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PROTECTION OF PATIENTS IN DIAGNOSTIC RADIOLOGY

REGULATORY GUIDE

PAKISTAN NUCLEAR REGULATORY AUTHORITY

For Further Details

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PROTECTION OF PATIENTS IN DIAGNOSTIC RADIOLOGY

ABSTRACT

“Radiology” is the most extensive and commonly used application of ionizing radiation and it gives largest amount of radiation dose to the population worldwide. Since, radiology is an important tool for diagnosis, therefore, diagnostic procedures have become routine part of clinical life and the number of such procedures is ever increasing. Keeping in view the diversity of patients and nature of their examinations, dose limits are not applicable in diagnostic procedures. In fact, the guidance levels are established for radiological procedure so that required clinical information for diagnosis may be obtained at a reasonable amount of radiation dose; which is the ultimate goal of “optimization in patient doses”.

The patient doses are affected by a number of parameters such as equipments, techniques and expertise. This regulatory guide addresses the appropriateness of operating parameters such as mAs, kVp and; equipments including grid, collimator and image receptors; techniques like general radiography, mammography and fluoroscopy; and knowledge/skills of operating personnel. In addition to this, various administrative issues such as responsibilities and training of workers have also been addressed in this regulatory guide.

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1 INTRODUCTION

Medical exposures constitute the largest component of radiation dose to population from radiation sources [1]. According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), there are over 3.6 billion medical radiation imaging procedures carried out annually. According to survey conducted by UNSCEAR for the period from 1997-2007, total effective dose from medical diagnostic examinations is estimated to have increased approximately 70% [2]. The radiation protection is, therefore, becoming increasingly important to ensure radiation safety of the patients. PNRA "Regulations on Radiation Protection - (PAK/904)" establish dose levels for diagnostic and interventional radiology. These guidance levels serve as baseline for the development of protocols for minimization of patient doses subject to diagnostic procedures. Dose reduction requires careful attention to equipment specifications. Any modifications in operational factors may result in variation of dose to patient(s). All attempts should be made to conform to good radiation practices and to minimize doses to individual patient.

2 OBJECTIVE

The objective of this regulatory guide is to provide guidance to the licensees of medical facilities and describe different ways through which doses can be reduced without compromising the diagnostic information.

3 SCOPE

This regulatory guide applies to individuals, practices or facilities where diagnostic or interventional diagnostic examinations are performed.

4 PRINCIPLES OF RADIATION PROTECTION AND PATIENT SAFETY

4.1. Justification

Medical exposures should be justified by weighing the diagnostic benefits they produce against the radiation detriment they might cause, taking into account the benefits and risks of available alternative techniques such as Ultrasonography (USG), Magnetic Resonance Imaging (MRI), etc.

4.2. Optimization

The optimization of radiation protection and safety, when applied to the exposure of workers and members of the public, attendants and comforters of patients undergoing radiological procedures, is a process of ensuring that likelihood and magnitude of exposures and the number of individuals exposed are As Low As Reasonably Achievable (ALARA), with economic, societal and environmental factors taken into account.

In diagnostic radiology, the required clinical information for diagnosis can be obtained with minimum exposure of patients by taking into account:

- The relevant information from previous examinations in order to avoid unnecessary additional examinations;
- Proper selection of equipment and procedures;
- Qualification and continuous training of workers;
- Effective quality assurance program;
- The relevant guidance levels for medical exposure;
- Assessment/audits of practices for continuous improvement.

5 RESPONSIBILITIES OF MEDICAL/HEALTH PROFESSIONALS

As per Regulation 35(1)(b) of "Regulations on Radiation Protection - (PAK/904)", "The licensee shall ensure that medical professionals are assigned the primary task and obligation of ensuring overall patient protection and safety in the prescription of, and during the delivery of, medical exposure" [3]. The first step in reduction of patient doses is the availability of a qualified Radiologist, Medical Physicist/Radiation Protection Officer (RPO) and Radiographer.

Responsibilities of medical/health professionals regarding protection of patients in diagnostic radiology are given below:

5.1. Responsibilities of Radiologist

The radiologist should ensure that:

i. Overall radiation protection of the patient is achieved;
ii. Exposure of the patient is kept to the minimum required to achieve the intended objective, taking into account the relevant guidance levels for medical exposure;
iii. Optimized protocols for diagnostic procedures are established;
iv. Guidance is being provided for examination of the pregnant women, pediatric patients, medico-legal procedures, and occupational health examinations;
v. Any radiation incident or accident is evaluated and investigated from medical point of view;
vi. Qualification and training needs of radiation workers including Medical Physicist/RPO and Radiographers are established;
vii. Appropriate training and retraining of radiation workers (i.e. Medical Physicist/RPO and Radiographers) is arranged periodically.

