology exams (Table 1). It is a good practice to maintain the ESE at lower value than the third quartile ESE values.

Table 1. Entrance Skin Exposures for selected radiographic exams

Medical ESE Values for Selected Radiographic Exams

Projection	Patient Thickness (cm)	Grid	SID (cm)	Median ESE (mR)	3rd Quartile ESE (mR)
Chest (P/A)	23 23	No Yes	183 183	9 13	13 18
Pediatric Chest (P/A)	15 month old / 11 kg infant	No Yes		4 8	5 10
Pediatric Chest (A/P)	15 month old / 11 kg infant	No Yes		5 8	9 14
Abdomen (A/P)	23	Yes	102	271	396
Lumbar Spine (A/P)	23	Yes	102	342	477
Full Spine (A/P)	23	Yes	183	260 (200 Speed) 145 (400 Speed)	
Cervical Spine (A/P)	13	Yes	102	135 (200 Speed) 95 (400 Speed)	
Skull (Lat)	15	Yes	102	145 (200 Speed) 70 (400 Speed)	

Measurement of Entrance Skin Exposure

The following protocol can be used for measuring and calculating entrance skin exposures (ESE) for routine diagnostic examinations (CRCPD, 2003). The protocol involves the use of a calibrated radiation measuring device and a patient equivalent phantom (Figure 1) [1]. The protocol involves the following steps:

1) Position the x-ray tube at the source-image receptor distance (SID) routinely used and adjust the collimation to the active portion of a radiation measuring device.

2) Measure the distanee from the x-ray source to the surface against which the patient rests. Subtraet the thickness of the patient to obtain the souree-skin distance (SSD). The standard patient thickness for each projection to be measured shall be approximately 23 cm for chest, abdomen, and lambo-sacral spine exams; 15 em for skull, 13 cm for cervieal spine; and 8 cm for extremities.

3) Place a radiation measuring device in the center of the useful beam, measure the Source to Detector Distance (SDD). Use of a test stand to position the device away from the table to reduce backscatter contribution.

4) Set the exposure technique as follows:

a) For non-phototimed x-ray systems, set the controls to the exposure technique used hy the x-ray operator for the standard patient thickness specified in step [3]. In this case the patient equivalent phantom is not needed.

b) For a phototimed x-ray systems, set the controls to the exposure technique used by the x-ray operator for the standard patient thickness. Place a phantom, to simulate body attenuation, in the useful beam between the radiation measuring device and the radiographic tabletop. (AAPM Report No. 31, 1990).

5) Make a radiographic exposure and record the reading obtained from the radiation measuring device.

6) Calculate the entrance skin exposure for the specific examination. The entrance skin exposure equals the product of the radiation exposure reading multiplied by the square of the ratio of the SDD, to the SSD.

$$ESE = \text{Dosimter Reading} \times (SDD^2 / SSD^2)$$

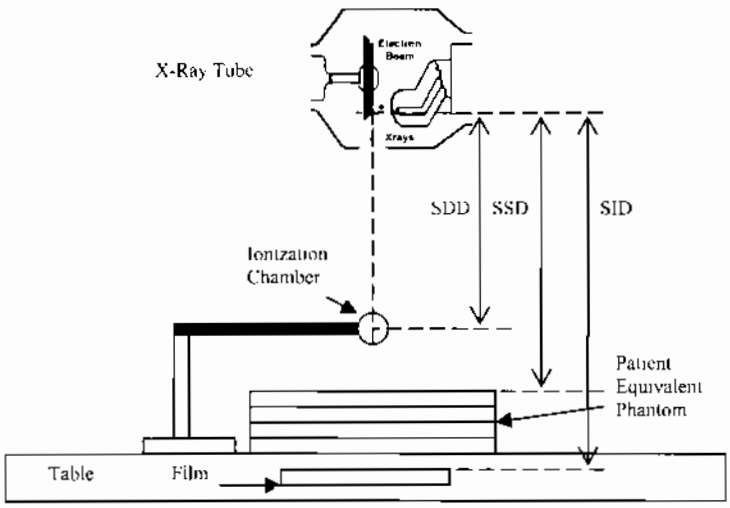

Fig. 1. Experimental setup for measurement of the Entrance Skin Exposure (ESE) for x-ray system with Automatic Exposure Control (AEC). For the manual mode (no AEC) there is no need to use the patient equivalent phantom.

Mammography Glandular Dose.