5.2. Responsibilities of Medical Physicist/Radiation Protection Officer (RPO)

The Medical Physicist/RPO is responsible for technical and administrative matters related to radiation protection at the facility. The Medical Physicist/RPO should ensure:

i. Overall radiation protection of patients at the facility;

ii. Development of Radiation Protection and Quality Assurance (QA) Program and relevant procedures;
iii. Implementation of regulatory requirements, Radiation Protection and QA Program and applicable procedures;
iv. Supervision/conduct of Quality Control (QC) test of X-ray machine(s) and other equipment/accessories;
v. Training of workers on radiation safety and radiological protection of patients;
vi. Maintenance of records relevant to QC of equipment and radiation protection.

5.3. Responsibilities of Radiographer/Operator

The main responsibility of the radiographer/operator is to:

i. Comply with the facility operating procedures;
ii. Identify the patient correctly by:
   - Name;
   - Gender;
   - ID/ CNIC/ Passport Number; and
   - Date of birth, address and any unique patient number.
iii. Verify that the female patient is not pregnant;
iv. Brief the patient(s) about the procedure, correct positioning and immobilization during exposure;
v. Use appropriate shielding for patient such as lead apron, gonad shield etc.;
vi. Perform QC tests under the supervision of Medical Physicist.

Additionally, operators should:

i. Be well aware of any dose reduction techniques specific to the equipment;
ii. Routinely review their work practices to optimize operational protocols.

6 FACTORS AFFECTING DOSES IN X-RAY IMAGING PROCEDURES

Factors affecting patient doses in all X-ray imaging procedures include beam energy, filtration, collimation, patient size, image processing and expertise of relevant staff. In conventional radiography, one of the important determinants of acceptable patient dose is the use of accurate peak kilo-voltage (kVp). Digital radiography allows much wider range of exposures than conventional radiography for producing diagnostic images. However, operators must be aware of subtle differences in techniques used with digital systems to avoid unnecessary exposure to patients. Mammography requires lower ranges of kVp; different target materials, filters, and screen-film combinations; special attention to breast thickness, composition and compression during the study; and different standards for grids, magnification and optical density. Although, kVp and tube current are important for controlling patient doses in fluoroscopy, however, collimation, source-to-skin and patient-to-image intensifier distances and control of beam-on time also play an important role. Computed

Tomography (CT) involves greater patient doses than conventional radiography. Although, primary radiation dose is delivered to smaller volumes, however, dose calculations in CT must account for dose received by the adjacent tissue section(s) as well.

6.1. Radiography

Radiography refers to create a planar image using X-rays. In radiography, Entrance Surface Dose (ESD) is very important factor which is proportional to the tube current, the length of exposure and the square of kVp. Another factor is inverse square law which states that when all other factors are held constant, the dose at any location is inversely proportional to the square of the distance from the source.

6.1.1 Factors Affecting Dose in Conventional Radiography.

i. ***Beam Energy and Filtration:*** Beam energy primarily depends on kVp selected and the amount of filtration in the beam. Selection of higher kVp increases beam penetrability. In practice, this may allow for use of a lower tube current or a shorter exposure, thereby reducing dose to the patient. It is advisable to use a total filtration (which includes the tube wall and any other added filtration) of at least 2.5 mm of Aluminum equivalent, if machines are operated at tube potentials above 70 kVp. This filtration preferentially absorbs the low energy X-rays in the beam. Without filtration, this low energy radiation may completely be absorbed in the patient's body, thereby contributing to patient dose without contributing to the image. However, added filtration increases the average energy of X-ray beam which results in better image quality.

ii. ***Collimation:*** During any diagnostic procedure, the area of patient's body exposed should be limited to the area of clinical interest. By using collimation, unnecessary patient exposure can be substantially reduced. It has an added effect by reducing the area of X-ray beam and the amount of scattered radiation that reaches the image receptor thereby increasing the contrast of the final images.

iii. ***Grid:*** Grid is used in radiography to reduce the amount of scattered radiation that reaches the image receptor, and to improve the image contrast. It, at the same time, results in higher patient dose. High quality images, obtained by using grid, may result in fewer retakes, however, more accurate diagnosis.

iv. ***Patient Size:*** With the increase in thickness of the imaging area, kVp should also be increased to obtain required results. Although no control can be exercised over the patient size, however, it is beneficial to know the types of exposures expected for examinations of different anatomical areas and patients of different sizes. Technique charts, that display different radiographic technique factors for various examinations, displayed near the operator's console may be helpful in this regard.

v. ***Screen-Film Combinations:*** Use of a faster screen-film combination can substantially reduce dose. Faster systems may result in some loss of details.

6.1.2 Factors Affecting Dose in Digital Radiography

Digital Radiography (DR) is the process in which X-ray image is captured through a digital image capture device, saved for future record and is made available for interpretation or further assessment. The advantages of DR over film include; immediate image preview and availability, a wider dynamic range which makes it more forgiving for over and under exposure as well as the ability to apply special image processing techniques that enhance overall display of the image. The largest motivator for healthcare facilities to adopt DR is its potential to reduce costs associated with processing, managing and storing films.