The Joint Commission on aeereditation of Health Care Organization (JACHO) and the American College of Radiology (ACR) requires the measurement of entrance skin exposure and mean glandular dose for mammography. The Mammography Quality Standards Act of 1992 MQSA and associated Food and Drug Administration Rules [3-5] require that average glandular doses to the breast be evaluated. For mammography exams, the MQSA gives guidelines for maximum glandular dose to the breast (Table 2). The mean glandular dose should be maintained at levels lower than the third quartile value. Observing these guidelines is very important to protect patients from the eareinogenie effects of ionizing radiation.

The Mean Glandular Dose (MGD) is the special dose quantity used in mammography. It is defined as the mean, or average, dose to the glandular tissue within the breast. The assumption is that the glandular tissue, and not the fat, is the tissue at risk from radiation exposure.

Table 2. Mean glandular dose for a mammography [1] .

Mammography Mean Glandular Dose

Projection	Compressed Breast Thickness (cm)	Grid	Median (mGy)	3rd Quartile (mGy)
Craniocaudal View	4.2	Yes	1.75	1.97

Note,

- Data source 2001 Mammography Quality Standards Act (MQSA) database (RMI 156 phantom equivalent to a 4.2 cm compressed breast tissue (50% glandular/50% adipose) for screen-film))

The entrance skin exposure for mammography can be measured using a setup similar to that of figure1. A standard Ameriean College of Radiology (ACR) phantom ean be used to acquire images at different values of x-ray tube voltage (kVp) and tube current-exposure time product (mAs). The phantom has a composition and a thickness that is equivalent to a 4.2 cm compressed breast consisting of 50% glandular and 50% adipose tissue. The measurements should be done with geometrical and exposure settings very similar to those used during patient proeedures. Using the measured exposure the mean glandular dose is calculated using table 3 [6-7]. The half value layer, which is the thickness of Aluminum that will attenuate the exposure to half its original value should also be measured. According to the MQSA the glandular dose should be less than 3 mGy.

Table 3. Glandular Dose (in mrad) for 1 Roentgen Entrance Exposure of 4.2 cm thick breast phantom (50% Adipose, 50% Glandular Breast Tissue

	Mo/Mo Target -Filter x-ray Tube Voltage (kVp)											With Al Target-Filter Combination
HVL	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	
0.23	116											
0.24	121	124										
0.25	126	129	131									
0.26	130	133	135	138								
0.27	135	138	140	142	143							
0.28	140	142	144	146	147	149						
0.29	144	146	148	150	151	153	154					
0.3	149	151	153	155	156	157	158	159				170
0.31	154	156	157	159	160	161	162	163	164			175
0.32	158	160	162	163	164	166	167	168	168	170	171	180
0.33	163	165	166	168	169	170	171	173	173	174	175	185
0.34	168	170	171	172	173	174	175	176	177	178	179	190
0.35		174	175	176	177	178	179	180	181	182	183	194
0.36			179	181	182	183	184	185	185	186	187	199
0.37				185	186	187	188	189	190	191	191	204
0.38					190	191	192	193	194	195	195	208
0.39						196	197	198	198	199	199	213
0.4							201	202	203	204	204	217
0.41								206	207	208	208	221
0.42									211	212	212	225
0.43										215	216	230
0.44											220	234
0.45												238

To convert from entrance skin exposure in air in Roentgen to mean glandular breast dose in millirads, multiply the entrance exposure by the factor in the table for the appropriate kVp and beam quality (HVL) combination. For example, a measured entrance skin exposure of 0.50 Roentgen at 30 kVp with a measured HVL of 0.36 mm aluminum yields an average glandular dose of (0.50 R) X (185 mrad/R) = 83 mrad = 0.93 mGy

Measurement of Contrast-Detail Curve

The Rose model is a probabilistic model of low-contrast detection of an object in a surrounding background in an image. The Rose model states that an observer can differentiate two regions of the image, called "target" and "background", only if there is sufficient information to do so. Specifically, if the "signal" is defined to be the difference in the number of photons used to each region, and the "noise" is the statistical uncertainty in each of those regions, the observer needs a certain signal-to-noise ratio to distinguish the target from its background Rose found that this value is in the range of 5 to 7.

Figure 4 shows a diagram of a tumor "target" with a cross sectional area A and thickness Δt is separated from its surrounding ("background") tissue by a contrast C.