In digital radiography, there is a trade-off between image quality, noise, and patient dose. Efforts to reduce radiation doses during imaging studies have been traditionally limited by a lower image quality, but the use of digital modalities may offer an opportunity to reduce exposure with images of adequate quality. Many approaches are available to acquire better image quality with minimum possible exposures. One way is to increase kVp with corresponding decrease in milliampere-seconds (mAs) product. This technique increases beam penetration thereby providing adequate exposure to image receptors while reducing relative absorption in patient and therefore, reducing patient dose.

6.2 Mammography

Mammography is an X-ray examination of the breast. It is the most reliable method of detecting breast cancer. Its principal purpose is to facilitate the detection of breast cancer at a point earlier in its natural history than is possible by clinical examination. The factors that affect diagnostic radiography also apply to mammography. However, it involves different parameters because of different nature of the tissue being imaged. Generally, the term “Average Glandular Dose" (AGD) is used to describe the dose to a breast tissue in mammography.

6.2.1 Factors Affecting Dose in Mammography

i. ***Beam Energy:*** The mammographic range of peak kVp is much lower than that used for all other applications of radiography because high contrast is required to image the soft breast tissues. Small differences in beam energy in mammography greatly affect the resulting dose to the patient.

ii. ***Target Material:*** Different target materials yield X-rays of different energies, therefore, patient dose is affected when different target materials are used. Molybdenum which emits characteristic X-rays of approximately 18 and 20 kV is used as a target material. Recently, Rhodium which emits characteristic X-rays of approximately 23 kV is being used for imaging thick or dense breasts. Tungsten has also been used as a target material. It is useful while imaging thick and dense breast tissues.

iii. ***Filter Material:*** Filters are used to shape the X-ray energy spectrum. Filters absorb low energy X-rays that do not contribute to image formation and high energy X-rays that would degrade image contrast. In mammography, imaging is performed at the characteristic energy of the target material. Therefore, to avail characteristic energy peak of the target material, same material is used as a filter. For example, Molybdenum and Rhodium are used as filter materials along with Molybdenum and Rhodium targets respectively. Molybdenum selectively filters out a high percentage of X-rays with energies more than 20 kV and Rhodium X-rays with energies more than 23 kV. Rhodium filters result in more penetrating X-ray beam and can provide a substantial dose reduction when imaging thick, dense breast tissues.

iv. ***Grid:*** In mammography, grid is used to reduce the amount of scattered radiation that reaches the image receptor. The bucky factor for mammography grid is usually in the range of 2-3.

v. ***Magnification:*** Magnification can be an excellent tool for imaging very small breast lesions but it also increases the AGD. Magnification is achieved by moving the breast further away from the image receptor and closer to the X-ray tube. The increase in the distance of breast from the image receptor and the fact that grid is removed during magnification results in increased AGD.

vi. ***Breast Thickness and Tissue Composition:*** Thickness and composition of breast tissues have substantial impact on patient dose. High energy X-ray beam and longer exposure time are required to obtain acceptable images in case of thick and dense breast tissue and hence results in high AGD.

vii. ***Compression:*** Compression of the breast tissue results in a lower AGD as the thickness is reduced. It also results in more uniform exposure to the breast.

viii. ***Image Optical Density:*** Optical Density (OD) refers to the darkness, or density of the exposed film. If greater optical density is required, more exposure will be needed. Increasing the optical density of films results in higher AGD to patients.

ix. ***Screen-Film Combinations:*** Screen-film combinations of various speeds can also be used in mammography. As in mammograms, greater detail is required, therefore, a slower screen-film combination is used which results in a higher AGD.

6.3 Fluoroscopy

Fluoroscopy is used to obtain real-time images for diagnostic purposes and to get guidance for other medical procedures.

6.3.1 Factors Affecting Dose in Fluoroscopy

i. ***Beam Energy and Tube Current:*** Beam energy (kVp) as well as tube current (mA) plays an important role in patient dose. Higher kVp and lower tube current results in more penetrating beam. Increasing tube current results in increasing the number of photons which ultimately yield to increasing patient dose. Maintaining the highest kVp that will produce acceptable image contrast leads to lower patient dose.

ii. ***Collimation:*** In fluoroscopy collimators are important in considerations of the patient dose. Extended "beam-on" time may be used in fluoroscopy which may result in substantially higher doses to the areas surrounding the area of clinical interest. This potential overexposure can easily be avoided by using small field size required to image the area of interest only. Proper collimation also reduces the contribution of scattered radiation and leads to higher quality images.

iii. ***Source-to-Skin Distance:*** The dose rate of a fluoroscopic X-ray beam as it exits the X-ray tube is extremely high. Increasing the source-to-skin distance decreases the dose to patient. Maintaining the maximum possible distance between X-ray source and the patient body is the most effective means of reducing patient dose.

iv. ***Patient-to-Image Intensifier Distance:*** Distance between the patient and the image intensifier also has substantial effect on patient dose. By decreasing the distance, the dose rate of the X-ray beam can be reduced. Decrease in dose rate results in lower cumulative dose to the patient. However, minimizing this distance also means that a large fraction of scattered radiation will contribute to image. It is widely accepted, however, that minimizing patient-to-image intensifier distance is the most preferred method to reduce patient dose.

v. ***Image Magnification:*** Image magnification results in higher patient dose. Magnification can be achieved by two means, namely; geometric and electronic. Geometric magnification is obtained by moving the image intensifier further away from the patient, by moving the X-ray source closer to the patient or both. In electronic magnification of the image, the size of X-ray beam may be restricted to impinge on a portion of the image intensifier only. This technique usually produces an increase in patient dose, although to a smaller degree than geometric magnification.

vi. ***Grid:*** Use of grid in fluoroscopy reduces the amount of scattered radiation and yields images with improved contrast. Patient doses, however, increase by a factor of two or more. In some cases grids may be removed without a substantial loss in image contrast e.g. when the patient is small and when the patient-to-image intensifier distances is sufficiently large.

vii. ***Patient Size:*** Thick patient or dense areas within patient body cause more X-ray beam to be absorbed or scattered. The backscatter factor also contributes to an increased ESD in thicker patients. Operators should realize that ESD accumulates more rapidly in obese patients making them more susceptible to radiation burns.

viii. ***Beam–On Time:*** The amount of dose delivered to a patient is directly proportional to the amount of time the X-ray source is energized, creating a real time image. Use of short intermittent exposures rather than extended continuous exposures also reduce patient dose. Keeping beam-on time to a minimum is the most effective way to reduce the patient dose. It is advisable to maintain written records of beam-on times. These records may prove useful if patient doses are to be estimated.

6.3.2 Patient Doses in Fluoroscopy

The dose rate to a patient in fluoroscopy is greatest at the skin. The entrance exposure limit for standard operation of a fluoroscope is 25 mGy/min for normal and 100 mGy/min for high level operation mode [3].

Appropriate protocols should be available at every facility for physicians to minimize doses to the patients in order to avoid deterministic effects (e.g. burns) and occurrence of stochastic effects (e.g. cancer).

6.4 Computed Tomography (CT)

CT stands for computed tomography. The CT scan can reveal anatomic details of internal organs that cannot be seen in conventional X-rays. The X-ray tube spins rapidly around the patient and the X-rays strike numerous detectors after passing through the body. These detectors are connected to sophisticated computers which generate images after image processing. The radiation dose of a CT scanner is much higher than a conventional X-ray, but the information obtained from a CT scan is often much greater.

Two most commonly reported doses for CT are those delivered during head and body scans. Currently, in latest equipment available in the market, CT Dose Index (CTDI) values are usually provided by the manufacturers.

Generally, in CT scan, Multi Scan Average Dose (MSAD) ranges from 40 – 60 mGy (4-6 rad) for head scans and from 10 – 40 mGy (1-4 rad) for body scans. Whereas, a scout scan usually results in a surface dose of approximately 1 mGy (100 mrad) [4].

6.4.1 Factors Affecting Dose in Conventional CT

i. ***Beam Energy and Filtration:*** Radiation dose in diagnostic radiology mainly depends on beam energy; the higher the beam energy for an exposure, the higher will be the patient dose. Use of most appropriate kVp for a given examination is important to keep patient doses minimum. The type of filter placed in the X-ray beam also plays an important role in resulting beam energy in CT. These filters may be shaped to present different thicknesses at different points across the X-ray beam. The type of filter used for a specific CT examination is usually determined by the manufacturer and can reduce the ratio of surface dose to midline dose.

ii. ***Collimation:*** Collimation of X-ray beam plays a significant role in patient doses in CT. Effective utilization of pre-patient collimators confine the beam to section thickness intended at the area of interest and keep the doses minimum to the adjacent tissues. Another set of collimators may be positioned post-patient or pre-detector to reduce the amount of scattered radiation that reaches the detector. Images with better contrast and resolution are obtained through this technique which may affect patient dose indirectly.

iii. ***Number and Spacing of Adjacent Sections:*** Patient dose in CT is also affected by the number and spacing of adjacent sections. When more sections are scanned, more volume of tissue is irradiated. The MSAD may increase because of the penumbra resulting from scattered radiation and possible beam divergence. With the increase in ratio between section thickness and section interval, the MSAD also increases because of increasing contributions from neighboring sections.

iv. ***Image Quality and Noise:*** Statistical noise and loss of image contrast as a result of scattered radiation are most important factors affecting image quality. The dose used to acquire the image increases with the decrease in noise. To maintain acceptable levels of noise, the kVp and tube current used to acquire the image may need to be increased.