The variables are:

N = number of photons in target ≈ number of photons in background
A = area of the target = area of background region
Φ = Photon fluence (number of photons per unit area)

then, the contrast (C) is related to the number of detected photons (N), and to the difference (ΔN) in the number of photons in the target and backgrouud by the relation:

$$C = \Delta N / N$$

From this the signal can be expressed in terms of the contrast and the number of detected photons as:

$$\text{Signal} = \Delta N = CN$$

For very low contrast, the number of photons in the target region is approximately equal to the number of photons in a background region (of the same area). For Poisson-distributed events, the noise equals the square root of the number of photons in the background region (N).

$$\text{Noise} = \sqrt{N}$$

so that the differential signal-to-noise ratio (k) is

$$k = \textbf{Error!} = C\textbf{Error!} = C\sqrt{\Phi A}$$

For a low contrast and small tumor, the photon fluence has to be high in order to achieve a minimum differential signal to noise ratio of 3 to 5. Below these values of differential signal to noise ratio the tumor will not be distinguished from the surrounding tissue. Increasing the fluence will increase the dose to the patient. Hence, there is a tradeoff between low contrast detection and dose.

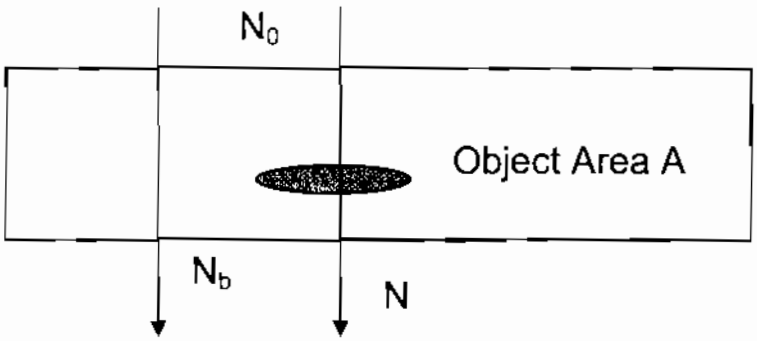

Fig. 2. Illustration of imaging an object in a surrounding structure.

The Contrast-Detail phantom (Figure 4-a) is usually a slab of Aluminum with holes of varying diameter with different depths. Each hole cross sectional area and depth simulates a tumor with the same cross sectional area and corresponding contrast. When the phantom is imaged using the same exposure parameters as a regular mammogram, the image shows the holes that are possible to see given the used exposure parameters (Figure 4-c). A curve of the visible holes can be plotted with increasing contrast (depth) in the Y axis and increasing detail (diameter) in the x-axis. This Contrast-Detail curve is a measure of image quality. It is desirable to have the highest contrast at the different levels of detail (resolution). The higher contrast and resolution allows the radiologists to better diagnose small contrast tumors and small size calcifications in the breast.