6.4.2 Factors Affecting Dose in Spiral CT

In spiral CT, continuous scanning of patient while the couch is moving through the scanner is possible. A large volume of the tissue can be scanned in a relatively short time in spiral CT. All the variables of traditional CT also apply to spiral CT, however, scan pitch is an additional important factor that must be considered in spiral CT.

Pitch is a ratio of distance that patient's couch travels during 360º gantry rotation to the section thickness. If the couch travels 10 mm during one rotation and the section thickness is 10 mm, the pitch would be 1 (one). The larger the pitch, more tissue can be imaged during the same scan interval.

For a spiral CT examination with a pitch of 1 (one), the dose to patient should be comparable with the dose delivered in a traditional CT of the same volume of the tissue. Patient dose is inversely proportional to pitch, as the pitch is increased, the dose at any point along the volume of tissue decreases and vice versa.

6.5 Dental Radiology

Dental radiography is the process of taking the X-ray images (pictures) of a teeth, bones, and soft tissues around them to help find problems with the teeth. It is one of the most frequent type of radiology procedures performed. Although, exposure associated with dental radiology is relatively low, however, radiological procedure should be justified and optimized to keep the radiation risk as low as reasonably possible. In dental radiology, ESD without backscatter for intraoral examinations and the Dose Width Product (DWP) for panoramic examinations is recommended for the setting of Diagnostic Reference Levels (DRLs) [5].

6.5.1 Factors Contributing Dose Variation

i. ***Collimation, Field- Size Trimming:*** Rectangular collimation which approximates the size and shape of the receptor reduces the dose significantly in comparison with circular collimation. A dose reduction exceeding 60% can be achieved in dental radiology by using rectangular collimation.

ii. ***Choice of Image Receptor:*** Digital detectors have the potential for further dose reduction, even compared with F-speed film, provided the repeat rate and use of higher exposure factors than necessary are controlled. The fastest available film consistent with achieving satisfactory diagnostic results should be used. E-speed and F-speed films reduce doses more than 50% compared with D-speed films.

iii. ***X-ray Generation and Kilo-voltage:*** For dental radiology, 65-70 kV is recommended as kilo-voltage of choice in intraoral X-ray sets using AC equipment, with 60 kV for those using DC X-ray sets.

iv. ***Filtration:*** X-ray tube filtration should be sufficient to reduce entrance surface dose to the patient consistent with producing satisfactory image quality. Filtration by aluminum is a key method of reducing skin dose to patients.

v. ***Position Indication Device:*** A position indication device which ensures minimum focus-to-skin distance of 20 cm should be attached to the tube head (e.g. by use of a long collimator/cone as compared to a short conical one).

6.6 In Utero Exposure in Diagnostic Radiography

PNRA Regulations on Radiation Protection (PAK/904), requires medical practitioners to avoid exposure to abdomen or pelvis of women patients who are or likely to be pregnant. If the exposure to any other body part or even to the abdomen/pelvis is justified, the medical practitioner is required to plan and conduct the exposure appropriately.

6.6.1 Factors Affecting Fetal Dose in Diagnostic Radiography

i. ***Direct (inside field of view) Exposure:*** If a fetus is located within the field of view of a particular examination, such as studies of the abdomen, pelvis and lumbar spine, it is exposed directly to primary beam radiation. This situation typically results in the highest fetal doses. Shielding in such situations becomes ineffective because it cannot cover the area being imaged.

ii. ***Indirect (outside field of view) Exposure:*** In case of examinations of skull and extremities, bulk of the exposure received by a fetus is from indirect scattered radiation from maternal tissues. The dose received in this situation is lower than the direct exposure. Shielding in this situation is again of limited value as most of the fetal dose results from internal scatter in the mother.

6.6.2 Fetal Dose Estimation in Diagnostic Radiography

Fetal doses are estimated using the following imaging techniques:

i. Output intensity (measured in exposure or air kerma) of the X-ray equipment for diagnostic exposures, entrance exposure (or air kerma rate) and fluoroscopic exposures, along with the conditions of the examination should be known;

ii. The Half-Value Layer (HVL) should be used to determine beam penetrability;

iii. Information about the conditions of procedure should include the location, number of images taken and radiographic exposure factors;

iv. For fluoroscopic procedures, the beam-on time and number of digital or cassette spot images taken should also be known;

v. Patient information should include fetal age at the time of exposure, patient's size and thickness, depth of fetus, and orientation of patient.

According to the data published in the Article of Radiographics [4], estimated doses to uterus from typical diagnostic procedures are listed in the Table-1.

Table-1 : Estimated Doses to the Uterus from Typical Diagnostic Procedures

EXAMINATION	**ABSORBED DOSE** **mGy**	**mrad**
Upper Gastrointestinal Tract (GIT) Series	1	100
Cholecystography	1	100
Lumbar Spine Radiography	4	400
Pelvic Radiography	2	200
Hip and Femur Radiography	3	300
Retrograde Pyelography	6	600
Barium Enema Study	10	1000
Abdominal Radiography (KUB)	2.5	250
Hysterosalpingography (HSG)	10	1000
CT • Head • Chest • Abdomen	 Approx 0 0.16 30	 Approx 0 16 3000

The medical/health professionals at a diagnostic radiology facility should be aware of the effect of the factors/technical parameters such as KVp, mAs, collimation etc. on dose and image quality and they should select appropriate parameters, as relevant, such that their combination produce the minimum patient exposure consistent with the acceptable image quality and clinical purpose of the examination.

6.7 Film Processing

Patients may undergo repeated X-ray examinations after their initial X-ray radiographs are rejected due to poor image quality. Good quality of radiographs cannot be acquired without proper film processing.

In manual processing, technical factors, such as developer temperature, developing time and chemistry replenishment, affect the quality of the films and are much more difficult to control. The darkrooms, in manual processing, should be equipped with a timer and thermometer, and a time-temperature development table which should be followed for processing all the films.

Automatic film processing is preferred because of less processing time. The film processor should be used according to the manufacturer's recommendations. If temperature, transport rate or replenishment rates differ substantially from the recommended values, the effects on the image quality can be significant which may lead to modification of radiographic techniques that in turn directly affect patient's dose.

Film processing conditions are also important in mammography. Manufacturer's recommendations for processing should be strictly followed. Deviations can lead to use of improper exposure techniques thereby increasing the patient dose. Another consideration is the length of film-processing cycle which can be either standard or extended. Extended cycle and processing allows a decrease in dose required to produce acceptable images. However, not all mammography films are compatible with extended-cycle processing.

7 MANAGING PATIENT DOSES

The factors affecting the management of patient doses are described in the following sections:

7.1 Developments in Equipments and Accessories

Technical development that made most significant contribution to patient dose reduction is the intensifying screen. From direct film radiography to modern rare earth phosphors (typically Oxysulphides or Oxybromides of Gadolinium and Lanthanum), dose reduction of a factor of 15-500 have been made possible, depending upon the type of screen and film used. Rare earth screens have three to five times better dose efficiency as compared to Calcium Tungstate screens which are still in common use [7]. Spectral sensitivity of a film should match the emission spectrum of the intensifying screen used. Any mismatch will have financial implications and it may lead to increased radiation doses to the patients. There is thus an immediate scope for dose reduction by switching over to rare earth screens.

Equipment with unsatisfactory safety and quality features should not be operated. Type approval of X-ray machines and registration may serve as an efficient method of ensuring conformity to specifications. New X-ray equipments may have malfunctions in one or more of their radiological parameters including; kVp, timing, beam congruence or centering and milli-ampere second linearity of some of their mechanical parameters which can be detected by acceptance testing. A qualified person, preferably a radiology medical physicist, may use these tests to verify that the initial performance of the equipment conforms to the manufacturer's specifications and international standards [8,9]. The person testing the equipment should thoroughly document the results of acceptance tests as those results might be used in part to define the acceptable range of parameters that will be monitored in any subsequent test. If no acceptance testing is carried out, there are 80% chances of starting with a poorly functioning unit.

After successful installation and acceptance of equipment, QC testing of the equipment must be carried out on an ongoing basis for continued and reliable performance. A medical physicist should perform QC testing of the equipment at a defined frequency to look for changes that may cause degradation of image quality or an increase in radiation exposure to patient.

Moreover, maintenance policy should be established for the maintenance of older equipment to avoid unnecessary exposures. Replacing/changing some of the accessories may also result in a patient dose reduction. Considerable attention should be given to introduction of Carbon fibers in table tops. Typically the dose can be reduced by 3-15% by changing the table top, 6-12% by changing the front of film cassette and 20-30% by using a grid with carbon fiber covers and fiber interspaces [10].

7.2 Referrals

Radiological examination is advised by the physicians to establish a diagnosis, however, not all the diagnostic examinations are clinically helpful. Expertise of physician, referring diagnostic examination, can help in saving the potential collective dose. Evidence based medicine has become an accepted practice, along with evidence based radiology.

The referring physician bears special responsibility and should use guidelines for diagnosis to a greater extent. The referring physician should take into account all clinical aspects regarding management of every patient individually/separately. In difficult cases, they should also consult with their colleagues in radiology in the selection of the most suitable procedure. Other possible procedures with lower or no exposure, such as USG or MRI, should be considered, if and when appropriate, before proceeding to radiological procedures.

7.3 Education and Training

The personnel involved in advice and delivery of any radiology examination should be qualified and receive adequate training. The role played by training and education must be emphasized when it comes to the dose reductions possible in the hands of operators, developing expertise to advice manufacturers, making the right choice of equipment at the time of purchase and spreading a culture of radiation protection among the personnel. A substantial dose reduction (nearly 40%) can be achieved by training of the staff. This is the responsibility of the licensee to plan and execute effective training and re-training programs for its workers.