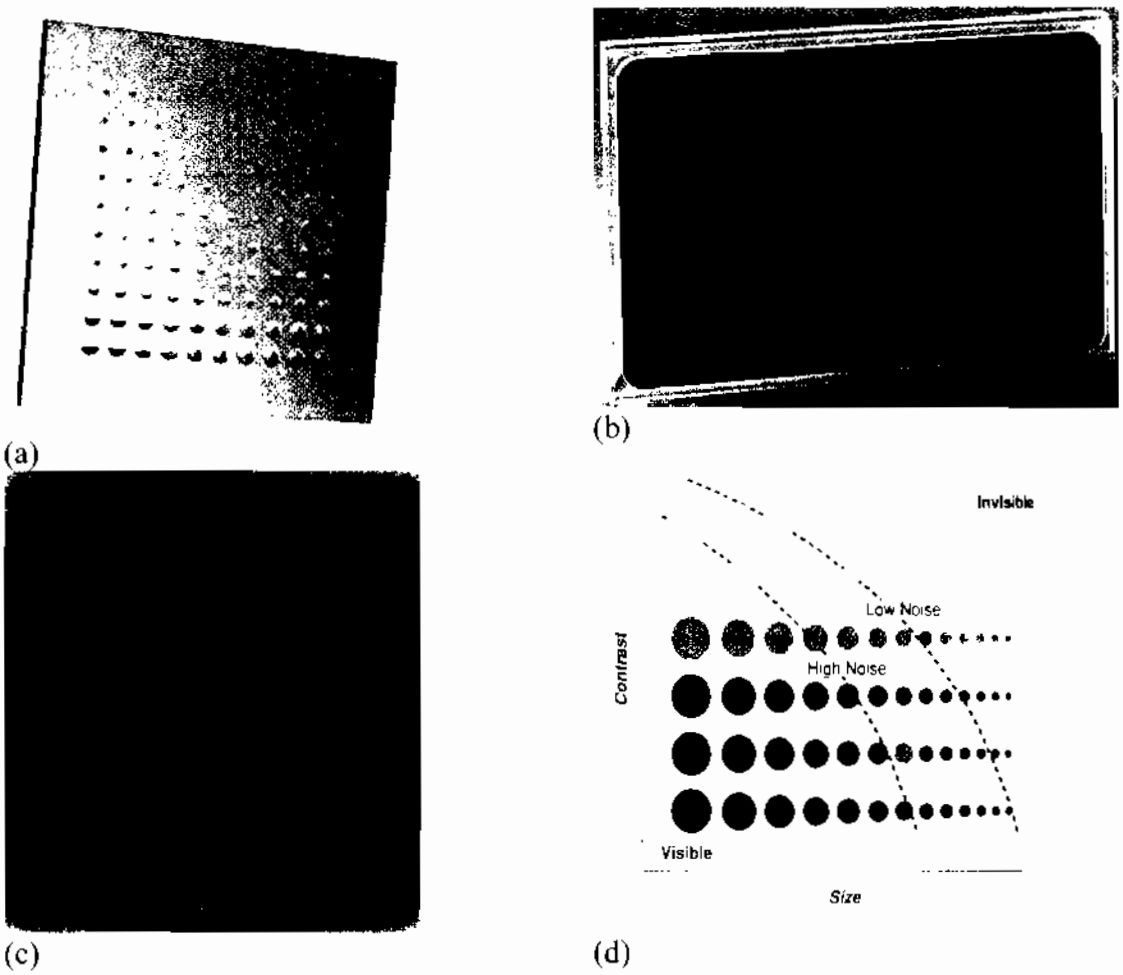

Fig. 3. (a) the Contrast-Detail phantom for radiography and fluoroscopy; (b) the Contrast-Detail phantom for mammography; (c) The image of a Contrast-Detail phantom shown in (a); Illustration of the Coutrast-Detail curve obtained from a Coutrast-Detail phantom.

Conclusion

It is essential to protect the patient from unnecessarily high exposure to radiation. Using the simple measurement of the entrance skin exposure and comparing them with recommended ranges will ensure that the patient dose is reasonable. It is also necessary to do routine quality eontrol measurement of image quality. Using the Contrast-Detail phantom allows us to construct a Contrast-Detail curve and evaluate the imaging quality. This will iusure that the imaging system gives the best image for the doctor to diagnose the disease.

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إجراءات مراقبة الجودة لتحسين التصوير التشخيصي والحماية من الإشعاع

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المستخلص. الدور الرئيسي للفيزيائي الطبي في التصوير التشخيصي هو الإشراف و تنفيذ برنامج مراقبة الجودة الذي يؤمن التّشخيص الدقيق للأمراض وحماية المرضى وموظّفي المستشفى من الإشعاع. في كثير من المستشفيات السّعودية لا يوجد برنامج محكم ومتواصل لمراقبة الجودة. يمكن أن تستخدم إجراءات بسيطة لتخفيض الجرعة الإشعاعية للمريض. باستخدام مجسم وكاشف من نوع غرفة التأيّن لقياس الجرعة الإشعاعية التي يتعرض لها جلد المريض خلال عمليات التصوير بالأشعة في الفحوصات المختلفة ومقارنتها مع المستويات القصوى المعمول بها في مثل هذه الفحوصات. كما يمكن تقييم جودة صور جهاز التصوير التشخيصي باستخدام مجسم Rose لقياس التباين Contrast والدقة Resolution. وبتحليل نتيجة الفحص ورسم مخطط بياني لجودة الصورة من حيث التباين والدقة يمكن تقييم قدرة الجهاز على كشف الأورام ذات التباين المنخفض والشروخ الدقيقة في العظام. إن هذه الإجراءات لمراقبة الجودة تحسن دقة التصوير التشخيصي من حيث الحساسية sensitivity والتحديد specificity وهذه ضرورية جدا خصوصا في الكشف المبكر لسرطان الثدي الذي هو أعلى نسبة للسرطان بين النّساء.