7.4 Dose Guidance Levels

Patient doses in diagnostic examinations are controlled by restricting dose up to a certain level, specific for an examination, suggesting that the dose is sufficient to create better quality image of human anatomy. Dose guidance levels have been replaced by dose reference levels in recent recommendations of ICRP on radiation protection [11]. The dose guidance levels for conventional radiography, computed tomography and mammography are given in Table-2, Table-3 and Table-4 respectively [3].

Table-2 : Dose Guidance Levels for Conventional Radiography

Examination	**Entrance Surface Dose per Radiograph* (mGy)**	
Lumbar Spine	AP LAT	10 30
Abdomen, Intravenous Urology and Cholecystography	LSJ AP	40 10
Pelvis	AP	10
Hip joint	AP	10
Chest	PA LAT	0.4 1.5
Dental	LAT Periapical AP PA	20 07 05 05
Skull	LAT	03

Notes: PA: posterior-anterior projection; LAT: lateral projection; LSJ: lumbo-sacral-joint projection; AP: anterior-posterior projection.

* In air with backscatter, these values are for conventional film-screen combination in the relative speed of 200. For high speed film-screen combinations (400- 600), the values should be reduced by a factor of 2 to 3.

Table-3: Dose Guidance Levels for Computed Tomography

Examination	**Multiple Scan Average Dose* (mGy)**
Head	50
Lumbar Spine	35
Abdomen	25

* Derived from measurements on the axis of rotation in water equivalent phantoms, 15 cm in length and 16 cm (head) and 30 cm (lumbar spine and abdomen) in diameter.

Table-4: Dose Guidance Levels for Mammography

Average Glandular dose (mGy) per Cranio-Caudal Projection*
1 (without grid) 3 (with grid)

* Determined in a 4.5 cm compressed breast consisting of 50 % glandular and 50 % adipose tissue, for film-screen systems and dedicated Mo-target Mo-filter mammography units.

Dose guidance levels have been established through worldwide survey practices. With the improvement of imaging technology, the radiation doses in an examination can be significantly reduced with good image quality. Furthermore, better performance and selection of proper technique in the same examination for different human beings further reduce the population dose. Many countries all over the world perform periodic surveys to assess the patient doses in diagnostic examinations. On the basis of the results thus obtained, the guidance levels are revised to lower doses.

7.5 Clinical Dosimetry in Radiology

Radiation protection of patients undergoing medical X-ray examinations is governed by the principles of justification and optimization. Radiation dosimetry is required to inform medical practitioners of the levels of exposure and hence the risks associated with the diagnostic procedures that they have to justify and to assist the operators of X-ray imaging equipment to determine whether their procedures are optimized. The dosimetric quantities to be considered during diagnostic work are:

- ESD for individual radiographs;
- Dose-Area Product (DAP) for individual radiographs;
- DAP for complete examinations involving radiography and/or fluoroscopy;
- Weighted CT Dose Index (CTDIw) per slice in spiral CT scanning or per rotation in helical CT scanning;
- Dose-Length Product (DLP) per complete CT examination.

7.5.1 Entrance Surface Dose

It is the entrance air Kerma with backscatter from patient skin. It is usually expressed in milligray (mGy) and can be measured directly with suitably calibrated TLDs attached to the patient's skin or with ionization chambers supported in free air on the X-ray beam axis, corrected to the Focus Skin Distance (FSD) and by a suitable backscatter factor. It is the quantity of more concern for practical patient dosimetry. Specific X-ray tube output measurements, as a function of tube voltage (kV) and charge (mAs) made during routine quality assurance programs, are frequently used to calculate ESD values from the exposure parameters (kV, mAs, FSD) used for radiographs on a particular patient [12].

7.5.2 Dose Area Product

It is the absorbed dose to air (or the air kerma) averaged over the area of X-ray beam in a plane perpendicular to the beam axis, multiplied by the area of beam (A) in the same plane. It is usually expressed in Gy-cm2 and being invariant with distance from X-ray tube focus, it is conveniently measured with special large area ionization chambers (DAP meters) attached to the diaphragm housing of the X-ray tube, which intercept the entire cross section of the beam. They essentially integrate the absorbed dose over whole beam area for any number of diagnostic or fluoroscopic exposures and can thus provide a single measurement of total amount of radiation used in a complete X-ray examination involving radiography and fluoroscopy. DAP meters should be calibrated after installation on an X-ray set to take account of the particular scatter conditions and attenuating material between the DAP meter and the patient (e.g. the table top for under-couch X-ray tubes) [12].

7.5.3 CT Dose Index

The principal dosimetric quantity used in CT is the CTDI. This is defined as the integral along a line parallel to the axis of rotation (z) of the dose profile [D(z)] for a single rotation and a fixed table position, divided by the nominal thickness of the X-ray beam. CTDI can be conveniently assessed using a pencil ionization chamber with an active length of 100 mm, so as to provide a measurement of CTDI100, expressed in terms of absorbed dose to air (mGy) [13].

$$\mathrm{CTDI}_{100} = 1/\mathrm{nT}\int_{-50}^{+50} D(z)dz$$

Where "n" is the number of tomographic slices, each of nominal thickness "T", imaged during a single rotation.

7.6 Assessment of Exposure to the Patient at Individual X-ray Facilities

Patient exposure assessment should always be associated with monitoring image information. Patient exposure and image quality assessments at individual facilities should be carried out on a sample of typical patients.

Assessment of patient doses serve the following purposes:

i. Establishing guidance levels (reference levels);
ii. Comparing doses and dose distributions for the same type of examination, done with different exposure parameters or with different equipment, or in different X-ray rooms or different hospitals or different countries, or to monitor improvement by making comparisons before and after changes;
iii. Comparing patient exposure for different types of examinations. Effective dose is, therefore, used for comparison; however, the caution of using effective doses for patients as indicated in UNSCEAR should be kept in mind;
iv. Assessing relative contributions to collective doses from various types of examinations or even comparing medical with non-medical radiation exposure of

the population;

v. Analyzing trends in the use of radiation e.g. change in frequency and dose per examination, introduction of new examination techniques or modification of techniques; and

vi. Comparison of patient doses with guidance levels to get an idea if doses are on the high side.

8 REFERENCES

1. IAEA, "Radiation Doses in Diagnostic Radiology and Methods for Dose Reduction", TECDOC-796, International Atomic Energy Agency (IAEA), Vienna (1995)
2. UNSCEAR, "Sources and Effects of Ionizing Radiation", Report 2008, Vol.1, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), New York (2010)
3. PNRA, "Regulations on Radiation Protection", PAK/904, Pakistan Nuclear Regulatory Authority (PNRA), October 2004. Publishing, (2001)
4. Radiographics: 1999 Sept-Oct: 19(5):1289-1302 - The AAPM/RSNA Physics Tutorial for Residents: Typical Patient Radiation Doses in Diagnostic Radiology
5. ICRP, "International Commission for Radiological Protection". Diagnostic Reference Levels in Medical Imaging: Review and Additional Advice. Ann. ICRP 31 (33-52) (2001)
6. EUROPEAN COMMISSION, European Guidelines on Radiation Protection in Dental Radiology, RP 136, Luxembourg (2004)
7. John E. Aldrich, Emerenciana Duran, Pat Dunlop, John R. Mayo "Optimization of Dose and Image Quality for Computed Radiography and Digital Radiography" J Digit Imaging Jun 2006; 19(2): 126-131
8. Institute of Physics and Engineering in Medicine (IPEM), Measurement of the Performance Characteristics of Diagnostic X-ray Systems Used in Medicine, Report No. 32, Part III: Computed Tomography X-ray Scanners, 2003
9. American Association of Physicists in Medicine (AAPM), Quality Control in Diagnostic Radiology, AAPM Report No. 74, Madison 2002
10. Hufton AP, Russell JG. The Use of Carbon Fibre Material in Table Tops, Cassette Fronts and Grid Covers: Magnitude of Possible Dose Reduction. Br J Radiol. 1986 Feb;59(698):157-63
11. ICRP, "2007 Recommendations of the International Commission on Radiological Protection", ICRP Publication 103, International Commission on Radiological Protection (ICRP), Pergamon Press, Oxford (2008)
12. B. F. Wall Radiation Protection Dosimetry for Diagnostic Radiology Patients. Radiation Protection Dosimetry, Vol. 109, No. 4, pp. 409-419 (2004)
13. EC European CT Study Group. European Guidelines on Quality Criteria for Computed Tomography. EUR 16262 (Luxembourg: Office for Official Publications of the European Communities) (1999)

GLOSSARY

ABSORBED DOSE: It is a measure of energy deposited per unit mass and it is measured in units of Gray(Gy) or milli-gray (mGy).

BUCKY FACTOR (B): It is the ratio of x-rays arriving at the grid (incident radiation) and those being transmitted through the grid.

DOSE LENGTH PRODUCT: It is the CTDI multiplied by the scan length in centimeters.

ENTRANCE SURFACE DOSE (ESD): It is defined as "the entrance air kerma with backscatter from the patient skin".

EXPOSURE: It refers to the amount of energy initially transferred from incident X-rays to charged particles per unit mass of air and it is measured in Roentgen ®.

HALF-VALUE LAYER (HVL): It is thickness of the material at which the intensity of radiation entering is reduced by one half.

KERMA: (Kinetic energy released in matter) is defined as the amount of energy transferred from the incident X-rays to charged particles per unit mass in the medium of interest. The unit of air kerma is same as the unit of absorbed dose i.e. Gray or milli-Gray.

MULTIPLE SCAN AVERAGE DOSE (MSAD): It is the dose from a multiple scan examination, averaged over one scan interval in the central portion of the multiple-scan dose profile.

TISSUE OR ORGAN DOSE: It refers to radiation absorbed dose delivered to the tissues or organs of a patient during a radiology examination.

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